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Parenting Skills and Early Childhood Development: Production Function Estimates from Longitudinal Data

Jade Marcus Jenkins,

School of Education, University of California, Irvine, 3200 Education, Irvine, CA 92697-5500

Sudhanshu Handa

Department of Public Policy, University of North Carolina at Chapel Hill and UNICEF, CB# 3435
Abernethy Hall, Chapel Hill, NC 27599

Abstract

We provide evidence on the importance of specific inputs for child cognitive skills by estimating alternative specifications of the early childhood production function, between birth and kindergarten. We identify a new input measure, parent-child interaction, which is both important for development and amenable to policy intervention because parenting skills can be taught. We find that the application of reading books and singing songs and sensitive and engaging parent-child interactions as early as 9 months of age have an important effect on reading among kindergarten children.

Keywords

early childhood development; parenting skills; education production function

1. Introduction

Cognitive achievement in early childhood is strongly associated with a range of welfare outcomes in later life. In the U.S., test scores as early as 2 years of age are associated with later educational attainment as well as adult wages (Feinstein 2003, Case and Paxson 2006). Moreover, a related literature establishes that the *gap* in cognitive achievement between children of low and high socioeconomic status appears very early in life (Grissmer and Eiseman 2008, Bradley and Corwyn 2002, Reardon 2011, Carneiro, Heckman, and Masterov 2005, Heckman 2011), prior to school-entry, as early as age one.¹ Ample explanation for the strong relationship between early development and later life outcomes comes from neurobiology, developmental psychology, and physiology research. At birth, the brain is dependent upon interactions, experiences, and environmental stimulation for healthy development (Als et al. 2004, Dawson, Ashman, and Carver 2000, Greenough, Black, and Wallace 1987, Lupien et al. 2000), and is extremely responsive to experiences during the

(949) 824-7987, JVJENKIN@UCI.EDU.

¹In poor countries, early cognition are strong determinants of school enrollment and achievement scores in adolescence, grade repetition, and overall grade attainment (Grantham-McGregor et al. 2007). This pattern in the achievement gap is also documented for a developing country in Paxson & Schady (2007).

first two years of life (Levitt 2008, Singer 1995, Fox, Levitt, and Nelson 2010, Knudsen 2004). Thus, experience-based development that occurs very early sets pathways for future learning that affect skills and well-being for life.

To address this very early gap in cognitive achievement, human capital interventions during early childhood are essential. Numerous scholars have illustrated the long-term individual, societal, and economic benefits of investing resources in early childhood development programs (Reynolds, Temple, and Ou 2010, Belfield et al. 2006, Bartik 2011, Campbell et al. 2012, Duncan and Magnuson 2013, Heckman and Mosso 2014). Most notably, Heckman and colleagues provide empirical evidence on the returns from early childhood interventions (Cunha and Heckman 2007, Heckman 2006, Cunha, Heckman, and Schennach 2010). They demonstrate that investments during early life affect a child's skills and abilities at later stages, and that the skills produced at earlier stages raise the *productivity* and *potential* of later investment. This body of research undergirds the recent investment growth in early childhood policy; federal spending in the U.S. and UK reached \$19.6 and £5.6 billion respectively in 2011 (Isaacs et al. 2012, Stewart 2013). This includes age-4 prekindergarten programs, which have been shown to improve children's school readiness and academic success (Duncan and Magnuson 2013, Gormley, Phillips, and Gayer 2008, Wong et al. 2008).

However, very young children spend a majority of their time in the home during the first five years of life. As such, other policy interventions work with parents to improve the home environment by teaching parenting skills or connecting parents with community resources (Brooks-Gunn and Markham 2005, Gomby, Culross, and Behrman 1999, Love et al. 2005). For example, home visitation is a core component of Early Head Start, a federally funded program in the U.S. targeting mothers during pregnancy through children's second year of life. Surprising then, is the dearth of evidence on the exact familial inputs that are important for a child's early cognitive development.

Motivated by the importance of early life experiences on later outcomes, this article estimates the production function for early childhood development using rich longitudinal data and a unique input—the quality of the parent-child interaction. The nature and quality of this interaction is a more direct measure of the production technology that is typically proxied by education or income. And unlike fixed characteristics such as intelligence and education, parental sensitivity and engagement with their child is a *manipulable* behavior that is amenable to policy intervention.

Most of the published work in economics estimates the education production function (EPF) on data from school-aged children and focuses on school inputs such as class size, peer effects, and teacher characteristics (Rivkin, Hanushek, and Kain 2005, Hanushek et al. 2003, Angrist and Lavy 1999). These inputs explain very little variation in test scores; by school-age, children are already locked into their development trajectory. For younger children, the child development production function (CDPF) literature investigates the effects of *family* inputs and home environment on child outcomes, and may also include child care (Todd and Wolpin 2003). Todd and Wolpin's (2007) CDPF study established that parent education and labor market skill measures account for nearly half of racial test score gaps, consistent with

studies linking parent socioeconomic status to child well-being (Bradley and Corwyn 2002, Currie 2009).

Central to the innovation of our study is the fact that parent's education can affect children's development through several avenues: purchased goods, time spent, or the efficiency or 'technology' of their time spent with children. For example, more educated parents and those who are higher earners spend more time interacting with their children (Guryan, Hurst, and Kearney 2008), as do parents who put their child in preschool (Baker and Milligan 2013, Gelber and Isen 2013). Bjorkland and Salvanes review the economic literature in this area and estimate that only 20% of the variation in children's years of schooling comes from parent's education (2011). Decades of research from psychology and cognitive science provide a promising insight; this literature shows that specific qualities of a *parent's interaction with their child*, particularly parenting skills such as engagement and sensitivity, have a direct impact on children's development (Brooks-Gunn, Han, and Waldfogel 2002, Blair et al. 2008, Hackman, Farah, and Meaney 2010), and can buffer the effects of poverty on development (Gershoff et al. 2007, Burchinal et al. 1997).

This article provides detailed estimates of the production function for early childhood development, extending the existing research on EPFs in many directions. First, ours is the first study to present estimates of the early childhood development production function which includes detailed information on familial inputs of time, goods, and parenting for current and prior periods between birth and age 5 using rich data from a large and representative sample of U.S. children. Inclusion of historic inputs is important because child development is cumulative and the timing of inputs is critical where some periods of early life are more sensitive than others. This builds upon the work of Todd and Wolpin (2007) who estimate the EPF for children of school age (6–13 years). We also add to the work of Heckman and colleagues in their study of early skill formation. Their studies often use data collected in 1979 where the first measurement of children is ages 6 and 7 that provide valuable information on the skill formation process, but cannot capture the nuances of parental investment in very early childhood as we do here, and with data that more closely reflects the current population (i.e., children born in 2001).

Second, we augment the standard economic inputs of 'time' and 'goods' with an observer-rated measure of the parent-child interaction derived from the child development literature, which, as we show below, provides new and unique information in the CDPF. Moreover, this input is 'manipulable' and can be addressed through policy intervention. Third, because we have four waves of data, we can provide estimates of alternative, commonly used specifications of the EPF such as the popular 'value-added model' and examine whether the lagged dependent variable is a sufficient statistic for the history of inputs during early childhood.

We identify four key take-home messages. First, the application of inputs such as parenting and reading books as early as 9 months of age predict reading cognition at age 5. Second, the parent-child interaction is an important input in the development process and one that is particularly amenable to policy. Third, the lagged dependent variable used in value-added modeling does well in capturing the history of home inputs and endowments. The fourth and

most important message is that due to the cumulative nature of child development, the most efficient time to intervene is at very young ages, as young as 9 months. Not only do inputs at this period have lasting associations with future cognition, but the likelihood of locking into a development trajectory is greater at 5 years relative to even 12 months earlier. This may suggest that policies like prekindergarten may be too late to provide the most effective human capital interventions in development.

2. Theoretical Framework and Specification of the Production Function

a. The household production model

In economics, the theoretical basis for the CDPF stems from Becker's (1965) model of time allocation and household production. In this framework, the family is an economic unit that buys commodities from the market for consumption and allocates household resources to produce goods and services at home, such as child cognitive development. This model is well known and so we choose to omit a formal presentation, but instead highlight two key elements that play a crucial role in guiding theoretically consistent empirical work.

First, the CDPF as envisioned in the theory is a purely technical relationship between inputs (e.g., reading books with child) on the one hand and output (e.g., child cognition) on the other. Its specification is guided by the physiology of child development. Thus only factors that directly 'produce' child development enter into this relationship. However, variables that *influence the family's demand* for child development, such as race or parental education, are often used in empirical specifications. The CDPF includes two distinct types of demand functions. Input demands govern the level of inputs chosen by parents to produce child cognition. Final demands are those items that enter directly into the utility function (leisure, consumption goods, and child cognition) and are functions of the same exogenous factors as the input demands. For example, region of residence may reflect relative prices or access to information which would influence the *choice* of inputs but would not affect the *technical relationship* between the inputs and output.²

Parental education—and maternal education specifically—is of particular interest here because it is a strong predictor of child cognition and likely enters into both the demand and production functions for different reasons. Parent education might simply influence parent demand for inputs (e.g., quality or quantity of child care) or input bundles (e.g., time spent with child along with purchased goods for child), reflecting allocative efficiency. Another possibility is that more educated parents may have more knowledge to transmit to their children. Parental education may also influence *how inputs are applied* whereby more educated parents are 'better teachers', and thus reflect technical efficiency. Yet if mothers with more education have better parenting skills—an input that is typically omitted from production function estimates—education or labor market skill measures could be masking the effect of a parent's *parenting* skills in the production technology. The point is that in the

²In particular, factors that represent relative prices (such as state of residence) or income do not enter into the production function. Region of residence may serve as a proxy for inputs that do directly affect cognition (such as environmental contamination or epidemiological conditions) in which case they may justifiably be included in the EPF. Race may reflect access to resources, which would also influence input choice, but not the technical relationship itself. However, if race reflects cultural practices, which in turn influences *how inputs are applied*, this reflects technical efficiency and would enter the CDPF.

estimation of the CDPF, the distinction between the demand function specification and production function specification may be important because it forces the analyst to consider the mechanism through which observed (and unobserved) factors influence child development. In this paper we focus on production function estimates, but also present the input demand functions in Appendix C.³

b. Specification of the child development production function

Todd and Wolpin (2003, 2007) present a thorough discussion of alternative specifications of the CDPF and the assumptions embodied in these alternatives. In this section we briefly summarize the main issues involved in the estimation of these functions and their testable implications with respect to the specification of inputs only (i.e., not addressing functional form). Equation (1) describes a flexible form of the CDPF which posits that period t achievement (T) of the i th child is a function of contemporaneous and historical inputs (X) going back to birth (period 0), endowed mental capacity (μ), and a random error term (ε):

$$T_{it} = \alpha_t X_{it} + \alpha_{t-1} X_{it-1} + \alpha_{t-2} X_{it-2} + \dots + \alpha_{t-10} X_{it-10} + \mu_i + \varepsilon_{it} \quad (1)$$

Empirical implementation of (1) is hampered by data constraints because it is rare to have information on the entire history of inputs. Consequently, most empirical studies make the simplifying assumption that the effect of all prior inputs on contemporaneous cognition can be summarized by the prior period cognition score; in other words, the lagged score is taken as a sufficient statistic for the entire history of inputs up to period $t-1$. This specification relates the current period score to current (or within) period inputs and the lagged score and is depicted in equation (2):

$$T_{it} = \alpha_t X_{it} + \gamma_{t-1} T_{it-1} + \mu_i + \varepsilon_{it} \quad (2)$$

There are several assumptions embodied in (2) that are worth highlighting. First, the coefficients of all prior inputs are weighted by γ , the coefficient of lagged achievement. Thus they have the same structure of ‘decay’—the impact of all inputs diminishes over time at the same rate.⁴ While this might not lead to large bias if the lasting impact of prior inputs is small, it does rule out the possibility that the timing of inputs matters in early childhood, which is clearly not consistent with the neurobiology of development. Furthermore, the application of inputs during certain crucial developmental windows may have a direct effect on future cognition over and beyond their effect on prior period cognition—this possibility is also ruled out under the maintained assumption of the strict value-added model.

Finally, both (1) and (2) suffer from standard endogeneity bias since input choices made by parents will be governed by a child’s endowed mental capacity (μ). Note that in (1) this

³Note that a large literature exists regarding VAMs in the economics of education literature for school-aged students (e.g., Sass, Semykina, and Harris 2014, Koedel, Mihaly, and Rockoff 2015, Chetty, Friedman, and Rockoff 2014); however, we restrict our focus here on how VAMs guide the specification of early childhood inputs, not as a method to evaluate teachers (or in our case—parents) in the development of human capital.

⁴This assumption also applies to the historical impact of endowed mental capacity (μ).

endogeneity affects all inputs over time since μ appears in each and every period-specific production function and parents may thus respond to it in each period. Furthermore, the lagged dependent variable in (2) is also subject to endogeneity bias because it contains μ , and is thus correlated with the error term in (2).⁵

We follow the approach of Todd & Wolpin (2007) in our analysis and estimate three distinct specifications of the production function as it relates to early childhood development. We begin with the classical value-added model with contemporaneous inputs (VAM). We compare this to the ‘cumulative’ specification given by equation (1) where the entire history of inputs is added directly to the production function. We then estimate the ‘VAM-plus’, which adds historic inputs to the VAM to test whether the lagged dependent variable is a sufficient statistic for the entire history of inputs. We include a child fixed effect model to address the potential for endogeneity bias from the child’s endowment. We present falsification tests for the child fixed effects models and also address the endogeneity of the lagged dependent variable using fixed-effects instrumental variables estimators (Appendix D).

Our primary focus in the paper is to explore the specification of parental inputs in developing a production function model during early childhood development because these inputs—to the extent that they are manipulable—can provide points of intervention for early childhood policy. We include a mix of parent characteristic and behavior measures as inputs. Developmental and population research suggests three key home environmental factors that facilitate early learning: Participation in literacy activities, availability of learning materials, and the quality of parents’ engagement with children (Rodriguez et al. 2009, Kalil, Ryan, and Corey 2012). Our first set of models includes standard measures of the first two, representing parental investment behavior (time) and purchased goods. Our second set of models presents a new measure of the last dimension, the parent-child interaction. We measure this with a score from an objective assessment of a structured parent-child interaction developed in psychology. Indeed, a recent review by Heckman and Mosso (2014) highlight the importance of studying the parent-child relationship, stating “Some of the most exciting recent research models parent-child [...] relationships as interactive systems, involving attachment and scaffolding as major determinants of child learning” (pp. 690).

3. Data and Descriptive Statistics

We use the Early Childhood Longitudinal Study- Birth cohort (ECLS-B), a nationally representative sample of ~10,700 children born in the U.S. in 2001 created by the National Center for Education Statistics (NCES). The goal of the ECLS-B was to examine the individual, family, and community level factors that are associated with children’s health and developmental trajectories in the first six years of life. The sample was collected using a stratified probability sampling design by selecting from the cohort of births using Vital Statistics records. The overall response rate for the study at the first wave was 77 percent.

⁵Todd & Wolpin (2003) discuss the issue of unmeasured inputs in the production function. To the extent that these are correlated with measured inputs they will also bias production function estimates in standard OLS type analysis.

The ECLS-B data are not only very rich in terms of the child and family variables but also include age-appropriate, direct child assessments at each wave, where each instrument used was decided by a technical review panel of child development experts. The data collection consisted of interviews with the primary caregiver (PCG; biological mother in 99 percent of cases) and several direct child assessments at approximately nine months of age, 24 months, at age-4 (preschool entry), and at U.S. kindergarten entry, between ages 5 and 6, providing us with ample measures of the history of inputs in the CDPF. The data also includes a computer-assisted personal interview administered to the PCG and in-home direct assessments of the child's development and caregiver child interaction patterns conducted by a trained administrator. The survey weighted descriptive statistics of all variables included in our analyses are displayed in Table 1.⁶ We present unweighted regressions here, and account for the complex sampling design by clustering standard errors by primary sampling unit and including the variables on which the sample was stratified (e.g., race, low birthweight, urbanicity).

a. Child ability measures

The NCES used Item Response Theory (IRT) to construct age-appropriate child ability measures in all four waves (Lord 1980, Crocker and Aligna 2008). This makes it possible to create comparable scores regardless of the items a child received during assessment. The 9-month and 2-year mental ability measures were generated from items adapted from the Bayley Scales of Infant Development-II into the Bayley Short Form—Research Edition (BSF-R; Bayley 1993). We standardized the BSF-R scale measure and use these scores to represent age-appropriate child reading ability. The age-4 and age 5–6 (kindergarten entry) reading ability measures come from a selected pool of items from several widely-used assessments of children's early language skills, which we standardized. Combined with the mental measures from the 9-month and 2-year wave, this reading measure is the dependent variable for all models. While the BSF is a different instrument than the reading composite, both measures represent the most developmentally appropriate assessments for the age of the children under study. See Appendix E for further detail on child assessment instruments.

b. Inputs and covariates

Parent characteristics—Family characteristics can represent both inputs in the production process and the production technology. For most of the sample, the PCG is the child's biological mother, and therefore we include in our specifications maternal characteristics and refer to them as so. We include mother's age in years at time of assessment and educational attainment as a dichotomous indicator of college degree or higher.⁷

Family inputs—These variables represent key inputs into the production of child development, measured both contemporaneously and historically, as represented by X in equations (1) and (2). Three measures of purchased inputs and time spent on child

⁶Note that there are differences in sample sizes across waves. See Table 1 for further detail.

⁷Unfortunately, the ECLS-B does not measure maternal intelligence directly through IQ tests or other similar assessments. This is noted in other recent studies using the data, which use educational attainment as the sole measure of maternal cognitive ability (e.g., Fryer, Roland, and Levitt 2013, Rothstein 2012).

development activities are derived from the parent interview portion of the Home Observation for Measurement of the Environment-Short Form (HOME-SF) version (Caldwell and Bradley 1984) that the NCES collected in all four waves: 1) How often do you sing songs to your child? 2) How often do you read books with your child? and 3) How many books does the child have?⁸ Items have ordinal answer choices that receive binary scoring. Respectively, the coding of these inputs is as follows: 1 if greater than 3 times per week, 1 if greater than 3 times per week, 1 if greater than 9 books. We include these three variables—sings songs, reads books, and number of books—individually in our analyses to understand the mechanisms that produce child development in the home ‘black box’. as opposed to an overall effect from an averaged HOME-SF score. ‘Reads books’ is particularly interesting because other work suggests that book-reading can attenuate social class differences from mother’s speech to children (Hoff-Ginsberg 1991, Hart and Risley 1995). In addition, recent work by Brunello and colleagues (2016) indicates that the returns to education can depend very strongly on access to books in the home.⁹

Parent-child interaction—A principal advantage of the ECLS-B is the inclusion of interviewer observational assessments of the parent-child interaction. The score from this in-home assessment captures the extent to which parents sensitively respond to, and engage in interaction with their child. This is an objective and valid measure of the quality of parent’s time spent with children (as opposed to amount of ‘quality time’), which we introduce in our CDPF models in section 2b as a theoretically important, but largely omitted input.

Parent-child interactions were assessed in the 9-month, age-2, and age-4 waves with two different age-appropriate instruments. The measure at the 9-month wave, the Nursing Child Assessment Teaching Scale (NCATS), is a videotaped parent-child interaction where the parent is given a standard list of activities and is then asked to select one that the child was not yet able to do to. At ages 2 and 4, the NCATS was replaced by the ‘Two Bags task’ (TBT) (Nord et al. 2006, Andreassen and Fletcher 2007). This is also a videotaped, structured play and reading interaction where one bag has a book and the other has a play activity. Interactions are coded by trained staff to describe the quality and quantities of interactive behaviors. We standardized these scores to generate the variable named *parent-child interaction*.

Child characteristics—Time-invariant child covariates include indicators for sex, race, and low birth weight.¹⁰ Another key component is exposure to preschool. Unlike EPF models where all children are exposed to schooling inputs, not all children attend preschool prior to kindergarten (Magnuson et al. 2004, Mulligan, Brimhall, and West 2005).¹¹ The processes determining both the dosage and quality of childcare are endogenous with respect to child and family characteristics, and we did not want to introduce this endogeneity into our estimates of home production (Duncan and Gibson-Davis 2006). Because children who

⁸Number of books was not measured at the 9-month wave.

⁹The NLSY data used in Todd & Wolpin (2007) has the complete HOME-SF measure (sum of all binary items), which serves as their sole measure of home inputs.

¹⁰We also control for child’s age in months at the time of assessment to account for between-child differences in the actual timing of the assessment as they were collected during the ECLS-B.

¹¹Many children in our sample are missing this input (50% at 9 mo. and 2 years, 21% at age 4, 60% at kindergarten).

are in childcare necessarily have less exposure to home inputs, we tested whether this influenced our results by including a time-varying indicator for childcare attendance, and the results remained identical to those presented.

4. Results

a. Alternative specifications of the CDPF

We begin with an assessment of alternative specifications of the production function, using reading in kindergarten as our dependent variable. Table 2 shows the three specifications described in Section 2b plus several other variations to help us understand the relationship between prior inputs and child reading ability at kindergarten. All coefficients represent a standard deviation (SD) change in children's reading ability assessed between ages 5 and 6 (age at U.S. kindergarten entry).

The VAM with contemporaneous inputs is the most common specification of the EPF in the literature and is shown in column 1—it relates current achievement to lagged achievement and current inputs. In this model, we assume that the lagged reading score summarizes the history of inputs and that the coefficients of all higher order lagged inputs are zero. The lagged reading score is strong and significant; a one SD increase in age-4 reading score is associated with a 0.57 SD increase in age-5 reading score. This suggests that state dependence—the extent to which a child's prior achievement predicts their future achievement—is strong, but prior scores are not entirely deterministic of current scores, which aligns with the research in early childhood development. Not surprisingly, reading books to the child at age 5 has a positive association with reading in kindergarten, but none of the other home inputs are significant. Having a caregiver who is college educated is also positive and significant, with an effect that is one-fifth the size of the lagged reading score (0.12) and nearly equivalent to the effect of reading books. Mother's education is important, but no more so than the application of inputs (i.e., reading books). Race is not significant when individual indicators are tested jointly.

Column 2 shows the cumulative model that, instead of including the lagged reading score, includes the historical inputs explicitly. This allows each input at each period to decay at different rates. Both the contemporaneous and lagged measures of reading books at age 4 and at 9 months are positive and significant. Even though the contemporaneous measures of singing songs and having more than 9 books in the home are not significant, their coefficients in the lagged periods are; singing songs at age 4 and 2 and number of books at age 4 have a positive and significant association with reading at age 5. Notice that low birthweight is substantially larger (−0.14) and is statistically significant; the lagged dependent variable in column (1) thus picks up the effects of prior inputs *and* child endowments. The size of the coefficient for mother attending college also triples in the cumulative specification.

Similar to Todd and Wolpin's calculations (2007), we compare the sum of the coefficients of the lagged inputs with that of the lagged dependent variable in column 1 (0.57). The sum of the coefficients on all lagged inputs (.066+.10+.08+.09+.19) is 0.526 which is very close to the effect of the inputs that is theoretically summarized by the lagged reading score. With

the simplifying assumption that our observed inputs capture the history of home investment, this finding may suggest that the lagged dependent variable is a sufficient statistic for the child's historical home inputs and individual endowments.

The VAM-plus combines the specifications in (1) and (2) by including lagged reading ability, contemporaneous inputs, and lagged inputs; here, if the coefficients of the lagged inputs are not significant, the VAM assumption is valid. This is precisely what the results indicate in column 3; the coefficient of the lagged reading score is large and positive, at the same strength as in (1). In contrast to Todd and Wolpin's VAM-plus results, none of the lagged inputs are significant except for books in the home. This again supports the assumption that the lagged dependent variable effectively summarizes the history of child development inputs.

Columns 4–6 provide several additional specifications to help us understand the role of historical inputs and outcomes in the production of child cognition. In (4) and (5), we add two and then three lags of the dependent variable. These are interesting because they exclude inputs and only use data on outcomes—large administrative data on K-12 student achievement scores do not contain data on home inputs but do contain multiple observations of test scores, so these are specifications which can be implemented with typical data sets (though serial correlation could certainly undermine this strategy). Results show very little change in the coefficient of the first period lagged dependent variable from the standard VAM (1), though the two-period lagged score is significant with a coefficient of 0.07, the third period lags (9 months) are never significant.

Column 6 presents a 'fully saturated' VAM-plus model where we add the entire history of inputs and lagged dependent variables to explore whether additional lags improve upon Todd and Wolpin's optimal specification. This adds very little additional information to (3) or (1); age-5 reading books is still significant and the same magnitude as the VAM in (1), as is the lagged dependent variable coefficient.

So far our production function estimates have provided us with the 'total' effect of an input on child development in that it includes both the technical relationship between the observed input and output as well as the behavioral choices of parents and the effects of other unobserved inputs including characteristics of parents themselves. These estimates provide valuable descriptive information on the key associations with early childhood development but are not purely causal. For younger children, the primary source of bias derives from correlations between input choice and child endowment (μ). *Compensating* or *remedial* behavior occurs when parents apply more or higher quality inputs to children with lower endowments, whereas *reinforcing* behavior occurs when parents apply more or higher quality inputs to children with higher endowments. Consider a first-difference or fixed effect version of the contemporaneous production function and the VAM:

$$\Delta T_{it} = \alpha_t \Delta X_{it} + \Delta \varepsilon_{it} \quad \text{contemporaneous} \quad (3)$$

$$\Delta T_{it} = \alpha_t \Delta X_{it} + \gamma_{t-1} \Delta T_{it-1} + \Delta \varepsilon_{it} \quad \text{VAM} \quad (4)$$

In (3) and (4) the Δ term indicates the difference between the period indicated and one period prior. In equation (3), since the endowment (μ) is fixed over time (a plausible assumption given the short time frame considered here) the fixed-effect estimator purges the regression of this source of endogeneity and can provide unbiased estimates of the effects of the inputs on child cognition.

Column 7 shows the fixed-effect estimates for the contemporaneous model where the parental behavioral choices are eliminated. Comparison with column 3 shows that the parental behavioral pattern is fairly consistent, but that parents display slightly reinforcing behavior with respect to reading books since the coefficient of reading books is higher in the OLS specification (0.14) than it is in the fixed-effects specification (0.07). However, parents show compensatory behavior for owning books, which is now significant and strongly predictive of reading cognition at age 5 (0.27), where it was small and insignificant in the OLS specifications. Overall, these results indicate that key home inputs are causally related to children's development. See section c below for falsification tests of the fixed-effect estimate.

Our conclusion from these alternative specifications is that the first period lagged dependent variable in the VAM does remarkably well in capturing the history of inputs, and that without measures on historical inputs, one further lag of the dependent variable explains additional variance in the dependent variable. Of course from a behavioral and policy perspective, the cumulative model is the most informative because it identifies the precise inputs that matter for child development, as well as the timing of those inputs. Furthermore, while maternal education is a consistent predictor of reading skills at kindergarten, the effect is slightly smaller than the application of a manipulable parent behavior, reading books to the child. This input remains significant in the child fixed effect model that addressed potential endogeneity of inputs.

b. Specifications of the CDPF including the parent-child interaction

Both theory and empirical research from psychology and education demonstrate that parents' *engagement* and *sensitivity* in responding to their child's expressions and verbalizations, directly impact development (Hackman, Farah, and Meaney 2010, Tamis-LeMonda et al. 2009). To test these ideas we incorporate a measure of these types of parent-child interactions into the estimation of the CDPF. As described in the data section, our measure of the parent-child interaction comes from an age-appropriate and reliable instrument of the intellectually and emotionally supportive parent behaviors that were observed by the interviewer during parent interactions with their child for the first three waves. This is a more objective measure of the quality of parent's time spent with children than are the parent self-report HOME scale items that we use in the age-5 models (reading books and singing songs). Indeed, pairwise correlations between the parent self-report inputs and the interviewer observed interaction show no correlation above 0.25 (Appendix A).

We select four specifications from Section 4a, the VAM, the VAM-plus, the VAM2-plus, and the child fixed effect, estimate them for *age-4 reading only* since this parenting variable was not measured at age 5, and then add the parent-child interaction measure.¹² Column 1 of Table 3 shows estimates for the cumulative model for age-4 reading for comparability with the age-5 model in column 2 of Table 2. Contemporaneous and historical measures of reading books and ownership of books are highly significant at this age, and only a one-period lag of singing songs is significant; this is roughly consistent with the age-5 estimates.¹³

Columns 2 and 3 show the VAM without and then with the additional ‘parent-child interaction’ input. In (2), the coefficient of the lagged dependent variable is 0.28, almost cut in half from the age-5 model—state dependency appears to be much lower at younger ages. Note that this coefficient represents the relationship between the age-2 BSF cognitive assessment and the age-4 reading assessment. Therefore, the coefficient on the lag in the age-5 models represents a ‘true’ value-added score, and in the age-4 models it is more of a proxy for the value-added. In (3), the parent-child interaction variable is significant with a coefficient of 0.091, and its inclusion reduces the effect of all the other contemporaneous inputs, which underscores the fact that this input adds new information to the production function. Its inclusion also slightly reduces the coefficients on the child endowment and maternal education, though they each still remain significant.

Columns 4 and 5 show that including parent-child interaction in the VAM-plus model reduces slightly the effects of reading in the contemporaneous period and completely eliminates the effect of contemporaneous book ownership. Meanwhile parent-child interaction in all three periods is statistically significant with a large decay in the first lag (from 0.063 to 0.043) but a much smaller decay between the first and second. This is an important result in that it shows that reading ability at age 4 is directly associated with inputs applied at age 9 and 24 months, even after controlling for cognition at 24 months.

The results in (6) and (7) with the VAM2-plus lagged inputs models are identical to those in (4) and (5), which only included the first period lagged dependent variable. It appears that during infancy, additional lagged cognition measures do not add information to the production function; this is consistent with the idea that child cognition is developing rapidly during this period (Shonkoff and Phillips 2000).

Column 8 shows the child fixed-effect estimate that include our key inputs, reading books, singing songs, and parent-child interactions, all of which vary between waves. Singing songs is now significant (0.10) but not reading books, and book ownership is strongly significant and of the same magnitude as it was in the age-5 fixed effect. Parenting increased in magnitude to .14, indicating slightly compensatory behavior on behalf of parents relative to the smaller coefficient (0.63) we found in the OLS results. These results indicate that our main correlational findings are robust to fixed, unobserved child and family characteristics

¹²Because the dependent variable is now reading skills at the age-4 wave, the maximum number of lags available is 2. Also, the models in Table 2 suggest that a third period lag added very little information.

¹³Of course the age-5 estimates do not include school inputs, which can be an important source of omitted variable bias. This source of bias is less of a concern for the age-4 (pre-school age) models.

and indicate a causal relationship between parenting and child cognitive development over and above other key inputs.

Note that the sample sizes differ between model specifications due to missingness on inputs. We estimate each of the specifications for age 5 shown in Table 2, and for age 4 shown in Table 3 using a common complete-case sample in Appendix F Tables 1 and 2. This comprises cases used to estimate the VAM3-plus lagged inputs at age 5 (the most data intensive specification) with complete parent-child interaction assessment data ($n=3900$). Results using this restricted sample are nearly identical to those presented in our main tables but with slightly larger standard errors, rendering some inputs marginally significant.

Overall, the estimates in Table 3 highlight two important findings. First, the coefficient on the lagged dependent variable is half of what it was in the age-5 models (though the instrument used for the age-2 lag score differs from the age-4 reading score), 0.56, a coefficient that is the same as that reported by Todd & Wolpin (2007) for children age 12–13. This underscores a key feature of child development of enormous policy relevance, that state dependency grows stronger as a child becomes older. Using fixed-effects instrumental variables estimates to address bias in (only) the coefficient on the lagged dependent variable (shown in Appendix D), we find that OLS estimates of the lagged outcome measures are biased upwardly, but that the pattern of increased state dependence still holds. Secondly, the coefficient on the contemporaneous and all the lagged parent-child interaction measures were significant and robust to different model specifications, notably, in the fixed effect model which addresses endogeneity. This variable not only provides new information for the CDPF, but it also highlights that the application of this input is important at very early stages. Furthermore, parent-child interactions can be taught through policy interventions, and estimates of demands for this input indicate that they are not determined by parent's education or endowment alone (see Appendix C).

c. Falsification of fixed effects estimator

The fixed-effects version of the cumulative model is consistent under the maintained assumption that current inputs do not depend on past outcomes. This assumption may not be tenable if parents change their investment behavior dynamically depending on their assessment of their child's ability at different stages, which our fixed effects comparisons with OLS may suggest.

Using 'reading books' as an example, we characterize each child according to the book-reading pattern by their parent over the four waves, and the age at which parents initiated reading, in Appendix B. Figure 1 plots average child reading score by the age at which parents *initiated* reading to see whether early reading initiation is related to child ability. This figure illustrates two main points. First, though most children have similar abilities at 9 months, children who are read to at 9 months have slightly higher initial scores, an indication of *reinforcing* behavior. However, children of parents who delay reading until 24 months have the *same initial reading ability* as children whose parents delay reading until preschool or later. The same reading initiation pattern is observed by children's birthweight status. Children who are low birthweight (i.e., low endowment) are not more or less likely to be read to earlier (i.e., compensatory behavior) or later in development (Appendix B, Figure

2). In other words, among those who begin reading to children after nine months, there is no systematic relationship between the timing of reading and initial endowment.

Appendix B Table 2 shows means for test scores and frequencies of other characteristics by investment pattern to examine whether systematic differences in investment exist based on child endowment or parental characteristics. There appears to be no relationship among the birthweight status of the child, whether the mother has a college degree, and reading to the child at 9 months, suggesting that early application of this input is neither a response to the child's endowment nor an endowed characteristic of the mother herself. This pattern, along with the fixed-effects results, suggest that parents are not necessarily responding to children's endowments, and that having some exposure to reading and other inputs prior to school entry is causally related to age-4 and age-5 test scores.

d. Heterogeneity and additional specifications

We ran several additional model specifications to test for heterogeneity and to better understand the mechanisms at play in the CDPF. First, we test whether our early childhood production function parameters differ by maternal education status (college degree vs. no college degree) and by child sex in Appendix G Table 1. For each subgroup we estimate the VAM2-plus model at ages 4 and 5 and compare the coefficients of our key inputs using an adjusted Wald test. For nearly each input, coefficients were not systematically different between either college and not-college educated mothers or between boys and girls. The only significant difference indicated an advantage of reading books at ages 4 and 2 for children of college-educated mothers.

We estimated our age-5 models with the inclusion of the lagged parent-child interaction inputs, shown in Appendix G Table 2. Results indicate that the age-2 and -4 parenting assessments were significantly related to children's reading skills at age-5 in the cumulative model, but were no longer significant once the lagged dependent variables were included in the VAM specifications. This is consistent with our finding that the VAM does well in capturing the history of inputs.

To better understand the parenting dimensions involved in the CDPF, we unpacked the parent-child interaction measures at ages 2 and 4 into its two key components (emotional support, stimulating cognitive development), including both as separate variables for three of our VAM specifications (VAM, VAM-plus, VAM 2-lags plus). ¹⁴ These results indicate that mothers' stimulation of children's cognitive development (e.g., scaffolding language) is most predictive of children's reading skills at age 4.

5. Discussion and Conclusion

We report some of the first estimates of the child development production function during early childhood, a critical period for investing in human capital. The results offer rich insights into the nature of child development, the benefits of alternative specifications of the

¹⁴The ECLS-B investigators report that the subscales 9-month NCATS data have low alphas, which suggests that these subscales do not measure unitary constructs (see ECLS-B 9-Month Psychometric Report (Andreassen, Fletcher & West, 2005) section 6.5, for more detail). For this reason we did not investigate the components of the 9-month assessment.

CDPF, the type and timing of inputs that are important for child development, and the potential policy options for enhancing the life chances of children.

Our discussion of results focuses on the age-4 estimates (preschool) because home inputs are more relevant at this age compared to ages 5–6 when children begin formal schooling in kindergarten. Results from the cumulative model for age-4 reading skills (Table 3) indicate that lagged inputs for reading books, singing songs and ownership of books are all important. Particularly noteworthy here is that the level of *all* these inputs applied at 24 months of age are statistically significant determinants of cognition at age 4, and reading books as early as 9 months has a direct association with cognition at age 4. These results are consistent with psychology and neuroscience research that highlight the importance of stimulating, rich experiences during the first three years of life for children's optimal development, especially the role of home literacy activities like book reading (Rodriguez and Tamis-LeMonda 2011, Hoff 2003, Raikes et al. 2006). This is because learning experiences during the preschool years build on children's learning experiences and language skills from earlier in development to support more complex aspects of literacy and cognition (i.e., skills beget skills; Heckman and Masterov 2007). Thus, our results are consistent with the idea that early skills derived from early application of key inputs are foundational for later success.

One of our main innovations is the introduction of a measure of parenting behavior to the child development production function, the sensitivity and engagement of the parent in their interaction with their child. We show that the parent-child interaction brings additional information beyond the other inputs and endowments to the production process; both contemporaneous and historical levels of this input, as far back as 9 months, are direct and important determinants of cognition at age 4, even after controlling for cognition at 24 months.¹⁵ This finding is essential to policy because parenting skills can be modelled and taught through interventions like home visitation.

Our different VAM estimates also provided some evidence that state dependency—the degree to which present cognitive ability perfectly predicts future ability—gets stronger as children age between age 4 and the start of kindergarten at ages 5–6. The relationship between contemporaneous and prior period cognition is significantly smaller (by half) prior to school entry, implying that children are much more likely to be locked into a development path after entering school. Our exploration of alternative specifications of the production function indicate that the lagged dependent variable in a contemporaneous VAM specification does well in capturing the history of home inputs as well as endowments, and that one further lag explains additional variance in later reading ability. Based on these results, it seems that the lagged dependent variable does operate as a 'sufficient' statistic for family and home inputs. However, the usefulness of this model is extremely limited for early intervention programs and policies because it does not provide insights into the 'black box' of parent behaviors, including input choices and the timing of critical inputs that determine cognition.

¹⁵While many of the caregivers in our sample were mothers, this is not to say that these aspects of parenting wouldn't be just as beneficial with fathers (Tamis-LeMonda et al. 2004).

Our findings suggest that public policy would do well to focus efforts at parents of very young children to correct deficiencies that can alter a child's life-chances (Heckman and Mosso 2014, Heckman and Masterov 2007, Cunha and Heckman 2007). Moreover, these results may suggest that popular early childhood policies such as prekindergarten programs for 4-year-olds could be too late in children's development to meaningfully alter their developmental trajectory. Indeed, recent follow-up evaluations of some initially successful prekindergarten programs in different states indicate that any detectable treatment effects fade-out by the time children enter first or third grade (Lipsey et al. 2013, Hill, Gormley, and Adelstein 2012). Investments in human capital must occur throughout the life course, and as Heckman and colleagues propose, they should be front-loaded during the early years for the largest returns to investment. Because our study allowed us to examine home investment during the first years of life, our results further suggest that policy investments should occur *very* early in infancy, and these investments would be reinforced by investments later on.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Child Reading ability by Age of Parent's Reading Initiation

Children are grouped by the time period (measurement wave) in which their parent initiated reading. The y-axis represents the average reading ability score for children in that reading initiation group at each of the four measurement waves. See Appendix B for more detail.

Table 1:

Descriptive statistics of Family Inputs and Characteristics by ECLS-B Measurement Wave (weighted)

	(1)	(2)	(3)	(4)
	5 years	4 years	2 years	9 months
<i>Inputs</i>				
Sings songs	0.66	0.77	0.87	0.88
Reads books	0.74	0.73	0.72	0.54
10 or more books in home	0.92	0.91	0.84	0.50
<i>Child and Family Characteristics</i>				
Reading scale score (std.)	0.13 (0.92)	−0.027 (0.96)	0.15 (0.97)	0.18 (0.97)
Male	0.51	0.51	0.51	0.51
Black	0.14	0.14	0.14	0.14
Hispanic	0.25	0.22	0.25	0.25
Asian	0.026	0.026	0.026	0.028
Other race	0.045	0.047	0.047	0.046
Low birthweight	0.075	0.074	0.075	0.075
College	0.27	0.26	0.25	0.24
Rural	0.15	0.15	0.15	0.14
Northeast	0.17	0.17	0.16	0.16
West	0.24	0.23	0.24	0.24
Midwest	0.22	0.23	0.23	0.23
South	0.37	0.37	0.37	0.37
Mother's age (at birth)	28.3 (6.37)	28.4 (6.38)	28.3 (6.32)	28.2 (6.31)
Top income quartile (at birth)	0.20	0.21	0.20	0.20
Observations	6700	8300	8900	10200

SD in parentheses shown for continuous variables only. Observations are rounded to the nearest 50 in compliance with the ECLS-B security requirements. The age-5 data were collected in the fall of the child's kindergarten year; Age-4 data were collected at approximately 48 months of age. The inputs in the top panel come from the following questions derived from parent interviews at each of the study waves that were binary coded: 1) How often do you sing songs to your child? 2) How often do you read books with your child? and 3) How many books does the child have? Respectively, the binary coding of these inputs is: 1 if greater than 3 times per week, 1 if greater than 3 times per week, 1 if greater than 9 books. Sample statistics are survey weighted. Survey (expansion) weights were developed by the NCES to produce population representative estimates. They are modified at each wave to account for differential nonresponse at each wave and attrition in the sample over time since the study is designed for inference of the sample data—including response status—to the population level. The characteristics of the sample change very little between waves. Missingness seems to be moderately related mother's education, and we control for this in our analysis. We also examined unweighted sample statistics and similarly, the only difference across waves is in college-educated parents, who are slightly overrepresented in the last wave of data.

Table 2:

Estimates of the CDPF for reading Skills at Age Five (Kindergarten Entry)

	(1) VAM	(2) Cumulative	(3) VAM-plus lagged inputs	(4) VAM - 2 lags	(5) VAM - 3 lags	(6) VAM-plus with 3 lags	(7) Child fixed effect [^]
<i>Contemporaneous Inputs</i>							
Sings songs – 5 yrs.	0.023 (0.029)	0.011 (0.034)	0.0020 (0.029)	0.029 (0.031)	0.029 (0.031)	0.012 (0.031)	0.025 (0.029)
Reads books – 5 yrs.	0.14 *** (0.029)	0.18 *** (0.035)	0.14 *** (0.030)	0.14 *** (0.032)	0.14 *** (0.032)	0.14 *** (0.032)	0.070 *** (0.023)
10 or more books in home – 5 yrs.	0.030 (0.050)	0.061 (0.069)	–0.011 (0.051)	0.039 (0.049)	0.038 (0.049)	0.0012 (0.054)	0.27 *** (0.039)
<i>Lagged Inputs</i>							
Sings songs – 4 yrs.		0.066 ** (0.033)	0.038 (0.024)			0.035 (0.027)	
Sings songs - 2 yrs.		0.10 ** (0.051)	0.039 (0.044)			0.022 (0.049)	
Sings songs - 9 mo.		0.055 (0.050)	0.032 (0.041)			0.012 (0.041)	
Reads books – 4 yrs.		0.080 ** (0.040)	0.0082 (0.034)			0.013 (0.032)	
Reads books - 2 yrs.		0.061 (0.044)	–0.00045 (0.037)			–0.016 (0.038)	
Reads books - 9 mo.		0.090 ** (0.037)	–0.016 (0.032)			–0.015 (0.032)	
10 or more books in home – 4 yrs.		0.19 *** (0.069)	0.095 * (0.056)			0.089 (0.062)	
10 or more books in home - 2 yrs.		0.046 (0.046)	–0.028 (0.039)			–0.027 (0.041)	
Reading scale score (std.) – 4 yrs.	0.57 *** (0.022)		0.56 *** (0.023)	0.55 *** (0.022)	0.55 *** (0.023)	0.55 *** (0.024)	
Reading scale score (std.) - 2 yrs.				0.073 *** (0.017)	0.070 *** (0.017)	0.071 *** (0.017)	
Reading scale score (std.) - 9 mo.					0.017 (0.027)	0.019 (0.027)	
<i>Child and Family Characteristics</i>							
Male	–0.039 (0.025)	–0.11 *** (0.030)	–0.034 (0.026)	–0.026 (0.025)	–0.026 (0.025)	–0.020 (0.026)	
Black	0.012 (0.039)	0.0045 (0.040)	0.023 (0.040)	0.038 (0.043)	0.038 (0.043)	0.048 (0.044)	

	(1) VAM	(2) Cumulative	(3) VAM-plus lagged inputs	(4) VAM - 2 lags	(5) VAM - 3 lags	(6) VAM-plus with 3 lags	(7) Child fixed effect [^]
Hispanic	0.056 (0.040)	-0.10** (0.045)	0.065 (0.039)	0.089** (0.045)	0.090** (0.044)	0.096** (0.043)	
Asian	0.27*** (0.052)	0.51*** (0.057)	0.28*** (0.052)	0.30*** (0.060)	0.30*** (0.060)	0.30*** (0.060)	
Other race	-0.051 (0.071)	-0.068 (0.079)	-0.036 (0.069)	-0.040 (0.079)	-0.034 (0.079)	-0.019 (0.077)	
Low birthweight	-0.048* (0.028)	-0.14*** (0.034)	-0.052* (0.028)	-0.014 (0.030)	-0.0057 (0.030)	-0.0080 (0.031)	
College	0.12*** (0.029)	0.39*** (0.032)	0.11*** (0.030)	0.11*** (0.031)	0.11*** (0.031)	0.10*** (0.032)	
Observations	6300	6600	6250	5850	5850	5800	15859 ^I

Standard errors in parentheses.

*
p<.10

**
p<.05

p<.01.

Observations are rounded to the nearest 50 in compliance with the ECLS-B security requirements. Coefficients represent a standard deviation change in observer-rated child reading ability between 5 and 6 years of age derived from the ECLS-B reading assessment (during the fall of their kindergarten year; see text and Appendix E for more detail). VAM (1) is the Value-added model, which includes contemporaneous inputs and the first period lag of the dependent variable (child reading score) from the age-4 wave. The Cumulative model in (2) includes all lagged and contemporaneous input measures, but not lagged reading scores. The VAM-plus (3) includes everything in (1) and adds the lagged inputs. The model in (4) VAM-2 lags adds to (1) the second period lagged reading score (at age 2), and the VAM-3 lags (5) adds both the second and third period lagged reading scores (ages 2 and 9 months). Model (6) adds to (5) the contemporaneous inputs and the history of lagged inputs. (7) is a within-child difference estimator that includes only time-varying inputs. Models estimated using a complete-case sample shown in Appendix F.

[^] Coefficients on inputs displayed for the age-5 wave, but are within-child estimates. Observation count represents unique cases.

^I Unique case count for the child fixed effect model is 6850.

Table 3:

Estimates of the CDPF for reading Skills at Age Four

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Cumulative	VAM	VAM with parenting measure	VAM-plus lagged inputs	VAM-plus with parenting	VAM-plus with 2 lags	VAM-plus with 2 lags & parenting	Child fixed effect [^]
<i>Contemporaneous Inputs</i>								
Sings songs – 4 yrs.	0.049 [*] (0.027)	0.075 ^{**} (0.029)	0.067 ^{**} (0.030)	0.039 (0.028)	0.022 (0.033)	0.037 (0.028)	0.021 (0.033)	0.10 ^{**} (0.040)
Reads books – 4 yrs.	0.17 ^{***} (0.029)	0.21 ^{***} (0.030)	0.18 ^{***} (0.031)	0.16 ^{***} (0.032)	0.13 ^{***} (0.037)	0.16 ^{***} (0.032)	0.12 ^{***} (0.037)	0.050 (0.031)
10 or more books in home – 4 yrs.	0.15 ^{***} (0.037)	0.18 ^{***} (0.042)	0.14 ^{***} (0.041)	0.13 ^{***} (0.043)	0.037 (0.055)	0.13 ^{***} (0.043)	0.035 (0.055)	0.27 ^{***} (0.053)
Parent-child interaction (TB subscales) – 4 yrs.			0.091 ^{***} (0.013)		0.063 ^{***} (0.017)		0.063 ^{***} (0.017)	0.14 ^{***} (0.014)
<i>Lagged Inputs</i>								
Sings songs - 2 yrs.	0.097 ^{***} (0.035)			0.066 [*] (0.037)	0.062 (0.045)	0.069 [*] (0.037)	0.063 (0.045)	
Sings songs - 9 mo.	0.012 (0.035)			0.0018 (0.034)	-0.035 (0.042)	-0.00089 (0.035)	-0.037 (0.042)	
Reads books - 2 yrs.	0.13 ^{***} (0.032)			0.10 ^{***} (0.035)	0.090 ^{**} (0.037)	0.10 ^{***} (0.035)	0.091 ^{**} (0.037)	
Reads books - 9 mo.	0.11 ^{***} (0.027)			0.089 ^{***} (0.026)	0.11 ^{***} (0.037)	0.086 ^{***} (0.026)	0.11 ^{***} (0.036)	
10 or more books in home - 2 yrs.	0.14 ^{***} (0.040)			0.082 [*] (0.042)	0.067 (0.046)	0.081 [*] (0.041)	0.067 (0.047)	
Parent-child interaction (TB subscales) - 2 yrs.					0.043 ^{**} (0.019)		0.042 ^{**} (0.019)	
Parent-child interaction (NCATS score) - 9 mo.					0.036 ^{**} (0.014)		0.034 ^{**} (0.014)	

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Cumulative	VAM	VAM with parenting measure	VAM-plus lagged inputs	VAM-plus with parenting	VAM-plus with 2 lags	VAM-plus with 2 lags & parenting	Child fixed effect [^]
Reading scale score (std.) - 2 yrs.		0.28 *** (0.013)	0.27 *** (0.016)	0.26 *** (0.014)	0.26 *** (0.020)	0.25 *** (0.014)	0.25 *** (0.020)	
Reading scale score (std.) - 9 mo.						0.039 (0.024)	0.040 (0.029)	
<i>Child and Family Characteristics</i>								
Male	-0.14 *** (0.026)	-0.043 * (0.026)	-0.047 * (0.026)	-0.047 * (0.026)	-0.043 (0.033)	-0.045 * (0.026)	-0.040 (0.032)	
Black	-0.020 (0.033)	0.022 (0.035)	0.033 (0.036)	0.063 * (0.034)	0.100 ** (0.043)	0.060 * (0.034)	0.099 ** (0.043)	
Hispanic	-0.24 *** (0.038)	-0.19 *** (0.034)	-0.16 *** (0.036)	-0.15 *** (0.034)	-0.084 * (0.044)	-0.16 *** (0.035)	-0.086 * (0.044)	
Asian	0.35 *** (0.047)	0.39 *** (0.046)	0.46 *** (0.056)	0.42 *** (0.046)	0.53 *** (0.066)	0.42 *** (0.045)	0.52 *** (0.066)	
Other race	-0.0054 (0.057)	0.039 (0.058)	0.064 (0.062)	0.049 (0.058)	0.067 (0.061)	0.021 (0.047)	0.069 (0.060)	
Low birthweight	-0.20 *** (0.027)	-0.084 *** (0.026)	-0.075 *** (0.026)	-0.087 *** (0.025)	-0.085 *** (0.032)	-0.067 *** (0.025)	-0.064 * (0.035)	
College	0.52 *** (0.033)	0.46 *** (0.034)	0.44 *** (0.037)	0.43 *** (0.033)	0.37 *** (0.039)	0.43 *** (0.033)	0.37 *** (0.039)	
Observations	8200	7550	6700	7550	5050	7550	5050	16525 [†]

Standard errors in parentheses.

*
p<.10**
p<.05***
p<.01.

Coefficients represent a standard deviation change in observer-rated child reading ability at 4 years of age (dependent variable) derived from the ECLS-B reading assessment (see text and Appendix E for more detail). Observations are rounded to the nearest 50 in compliance with the ECLS-B security requirements. The Cumulative model in (1) includes all lagged and contemporaneous input measures, but

not lagged reading scores. VAM (2) is the Value-added model, which includes contemporaneous inputs and the first period lag of the dependent variable (child reading score) from the age-2 wave. Model (3) adds to (2) the contemporaneous parent-child interaction assessment score. The VAM-plus (4) includes everything in (2) and adds all the lagged inputs less the lagged parent-child interaction scores, which is added in (5). The VAM-plus with 2 lags (6) adds to (4) the second period lagged reading score (at 9 months). Model (7) adds to (6) the contemporaneous and lagged parent-child interaction scores. (8) is a within-child difference estimator that includes only time-varying inputs. Models estimated using a complete-case sample shown in Appendix F.

^a Coefficients on inputs displayed for the age-4 wave, but are within-child estimates. Observation count represents unique cases.

^b Unique case count for the child fixed effect model is 6650.