The Role of Parental Investments for cognitive and noncognitive skill formation – Evidence for the first 11 years of life

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Abstract:
This paper examines the impact of parental investments on the development of cognitive, mental and emotional skills during childhood using data from a longitudinal study, the Mannheim Study of Children at Risk, starting at birth. Our work offers three important innovations. First, we use reliable measures of the child’s cognitive, mental and emotional skills as well as accurate measures of parental investment. Second, we estimate latent factor models to account for unobserved characteristics of children. Third, we examine the skill development for girls and boys separately, as well as for children who were born with either organic or psychosocial risk. We find a decreasing impact of parental investments on cognitive and mental skills, while emotional skills seem to be unaffected by parental investment throughout childhood. Thus, initial inequality persists during childhood. Since families are the main sources of education during the first years of life, our results have important implications for the quality of the parent-child relationship.

Keywords: cognitive skills, noncognitive skills, critical periods, sensitive periods, initial risk

JEL-classification: I12, I21, J13

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1. Introduction
Recent interdisciplinary evidence has shown that early years are a crucial period for the development of human capital over the whole life cycle, but there is still much debate about the specific skill effects. In accordance with the technology of skill formation (Cunha et al. (2006), Cunha and Heckman (2007) and Cunha and Heckman (2008)), this paper addresses this issue by investigating the impact of parental investments on children’s cognitive, mental and emotional skill development in Germany. There is growing evidence for long-term effects of poor child skills and health on future economic as well as on non-economic outcomes. Cognitive and noncognitive abilities are important predictors for wages, education, crime and health, (e.g. Carneiro et al. (2008), Borghans et al. (2008) or Duckworth and Seligman (2005)).

At the same time, many studies have shown that human capital investments later in life (increasing school quality, teacher/student ratio or participation in active labor market policies) are less efficient than earlier investments (e.g. Carneiro and Heckman (2003)). Our primary goal is to address the issue of the optimal timing of investments regarding different skills during childhood. Our analysis enriches the research by following infants from birth until the age of 11 years using reliable psychometric measures of skills as well as of parental investments. Analysing this issue already from the beginning is of utmost interest, because there is various evidence that the IQ is stable by the age of ten years (Schuerger and Witt (1989)). However, most previous studies addressing this issue were unable to follow skill formation from birth on and lacked adequate measures of child skills and home environment. In our data, we have reliable expert ratings of skills and investments in each period during childhood, enabling us to improve on measurement error issues.

Our data contains a variety of measurements of cognitive, mental and emotional skills as well as various measurements of parental investments. This data has been studied recently by Blomeyer et al. (2009), who look at particular measurements and find the measured abilities at preschool age as well as initial risk conditions at birth to be important for performance later in life. Even though we use advanced skill and investment measurements, we face the problem that our inputs of the technology of skill formation are not exogenous. In fact, families with higher abilities and preferences for higher education are more likely to invest more, and not accounting for this will lead to an overestimation of the effect of parental investments. At the same time, skills acquired one period earlier are potentially endogenous, because they reflect unobserved abilities and preferences; hence, ignoring these issues might cause biased estimates. This paper improves on this earlier approach by Blomeyer et al. (2009). Instead of only using some particular measurements, we employ the complete measured information on skills and investments available to proxy latent skills by using factor models. The identified latent factors isolate different skills and investments from each other, thus reducing measurement error bias.

Skill gaps might already arise immediately after birth and increase during childhood long before formal education starts. Early family environment explains a crucial part of these gaps. Our data permit us to distinguish between children born with organic risk, e.g. low birth weight (LBW) or asphyxia, and children born with psychosocial risk, e.g. low educational level of the parents or early parenthood (for a detailed description of organic and psychosocial risk, see Blomeyer et al. (2008)).
Considerable evidence suggests that noncognitive skills are more malleable until later ages, while cognitive skills are not (Borghans et al. (2008)). However, assessments of skills might depend, at least to some extent, on both cognitive and noncognitive skills. In this study, we deal with this fact by differentiating noncognitive skills in two relatively independent dimensions. We exploit results from cluster and factor analyses to distinguish between mental skills and emotional skills, the former being more and the latter being less correlated with cognitive skills.

Our findings suggest that the importance of previous skills for later skill development (self-productivity) increases with age and differs among skills. It is highest for cognitive skills for each model. We find evidence for sensitive and critical periods of cognitive and mental skills. This implies that parental investments are most effective for both types of skills directly after birth and less effective at age eight (sensitive period). After this age their effects turn statistically insignificant (critical period).

Additional analyses by initial risk group status indicate that children who are born with organic risk have a lower self-productivity and benefit less from parental investments. We also find that boys tend to benefit more from investments in their cognitive skill development, while girls tend to benefit more in their mental skill development. Further, our analyses indicate that cognitive skills are most important for predicting school success, followed by mental skills, while emotional skills are less important.

The rest of the paper is organized as follows. Section 2 provides information about critical and sensitive periods and summarizes the previous literature. Section 3 describes the data and variables, while section 4 describes the method. In section 5, we present our estimation results, and section 6 concludes.

2. Background

The underlying concept of critical and sensitive periods is based on interdisciplinary research on brain development and is incorporated in the technology of skill formation (e.g. Shonkoff and Phillips (2000)). Both concepts are based on the pace of adoption of early experience of the biochemistry and architecture of neural circuits (Knudsen (2004)). A critical period is defined as a period during which investments have an impact for a limited time span only. If a child does not receive the appropriate stimulation during this period, it may be difficult or even impossible to develop certain functions later in life. In contrast, sensitive periods usually last for a longer time. In the case of sensitive periods, opportunities to attain certain skills exist that may not exist to the same extent in other periods. However, if chances to acquire these skills were not seized during a sensitive period, there may still be a chance to catch up on these skills later in life to attain the same goal (contrasting for critical periods) (Siegler (2006)).

A typical example for a critical period is language acquisition. Acquiring a language is relatively easy for children up to age of six; afterwards, the acquisition of language skills becomes more and more difficult (Pinker (1994)). Moreover, the United Nations Standing Committee on Nutrition recently stated that “while undernutrition kills during early life, it usually also leads to a high risk of disease and death later in life.” The “window of opportunity” spans from pre-pregnancy to around 24 months of a child’s age. Health and physical characteristics in adult life are significantly influenced by early
life conditions. The human muscle structure, for instance, has a critical period of development before birth and during the first six months of life (Barker et al. (2002)).

While critical periods in human development have received a lot of attention in medical and psychological studies, the relation between cognitive (intelligence, memory power and reasoning) and noncognitive (persistence, emotion, adaptability and temperament) skill development and the quality of stimulation in the early home environment has barely been addressed in economic research until now. In consequence, even less attention has been given to the way critical and sensitive periods may differ among heterogeneous individuals and their economic outcomes. However, both concepts have important implications for developing educational policies and the optimal timing of human capital investments.

We extend the existing literature by investigating the relationship between parental investments and skill development depending on the initial risk status. In the economic literature, there are only few studies that focus on critical periods in skill development over the life cycle. For example, the study by Todd and Wolpin (2004) uses the NLSY79 to quantify the impact of the HOME (Home Observation Measurement of the Environmental) inputs, school inputs and mothers’ ability on children’s’ achievement. Mothers’ abilities and HOME inputs combined explain more than half of the test score gap between individuals, while school inputs and mothers’ schooling level account only for a very small part of the test score gap. This finding suggests the importance of early investments for cognitive skill development.

Various studies by Heckman and co-authors investigate critical and sensitive periods based on the technology of skill formation starting at the age of six. Cunha and Heckman (2008), for example, find that parental investments affect cognitive skills more at earlier stages than at later stages, while they affect noncognitive skills more between the ages of six and 13 years. However, one limitation of these studies is that they investigate children’s skill development from the age of six years on, a time at which the brain has already developed to a large extent. The data we use follow individuals from birth until adolescence, which gives us the opportunity to examine critical and sensitive periods for cognitive and noncognitive skills starting at birth. A more recent study for Germany, using the same data, finds that noncognitive skills are more malleable during the first 11 years in comparison to cognitive skills (Blomeyer et al. (2009)).

3. Data and descriptive analysis

3.1 The Mannheim Study of Children at Risk

Detailed data on psychometric skills measures and investments come from the Mannheim Study of Children at Risk, a longitudinal epidemiological cohort study following infants at risk from birth to adulthood. The initial sample contains 382 children (184 boys, 198 girls) born between February 1986 and February 1988. Infants were selected according to their degree of exposure to organic and psychosocial risks. Organic risk reflects peri- and prenatal complications, such as LBW or asphyxia, while psychosocial risk covers risks e.g. related to low socio-economic environments such as a low educa-

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1 For a more detailed explanation of the study, see Blomeyer et al. (2008) or Laucht et al. (2004).
tional level of the parents or early parenthood. Organic and psychosocial risks were scaled into “no risk”, “moderate risk” and “high risk”. Children were assigned to one of the nine groups resulting from the two-factorial (3x3) design (see Figure 1). All groups have about equal size with a slight oversampling of high-risk combinations and equal gender ratios in all subgroups.

To control for confounding effects of family environment and infant medical status, only firstborn children with singleton births and German-speaking parents were enrolled in the study. Furthermore, children with severe physical handicaps, obvious genetic defects or metabolic diseases were excluded. The medical and psychological examinations of the research waves took place when the children were 3 months, 2, 4.5, 8, 11 and 15 years old and are still going on. Participation rates between the six waves are high, despite the extensive survey procedure, comprising a large number of medical and psychological examinations. 95.3 percent of the infants in the initial level participated. Our working sample amounts to 364 observations. Due to missing data, only 357 observations (88.5%) could be used.

3.2 Infant skills
3.2.1 Cognitive skills
Cognitive skills include memory power, information processing speed, intellectual power, linguistic skills, motor skills as well as general problem solving abilities (Borghans et al. (2008) or Knudsen et al. (2006)). In our dataset, measures for cognitive skills are represented by the IQ, the verbal IQ, the nonverbal IQ and the motor quotient (MQ). Each test consists of a variety of subtests such as numeracy, memory, receptive and expressive language skills. For the first time in the literature, cognitive tests are assessed from three months until the age of 11 years. IQ was measured in a verbal as well as in a nonverbal dimension from the age of two years onwards, since the development of verbal skills starts between 10 and 14 months (Tracy (2000)). For each period, cognitive skills were standardized (mean 0, std.dev.31). Means of the original variables in our dataset do not change over time. We use all measurements related to cognitive skills to proxy cognitive skills applying factor analysis.

3.2.2 Noncognitive skills
In line with the economic literature, we use different aspects of a child’s temperament as a measure for noncognitive skills during childhood. The assessment of noncognitive skills took place in two ways: within a standardized parent-interview and during structured direct observations in four standardized settings on two different days in both familiar (home) and unfamiliar (laboratory) surroundings. All ratings were assessed by trained judges on 5-point rating scales of nine temperamental dimensions adapted from the New York Longitudinal Study NYLS (Thomas et al. (1968)). Measuring tempera-

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2 The study was approved by the ethics committee of the University of Heidelberg and written informed consent was obtained from all participating families.
3 For each age, the cognitive tests were assessed with different psychometric measures. See the appendix for a more detailed description.
4 At the ages of 3 months and 2 years, the interrater reliability was measured in a preliminary study of 30 children.
mental characteristics at the age of three months already is quite reliable.\footnote{Satisfactory interrater agreement was obtained between two raters (3 months: $\bar{\kappa} = 0.68$, range 0.51 - 0.84; 2 years: $\bar{\kappa} = 0.82$, range 0.52 - 1.00).} We use five dimensions of a child’s noncognitive skills: approach/withdrawal, adaptability, prevailing mood, persistence and activity. In accordance with cognitive skills, all noncognitive skills are standardized (mean 0, std.dev. 1).

*Persistence* refers to a child's ability to pursue a particular activity and its continuation in the face of obstacles.

*Activity* describes the frequency and intensity of motor behavior ranging from being inactive and slow to being overactive and restless.\footnote{For the interpretation it is necessary to adjust the scale of activity. In the original version, the variable has a bipolar scale, which means that an average activity level indicates high noncognitive skills while very high and very low levels rather indicate low noncognitive skills. We transform the scale in such the way that high values indicate a high noncognitive skill level and low values, a small skill level.}

*Approach/withdrawal* describes the initial reaction to new stimuli (e.g. strangers, new food, or unfamiliar surroundings).

*Adaptability* denotes the length of time that is needed to be habituated to the new stimuli (at the age of 11 years, also including aspects of manageability such as the ability to cooperate with unpleasant occurrences, e.g. conflicts in the peer group or parental admonitions).

*Prevailing mood* describes the general tendency of the child to be in a good or a bad temper.

Besides the personality measures we use, a variety of competing taxonomies coexists. Adult personality is often measured by the Big five (Borghans et al. 2008). In contrast to that child and developmental psychologists usually focus on temperamental taxonomies that are better suited to assess the developmental process of personality from infancy to childhood (Thomas et al. 1968). In order to be able to measure child personality those taxonomies are usually based on parent-interviews and direct observations instead of questionnaires.

There exist studies that try to relate existing temperamental measures to the Big Five (Rothbart et al. 1998). They indicate that temperament scores load substantially on four of the Big Five personality factors. Our temperamental measure mood is most closely related to neuroticism and agreeableness. Approach and activity are related to extraversion. Persistence correlates the most with conscientiousness. The factor openness however seems barely related to any temperamental measures.

### 3.2.3. Latent skills

Even though the economic literature recently began to distinguish between cognitive and noncognitive skills, it is still a challenge to disentangle both skills, because measuring cognitive skills might also capture aspects of noncognitive skills and vice versa (e.g. Borghans et al. (2008) or Cunha and Heckman (2009)). E.g. typical noncognitive skills, such as the ability to persist and concentrate in performing a task might improve the results of an IQ test and thus lead to overestimation of cognitive skills. For our analysis, it is a useful tool to examine the way characteristics of both skills are related, e.g. put-
ting all skills into one regression would cause a lot of multicollinearity problems. In order to obtain an overview of how the skills are related, we conduct a cluster analysis. We use a hierarchical clustering to group our data into clusters, in such a way that objects in the same cluster are similar and the objects in different clusters are distinct. First we determine the distance between objects in order to find similarities and dissimilarities between every pair of objects in our data by calculating absolute correlations. Next we link pairs of objects that are in close proximity using the information generated in the first step. As objects are paired into binary clusters, the newly formed clusters are grouped into larger clusters until a hierarchical tree is formed (see Figure 2).

Figure 2 shows that the three noncognitive skills\textsuperscript{7} approach, adaptability and prevailing mood form one group, while activity and persistence form another group which is more closely related to cognitive skills. The MQ (motor quotient) sorts into the cognitive skill group. Our findings suggest that noncognitive skills seem to include a much more heterogeneous set of skills than cognitive skills.

To overcome the problem described above, we conduct a factor analysis. In a first step, we need to determine the number of latent factors required to reflect the data. We compute the number of eigenvalues of the correlation matrix that is greater than 1 (Kaiser 1960). Figure 3 shows the number of the eigenvalues of the correlation matrix. This analysis suggests three latent factors to reflect the data (which is in line with the results from the cluster analysis).

We use the orthomax-rotation which assumes latent factors to be orthogonal. Even if independence among latent factors is a strong assumption, it eliminates multicollinearity problems in the regressions.\textsuperscript{8}

Table 1 shows the correlations of the identified latent factors with the measurements.\textsuperscript{9} This yields three different types of skills: cognitive, mental and emotional skills (see Table 1). Noncognitive skills are split into two dimensions: mental and emotional skills.

\textsuperscript{7} For a detailed description of cognitive and noncognitive skills, see sections 3.2.1 and 3.2.2.

\textsuperscript{8} The orthomax rotation maximizes the variance of the squared factor loadings of a variable in a common factor (Frank and Todeschini 1994). It aims at obtaining common factors that are composed of only a few variables. Large factor loadings are further increased and small factor loadings further decreased. This results in uncorrelated and linearly independent factor scores. It moves the whole factor structure in a rigid frame around the origin unlike oblique techniques (e.g. the promax rotation) that rotate each factor separately. Alternatively, we conducted an oblique promax-rotation which generated very similar results, with coefficients being slightly greater due to higher multicollinearity among factors. The promax rotation relaxes the orthogonally requirement to achieve a simpler structure by normalizing the orthogonal loading matrix that was calculated by an orthogonal rotation by rows and columns and taking the $n^{th}$ power of each loading. This leads the loadings to be even closer to 0 and 1. The aim is to find an ideal matrix with even higher loadings.

\textsuperscript{9} A factor analysis revealing only two instead of three factors was also conducted. In this analysis, only cognitive skills and emotional skills are identified. Thus, important noncognitive traits like persistence and activity are not taken into account.
Mental skills are a mix of the optimal activity level and persistence.\(^\text{10}\) Emotional skills sum up traits like adaptability, approach and prevailing mood. Mental skills are more related to cognitive skills, while emotional skills form a completely different group. This result might have important implications for the malleability of both types of skills. We follow this strategy to improve our understanding on how different aspects of non-cognitive skills develop during childhood. Results presented in Table 1 show that the first factor is highly correlated with IQ, the second factor is highly correlated with persistence and activity and the third factor is highly correlated with approach, adaptability and prevailing mood. Descriptive evidence in Figure 4 indicates that children born with neither organic nor psychosocial risks have on average significantly higher cognitive skills compared to children born with either risk. Organic risk seems to affect cognitive abilities much stronger than psychosocial risk during childhood. Moreover, for children born with the highest degree of both types of risk, cognitive skills are lowest in comparison to all other risk combinations throughout childhood. However, the variance within this high-risk group is larger compared to other cells of the matrix, in particular the risk to have very low cognitive skills considerably.

Figure 5 and 6 present the distribution for mental and emotional skills, respectively. Differences in the mean values of mental skills are significantly lower among children born with psychosocial risk than among children born with organic risk throughout childhood. It is also important to note that the mean of mental skills is significantly lower if children were born with a combination of both risk types compared to any other case. The variation in mental skill levels increases with both the degree of organic and psychosocial risk. In contrast to mental skills, for emotional skills, living with organic risk seems to be more harmful than living with psychosocial risk (see Figure 6). The descriptive evidence suggests that cognitive and mental skills on average seem to behave more similarly to each other during childhood than emotional skills, while the distribution tends to depend on the initial risk conditions of the children.

### 3.3 Parental investments

Already in the early 80s, psychological studies indicated a strong link between cognitive abilities and the so-called “HOME” as a relevant measure for preparing and fostering abilities starting in early childhood (e.g. Bradly (1982)). Moreover, these studies show that mental test scores are more closely related to specific environmental processes than family background related variables. Instead of solely observing family income as a measure of parental investments, we focus on the quality of the home environment which also includes aspects of the parent-child relationship in this study using a modified version of the original HOME inventory (Bradly and Caldwell (1980)). To proxy the latent variable “parental investments”, we use all items of the HOME as a measurement at the ages of 3 months, 2 years, 4.5 years, 8 and 11 years. The HOME consists of six subscales: (1) emotional and verbal responsibility of the mother, (2) acceptance of the child, (3) organization of the environment, (4) provision of appropriate toys and (6) maternal involvement with the child. The number of items varies between 38 in the first period (age 3 month) and 81 at the age of 11 years. Similar to the skill measurements, mental skills are closely related to mental health (ADHD).\(^\text{10}\)
all items of the HOME score are also assessed by trained interviewers. The distribution of parental investment for each risk group and age is presented in Figure 7. Parental investments are also standardized by (0, 1). Figure 7 shows that they are quite high for children with no psychosocial risk and for children with low or high organic risk, on average. In particular, it seems to be that parental investments are slightly higher for children who were born with a high organic risk, which could imply that parents try to compensate initial organic risk. The reverse is true when we regard mean investments for children born with psychosocial risk. These systematic differences for children born with psychosocial risk demonstrate the importance of initial conditions followed by low parental investments. Moreover, it is obvious that the parental investments are relatively stable during childhood, in particular for children born with high psychosocial risk. However, there is still a large variation between the 90th and 10th percentile in mean parental investments.

4. Methods
As discussed in previous sections, we analyse how parental investments affect cognitive and noncognitive skill developments during five crucial periods of early childhood (at the ages of 3 month, 2 years, 4.5 years, 8 years, 11 years, respectively). In accordance to Cunha and Heckman (2007), we estimate a linear-specified technology of skill formation. Instead of using noncognitive skills as one single measure, we differentiate between mental and emotional skills:

\[
S_t^c = f_t(S_{t-1}^c, S_{t-1}^m, S_{t-1}^e, I_t)
\]

\[
S_t^c = a_0^c + a_{1,t-1}^c S_{t-1}^c + a_{2,t-1}^m S_{t-1}^m + a_{3,t-1}^e S_{t-1}^e + b_t^c I_t + \eta_t^c
\]  \hspace{1cm} (1a)

\[
S_t^m = f_t(S_{t-1}^c, S_{t-1}^m, S_{t-1}^e, I_t)
\]

\[
S_t^m = a_0^m + a_{1,t-1}^c S_{t-1}^c + a_{2,t-1}^m S_{t-1}^m + a_{3,t-1}^e S_{t-1}^e + b_t^m I_t + \eta_t^m
\]  \hspace{1cm} (1b)

\[
S_t^e = f_t(S_{t-1}^c, S_{t-1}^m, S_{t-1}^e, I_t)
\]

\[
S_t^e = a_0^e + a_{1,t-1}^c S_{t-1}^c + a_{2,t-1}^m S_{t-1}^m + a_{3,t-1}^e S_{t-1}^e + b_t^e I_t + \eta_t^e
\]  \hspace{1cm} (1c)

Where \(S_t^c\), \(S_t^m\) and \(S_t^e\) denote cognitive, mental and emotional skills in period \(t\) and \(I_t\) denotes parental investment in their child’s skills for each period \(t\). In accordance to Cunha and Heckman (2007), we define critical and sensitive periods as follows:

**Period \(t\) is a critical period for \(S_t^c, S_t^m, S_t^e\) if:**

\[
\frac{\partial}{\partial I_t^k} S_{t+1}^k = \frac{\partial}{\partial I_t^k} S_{t+1}^m = \frac{\partial}{\partial I_t^k} S_{t+1}^e = \frac{\partial}{\partial I_t^k} f_t(S_t^c, S_t^m, S_t^e, I_t^k) = 0 \quad \forall \quad S_t^c, S_t^m, S_t^e, I_t^k \quad \text{for} \quad k = c, m, e
\]

but

\[
\frac{\partial}{\partial I_t^k} S_t^c = \frac{\partial}{\partial I_t^k} S_t^m = \frac{\partial}{\partial I_t^k} S_t^e = \frac{\partial}{\partial I_t^k} f_t(S_{t-1}^c, S_{t-1}^m, S_{t-1}^e, I_t^k) > 0 \quad \text{for some} \quad S_t, I_t^k \quad \text{for} \quad k = c, m, e
\]

**Period \(t\) is a sensitive period for \(S_t^c, S_t^m, S_t^e\) if**

\[
(2)
\]
A **critical** period describes a time span $t$ for cognitive (mental or emotional) skill development if parental investments are productive in period $t-1$, but not in the subsequent period $t$ (see equation (2)). A **sensitive period** denotes a time span $t$ for cognitive (mental or emotional) skill development if the same amount of parental investments is more productive in period $t-1$ than in period $t$. Using a linear specification, we can observe critical and sensitive periods for cognitive, mental and emotional skills. Moreover, it is possible to observe self-productivity and direct-complementarities among these three skills. Self-productivity means that the formation of skills is the more productive the higher the stock of skills at the previous period. In accordance to self-productivity, direct-complementarities apply if cognitive skills are productive for the formation of non-cognitive skills at previous periods and vice versa. Instead of using single proxies for cognitive and noncognitive skills, we use cognitive test scores and behavioral measures as well as parental inputs as indicators for latent skills and latent parental investments.\(^{11}\)

Equations (4a) - (4d) describe the measurement equations for all skills ($Y$) and parental investments ($X$) in each period during childhood:

\[
Y_{j,t} = \alpha_{j,t}^c + \beta_{j,t}^c S_t^c + \epsilon_{j,t}^c \quad \forall t = 1, \ldots, 5 \tag{4a}
\]

\[
Y_{j,t} = \alpha_{j,t}^m + \beta_{j,t}^m S_t^m + \epsilon_{j,t}^m \quad \forall t = 1, \ldots, 5 \tag{4b}
\]

\[
Y_{j,t} = \alpha_{j,t}^e + \beta_{j,t}^e S_t^e + \epsilon_{j,t}^e \quad \forall t = 1, \ldots, 5 \tag{4c}
\]

\[
X_{j,t} = \alpha_{j,t}^i + \beta_{j,t}^i I_t^i + \epsilon_{j,t}^i \quad \forall t = 1, \ldots, 5 \tag{4d}
\]

Instead of using the unobserved vectors for skills and parental investments $S$ and $I$, we use measurements $j$ for each skill and investment at each stage. We normalize the first $\beta$ to $\beta_{j,t}^c = \beta_{j,t}^m = \beta_{j,t}^e = \beta_{j,t}^i = 1$. Substituting measurement equations (4a) – (4d) into equations (1a) – (1b) yields:

\[
y_{t,i} = \gamma_{1,i}^c Y_{i,1}^c + \gamma_{2,i-1}^c Y_{i,1-i}^c + \gamma_{3,i}^c Y_{i,1}^e + \gamma_{4,i-1}^c X_{i,1}^c + u_{t}^c \quad \forall t = 1, \ldots, 5 \tag{5a}
\]

\[
y_{t,i} = \gamma_{1,i}^m Y_{i,1}^m + \gamma_{2,i-1}^m Y_{i,1-i}^m + \gamma_{3,i}^m Y_{i,1}^e + \gamma_{4,i-1}^m X_{i,1}^m + u_{t}^m \quad \forall t = 1, \ldots, 5 \tag{5b}
\]

\[
y_{t,i} = \gamma_{1,i}^e Y_{i,1}^e + \gamma_{2,i-1}^e Y_{i,1-i}^e + \gamma_{3,i}^e Y_{i,1}^e + \gamma_{4,i-1}^e X_{i,1}^e + u_{t}^e \quad \forall t = 1, \ldots, 5 \tag{5c}
\]

The error term of each equation (5a) – (5c) $u_t$ includes all errors $\epsilon$ from (4a) – (4b) and the error term from equation (1a) – (1c): For example, the error term $u_t^c$ for equation (5a) is:

\[
u_t^c = \epsilon_{1,t}^c - \gamma_{1,i-1}^c \epsilon_{1,i-1}^c - \gamma_{2,i-1}^c \epsilon_{1,i-1}^e - \gamma_{3,i-1}^c \epsilon_{i,t}^e - \gamma_{4,i-1}^c \epsilon_{i,t}^i + \eta_t^c
\]

We estimate equations (5a) – (5c) by least squares. The problem arising when estimating these models applying least squares is that we have to assume that the errors $u_t$ are uncorrelated with all latent skills and parental investments in each. Otherwise, our pa-

\(^{11}\) See section 3 for a detailed description.
rameters of interest are biased. Under the assumption that the errors \( e \) are mutually independent and uncorrelated over time, it is possible to identify the parameters of interest \( \gamma \) (Cunha and Heckman (2008)). However, many variables used in empirical analysis are recoded with error. The error can be random and/or systematic. In the latter case, the errors are not independent and uncorrelated and thus the estimates are biased. The question is how to reduce the (systematic) measurement error in the variables. Skills and investments are more likely to measure with a systematic error if these measures are unable to reflect the true variable. This can result from an interviewer or respondent bias. We would expect that the measurement error in our data is quite small for two reasons: First, the interviewers were trained for each interview and for each assessment, for HOME score as well as for psychometric tests. Often, different interviewers performed the same assessments repeatedly. The intrarater reliability defines the correlation of the test result for one individual between interviewers. In most cases, this score has a correlation which varies between 0.6 and 0.8; secondly: the respondent bias due to misunderstanding questionnaires is not problematic in our data, because measure referring the child was commonly assessed by the trained interviewers. The assessments of skills and investments occurred in different standardized surroundings and on different days and is, therefore, highly valid. Additionally, the quality of the assessments is high, because trained interviewers observe children and their parents from birth on. This results in a trustful relationship and reduces non-response of difficult and critical questions. Thus, we would expect a relatively small measurement error in the estimates at each period and, therefore, less biased estimates of the parameters of the skill production function.

In the next section, we illustrate our estimation results. Therefore, we separately estimate equations for each latent skill (cognitive, mental and emotional) at each stage during childhood (2 years, 4.5 years, 8, years and 11 years).

5. Results

5.1 Skill production function with cognitive, mental and emotional skills

Figure 8 presents our estimates for cognitive, mental and emotional skills during the first 11 years of life. We estimate the same models as in section 4, but we explicitly allow for two different measures of noncognitive skills. We use bootstrapped standard errors with 500 replications. The upper row of graphs shows the estimation results for self-productivity of cognitive skills (cognitive\(\rightarrow\)cognitive) and direct-complementarities between cognitive and mental as well as between cognitive and emotional skills (cognitive\(\rightarrow\)mental and cognitive\(\rightarrow\)emotional). Graphs in the second row illustrate estimation results for self-productivity of mental skills (mental\(\rightarrow\)mental) and direct complementarities between mental and cognitive skills (mental\(\rightarrow\)cognitive) and direct-complementarities between mental and emotional skills (mental\(\rightarrow\)emotional). The third row presents estimation results for emotional skills: firstly direct-complementarities between emotional and cognitive skills and between emotional and mental skills (emotional\(\rightarrow\)cognitive and emotional\(\rightarrow\)mental), secondly self-productivity for emotional skills (emotional\(\rightarrow\)emotional). The bottom row shows estimation results for the impact of parental investment for each skill, respectively. For the following analysis, we structure the presentation of our estimation results in the same way.

Our results indicate different patterns for the development of skills during childhood. All skills have in common that the stock of skills acquired during previous periods is
essential for the skill formation in later periods (cognitive→cognitive, mental→mental and emotional→emotional). In fact, self-productivity steadily increases during childhood; however, the estimates suggest that self-productivity for mental skills is important only after the age of four. In contrast to that even innate cognitive and emotional skills contribute to their further development. Self-productivity is the largest for cognitive skills (cognitive→cognitive).

Regarding direct-complementarities between these skills, it is obvious that cognitive skills foster mental skills and vice versa (e.g. cognitive→mental and mental→cognitive in figure 8), but neither cognitive nor mental skills have an effect on the development of emotional skills (e.g. cognitive→emotional and mental→emotional). Sensitive and critical periods are found for cognitive and mental skills (home→cognitive and home→mental), while emotional skills are not affected by the HOME score (home→emotional). Surprisingly, regarding the effect of the HOME scores on cognitive and on mental skills, both skills behave quite similar. The estimated effect of the HOME score is higher directly after birth compared to the impact of the HOME score two years later and 4 years later, while it becomes insignificant at age eight. Moreover, the effect is nearly twice as large for mental skills compared to cognitive skills.

The coefficient of the investment on cognitive skills at the age of 2 years is approximately 0.13. For the 50th percentile of the cognitive skill distribution this corresponds to an increase to the 56th percentile. For the mental skill distribution the coefficient of 0.27 even corresponds to an increase from the 50th to the 66th percentile. This example illustrates the shaping role of parental investments in early childhood.

The results also imply that there are differences in the effectiveness of investments, since mental skills are malleable, while emotional skills seem not to be affected by the HOME score (home→mental and home→emotional). This result suggests that other factors such as genetic endowment or peers are more important for the development of emotional skills.

Our sample is not representative for the overall population, due to an oversampling of children at risk. Hence, we re-estimate the models for a weighted representative sample (for the calculation of the weights, see Table 1b in Appendix). Our data contains 110 individuals from a representatively selected sample. To generate weights, we calculate the fraction of the representative observations on the overall observations for each risk group. The results are reported in Figure 9. The baseline pattern of critical and sensitive periods is not affected when using a (weighted) representative sample instead of the originally (risk) sample, however, the impact of the HOME score on cognitive skills seems to be more similar to mental skills. The coefficient of the investment on cognitive skills at the age of 2 years is approximately 0.19. For the 50th percentile of the cognitive skill distribution this corresponds to an increase to the 59th percentile. For the mental skill distribution the coefficient of 0.2 corresponds to an increase from the 50th to the 61th percentile.

This indicates that a high organic risk at birth might have an adverse effect on the impact of the HOME score on cognitive skills. This result is confirmed by the analysis in Section 5.2. Besides, for the representative sample, we find a significantly positive effect of the HOME score on emotional skills in late childhood.
5.2 Skill production function with cognitive, mental and emotional skills by initial risk status

In addition to the results presented in the section before, we differentiated by the initial risk-group status. In order to assess how the results might be affected by risk-group status at birth, we re-estimate our models presented in the previous section for three different risk groups (see Figure 10). First, we are interested in the skill development in children who were born with organic (medium or high) risk. Secondly, we compare the skill development of children who were born with psychosocial (medium or high) risk. And thirdly, we re-estimate all models for children with combined risks. Clearly, our sub-sample size varies between 80 and 160 observations, leading to less precise estimates. However, our intention is merely to get an idea of how initial conditions matter in the skill developmental process during childhood.

The main pattern of Figure 10 (homeÆcognitive) is that we find significant effects the HOME score on cognitive skill development during childhood only for children with psychosocial risk. For children born with organic risk, the HOME score seems to have no effects on cognitive skill development indicating that organic risk impairs skill development during childhood. It is essential to note that children born with organic risk often tend to experience an above average amount of parental investments (compare Figure 7). However, this adverse initial organic condition seems to remain persistent, even with high parental investments, at least during the first 11 years of life.

In contrast, being part of a high risk group barely seems to have an effect on HOME score impacts on mental skill development and differences are generally insignificant (homeÆmental). Emotional skills, on the other hand, seem to be positively influenced by high HOME scores in the group with high psychosocial risk during late childhood (homeÆemotional). Just like for cognitive skill development, high organic risk seems to have adverse effects. In all risk groups, the HOME score has a significantly positive effect on mental skill development.

Self-productivity tends to be less pronounced among children born with organic risk compared to psychosocial or combined risk groups when regarding cognitive and mental skills (see cognitiveÆcognitive, mentalÆmental and emotionalÆemotional). For emotional skills, the group of children born with combined risk indicates a high self-productivity for most stages during childhood. For cognitive skills, we find self-productivity to be positive at least from the age of two years on for all risk groups. For mental and emotional skills, self-productivity is significant from the age of four on.

The adverse effects of organic risk on skill development in our results are consistent with findings from the low birth weight (LBW) literature, showing lasting impacts of LBW in school and even in the labor market (e.g. Oreopoulos et al. (2008)) In contrast, children born with psychosocial risk mostly benefit from parental investments throughout childhood. The effect decreases over time and is insignificant only at age four. Our estimates display the following pattern: organic risk at birth is much more harmful for cognitive skill development than psychosocial risk during childhood. Even in the case of high parental investments, these are less effective for cognitive skill development for children born with organic risk compared to children born with psychosocial
risk. This in line with findings that organic risk such as LBW significantly reduces outcomes later in life (Black et al. 2007). For mental skills, parental investment matters more for children born with organic risk than for children born with psychosocial risk. For emotional skills, we find no significant impact of parental investments depending on status and stages. Even in these small samples, our results indicate that initial conditions matter throughout childhood and that organic risk is more detrimental for the development of cognitive skills, while psychosocial risk is more detrimental for the development of mental and emotional skills, regarding the effect of parental investments.

5.3 Skill production function with cognitive, mental and emotional skills by gender

Gender differences in the development of skills exist but seem to be quite small (see Figure 11). We observe evidence of self-productivity for cognitive, mental and emotional skills in both girls and boys (see cognitive → cognitive, mental → mental and emotional → emotional). Regarding cognitive skills, self-productivity is larger from age four on in girls, but at the end of childhood, gender differences seem to vanish (cognitive → cognitive). For mental skills, self-productivity is larger for boys, while, generally, self-productivity for emotional skills is quite larger for girls.

Cognitive skills foster mental and emotional skills equally in both genders. This effect is larger for girls, while the cross-effects between mental and emotional skills are insignificant for girls and boys. In line with previous results, there are no significant gender-specific effects of emotional skills on cognitive and mental skills.

For boys, the effect of parental investment on cognitive skills is significantly decreasing up to the age of eight years (sensitive periods). Afterwards, cognitive skills seem to be unaffected by parental investment (critical period). In contrast, parental investments seem to have a smaller impact on a girl’s cognitive skill development throughout childhood compared to boys. Gender-specific differences also arise in mental skills. Here, girls benefit remarkably more than boys from parental investments at each stage during childhood (see last row). To both genders equally applies that emotional skills are not influenced by parental investments.

The results support evidence that girls tend to surpass boys with respect to noncognitive skills (Jacob 2002) while boys tend to perform better in cognitive skill based subjects like mathematics (Husain and Millimet 2009).

5.4 Relationship between skills and educational performance

In this section, we address the well-known finding that skills attained during childhood are important predictors of school success. First, we look at the relationship of cognitive, mental and emotional skills attained during childhood with grades in math, German and the first foreign language at age 11 and 15 using an aggregate grade score (see Table 2). The distribution of school grades is presented in Figure 1a, Appendix. Second, we focus on the probability to attain a high school degree (see Table 3).

Although these results cannot be interpreted in a causal manner, they are useful for the prediction of school achievement and give some hint on how important early skills are and which kind of skills matter.

12 Often, educational studies use test scores like PISA or PIRLS as a measure of student performance. However, we are unable to observe more objective students tests within the data.
The results indicate that cognitive and mental skills are important predictors of school grades, and the prediction increases with age. Cognitive skills significantly predict school grades already at the age of three months. From age two on, children with high mental skills perform significantly better in school. In contrast, emotional skills seem to be less important for school success. If we would aggregate the coefficient for cognitive, mental and emotional skills (0.21+0.15+0.07) attained at the age of 11 years, grades at school improve by nearly half a grade. This finding supports evidence that both cognitive and noncognitive skills equally seem to contribute to economic success later in life (Borghans et al. 2008, Heckman 2008).

Table 3 presents the relationship between cognitive, mental and emotional skills and the probability of attaining a high school degree (Abitur). In accordance with school grades, our results suggest that cognitive and mental skills are the most important skills for school success. An increase in cognitive and mental skills by one standard deviation increases the probability of attaining a high school degree by seven percentage points. The probability increases with age. For example, the marginal probability of attaining a high school degree is 0.18 percentage points at age 11. Emotional skills obtained at age two and 4.5 are predictors for secondary school track, but later on, they are no longer important.

Altogether, these results show two important patterns. First, even skills observed directly after birth are related to later school achievement. Due to the relevance of self-productivity for cognitive, mental and emotional skills (see results from previous sections), this result implies that inequality starts very early and increases during childhood. Secondly, cognitive and mental skills, which comprise, for example, the ability to pay attention, are more important for school achievement than emotional skills.

6. Conclusion

We provide new evidence regarding the skill formation process during childhood. While investigation of the skill formation process in conventional economic studies starts very late in childhood (at the age of six years), we explicitly account for the skill formation process during early childhood, starting directly after birth. Moreover, we deal with the heterogeneity of noncognitive skills by using two instead of only one non-cognitive skill dimension.

We find the distributions of mental and cognitive skills to be closely related and emotional skills to be more distinct. In line with that our estimation results indicate that investment in cognitive and mental skills measured by the HOME score also seems to be more productive than investments in emotional skills.

We find evidence for critical and sensitive periods for cognitive and mental skills. Our estimation results show a decreasing impact of the HOME score (sensitive periods) during infancy. The effect becomes insignificant during the time span between 4.5 and 8 years for cognitive skills and after the age of eight years for mental skills (critical periods). In contrast to that we find no impact of the HOME on emotional skills during the entire 11 years of childhood.
However, this result refers only to specific aspects of parental investments measured by the HOME and does not generalize with regard to other kinds of parental investments. It suggests that other factors such as genetic endowment or peers may be more important for the development of emotional skills.

Relating to skill self-productivity and direct-complementary our latent factor estimates suggest that increases in cognitive, mental and emotional skills raise the stock of cognitive, mental and emotional skills at later stages during childhood. Self-productivity increases with age and differs with regard to skills, being highest in cognitive skills in each model. This result is in line with the literature suggesting noncognitive skills to be more malleable than cognitive skills (Cunha and Heckman 2007). Further, direct-complementarities are observed between cognitive and mental skills. Cognitive skills foster the development of noncognitive skills and vice versa.

Additional analyses by initial risk group status indicate that children who are born with organic risk have a lower self-productivity and benefit less from parental investments. Parental investments in cognitive skill development, for instance, have no impact on cognitive skills, neither at birth nor at the end of childhood. In contrast, parental investments have the largest effect on cognitive skill development among children born with initial psychosocial risk, but the lowest impact regarding emotional development. This finding supports the hypothesis that children born with LBW or born preterm tend to be less able to catch up these adverse initial conditions. Given this finding investments during pregnancy are essential for the further development. This is in line with studies indicating the adverse effects of maternal smoking, health problems, depression and SES during pregnancy (Barker et al. 2002).

Gender specific differences regarding the skill formation process are small. The amount of self-productivity and direct-complementary is quite similar. Differences between girls and boys arise when observing the effect of parental investments. Here, boys gain more in terms of cognitive skill development, while girls gain more with respect to their mental skill development. Finally, we actually ask how important cognitive, mental and emotional skills are for school success. Our results indicate that cognitive skills are most important for explaining school success, followed by mental skills, while emotional skills are less important. Even at the age of three month cognitive skills are already an important predictor for school success. The relationship increases with age.
References


Figures:

Figure 1: The Mannheim Study of Children at Risk

Source: Mannheim Study of Children at Risk.

Figure 2: Cluster analysis

Source: Mannheim Study of Children at Risk. Own calculations.
Figure 3: Eigenvalues of the correlation matrix

Source: Mannheim Study of Children at Risk. Own calculations.
Figure 4: Distribution of cognitive skills by age and risk status

Note: Mean (and grey-shaded 95 % confidence bounds), the 10th, 90th percentile of standardized cognitive skills.
Source: Mannheim Study of Children at Risk. Own calculations.
Figure 5: Distribution of mental skills by age and risk status

Note: Mean (and grey-shaded 95% confidence bounds), the 10th, 90th percentile of standardized mental skills.

Source: Mannheim Study of Children at Risk. Own calculations.
Figure 6: Distribution of emotional skills by age and risk status

Note: Mean (and grey-shaded 95% confidence bounds), the 10th, 90th percentile of standardized emotional skills.
Source: Mannheim Study of Children at Risk. Own calculations.
Figure 7: Distribution of parental investments by age and risk status

Note: Mean (and grey-shaded 95% confidence bounds), the 10th, 90th percentile of standardized parental investments.

Source: Mannheim Study of Children at Risk. Own calculations.
Figure 8: Estimates of the skill production function with three skill factors

Note: 95% confidence bounds are dashed lines (bootstrapped standard errors) 357 observations.
Source: Mannheim Study of Children at Risk. Own calculations.
Figure 9: (Weighted) estimates of the skill production function with three skill factors

Note: 95% confidence bounds are dashed lines (bootstrapped standard errors) 357 observations.
Source: Mannheim Study of Children at Risk. Own calculations.
Figure 10: Estimates of the skill production function with three skill factors by initial risk status

![Graphs showing skill production function estimates for cognitive, mental, and emotional skills across different risk statuses.](image)

**Note:** 95% confidence bounds are dashed lines (bootstrapped standard errors) 357 observations.

**Source:** Mannheim Study of Children at Risk. Own calculations.
Figure 11: Estimates of the skill production function with three skill factors by gender

Note: 95 % confidence bounds are dashed lines (bootstrapped standard errors) 357 observations.
Source: Mannheim Study of Children at Risk. Own calculations.
### Table 1: Correlations of skill measures with latent factors

<table>
<thead>
<tr>
<th>age</th>
<th>IQ</th>
<th>MQ</th>
<th>NV-IQ</th>
<th>V-IQ</th>
<th>Activity</th>
<th>Approach</th>
<th>Adaptability</th>
<th>Mood</th>
<th>Persistence</th>
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</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.92</td>
<td>0.53</td>
<td>-0.07</td>
<td>0.18</td>
<td>0.08</td>
<td>0.15</td>
<td>0.07</td>
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<tr>
<td>2</td>
<td>0.83</td>
<td>0.61</td>
<td>0.63</td>
<td>0.60</td>
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<td>0.18</td>
<td>0.13</td>
<td>0.21</td>
<td>0.23</td>
</tr>
<tr>
<td>4.5</td>
<td>0.82</td>
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<td>0.61</td>
<td>0.77</td>
<td>0.09</td>
<td>0.09</td>
<td>0.18</td>
<td>0.13</td>
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<td>8</td>
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<td>0.45</td>
<td>0.64</td>
<td>0.61</td>
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<td>0.01</td>
<td>0.18</td>
<td>0.01</td>
<td>0.38</td>
</tr>
<tr>
<td>11</td>
<td>0.92</td>
<td>0.52</td>
<td>0.41</td>
<td>0.70</td>
<td>0.05</td>
<td>-0.04</td>
<td>0.22</td>
<td>-0.12</td>
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#### Cognitive Skills

<table>
<thead>
<tr>
<th>age</th>
<th>0.25</th>
<th>-0.05</th>
<th>-0.09</th>
<th>0.66</th>
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<td>0.00</td>
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<td>8</td>
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<td>0.74</td>
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<td>0.57</td>
<td>0.13</td>
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#### Mental Skills

<table>
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<tr>
<th>age</th>
<th>0.25</th>
<th>0.20</th>
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<th>0.96</th>
<th>0.61</th>
<th>0.69</th>
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<td>0.97</td>
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<td>0.00</td>
<td>0.96</td>
<td>0.42</td>
<td>0.78</td>
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</table>

#### Emotional Skills

Source: Mannheim Study of Children at Risk. Own calculations.

### Table 2: Predicting school grades at the age of 11 and 15 years

<table>
<thead>
<tr>
<th>stage (t)</th>
<th>cognitive skills</th>
<th>mental skills</th>
<th>emotional skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 months</td>
<td>0.09* (0.03)</td>
<td>0.05 (0.03)</td>
<td>0.06 (0.03)</td>
</tr>
<tr>
<td>2 years</td>
<td>0.19* (0.04)</td>
<td>0.11* (0.03)</td>
<td>0.00 (0.03)</td>
</tr>
<tr>
<td>4.5 years</td>
<td>0.24* (0.04)</td>
<td>0.07* (0.03)</td>
<td>0.00 (0.03)</td>
</tr>
<tr>
<td>8 years</td>
<td>0.25* (0.04)</td>
<td>0.14* (0.03)</td>
<td>0.07* (0.03)</td>
</tr>
<tr>
<td>11 years</td>
<td>0.21* (0.04)</td>
<td>0.15* (0.03)</td>
<td>0.07* (0.03)</td>
</tr>
</tbody>
</table>

Source: Mannheim Study of Children at Risk. 357 observations, own calculations. Note: standard errors are in parenthesis: * significant at 1% level; The dependent variable is an average over the six different grades at age 11 and 15. Mean = 4.07, min = 2.17, max = 5.95, with grades being transformed to 1=fail, 2=insufficient, 3=fair, 4=satisfactory, 5=good, 6=excellent.
<table>
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<tr>
<th>stage (t)</th>
<th>cognitive skills</th>
<th>mental skills</th>
<th>emotional skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 months</td>
<td>0.07*</td>
<td>0.07*</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>(0.02)</td>
<td>(0.02)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>2 years</td>
<td>0.13*</td>
<td>0.10*</td>
<td>-0.06**</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>4.5 years</td>
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<td>0.14*</td>
<td>-0.06*</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.02)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>8 years</td>
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<td>0.14*</td>
<td>-0.001</td>
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<tr>
<td></td>
<td>(0.03)</td>
<td>(0.02)</td>
<td>(0.02)</td>
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<tr>
<td>11 years</td>
<td>0.18*</td>
<td>0.17*</td>
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</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.02)</td>
<td>(0.03)</td>
</tr>
</tbody>
</table>

Source: Mannheim Study of Children at Risk. 357 observations.
Note: standard errors are in parenthesis: * significant at 1% level, ** significant at 5% level. Share of children attending Gymnasium: 32.5%.
Appendix:

Figure 1a: The distribution of school grades

Source: Mannheim Study of Children at Risk. 357 observations. Own calculations.

Table 1b: Sample weights

<table>
<thead>
<tr>
<th>Source: Mannheim Study of Children at Risk. Own calculations.</th>
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<tbody>
<tr>
<td>Psycho-social risk</td>
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<tr>
<td></td>
</tr>
<tr>
<td>high</td>
</tr>
<tr>
<td>low</td>
</tr>
</tbody>
</table>

Source: Mannheim Study of Children at Risk. Own calculations.
Detailed description on the measurements of cognitive skills:

3 months: Cognitive abilities, \( IQ \), were measured using the Mental Developmental Index (MDI) of the Bayley Scales of Infant Development (Bayley, 1969). The fine and gross motor abilities, \( MQ \) (called the motor quotient), were assessed by the Psychomotor Developmental Index (PDI) of the Bayley Scales.

2 years: The \( IQ \) was derived from the Mental Developmental Index (MDI) of the Bayley Scales of Infant Development. A differentiation is made between verbal abilities, \( V-IQ \), and nonverbal cognitive abilities, \( NV-IQ \). The verbal ability score is derived from the items of the Bayley Scales indicating language development, in combination with the expressive and the receptive language scales of the Münchener Funktionale Entwicklungsdiagnostik (MFED) (Köhler and Egelkraut, 1984). The nonverbal cognitive abilities are derived from the nonverbal items of the Bayley Scales, indicating basic, general abilities such as perception and logical and figural reasoning. The \( MQ \) was assessed by the Psychomotor Developmental Index (PDI) of the Bayley Scales.

4.5 years: The composite score of the \( IQ \) contained the Columbia Mental Maturity Scale (CMMS) (Burgmeister et al., 1972) and the subtest "sentence completion" of the Illinois Test of Psycholinguistic Abilities (ITPA), (Kirk et al., 1968; for the German version, see Angermaier, 1974). From these, a differentiation is made between \( V-IQ \), language-dependent abilities and \( NV-IQ \), indicating nonverbal abilities. The \( MQ \) was derived from the Test of Motor Abilities (MOT) 4-6 (Zimmer and Volkamer, 1984).

8 years: The composite score of the \( IQ \) was assessed by the Culture Fair Test (CFT) 1 (Weiss and Osterland, 1977), measuring nonverbal skills, such as the ability to perceive and integrate complex relationships in new situations, and the subtest “sentence completion” of the ITPA, mentioned above, indicating verbal reasoning (\( V-IQ \)). The \( MQ \) was assessed with the body coordination test for children (KTK) (Kiphard and Shilling, 1974).

11 years: The \( IQ \) was measured by the CFT 20 (Cattell, 1960) and a vocabulary test of the CFT 20, again allowing verbal, \( V-IQ \), and nonverbal abilities, \( NV-IQ \), to be distinguished. The MQ at age 11 years was assessed by means of a short version of the body coordination test for children (KTK).

Appendix References:


Zimmer, R. and M. Volkamer (1984), Motoriktest für 4-6jährige Kinder (MOT 4-6), Beltz, Weinheim.