Discussion Paper No. 10-028

The Role of Parental Investments for Cognitive and Noncognitive Skill Formation – Evidence for the First 11 Years of Life

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Non-technical summary

Skill gaps often arise already immediately after birth and increase during childhood long before formal education starts. Thus, early family environment can explain a crucial part of skill heterogeneity among individuals during childhood and adolescence and has a significant influence on the human capital accumulation across the whole life cycle. Medical and psychological studies have shown the existence of critical and sensitive periods in the formation of skills. If a child does not receive the appropriate stimulation during a critical period, it may be very difficult to develop certain functions later in life. Additionally, during sensitive periods, opportunities to attain certain skills exist which do not exist in subsequent periods. This has important implications for developing educational policies and the optimal timing of human capital investments.

This study examines the impact of parental investments on the development of cognitive, mental and emotional skills during childhood using data from a 20-year longitudinal study, the Mannheim Study of Children at Risk, starting at birth. We find empirical evidence for sensitive and critical periods of cognitive and mental skills within the first eleven years of life. This implies that parental investments are most efficient for both types of skills directly after birth and less efficient at age eight and turn ineffective later on. We find that cognitive skills are most important for predicting school success, followed by mental skills, while emotional skills are less important.

Our results indicate that initial conditions matter throughout childhood and that organic risk (e.g. low birth weight) is more detrimental for the development of cognitive skills, while psychosocial risk (e.g. early pregnancy) is more detrimental for the development of mental and emotional skills regarding the effect of parental investments. We also find differences between girls and boys considering the effect of parental investments. Boys profit more from parental investments in terms of cognitive skill development, while their mental skill development is more independent. Girls, on the other hand, benefit more from high investments with respect to their mental skill development.

Das Wichtigste in Kürze

Die Familie ist der zentrale Akteur bei der Entwicklung von Fähigkeiten innerhalb der (frühen) Kindheit. Sowohl die Intensität als auch die Ausgestaltung „elterlicher“ Investitionen entscheiden bereits unmittelbar nach der Geburt über die Startbedingungen und somit über den weiteren Humankapitalbildungsprozeß im Lebenszyklus. Eine zentrale bildungsökonomische Fragestellung ist dabei jene des optimalen Zeitpunktes von Investitionen. Aus den Erkenntnissen der Neurowissenschaften geht hervor, dass sogenannte „Zeitfenster“ existieren, in denen sich Fähigkeiten optimal entwickeln, außerhalb dieser Perioden sind Fähigkeiten nur noch wenig bzw. gar nicht mehr beeinflussbar. In der Literatur ist dieses Phänomen unter dem Begriff der sensitiven bzw. kritischen Perioden bekannt. Demnach wirken Investitionen optimal innerhalb der Zeitfenster.

Diese Studie zeigt empirische Evidenz für sensitive und kritische Perioden innerhalb der ersten elf Lebensjahre. Betrachtet werden drei elementare Fähigkeiten, kognitive, mentale und emotionale, für die gezeigt werden kann, dass sie maßgeblich den Schulerfolg beeinflussen. Datengrundlage ist die Mannheimer Risikokinderstudie, eine psychologische Längsschnittstudie, die eine Vielzahl valider Fähigkeitsmaße ab der Geburt wiederholt beobachtet.

Unsere Ergebnisse deuten darauf hin, dass kognitive Fähigkeiten (z.B. der IQ) bis zum Alter von 4.5 Jahren in hohem Maße von Investitionen beeinflusst werden, später hingegen kein Einfluss mehr beobachtbar ist. Für die Entwicklung von mentalen Fähigkeiten (z.B. die Konzentrationsfähigkeit), zeigen die Ergebnisse von der Geburt an bis zum Alter von 11 Jahren einen positiven Einfluss elterlicher Investition, allerdings von Beginn an mit einer geringeren Wirkung. Untersuchungen in unterschiedlichen Risikogruppen zeigen darüber hinaus, dass kognitive Fähigkeiten deutlich geringer beeinflussbar sind wenn Kinder beispielsweise mit hohem organischem Risiko, wie niedrigem Geburtsgewicht, geboren werden. Abschließend deuten getrennte Analysen für Jungen und Mädchen darauf hin, dass Jungen von identischen Investitionen stärker bei der Entwicklung kognitiver, Mädchen dagegen stärker bei der Entwicklung mentaler Fähigkeiten profitieren.

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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 and sensitive periods, self-productivity, inequality, organic risk, psychosocial 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. 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 efficient for both types of skills directly after birth and less efficient at age eight *(sensitive period).* After age eight, they even become ineffective *(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.

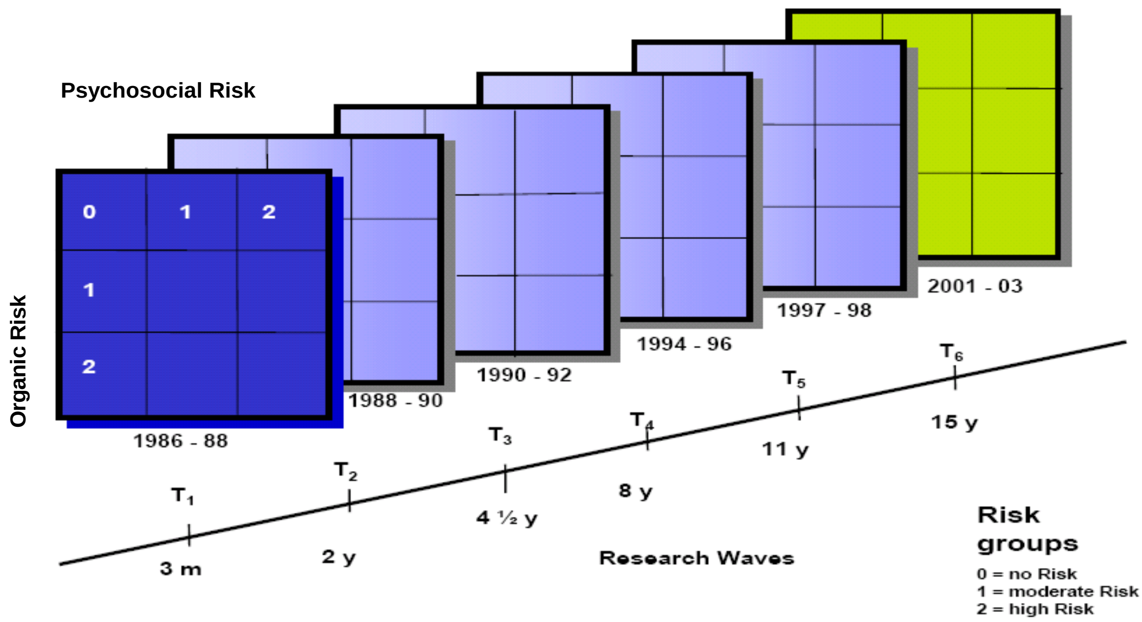
Various studies by Heckman and co-authors investigate critical and sensitive periods based on the technology of skill formation starting at the age of six. Cunha and Heckman (2008), for example, find that parental investments affect cognitive skills more at earlier stages than at later stages, while 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.[1] 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 educational 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.

Figure 1: The Mannheim Study of Children at Risk



Source: Mannheim Study of Children at Risk.

[1] For a more detailed explanation of the study, see Blomeyer et al. (2008) or Laucht et al. (2004).

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.[2] 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. 1).[3] 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

[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. For a detailed explanation of these test batteries, see, for instance, Laucht et al. (2004) or Blomeyer et al. (2008).

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)).[4] Measuring temperamental characteristics at the age of three months already is quite reliable.[5] 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.

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.

3.2.3. Latent skills

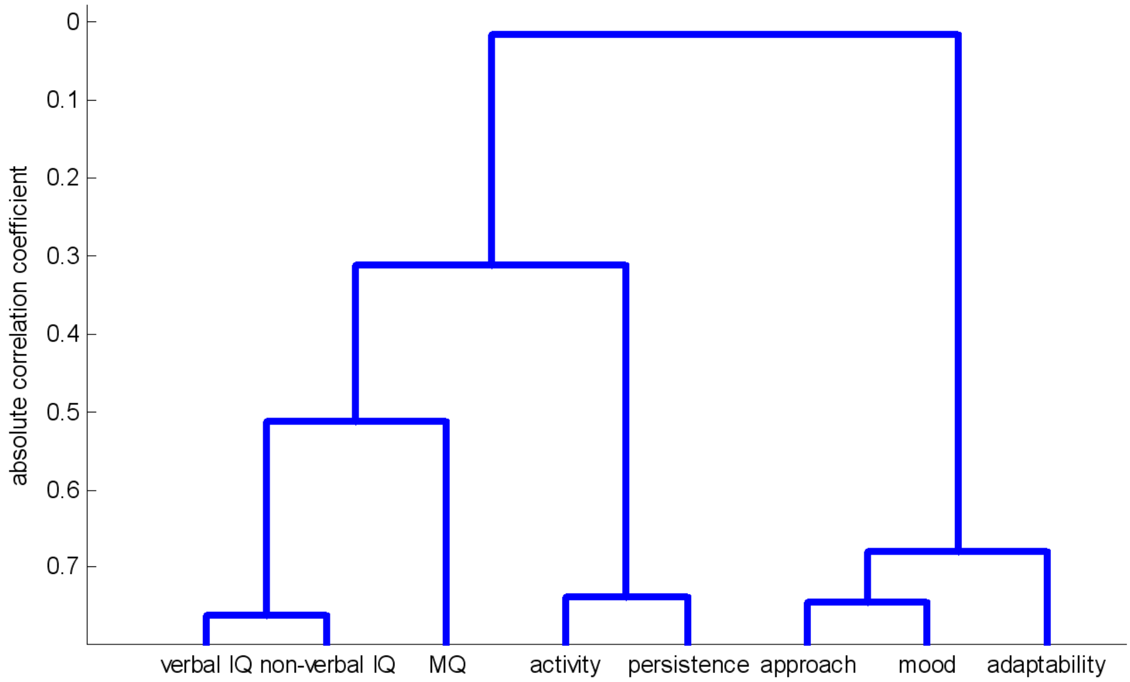
Even though the economic literature recently began to distinguish between cognitive and noncognitive skills, it is still a challenge to disentangle both skills, because measuring cognitive skills might also capture aspects of noncognitive skills and vice versa (e.g. Borghans et al. (2008) or Cunha and 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-

[4] At the ages of 3 months and 2 years, the interrater reliability was measured in a preliminary study of 30 children.

[5] Satisfactory interrater agreement was obtained between two raters (3 months: Øκ = 0.68, range 0.51 - 0.84; 2 years: Øκ = 0.82, range 0.52 - 1.00).

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 (see Figure 2).

Figure 2: Cluster analysis



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

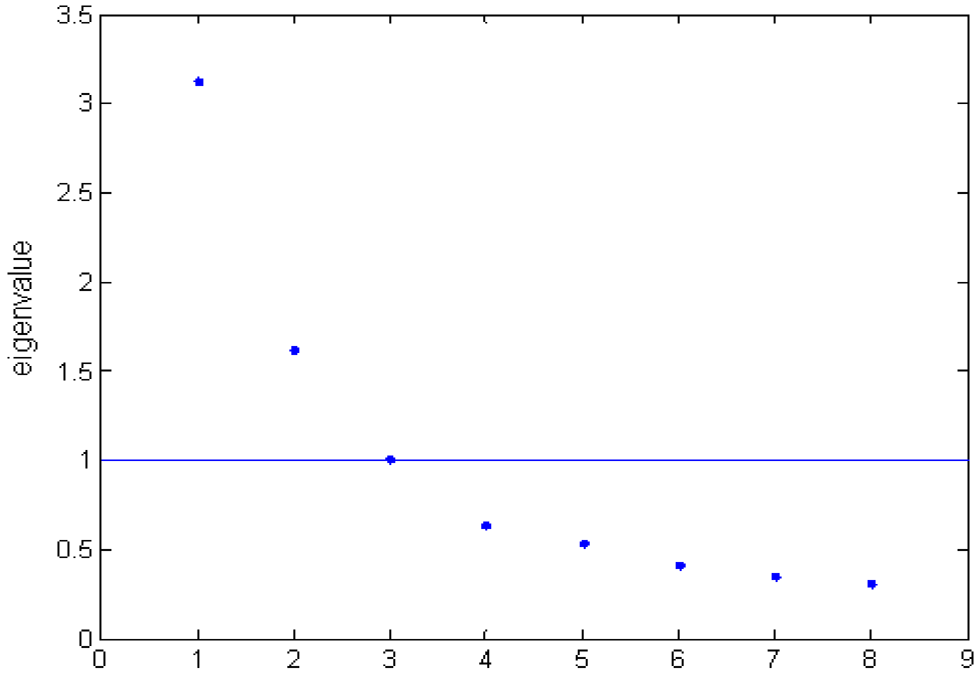
Figure 2 shows that the three noncognitive skills[6] *approach, adaptability* and *prevailing mood* form one group, while *activity* and *persistence* form another group which is more closely related to cognitive skills. The *MQ (motor quotient)* sorts into the cognitive skill group. Our findings suggest 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

[6] For a detailed description of cognitive and noncognitive skills, see sections 3.2.1 and 3.2.2.

analysis suggests three latent factors to reflect the data (which is in line with the results from the cluster analysis).

Figure 3: Eigenvalues of the correlation matrix



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

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.[7] Table 1 shows the correlations of the identified latent factors with the measurements.[8]

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. Mental skills are a mix of the optimal activity level and persistence.[9] 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.

[7] Alternatively, we conducted an oblique promax-rotation which generated very similar results, with coefficients being slightly greater due to higher multicollinearity among factors.
[8] 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.
[9] Mental skills are closely related to mental health (ADHD).

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.

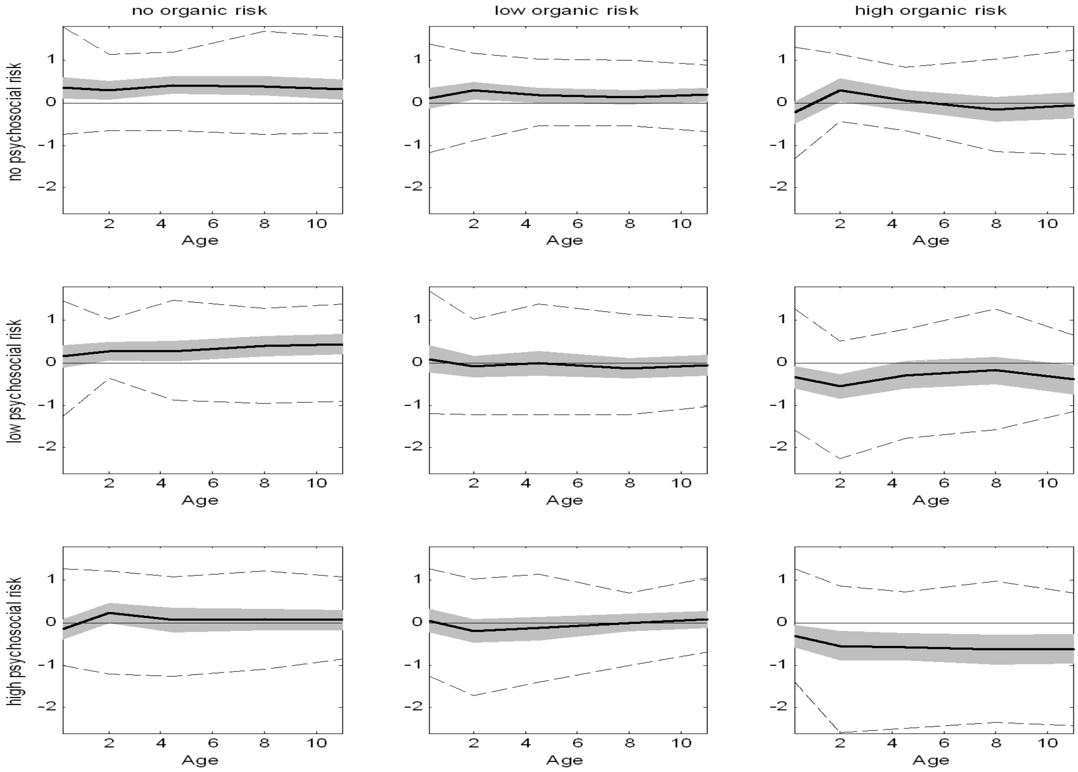
Table 1: Correlations of skill measures with latent factors

age	IQ	MQ	NV-IQ	V-IQ	Activity	Appro-ach	Adapta-bility	Mood	Per-sistence
Cognitive Skills									
0.25	**0.92**	0.53			-0.07	0.18	0.08	0.15	0.07
2	**0.83**	0.61	0.63	0.60	0.10	0.18	0.13	0.21	0.23
4.5	**0.82**	0.62	0.61	0.77	0.09	0.09	0.18	0.13	0.38
8	**0.89**	0.45	0.64	0.61	0.04	0.01	0.18	0.01	0.38
11	**0.92**	0.52	0.41	0.70	0.05	-0.04	0.22	-0.12	0.32
Mental Skills									
0.25	-0.05	-0.09			0.66	-0.01	0.12	0.13	**0.83**
2	0.17	-0.08	0.12	0.18	**0.83**	-0.17	-0.02	0.13	**0.85**
4.5	0.20	0.18	0.18	0.22	**0.86**	-0.06	0.00	0.16	**0.84**
8	0.29	0.18	0.29	0.29	**0.85**	-0.06	0.24	0.11	**0.85**
11	0.13	0.11	0.32	0.20	**0.74**	-0.19	0.57	0.13	**0.82**
Emotional Skills									
0.25	0.20	0.10			0.05	**0.96**	0.61	0.69	0.29
2	0.20	0.24	0.15	0.22	0.06	**0.97**	0.57	**0.75**	0.08
4.5	0.12	0.20	0.05	0.14	0.04	**0.98**	**0.90**	**0.79**	0.16
8	0.07	0.05	0.08	0.06	0.09	**0.98**	**0.79**	**0.73**	0.11
11	-0.02	-0.01	-0.04	0.05	0.00	**0.96**	0.42	**0.78**	0.09

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

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.

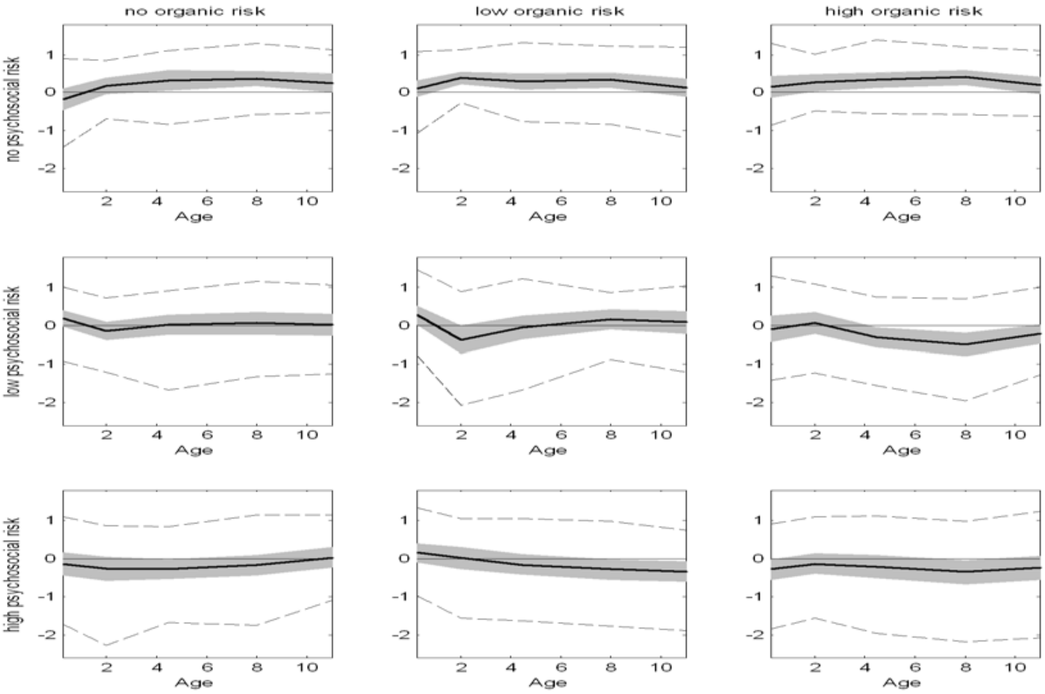
Figure 4: Distribution of cognitive skills by age and risk status



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.

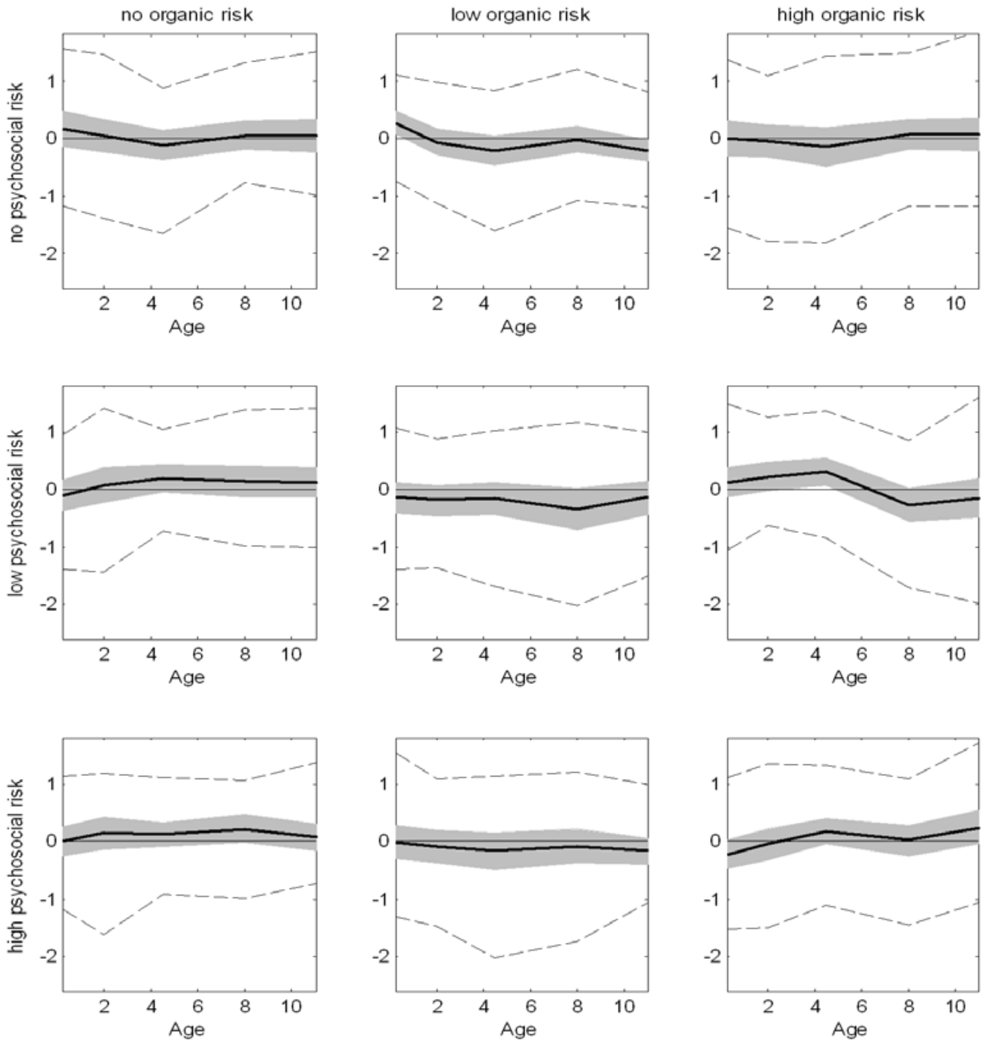
Figure 5 and 6 present the distribution for cognitive, mental and emotional skills, respectively. Differences in the means of mental skills are significantly lower among children born with psychosocial risk than among children born with organic risk throughout childhood. It is also important to note 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 shows that cognitive and mental skills behave more similarly during childhood than emotional skills, while the distribution strongly depends on the initial risk conditions of the children.

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

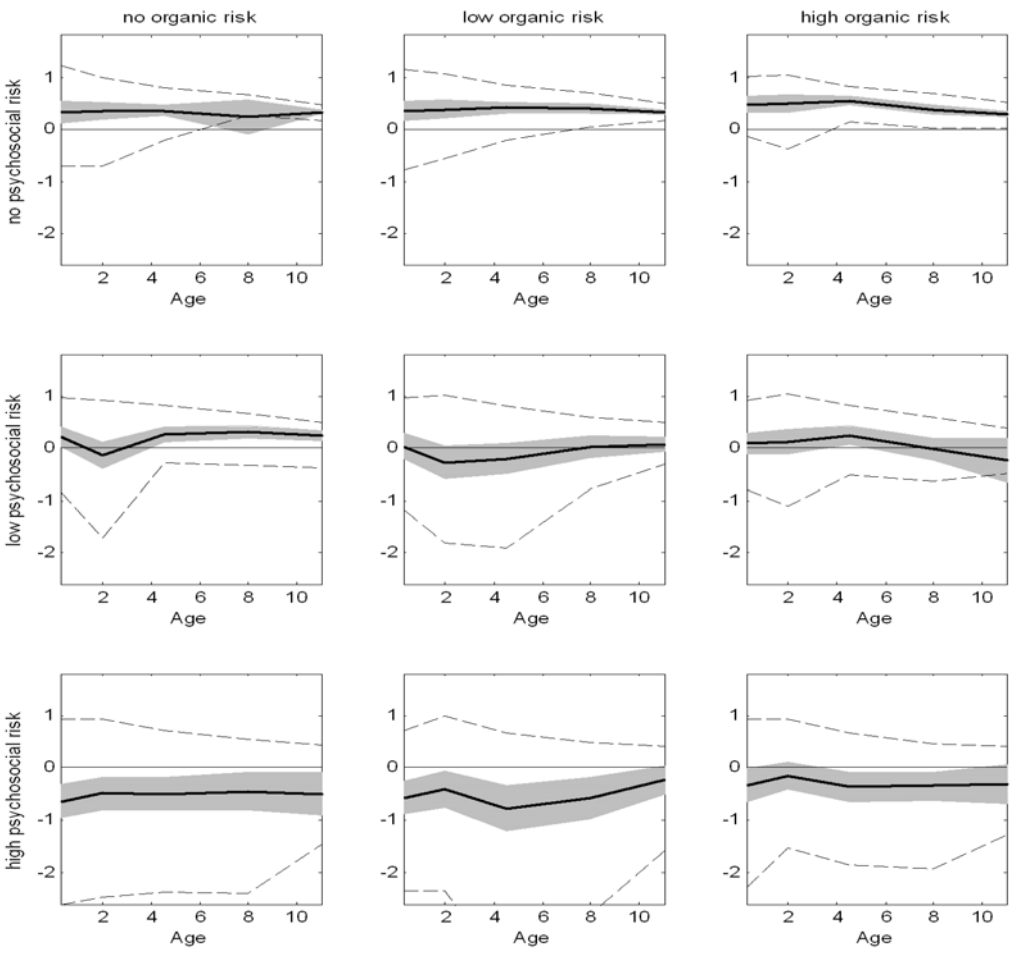


Note: Mean (and grey-shaded 95 % confidence bounds), the 10th, 90th percentile of standardized emotional skills.
Source: Mannheim Study of Children at Risk. Own calculations.

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 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, 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.

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.

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-specification of the technology of skill formation. Instead of using noncognitive skills as one single measure, we differentiate between mental and emotional skills:

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

$$S_t^c = a_0^c + a_{1,t-1}^c S_{t-1}^c + a_{2,t-1}^m S_{t-1}^m + a_{3,t-1}^e S_{t-1}^e + b_t^c I_t^c + \eta_t^c \tag{1a}$$

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

$$S_t^m = a_0^m + a_{1,t-1}^c S_{t-1}^c + a_{2,t-1}^m S_{t-1}^m + a_{3,t-1}^e S_{t-1}^e + b_t^m I_t + \eta_t^m \tag{1b}$$

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

$$S_t^e = a_0^e + a_{1,t-1}^c S_{t-1}^c + a_{2,t-1}^m S_{t-1}^m + a_{3,t-1}^e S_{t-1}^e + b_t^e I_t^e + \eta_t^e \tag{1c}$$

Where S_t^c, S_t^m and S_t^c 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: (2)

$$\frac{\partial S_t^c}{\partial I_t^c} = \frac{\partial S_t^m}{\partial I_t^m} = \frac{\partial S_t^e}{\partial I_t^e} = \frac{\partial f_t S(S_{t-1}^c, S_{t-1}^m, S_{t-1}^e)}{\partial I_t^k} = 0 \quad \forall\, S_{t-1}^c, S_{t-1}^m, S_{t-1}^e, I_t^k \;\; for\ k = c,m,e$$

but

$$\frac{\partial S_t^c}{\partial I_{t-1}^c} = \frac{\partial S_{t-1}^m}{\partial I_{t-1}^m} = \frac{\partial S_{t-1}^e}{\partial I_{t-1}^e} = \frac{\partial f_{t-1}(S_{t-1}^c, S_{t-1}^m, S_{t-1}^e)}{\partial I_{t-1}^k} > 0 \quad for\ some\ S_0, I_{t-1}^k \;\; for\ k = c,m,e$$

Period *t* is a sensitive period for S_t^c, S_t^m, S_t^e if (3)

$$\frac{\partial S_t^c}{\partial I_t^c} = \frac{\partial S_t^m}{\partial I_t^m} = \frac{\partial S_t^e}{\partial I_t^e} \Big| S_{t-1} = S, I_t = i < \frac{\partial S_{t-1}^c}{\partial I_{t-1}^k} = \frac{\partial S_{t-1}^m}{\partial I_{t-1}^k} = \frac{\partial S_{t-1}^e}{\partial I_{t-1}^e} \Big| S_0 = S, I_t^k = i$$

A c*ritical* 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 noncognitive 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.[10] Equations (4a) - (4d) describe the measurement equations for all skills (*Y)* and parental investments (*X)* in each period during childhood:

$$Y_{j,t}^c = \alpha_{j,t}^c + \beta_{j,t}^c S_t^c + \varepsilon_{j,t}^c \qquad \forall\, t = 1,...,5 \tag{4a}$$

$$Y_{j,t}^m = \alpha_{j,t}^m + \beta_{j,t}^m S_t^m + \varepsilon_{j,t}^m \qquad \forall\, t = 1,...,5 \tag{4b}$$

$$Y_{j,t}^e = \alpha_{j,t}^e + \beta_{j,t}^e S_t^e + \varepsilon_{j,t}^e \qquad \forall\, t = 1,...,5 \tag{4c}$$

[10] See section 3 for a detailed description.

$$X^{i}_{j,t} = \alpha^{i}_{j,t} + \beta^{i}_{j,t} I^{i}_{t} + \varepsilon^{i}_{j,t} \qquad \forall\, t = 1,...,5 \tag{4d}$$

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 β to $\beta^{c}_{j,t} = \beta^{m}_{j,t} = \beta^{e}_{j,t} = \beta^{i}_{j,t} = 1$. Substituting measurement equations (4a) – (4d) into equations (1a) - (1b) yields:

$$y^{c}_{1t} = \gamma 1^{c}_{,t-1} Y^{c}_{1,t} + \gamma^{m}_{2,t-1} Y^{m}_{1,t-1} + \gamma^{e}_{3,t} Y^{e}_{1,t-1} + \gamma_{4,t-1} X_{1,t} + u^{c}_{t} \tag{5a}$$

$$y^{m}_{1t} = \gamma 1^{c}_{,t-1} Y^{c}_{1,t} + \gamma^{m}_{2,t-1} Y^{m}_{1,t-1} + \gamma^{e}_{3,t} Y^{e}_{1,t-1} + \gamma_{4,t-1} X_{1,t} + u^{m}_{t} \tag{5b}$$

$$y^{e}_{1t} = \gamma 1^{c}_{,t-1} Y^{c}_{1,t} + \gamma^{m}_{2,t-1} Y^{m}_{1,t-1} + \gamma^{e}_{3,t} Y^{e}_{1,t-1} + \gamma_{4,t-1} X_{1,t} + u^{e}_{t} \tag{5c}$$

The error term of each equation (5a) – (5c) u_t includes all errors ε from (4a) – (4b) and the error term from equation (1a) – (1c): For example, the error term u^{c}_{t} for equation (5a) is:

$$u^{c}_{t} = \varepsilon^{c}_{1,t} - \gamma^{c}_{1,t-1}\varepsilon^{c}_{1,t-1} - \gamma^{c}_{2,t-1}\varepsilon^{m}_{1,t-1} - \gamma^{c}_{3,t-1}\varepsilon^{e}_{1,t-1} - \gamma^{c}_{4,t}\varepsilon^{i}_{1,t} + \eta^{c}_{t}$$

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 parameters of interest are biased. Under the assumption that the errors ε are mutually independent and uncorrelated over time, it is possible to identify the parameters of interest γ (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 interrater 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.

5. Results

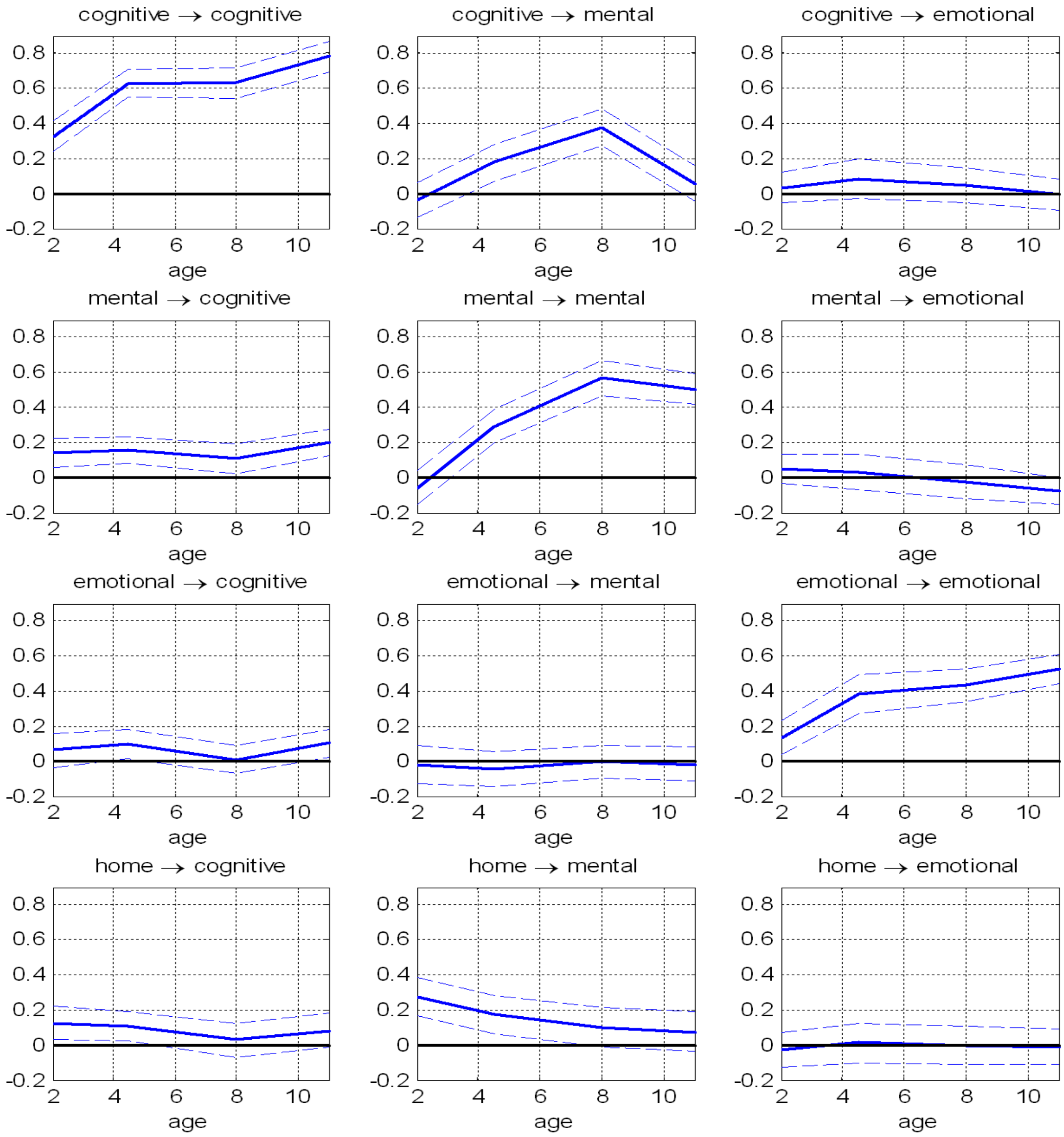
Figure 8 presents our estimates for cognitive, mental and emotional skills during the first 11 years of life. We estimate the same models as in section 4, but we explicitly allow for two different measures of noncognitive skills. We use bootstrapped standard errors with 500 replications. Our results 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. In fact, self-productivity steadily increases during childhood, however, the estimates suggest that self-productivity for mental skills is important up to age four, while for the development of emotional skills, innate emotional skills are important. Self-productivity is largest for cognitive skills.

Regarding direct-complementarities between these skills, it is obvious that cognitive skills foster mental skills and vice versa, but neither cognitive nor mental skills have an effect on the development of emotional skills. Sensitive and critical periods are found for cognitive and mental skills, while emotional skills are not affected by the HOME score in our data. Surprisingly, regarding the effect of the HOME scores on cognitive and on mental skills, both skills behave quite similar. The effect of the HOME score steadily decreases with the child's age, while it becomes insignificant at age eight. Moreover, the effect is nearly twice as large for mental skills compared to cognitive skills.

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. This result suggests that other factors such as genetic endowment or peers are more important for the development of emotional skills.

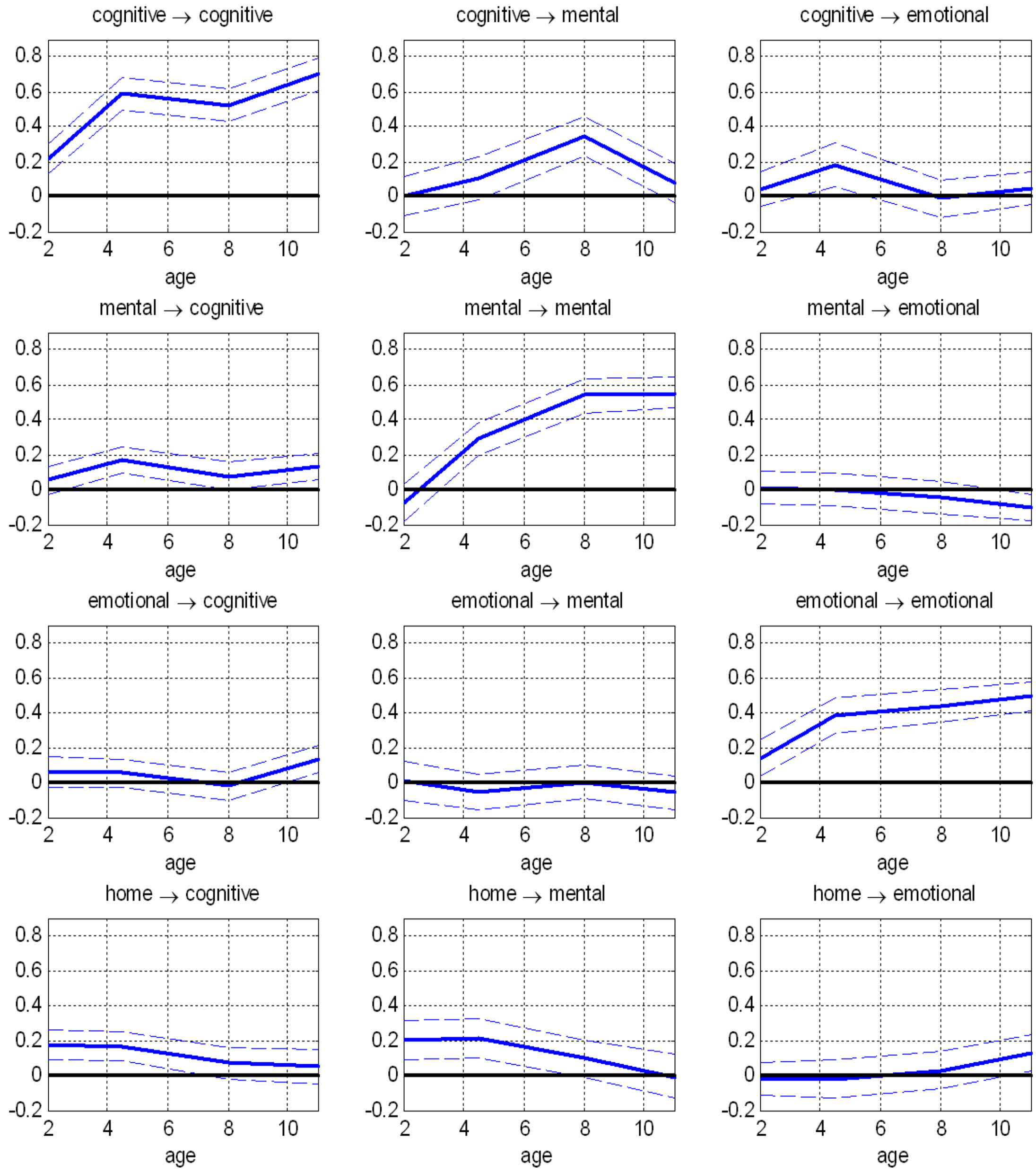
Our sample is not representative for the overall population, due to an oversampling of children at risk. Hence, we re-estimate the models for a weighted representative sample (for the calculation of the weights, see Table 1b in Appendix). Our data contains 110 individuals from a representatively selected 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. 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 5.3. Besides, for the representative sample, we find a significantly positive effect of the HOME score on emotional skills in late childhood.

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.

5.3 Skill production function with cognitive, mental and emotional skills by initial risk status

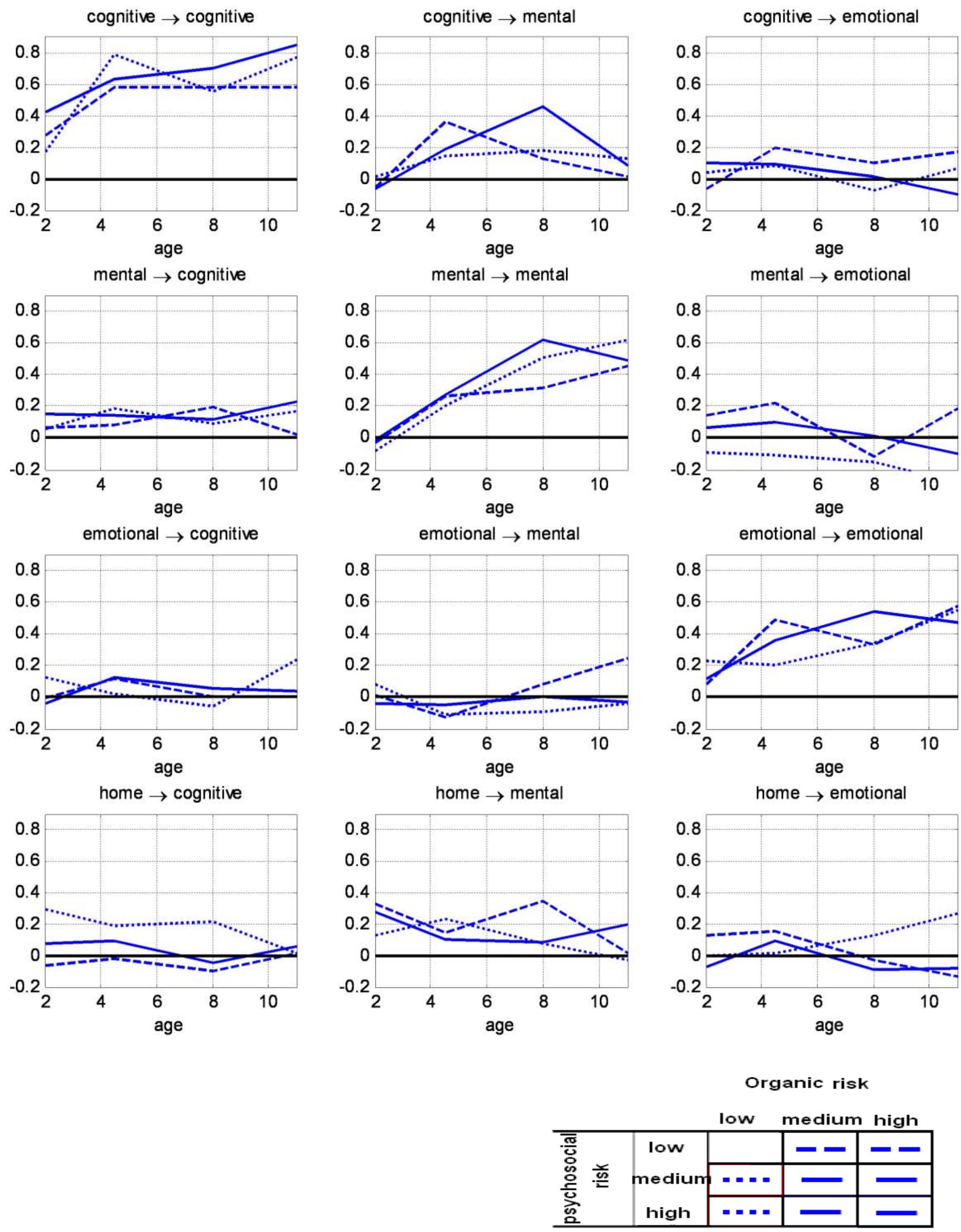
In order to assess how the results might be affected by risk-group status at birth, we re-estimate our models presented in the previous section for three different risk groups (see Figure 10). First, we are interested in the skill development in children who were born with organic (medium or high) risk. 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 (lower part) 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. 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. 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. 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.

Figure 10: Estimates of the skill production function with three skill factors by initial risk status



Note: 95 % confidence bounds are dashed lines (bootstrapped standard errors) 357 observations.
Source: Mannheim Study of Children at Risk. Own calculations.

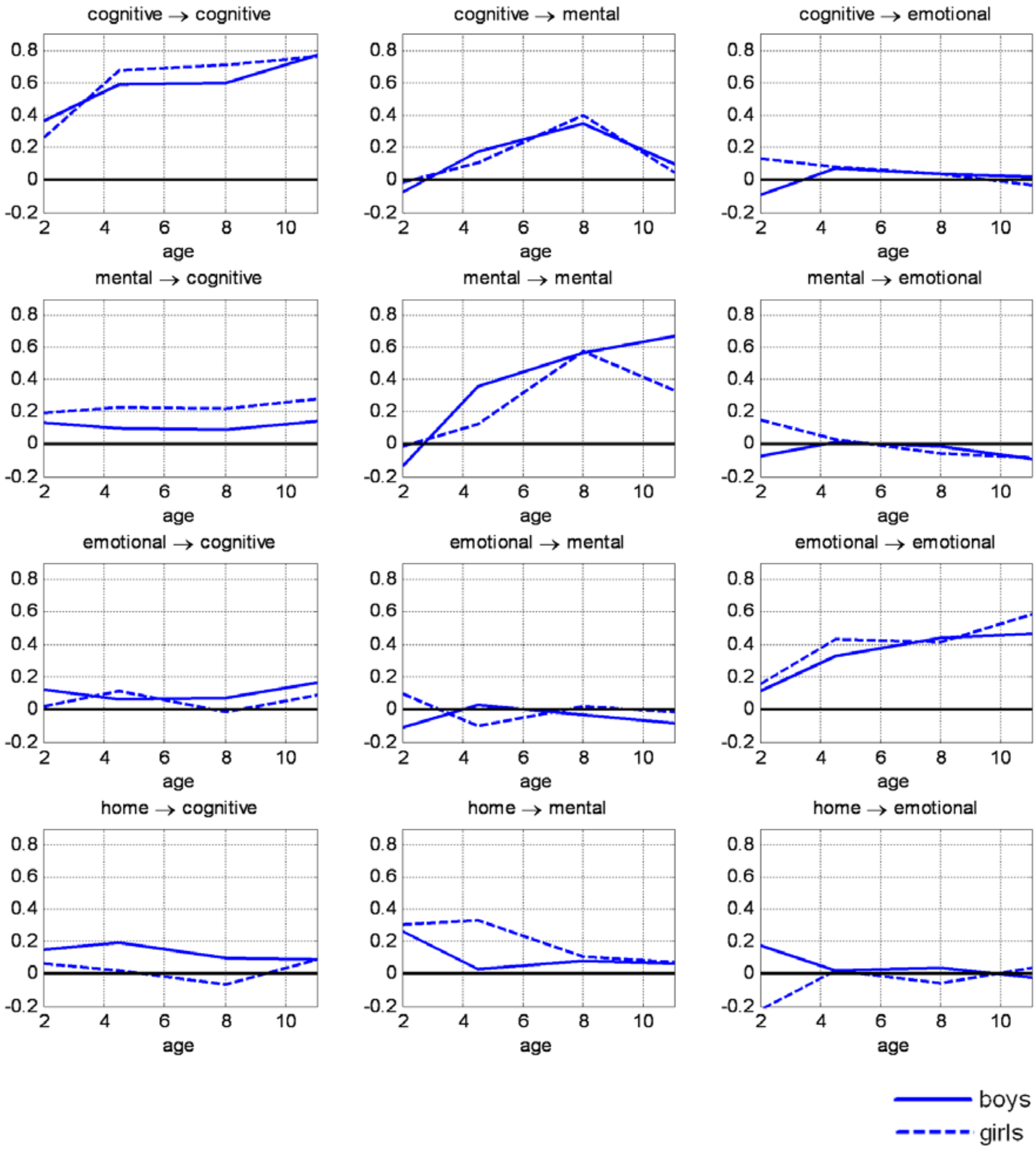
The adverse effects of organic risk on skill development in our results are consistent with findings from the low birth weight (LBW) literature, showing lasting impacts of LBW in school and even in the labor market (e.g. Oreopoulos et al. (2008)) In contrast, children born with psychosocial risk mostly 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.

5.4 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. Regarding cognitive skills, self-productivity is larger from age four on in girls, but at the end of childhood, gender differences seem to vanish. 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.

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.

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. 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).

5.5 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).[11] The distribution of school grades is presented in Figure 1a, Appendix. Secondly, we focus on the probability to attend Gymnasium, which is the highest secondary school track in Germany (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.

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

stage (t)	cognitive skills	mental skills	emotional skills
3 months	**0.09***	0.05	0.06
	(0.03)	(0.03)	(0.03)
2 years	**0.19***	**0.11***	0.0
	(0.04)	(0.03)	(0.03)
4.5 years	**0.24***	**0.07***	0.0
	(0.04)	(0.03)	(0.03)
8 years	**0.25***	**0.14***	**0.07***
	(0.04)	(0.03)	(0.03)
11 years	**0.21***	**0.15***	**0.07***
	(0.04)	(0.03)	(0.03)

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.

[11] 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.

Table 3: Marginal Probability of attaining a high school degree

stage (t)	cognitive skills	mental skills	emotional skills
3 months	**0.07***	**0.07***	-0.03
	(0.02)	(0.02)	(0.02)
2 years	**0.13***	**0.10***	**-0.06****
	(0.03)	(0.03)	(0.02)
4.5 years	**0.18***	**0.14***	**-0.06***
	(0.03)	(0.02)	(0.02)
8 years	**0.18***	**0.14***	-0.001
	(0.03)	(0.02)	(0.02)
11 years	**0.18***	**0.17***	0.03
	(0.03)	(0.02)	(0.03)

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%.

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 noncognitive skill dimension.

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. Further, direct-complementarities are observed between cognitive and mental skills. Cognitive skills foster the development of noncognitive skills and vice versa. In addition, we find evidence of sensitive and critical periods for cognitive and mental skills. Parental investments are most efficient directly after birth and less efficient from the age of eight years on.

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.

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. Cognitive skills are already at birth an important predictor for school success. The relationship increases with age.

Altogether, our results have important implications for family and educational policies. First, investment should start directly after birth. Because investments affect different kinds of skills in different ways, it is important to know when, for which skill and for which children at risk, investments should be undertaken. Second, it distinguishes between mental and emotional skills. While the former are more closely related to cognitive skills, the later seems to be more independent. Thus, investments in mental skills are more productive than investments in emotional skills. Finally, gender-specific investments are the most productive in cognitive skills for boys and in mental skills for girls.

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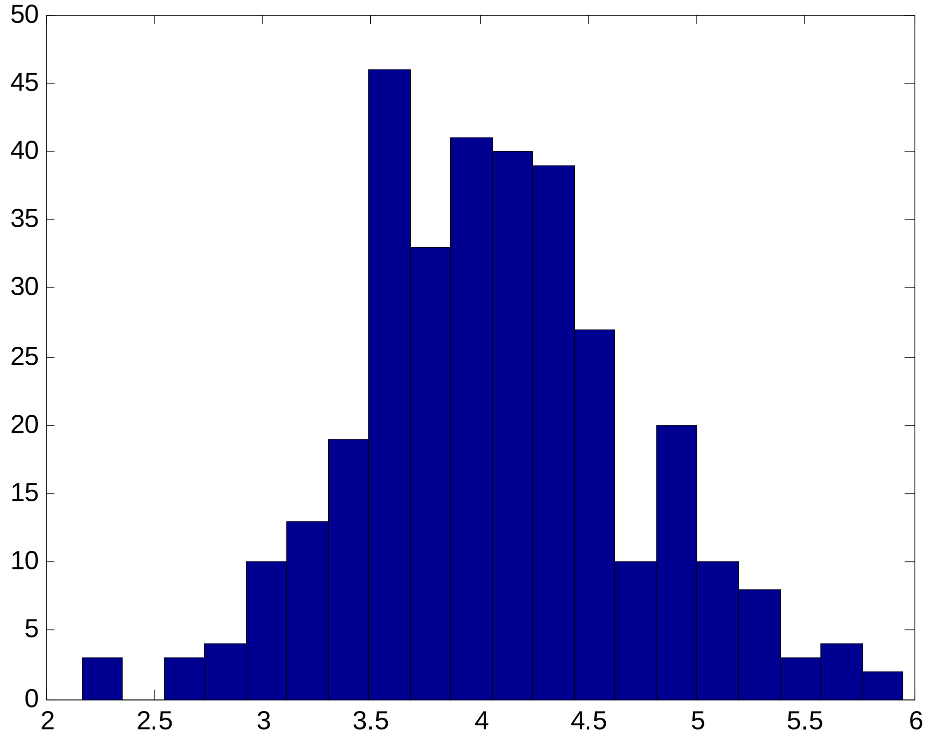
Appendix*:*

Figure 1a: The distribution of school grades



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

Table 1b: Sample weights

		Organic risk		
		low	medium	high
	low	0.35	0.32	0.11
Psycho-social risk	medium	0.36	0.41	0.11
	high	0.37	0.30	0.13

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