Early Health Shocks, Parental Responses, and Child Outcomes *

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Abstract

This paper studies how early health shocks affect human capital formation. We first formulate a theoretical model to understand how early health shocks affect child outcomes through parental responses. We nest a dynamic model of human capability formation into a standard intrahousehold resource allocation framework. By introducing multidimensionality of child endowments, we allow parents to compensate and reinforce along different dimensions. We then test our main empirical predictions using a Chinese child twins survey, which contains detailed information on child- and parent-specific expenditures. We can differentiate between investments in money and investments in time. On the one hand, we find evidence of compensating investment in child health but of reinforcing investment in education. On the other hand, we find no change in the time spent with the child. We confirm that an early health insult negatively affects the child under several different domains, ranging from later health, to cognition, to personality. Our findings suggest caution in interpreting reduced-form estimates of the effects of early-life shocks. In the presence of asymmetric parental responses under different dimensions of the child's human capital, they cannot even be unambiguously interpreted as upper or lower bounds of the biological effects.

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1 Introduction

The literature on the effects of early-life conditions on late-life circumstances is burgeoning (Case, Fertig, and Paxson, 2005; Grantham-McGregor, Cheung, Cueto, Glewwe, Richter, Strupp, and The International Child Development Steering Group, 2007). This literature has achieved a consensus on the negative effects of an early-life health insult on both short-run (Currie, Stabile, Manivong, and Roos, 2010) and long-run outcomes (Smith, 2009). However, the role played by parental behavior is still not well understood, but its importance is being increasingly recognized (Case and Paxson, 2002; Almond and Currie, 2011). The central message of this paper is that, in general, in the presence of parental investments, the reduced-form estimates of the effects of early-life shocks do not necessarily represent a biological effect. Moreover, in case parents make compensating and reinforcing investments along different dimensions of human capital, they cannot be even unambiguously interpreted as upper or lower bounds of the biological effects.

These considerations may play a crucial role in developing countries, where national health insurance, public education, and old-age pension systems are inadequate or absent (Glewwe and Miguel, 2007). First, in the absence of public health insurance and with a tight budget, a child affected by a health insult may not receive appropriate medical treatment, and thus the early shock may have long-lasting consequences. In addition to this, in the absence of a well-functioning public education system, the consequences of an early health shock may be exacerbated, and also impair human capital formation. Finally, the absence of an old-age pension system may drive parents to base their intrahousehold resource allocation decisions on efficiency rather than on equity concerns. In this case, parents are more likely to reinforce the harmful effects of an early health insult, by devoting fewer resources to the less well-endowed child (Behrman, Rosenzweig, and Taubman, 1994). Hence, unpacking parental intrahousehold resource allocation responses is crucial to understand how early health shocks affect human capital formation, especially in developing countries. The role of the family must be taken into account when designing public policies to remediate the effects of inequality at birth or in early childhood.

Understanding how parents allocate resources across children has been researched in economics since the seminal work of Becker and Tomes (1976) and Behrman, Pollak, and Taubman (1982). However, since neither the wealth model nor the separable earnings-transfer model make unequivocal predictions regarding parental investments, whether parents exhibit a reinforcing, compensating, or neutral behavior has ultimately been an empirical question. Indeed, several papers have been devoted to testing parental strategies. The literature, nonetheless, has yet to achieve a consensus: whereas some studies have found evidence of reinforcing behavior (see, e.g., Behrman, Rosenzweig, and Taubman (1994) and Rosenzweig and Zhang (2009)), others have found empirical support for a compensating strategy (see, e.g., Behrman, Pollak, and Taubman (1982) and Pitt, Rosenzweig, and Hassan (1990)).[1] One common point to be noted is that these papers usually assume the existence of only one dimension under which parents can compensate or reinforce. Moreover, they frequently use measures of children's outcomes, such as educational attainment and test scores, to infer parental investments. We overcome both limitations in our work.

In this paper, we combine two strands of literature: the recent literature on the long-lasting effects of early-life conditions, and the more consolidated literature on intrahousehold allocation of resources. We combine them using a dynamic model of human capability formation (Heckman, 2007), which links early endowments to later outcomes through both self- and cross-productivity effects and parental investment behavior. By merging the two strands of literature we are able to model the mechanisms - parental reinforcing or compensating responses - through which an early-life health shock affects later-life outcomes along different dimensions.

The key insight of our model is based on the following result: in the presence of multidimensional child endowments whose evolution is governed by a dynamic production technology, an early health shock works through a third effect in addition to the classical wealth and price effects a' la Becker and Tomes (1976) on parental investment[2] – a reallocation of resources by the parents across health and cognitive skills. Since this resource reallocation process is governed by the production technology, we call it a *technological effect*: its direction is determined by the degree of substitutability or complementarity between health and cognitive skills, and between health (cognitive skills) and investment in health (cognitive skills). In this scenario, the within-family differences in investments in children are no longer uniquely determined by parental preferences towards inequal-

[1] Behrman (1988) finds evidence in support of both hypotheses for rural India depending on food availability: during the lean season when food is scarce, parental allocations are significantly pro-son and quite focused on efficiency, whereas there is no gender differential during the surplus season, and parental behavior is compensating.

[2] The wealth effect denotes the reduction in the human capital stock of the family as consequence of the early health shock. The price effect denotes the change in the relative valuation that the parent has of the child in response to an early health shock.

ity, or the price effect.[3] Rather, these differences reflect a mixture of the price effect and of the technological effect. We show that, under plausible assumptions of complementarity between health and cognitive skills, as well as substitutability between health (cognitive skills) and investment in health (cognitive skills), our theoretical model predicts that parents will unambiguously exhibit a reinforcing investment strategy in cognitive skills, and may exhibit a compensating investment strategy in health in response to an early health shock, if they do not have preferences for inequality aversion. The intuition is as follows: if parents do not avert inequality, they will reallocate resources from the insulted child to the healthy one, improving investments on both her health and cognitive skills. However, this does not necessarily imply a reduction in both types of investment in the sick child: as a consequence of the complementarity between health and cognitive skills as well as the substitutability between health (cognitive skills) and investment in health (cognitive skills), parents will unambiguously reduce the investment in cognitive skills, but may increase the investment in health.[4]

Our result has important implications. On the one hand, in the presence of responsive investments, reduced-form estimates of the effects of early-life shocks cannot be interpreted as a purely *biological effect*. On the other hand, if behavioral adjustments in response to shocks can be compensating and/or reinforcing along different dimensions, we cannot even unequivocally determine if reduced-form estimates represent upper- or lower-bounds of the biological effects. In our application, ignoring the intrahousehold allocation process leads to an *underestimation* of the biological effect of an early health shock on late-life health, but to an *overestimation* of its effect on cognition and related domains.

The paper is organized as follow. We derive our theoretical model in Section 2 and relate it to our econometric specification in Section 3. We describe the Chinese Child Twins Survey we use to test our theoretical predictions in Section 4. Finally, Section 5 presents the results, and Section 6 concludes.

[3]The wealth effect is removed by the within-family estimator that we use.

[4]The study spiritually closest to ours is Behrman and Lavy (1997). However, they do not explicitly model the intrahousehold resource allocation process, which becomes enacted in response to the early-life health shock.

2 A Dynamic Model of Early Shocks, Parental Responses, and Child Outcomes

In this section, we extend the dynamic model of human capability formation developed in Heckman (2007) to a multiple siblings setting, and nest it into a standard model of intrahousehold resource allocation (Becker and Tomes, 1976; Behrman, Pollak, and Taubman, 1982). We show that an early health shock can affect child outcomes through two channels: a direct channel – the production of human capital – and an indirect one – the process of intrahousehold resource allocation. The latter is affected by three factors: the wealth effect, the price effect, and the technological effect. By introducing multidimensionality of child endowments, we allow parents to compensate and reinforce along different dimensions of the child's human capital.

2.1 The Production Technology

We assume that each family has two children ($\iota = i, j$) and that they are twins.[5] There are two periods of childhood ($t = 1, 2$). Each child has a bidimensional skill set: health (H) and other skills. The latter includes both cognitive and noncognitive skills, but we refer to them as cognitive skills (C) in the theoretical section for ease of notation.[6] We denote the endowments and investments in each period as $\theta^k_{\iota,t}$ and $I^k_{\iota,t}$, respectively, where $\iota = i, j$ indexes the child, $t = 0, 1, 2$ is the time period (0 is pre-birth), and $k = H, C$.[7] Following Heckman (2007), we write the production technologies

[5]This assumption is dictated by the data we use in our empirical analysis. It would be natural to extend the model to a general case with n children in the family. However, fertility and birth spacing may be endogenous to health conditions of existing children (Rosenzweig and Wolpin, 1988). We leave this extension to another occasion.

[6]In our empirical analysis, we distinguish between cognitive and noncognitive skills.

[7]$I^k_{\iota,0}$ indicates maternal investment (e.g. nutritional intake) during pregnancy. Given that our empirical analysis focuses on twins, we can safely assume that $I^k_{i,0} = I^k_{j,0}$ or $I^k_{\iota,0}$ is exogenous across twin siblings. In other words, even if the mother can decide how much to invest during pregnancy, she cannot differentially allocate resources across twin pairs.

and the investment functions for child i as follows:[8]

$$\begin{aligned}
\theta^H_{i,1} &= f^H(\theta^H_{i,0}, \theta^C_{i,0}, I^H_{i,0}, e^H_{i,1}), & (1)\\
\theta^C_{i,1} &= f^C(\theta^H_{i,0}, \theta^C_{i,0}, I^C_{i,0}), & (2)\\
I^H_{i,1} &= f^H(\theta^H_{i,1}, \theta^C_{i,1}, \theta^H_{j,1}, \theta^C_{j,1}), & (3)\\
I^C_{i,1} &= f^C(\theta^H_{i,1}, \theta^C_{i,1}, \theta^H_{j,1}, \theta^C_{j,1}), & (4)\\
\theta^H_{i,2} &= f^H(\theta^H_{i,1}, \theta^C_{i,1}, I^H_{i,1}), & (5)\\
\theta^C_{i,2} &= f^C(\theta^H_{i,1}, \theta^C_{i,1}, I^C_{i,1}), & (6)
\end{aligned}$$

where $e^H_{i,1}$ is defined as a negative health shock affecting child i in period 1, i.e., $\frac{\partial \theta^H_{i,1}}{\partial e^H_{i,1}} < 0$. We assume that the early health shock $\left(e^H_{i,1}\right)$ only has a direct effect on her own health in the first period, whereas it affects second-period outcomes through two channels: parental investments (3)-(4) and the process of health and cognitive capital accumulation (5)-(6).[9] Note that in equations (1)-(2) and (5)-(6), we assume that children born in the same family share the same production technology, whereas we allow for the production technology of health to differ from that of cognitive skills. All functions are assumed to be continuously twice differentiable and quasi-concave.

We now analyze the different channels through which an early health shock to child i ($e^H_{i,1}$) operates. First, the total effect on child's i health in the second period can be decomposed as follows:

$$\frac{d\theta^H_{i,2}}{de^H_{i,1}} = \frac{\partial \theta^H_{i,2}}{\partial \theta^H_{i,1}} \cdot \frac{\partial \theta^H_{i,1}}{\partial e^H_{i,1}} + \frac{\partial \theta^H_{i,2}}{\partial I^H_{i,1}} \cdot \frac{\partial I^H_{i,1}}{\partial \theta^H_{i,1}} \cdot \frac{\partial \theta^H_{i,1}}{\partial e^H_{i,1}}, \quad (7)$$

where the first term is a biological effect (self-productivity as in Heckman (2007)). We define the second term as a resource reallocation effect (parents reallocate family resources in response to a health shock on child i). Second, the total effect of an early health shock to child i ($e^H_{i,1}$) on her own cognitive capacity in the second period can also be decomposed into two channels:

$$\frac{d\theta^C_{i,2}}{de^H_{i,1}} = \frac{\partial \theta^C_{i,2}}{\partial \theta^H_{i,1}} \cdot \frac{\partial \theta^H_{i,1}}{\partial e^H_{i,1}} + \frac{\partial \theta^C_{i,2}}{\partial I^C_{i,1}} \cdot \frac{\partial I^C_{i,1}}{\partial \theta^H_{i,1}} \cdot \frac{\partial \theta^H_{i,1}}{\partial e^H_{i,1}}, \quad (8)$$

[8] For simplicity, we assume away contagion effects between twins throughout the paper.

[9] A child can also be hit by a health shock in the second period. We assume that health shocks in the second period are serially uncorrelated with health shocks in the first period, conditional on health in the first period. This assumption can be easily relaxed. It is dictated by the information we have available in our data.

where the first term is once again a biological effect (cross-productivity similar to equation (6)), and the second term is an intrahousehold resource reallocation effect. Finally, an early health shock on child i can also affect child j's ($j \neq i$) health and cognitive skills through the intrahousehold resource reallocation process in both cases. Specifically, the cross-effects of child i's health shock on child j's health and cognitive skills are as follows:

$$\frac{d\theta^H_{j,2}}{de^H_{i,1}} = \frac{\partial\theta^H_{j,2}}{\partial I^H_{j,1}} \cdot \frac{\partial I^H_{j,1}}{\partial\theta^H_{i,1}} \cdot \frac{\partial\theta^H_{i,1}}{\partial e^H_{i,1}}, \tag{9}$$

$$\frac{d\theta^C_{j,2}}{de^H_{i,1}} = \frac{\partial\theta^C_{j,2}}{\partial I^C_{j,1}} \cdot \frac{\partial I^C_{j,1}}{\partial\theta^H_{i,1}} \cdot \frac{\partial\theta^H_{i,1}}{\partial e^H_{i,1}}. \tag{10}$$

Combining equations (7)-(10), we derive the net effect of an early health shock affecting child i on the twins' health and cognitive capital as follows:

$$\frac{d\theta^H_{i,2}}{de^H_{i,1}} - \frac{d\theta^H_{j,2}}{de^H_{i,1}} = \frac{\partial\theta^H_{i,2}}{\partial\theta^H_{i,1}} \cdot \frac{\partial\theta^H_{i,1}}{\partial e^H_{i,1}} + \left(\frac{\partial\theta^H_{i,2}}{\partial I^H_{i,1}} \cdot \frac{\partial I^H_{i,1}}{\partial\theta^H_{i,1}} - \frac{\partial\theta^H_{j,2}}{\partial I^H_{j,1}} \cdot \frac{\partial I^H_{j,1}}{\partial\theta^H_{i,1}}\right) \cdot \frac{\partial\theta^H_{i,1}}{\partial e^H_{i,1}}, \tag{11}$$

$$\frac{d\theta^C_{i,2}}{de^H_{i,1}} - \frac{d\theta^C_{j,2}}{de^H_{i,1}} = \frac{\partial\theta^C_{i,2}}{\partial\theta^H_{i,1}} \cdot \frac{\partial\theta^H_{i,1}}{\partial e^H_{i,1}} + \left(\frac{\partial\theta^C_{i,2}}{\partial I^C_{i,1}} \cdot \frac{\partial I^C_{i,1}}{\partial\theta^H_{i,1}} - \frac{\partial\theta^C_{j,2}}{\partial I^C_{j,1}} \cdot \frac{\partial I^C_{j,1}}{\partial\theta^H_{i,1}}\right) \cdot \frac{\partial\theta^H_{i,1}}{\partial e^H_{i,1}}. \tag{12}$$

These equations clearly show the two channels through which early health shocks affect the distribution of health and cognitive capital within families.[10] The first terms on the right-hand side of equations (11) and (12) show how an early health shock $e^H_{i,1}$ affects the health and cognitive capital of child i through self- and cross-productivity: both terms are always negative by definition. The second terms of both equations show how the early health shock operates through the intrahousehold resource allocation process. As they are governed by parental preferences, we now proceed to model them.

2.2 Parental Preferences and Budget Constraint

We assume that parents are altruistic and care about both their own consumption and the quality of their children. Thus, parental preferences can be represented by a utility function of the following

[10] Our within-twin-pair fixed-effects estimator gives us an estimate of these effects.

form:[11]

$$U_P = U_P[c, V(\theta^H_{i,2}, \theta^C_{i,2}), V(\theta^H_{j,2}, \theta^C_{j,2})], \tag{13}$$

where c is parental consumption,[12] and $V(\theta^H_{\iota,2}, \theta^C_{\iota,2})$ is the child quality function ($\iota = i, j$). Note that both children have the same quality function but may have different health and cognitive skills in the second period. The budget constraint is specified as follows:[13]

$$p_c \cdot c + I^H_{i,1} + I^H_{j,1} + I^C_{i,1} + I^C_{j,1} = Y,$$

where p_c is the price of parental consumption, Y is the parents' total resources, the price of investment is normalized to one, and it is independent of the type of investment. We denote the total value of the resources allocated to children as follows:[14]

$$I = I^H_{i,1} + I^H_{j,1} + I^C_{i,1} + I^C_{j,1} \tag{14}$$

Following Behrman, Pollak, and Taubman (1982), we assume that the utility parents derive from children can be separated from parental consumption. Thus, we can rewrite the utility function (13) as follows:[15]

$$U_P = U_P\{c, U[V(\theta^H_{i,2}, \theta^C_{i,2}), V(\theta^H_{j,2}, \theta^C_{j,2})]\}, \tag{15}$$

The separability assumption is very convenient because it allows us to focus on the allocation of resources across children without considering its effects on parental consumption. Thus, we can restate the problem of parental investments in children as that of maximizing the following utility function:

$$U = U[V(\theta^H_{i,2}, \theta^C_{i,2}), V(\theta^H_{j,2}, \theta^C_{j,2})], \tag{16}$$

[11] The parental utility function should also include the number of children. However, we omit this argument because the implementation of the "One-Child" policy at the time of the data collection allows us to assume away issues of endogenous fertility.

[12] We assume that children's consumption (excluding investments) is a basic need and that parents allocate resources identically across them. Thus, we can ignore this term in the parental utility function.

[13] We assume no borrowing or saving. Although this assumption can be easily relaxed along the lines of Behrman, Pollak, and Taubman (1982), on the one hand it is dictated by the information available in our data, and on the other it has empirical plausibility given the structure of the banking system in the Yunnan region for the period we consider, as described in Section 4.

[14] We assume that parents provide all investment to children; i.e., there is no public intervention. This assumption is plausible in our case, given the absence of public programs in the Yunnan region for the period we consider, as described in Section 4.

[15] We implement a test of this separability assumption in Section 5.3.

subject to the investment budget constraint (14),[16] the production technologies of health and cognitive skills (1)-(2) and (5)-(6), and the quality function.

2.3 Early Health Shocks and Parental Resource Reallocation

To derive the comparative static results of the effects of an early health shock on parental resource reallocation, we follow Behrman, Pollak, and Taubman (1982) and specify parental preferences using a CES utility function[17]

$$U = \{[V(\theta_{i,2}^H, \theta_{i,2}^C)]^\rho + [V(\theta_{j,2}^H, \theta_{j,2}^C)]^\rho\}^{\frac{1}{\rho}}, \tag{17}$$

where $\rho < 1$.[18] An excellent feature of the CES representation of the parental utility function is that ρ measures the degree of parental inequality aversion across children. When $\rho < 0$, parents exhibit inequality aversion and allocate more resources to the sick child. However, when $0 < \rho < 1$, parents do not exhibit inequality aversion and allocate more resources to the healthy child. Conceptually, the sign of ρ is determined by the tradeoff between efficiency and equality. If the decision of investing in children is mainly motivated by efficiency, then $0 < \rho < 1$. Otherwise, the equality motive outweighs the efficiency motive, and $\rho < 0$ (Behrman, Pollak, and Taubman, 1982). In developing countries, efficiency may be the major consideration (at least, in cases when resources are constrained), and ρ would be more likely to be positive. In contrast, equality may be the major consideration in developed countries, and thus ρ would be more likely to be negative.

We then assume the following functional form for the child quality function $V(\theta_{\iota,2}^H, \theta_{\iota,2}^C)$ $(\iota = i, j)$:

$$V(\theta_{\iota,2}^H, \theta_{\iota,2}^C) = (\theta_{\iota,2}^H)^{\alpha_H} (\theta_{\iota,2}^C)^{\alpha_C}, \tag{18}$$

[16] Although we also analyze the effects of the early health shock on parental time investment, for simplicity we do not include a time constraint in our theoretical model. We leave this extension to another occasion.

[17] We assume that parents have equal concerns for their children. Thus, the weights in the child quality function are equal and normalized to one. Graphically, this means that the parental welfare function (equation (17)) is symmetrical around the 45^o ray from the origin. However, it does not automatically imply that resources are equally distributed across children because they may have different endowments or may be differentially affected by shocks, as the current paper shows. Note that, although the optimal level of investments will be changed, the analytical results of the comparative statics remain qualitatively the same if we assume that parents put different weights on the quality of different children. For more discussions on the parental welfare function, see Behrman, Pollak, and Taubman (1982).

[18] ρ is a continuous variable, and it implies that all parents have both efficiency and equality considerations unless $\rho = 1$ or $\rho = -\infty$. $\rho = 1$ means that parents only care about efficiency, whereas $\rho = -\infty$ means that parents only care about equality. The latter is the Rawlsian case, in which case the parental utility function (16) can be rewritten as $U = U\,[min\,(V_i, V_j)]$.

where $0 < \alpha_H, \alpha_C < 1$, and $\alpha_H(\alpha_C)$ measures the importance of health (cognition) in the quality function. Finally, following Behrman, Pollak, and Taubman (1982) and Cunha and Heckman (2008), we assume substitutability between investment in health ($I^H_{\iota,1}$) and the stock of health ($\theta^H_{\iota,1}$) in the health production function ($\theta^H_{\iota,2}$),[19] as well as between investment in cognitive skills ($I^C_{\iota,1}$) and the cognitive stock ($\theta^C_{\iota,1}$) in the cognitive skills production function ($\theta^C_{\iota,2}$). Thus, we can specify the following functional forms for the production technologies:[20]

$$\theta^H_{\iota,2} = (\theta^C_{\iota,1})^\gamma [\beta_\theta \theta^H_{\iota,1} + \beta_I I^H_{\iota,1}]^{1-\gamma}, \tag{19}$$

$$\theta^C_{\iota,2} = (\theta^H_{\iota,1})^\gamma [\beta_\theta \theta^C_{\iota,1} + \beta_I I^C_{\iota,1}]^{1-\gamma}, \tag{20}$$

where $0 < \gamma < 1$ and $0 < \beta_\theta, \beta_I < 1$. The parameter γ can be interpreted as the importance of the first-period cognition (health) in producing health (cognition) in the second period, whereas the parameter β_θ can be interpreted as the *relative* importance of the first-period health (cognition) in producing health (cognition) in the second period, relative to investment in health (cognition) in the first period.

By solving the parental optimization problem,[21] we derive the optimal investment in the health and cognition of child i as follows:[22]

$$I^{H*}_{i,1} = \frac{\alpha_H}{\beta_I} W \pi_i - \frac{\beta_\theta}{\beta_I} \theta^H_{i,1}, \tag{21}$$

$$I^{C*}_{i,1} = \frac{\alpha_C}{\beta_I} W \pi_i - \frac{\beta_\theta}{\beta_I} \theta^C_{i,1}, \tag{22}$$

where:

$$W = \beta_\theta \left(\theta^H_{i,1} + \theta^C_{i,1} + \theta^H_{j,1} + \theta^C_{j,1}\right) + \beta_I I, \tag{23}$$

$$\pi_i = \frac{V\left(\theta^H_{i,2}, \theta^C_{i,2}\right)^\rho}{U^\rho}. \tag{24}$$

[19] This assumption is also consistent with the original formulation in Grossman (1972): $H_{t+1} = I_t + (1-\delta) H_t$, where H is the stock of health, I is gross investment, and δ is depreciation.

[20] We assume a Cobb-Douglas production technology to simplify the calculations. Our basic results are unchanged if we assume a general CES production technology and relax the assumption of substitutability between investments and stocks of skills. The results with this alternative specification are reported in the appendix.

[21] The solution to the parental optimization problem is obtained by maximizing the utility function (17) subject to the investment budget constraint (equation (14)), the production technologies (equations (19)-(20)), and the quality function (equation (18)).

[22] The formal derivation is reported in the appendix.

Let us first consider equation (23). W measures the *full resources* devoted to the production of health and cognitive skills in the second period, which includes the health and cognitive stock of both children in the first period and the total resources allocated to children in the first period, weighted by their relative importance in the production function (equations (19)-(20)). Note that $dW/d\theta_{i,1}^{H} = \beta_{\theta} > 0$: a one-unit increase in child i's health in the first period increases the *full resources* by β_{θ}. We call this the *wealth effect* as in Becker and Tomes (1976). The wealth effect is always positive. Let us now consider equation (24): π_i measures the relative importance of child i in the parental utility function.[23] Thus, $W\pi_i$ measures the share of total resources allocated to child i. It is important to note that the sign of $d\pi_i/d\theta_{i,1}^{H}$ is unambiguously determined by the parental inequality aversion parameter ρ:[24] when $\rho > 0$, parents give more weight to efficiency than to equality, so they allocate more resource to child i if this child has better health in the first period. Following Becker and Tomes (1976), we interpret $d\pi_i/d\theta_{i,1}^{H}$ as a "*price effect*", as an increase in child i's health stock changes the child's relative importance or *shadow price* in the parental utility function.[25] Let us finally consider the equation for optimal investment in health (equation (21)). In this equation, α_H measures the relative importance of health in the child quality function (equation (18)); β_I measures the productivity of the investment in health (equation (19)); and β_{θ}/β_I measures the trade-off between health in the first period and investments in health in the production technology (equation (19)). An analogous interpretation applies to equation (22) for optimal investment in cognitive skills.

We now derive the comparative static results for the effect of health in the first period on investment in health and cognitive skills for child i:

$$\frac{\partial I_{i,1}^{H*}}{\partial \theta_{i,1}^{H}} = \frac{\alpha_H}{\beta_I}\left(\frac{\partial W}{\partial \theta_{i,1}^{H}}\pi_i + \frac{\partial \pi_i}{\partial \theta_{i,1}^{H}}W\right) - \frac{\beta_{\theta}}{\beta_I}, \tag{25}$$

$$\frac{\partial I_{i,1}^{C*}}{\partial \theta_{i,1}^{H}} = \frac{\alpha_C}{\beta_I}\left(\frac{\partial W}{\partial \theta_{i,1}^{H}}\pi_i + \frac{\partial \pi_i}{\partial \theta_{i,1}^{H}}W\right). \tag{26}$$

Note that, in addition to the wealth effect and the price effect discussed above, equation (25) also includes an additional term, $(-\beta_{\theta}/\beta_I)$: we call this term the *technological effect*, because it stems directly from the health production technology (equation (19)). Due to the substitutability between

[23]Note that $U^{\rho} = V_i(\theta_{i,2}^{H}, \theta_{i,2}^{C})^{\rho} + V_j(\theta_{j,2}^{H}, \theta_{j,2}^{C})^{\rho}$.

[24]The mathematical derivation is shown in the appendix.

[25]The shadow price here involves not only resources but also utility.

the health stock in the first period and the investment in health (equation (19)), an increase in the health stock in the first period will reduce the amount invested in health. Thus, the technological effect is always negative. As noted above, the wealth effect is always positive, whereas the sign of the price effect depends on the parental degree of inequality aversion: $\partial\pi_i/\partial\theta^H_{i,1}$ is positive if $\rho > 0$ (efficiency outweighs equality), whereas it is negative if $\rho < 0$ (equality outweighs efficiency). In either case, the own effect of first-period health on investment in health is ambiguous. On the contrary, the own effect of first-period health on investment in cognitive skills is always positive if parents exhibit no inequality aversion, as both the wealth effect and the price effect are positive (equation (26)).

We now investigate the cross-effects of child i's health in the first period on investment in health and cognitive skills of child j:

$$\frac{\partial I^{H*}_{j,1}}{\partial\theta^H_{i,1}} = \frac{\alpha_H}{\beta_I}\left(\frac{\partial W}{\partial\theta^H_{i,1}}\pi_j + \frac{\partial\pi_j}{\partial\theta^H_{i,1}}W\right), \tag{27}$$

$$\frac{\partial I^{C*}_{j,1}}{\partial\theta^H_{i,1}} = \frac{\alpha_C}{\beta_I}\left(\frac{\partial W}{\partial\theta^H_{i,1}}\pi_j + \frac{\partial\pi_j}{\partial\theta^H_{i,1}}W\right). \tag{28}$$

Note that $\partial\pi_j/\partial\theta^H_{i,1}$ has a sign opposite to $\partial\pi_i/\partial\theta^H_{i,1}$ because $\pi_i + \pi_j = 1$.[26] Hence, the price effects on investments in health and cognition are always negative if parents exhibit no inequality aversion. Subtracting pairwise the equations (25)-(28), we obtain the following:[27]

$$\frac{\partial I^{H*}_{i,1}}{\partial\theta^H_{i,1}} - \frac{\partial I^{H*}_{j,1}}{\partial\theta^H_{i,1}} = \frac{\alpha_H}{\beta_I}\left(\frac{\partial\pi_i}{\partial\theta^H_{i,1}} - \frac{\partial\pi_j}{\partial\theta^H_{i,1}}\right)W - \frac{\beta_\theta}{\beta_I}, \tag{29}$$

$$\frac{\partial I^{C*}_{i,1}}{\partial\theta^H_{i,1}} - \frac{\partial I^{C*}_{j,1}}{\partial\theta^H_{i,1}} = \frac{\alpha_C}{\beta_I}\left(\frac{\partial\pi_i}{\partial\theta^H_{i,1}} - \frac{\partial\pi_j}{\partial\theta^H_{i,1}}\right)W. \tag{30}$$

When parents give more weight to efficiency than to equality ($\rho > 0$), $\partial I^{C*}_{i,1}/\partial\theta^H_{i,1} - \partial I^{C*}_{j,1}/\partial\theta^H_{i,1}$ is positive, whereas the sign of $\partial I^{H*}_{i,1}/\partial\theta^H_{i,1} - \partial I^{H*}_{j,1}/\partial\theta^H_{i,1}$ is undetermined because it depends on the relative magnitude of the price effect $\left(\frac{\partial\pi_i}{\partial\theta^H_{i,1}} - \frac{\partial\pi_j}{\partial\theta^H_{i,1}}\right)$, which is positive, and the technological effect $-\left(\frac{\beta_\theta}{\beta_I}\right)$, which is negative.

We now summarize the main predictions of our theoretical model that we will test empirically.

[26] For example, when efficiency outweighs equality ($\rho > 0$), $\partial\pi_i/\partial\theta^H_{i,1} > 0$, while $\partial\pi_j/\partial\theta^H_{i,1} < 0$.

[27] Note we assume $\pi_j = \pi_i$, consistently with the assumption that parents have equal concerns.

The first prediction is related to the effect of an early health shock affecting child i on the difference in investment in health and cognitive skills across twins. It is obtained directly from equations (29) and (30):

$$\left(\frac{\partial I_{i,1}^{H*}}{\partial \theta_{i,1}^{H}} - \frac{\partial I_{j,1}^{H*}}{\partial \theta_{i,1}^{H}}\right)\frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}} = \left[\frac{\alpha_H}{\beta_I}\left(\frac{\partial \pi_i}{\partial \theta_{i,1}^{H}} - \frac{\partial \pi_j}{\partial \theta_{i,1}^{H}}\right)W - \frac{\beta_\theta}{\beta_I}\right]\frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}}, \tag{31}$$

$$\left(\frac{\partial I_{i,1}^{C*}}{\partial \theta_{i,1}^{H}} - \frac{\partial I_{j,1}^{C*}}{\partial \theta_{i,1}^{H}}\right)\frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}} = \left[\frac{\alpha_C}{\beta_I}\left(\frac{\partial \pi_i}{\partial \theta_{i,1}^{H}} - \frac{\partial \pi_j}{\partial \theta_{i,1}^{H}}\right)W\right]\frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}}. \tag{32}$$

When $\rho > 0$, the within-twin-pair fixed-effects estimate of the effect of an early health shock on the investment in cognitive skills is predicted to be negative (equation (32)). However, the sign of the effect on investment in health is ambiguous (equation (31)), because it depends on the relative magnitude of the price effect (which is positive) and the technological effect (which is negative). The case when $\rho < 0$ can be analyzed in a similar way.

The second prediction is related to the effect of an early health shock on health and cognition in the second period. By plugging equations (29)-(30) into equations (11)-(12) and assuming that the productivity of the investment is the same across twins $\left(\text{i.e.} \frac{\partial \theta_{i,2}^{H}}{\partial I_{i,1}^{H}} = \frac{\partial \theta_{j,2}^{H}}{\partial I_{j,1}^{H}} \text{ and } \frac{\partial \theta_{i,2}^{C}}{\partial I_{i,1}^{C}} = \frac{\partial \theta_{j,2}^{C}}{\partial I_{j,1}^{C}}\right)$, we obtain the following:

$$\frac{d\theta_{i,2}^{H}}{de_{i,1}^{H}} - \frac{d\theta_{j,2}^{H}}{de_{i,1}^{H}} = \frac{\partial \theta_{i,2}^{H}}{\partial \theta_{i,1}^{H}} \cdot \frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}} + \frac{\partial \theta_{i,2}^{H}}{\partial I_{i,1}^{H}} \cdot \left[\frac{\alpha_H}{\beta_I}\left(\frac{\partial \pi_i}{\partial \theta_{i,1}^{H}} - \frac{\partial \pi_j}{\partial \theta_{i,1}^{H}}\right)W - \frac{\beta_\theta}{\beta_I}\right] \cdot \frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}}, \tag{33}$$

$$\frac{d\theta_{i,2}^{C}}{de_{i,1}^{H}} - \frac{d\theta_{j,2}^{C}}{de_{i,1}^{H}} = \frac{\partial \theta_{i,2}^{C}}{\partial \theta_{i,1}^{H}} \cdot \frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}} + \frac{\partial \theta_{i,2}^{C}}{\partial I_{i,1}^{C}} \cdot \left[\frac{\alpha_C}{\beta_I}\left(\frac{\partial \pi_i}{\partial \theta_{i,1}^{H}} - \frac{\partial \pi_j}{\partial \theta_{i,1}^{H}}\right)W\right] \cdot \frac{\partial \theta_{i,1}^{H}}{\partial e_{i,1}^{H}}. \tag{34}$$

When $\rho > 0$, the within-twin-pair fixed-effects estimate of the effect of the early health shock on cognitive skills in the second period is predicted to be negative (equation (34)). However, the sign of the effect of the early health shock on health in the second period is ambiguous (equation (33)), because it depends on the relative magnitude of the price effect (which is positive) and the technological effect (which is negative). The case when $\rho < 0$ can be analyzed in a similar way.

Finally, before moving on to the econometric model, we discuss the implications of our theoretical model and its relationship with the empirical analysis below. An ambitious objective is to estimate the dynamic model as we have laid it out and to identify separately the parental preferences from the technology parameters. Unfortunately, we are not able to achieve this objective in this paper because our data do not contain information on the child's health and cognitive skill stock in the first period $\left(\theta_{i,1}^H \text{ and } \theta_{i,1}^C\right)$.[28] Thus, we carry out the reduced-form estimation of equations (31)-(34) below.[29] However, although we cannot estimate the entire structural system, our theoretical model plays a key role in guiding the interpretation of our empirical results. First, the model rationalizes that parents can make compensating and reinforcing investments along different dimensions during the same time (equations (31)-(32)). This is the key insight we plan to test in the empirical part. Second, it lays down the basic framework that can be used to interpret the within-twin-pair fixed-effects estimates by using the estimates from equations (33)-(34) as the lower or upper bound of the biological effects.[30] Because we are able to estimate the reduced-form effects of an early health shock on investment in health $\left[\frac{\alpha_H}{\beta_I}\left(\frac{\partial \pi_i}{\partial \theta_{i,1}^H} - \frac{\partial \pi_j}{\partial \theta_{i,1}^H}\right)W - \frac{\beta_\theta}{\beta_I}\right]$ and cognitive skills $\left[\frac{\alpha_C}{\beta_I}\left(\frac{\partial \pi_i}{\partial \theta_{i,1}^H} - \frac{\partial \pi_j}{\partial \theta_{i,1}^H}\right)W\right]$ from equations (31) and (32), and the signs of $\frac{\partial \theta_{i,2}^H}{\partial I_{i,1}^H}$ (equation (33)) and $\frac{\partial \theta_{i,2}^C}{\partial I_{i,1}^C}$ (equation (34)) are always positive, we are able to infer whether the reduced-form estimates of $\frac{d\theta_{i,2}^H}{de_{i,1}^H} - \frac{d\theta_{j,2}^H}{de_{i,1}^H}$ (equation (33)) and $\frac{d\theta_{i,2}^C}{de_{i,1}^H} - \frac{d\theta_{j,2}^C}{de_{i,1}^H}$ (equation (34)) are *lower* or *upper* bounds of the biological effects. Third, the theoretical model provides a framework to interpret the differences between the OLS and the within-twin-pair fixed-effects estimates, as we will discuss in a later section. Therefore, we will discuss our empirical results in light of our theoretical framework in the following sections.

3 The Econometric Analysis

In this section, we present the econometric specification we estimate, guided by our theoretical model. We first analyze how parents respond to an early health shock, by specifying the stochastic version of the parental investment equation as follows:

$$I_{\iota,\tau}^{\kappa} = \alpha^{\kappa} e_{\iota,\tau}^{H} + X_{\iota,\tau}\beta^{\kappa} + \zeta_{\tau}\varphi^{\kappa} + \mu_{\tau} + \epsilon_{\iota,\tau}^{\kappa}, \tag{35}$$

[28]The data set will be discussed in detail in section 4. The data we use are essentially cross-sectional, and the early health shock variable is constructed retrospectively.

[29]One consequence of this is that, for example, we will not be able to ascertain if the negative health effects of an early health shock are derived from a change in the production technology.

[30]The biological effects are represented by $\frac{\partial \theta_{i,2}^H}{\partial \theta_{i,1}^H} \cdot \frac{\partial \theta_{i,1}^H}{\partial e_{i,1}^H}$ (equation (33)) and $\frac{\partial \theta_{i,2}^C}{\partial \theta_{i,1}^H} \cdot \frac{\partial \theta_{i,1}^H}{\partial e_{i,1}^H}$ (equation (34)).

where $\kappa = H, C$, and ι indexes individual twins and τ households. $I^{\kappa}_{\iota,\tau}$ is the investment in κ during the first period; $e^{H}_{\iota,\tau}$ is a health shock in the first period;[31] $X_{\iota,\tau}$ is a vector of child-specific characteristics; ζ_{τ} is a vector of observed household characteristics affecting parental investment decisions; μ_{τ} is the unobservable household heterogeneity such as reporting heterogeneity which will be discussed later; and $\epsilon^{\kappa}_{\iota,\tau}$ is the disturbance term. To sweep out family-level unobserved heterogeneity, we use the following within-twin-pair fixed-effects specification:

$$I^{\kappa}_{i,\tau} - I^{\kappa}_{j,\tau} = \alpha^{\kappa}\left(e^{H}_{i,\tau} - e^{H}_{j,\tau}\right) + \left(X_{i,\tau} - X_{j,\tau}\right)\beta^{\kappa} + \epsilon^{\kappa}_{i,\tau} - \epsilon^{\kappa}_{j,\tau}, \tag{36}$$

where i and j index the two twins in the pair. Equation (36) is the empirical counterpart of equations (31)-(32). Our theoretical model shows that the within-twin-pair estimator, in removing the family-level unobserved heterogeneity, also sweeps out the wealth effect induced by an early health shock. Thus, when parents give more weight to efficiency than to equality, i.e., $\rho > 0$, our theoretical model unambiguously predicts α^{C} to be negative. However, the sign of α^{H} remains undetermined because it depends on the trade-off between the degree of parental inequality aversion (the price effect) and the substitutability between investment in health and the stock of health in the first period to produce health in the second period (the technological effect).

We then analyze how an early health shock affects later outcomes, using the following specification:

$$\theta^{\kappa}_{\iota,\tau} = \gamma^{\kappa} e^{H}_{\iota,\tau} + X_{\iota,\tau}\delta^{\kappa} + \zeta_{\tau}\psi^{\kappa} + \mu_{\tau} + \varepsilon^{\kappa}_{\iota,\tau}, \tag{37}$$

where $\theta^{\kappa}_{\iota,\tau}$ is the outcome κ for twin ι in household τ in the second period,[32] and all the other terms are defined as in equation (35). The corresponding within-twin-pair fixed-effects specification is:

$$\theta^{\kappa}_{i,\tau} - \theta^{\kappa}_{j,\tau} = \gamma^{\kappa}(e^{H}_{i,\tau} - e^{H}_{j,\tau}) + (X_{i,\tau} - X_{j,\tau})\delta^{\kappa} + \varepsilon^{\kappa}_{i,\tau} - \varepsilon^{\kappa}_{j,\tau}. \tag{38}$$

Equation (38) is the empirical counterpart of equations (33)-(34). Our theoretical model predicts the sign of γ^{C} to be unambiguously negative if efficiency outweighs equality when parents make

[31] As clarified in Section 4, the health shock, as measured in our data, occurs between the ages of 0 and 3, and parental investment refers to the year prior to the survey (the twins are between 6 and 18 years old, with mean age 11, at the time of the survey; see Table 1).

[32] As clarified in Section 4, the outcomes refer to the year of the survey when the twins are between 6 and 18 years old (mean age 11; see Table 1).

investment decisions. However, the sign of γ^H is undetermined, as discussed in Section 2.

Before proceeding to the data description, we now discuss our identification strategy. On the one hand, although siblings are biologically similar to dizygotic twins, the within-twin-pair fixed-effects estimator requires much weaker identification assumptions than the within-siblings fixed-effects estimator when estimating child outcomes production functions (Todd and Wolpin, 2007). Specifically, the within-siblings fixed-effects estimator requires three additional assumptions. First, the effects of an early health shock must be either independent of age if siblings' outcomes are measured at different ages but at the same point in time, or independent of time if siblings' outcomes are measured at the same age but at different points in time. Second, parents must not make time-varying investments across siblings. Third, parents must not adjust their fertility choices and investment behavior in response to a health shock affecting their existing children, an assumption which seems untenable according to Rosenzweig and Wolpin (1988) and the suggestive evidence we provide.[33]

On the other hand, our within-twin-pair fixed-effects estimator still relies on the assumption that $\varepsilon_{i,\tau} - \varepsilon_{j,\tau}$ and $\epsilon_{i,\tau} - \epsilon_{j,\tau}$ are uncorrelated with $e^H_{i,\tau} - e^H_{j,\tau}$, conditional on the observables. In other words, our key identification assumption is that, conditional on the observed covariates, the early health shock occurs randomly within twin pairs. Of course, there is always the possibility that it can reflect unobserved health differences. Unfortunately, due to data limitations, we cannot estimate a model that also includes individual-level unobserved heterogeneity, but we try to address this concern by controlling for birth weight in all our specifications. Our rationale for doing so is that birth weight can be considered a proxy for the child's stock of health capital at birth, before the occurrence of the early health shock at ages 0-3 (Behrman and Rosenzweig, 2004; Almond, Chay, and Lee, 2005).[34]

[33]Table 1 in the appendix provides suggestive evidence that the fertility decision is significantly affected by the health status of the first child: the occurrence of a health shock in the child at ages 0-1 has a significantly negative association with the probability that the mother has a second child. This table is based on the comparison group of non-twin households in our survey data (see the data description section below). Our results are consistent with the findings of Rosenzweig and Wolpin (1988), and show the usefulness of adopting the twin-fixed-effects method in the presence of the "One-Child" policy.

[34]Evidence and discussion on the randomness of early health shocks within twin pairs are shown in a later section.

4 Data

4.1 The Chinese Child Twins Survey

The data we use for this study come from the Chinese Child Twins Survey (CCTS), which is the first census-type child twins survey of which we are aware.[35] The survey was carried out by the Urban Survey Unit (USU) of the National Bureau of Statistics (NBS) in late 2002 and early 2003 in the Kunming district of China. Kunming is the capital of Yunnan Province, which is located in the far southwestern corner of China and has a total population of about 5 million.

The CCTS includes a sample of households with twins aged between 6 and 18 years living in Kunming in 2002. The households were initially identified by the USU based on the 2000 population census according to whether the children have the same birth year and month and the same relationship with the household head. The addresses of these households were then obtained from the census office, and the presence of twins was verified with a visit to the household. Starting from 2,300 pairs of potential twins identified in the census, 1,694 households with twins were successfully interviewed; among these, 1,300 households had twins on the first birth and 394 households had twins on the second birth.[36] A comparison sample of 1,693 households with no twins was also surveyed using the same questionnaire.[37]

The questionnaire was designed by Junsen Zhang in close consultation with Mark Rosenzweig and Chinese experts at the National Bureau of Statistics. Based on existing twins and child questionnaires in the US and elsewhere, the survey covers an extensive range of information about inputs and outcomes of children, in addition to a wide range of demographic, social, and economic information at the household level. The questionnaire is divided in two parts. The first part is answered jointly by the father, mother, and children, and collects information on the household situation, parents, schooling and health of the children, and parental investments. After completing the first part, each parent and each child are separately interviewed in different rooms. The

[35] See Rosenzweig and Zhang (2009) for a detailed description of the CCTS.

[36] The "One-Child" policy is strictly implemented in urban areas in Kunming. In rural areas, however, households are encouraged to have one child, but are exempted from the strict "One-Child" policy (although they are allowed to have two children at most (Family Planning Commission of Yunnan Province, 2003)). This is evident in Panel H of Table 1, where the proportion of twins born at the second birth is much higher in rural (0.33) than in urban (0.07) areas. In our analysis, we include both first-birth (in which case parents are not allowed to have any more children) and second-birth twins because the results are qualitatively the same if we exclude the latter sample.

[37] To guarantee the comparability of the non-twin group, the fourth household on the right-hand side of the same block of the twin household was chosen as the non-twin comparison. If the fourth household had no children aged 6-18, then interviewers continued with the fifth, sixth, etc.

second part covers information on home tutoring, children's schooling and academic performance, entertainment, and social activities.

We exploit two features of the Chinese institutional system in our empirical analysis. First, the existence of the "One-Child" policy serves as a natural experiment to eliminate the possibility that the fertility decision will be endogenously affected by the health condition of the twin children (this is an issue raised by Rosenzweig and Wolpin (1988)). The second feature of the Chinese system that we exploit in our empirical analysis is the strict household registration policy known as *hukou*. The *hukou* system was established in the early 1950s to consolidate socialist governance, control population flow, and administer the planned economy. Under this system, every person is required to be registered where she is born and to obtain a *hukou* certificate: all administrative activities, such as land distribution, issuance of ID cards, registration of a child in school, and registration of marriage, are based on the *hukou* status.[38] Conveniently, at the time the survey was carried out, the *hukou* system was still very strict in the Kunming district. This allows us to compare rural and urban samples without worrying about selectivity concerns arising from migration into the richer urban areas. Therefore, we can interpret these results in light of the differences in the institutional backgrounds between urban and rural areas (West and Zhao, 2000). First, at the time of the survey, the medical insurance system was almost absent in rural areas,[39] whereas medical expenditures on children could be partly reimbursed by the government if the parents were affiliated with government departments or state-owned enterprises in urban areas (Liu, Rao, Wu, and Gakidou, 2008). Second, although public education was not free in both urban and rural areas at the time of the survey,[40] its quality in urban areas was much higher than that in rural areas. Finally, residents in urban areas were covered by the old-age pension system (although the amount of money provided by the government may have been insufficient to satisfy the basic needs), whereas there was no old-age pension system in rural areas at all. We will return to and take all

[38]Until the early 1990s, it was also used to distribute food, cooking oil, and clothing coupons. Moreover, it imposed strong restrictions in moving across localities, both in urban and rural areas. Although the Chinese government has been gradually reforming it since the mid-1990s, the *hukou* system is still very strict in most places (Yusuf and Saich, 2008).

[39]The Chinese government began to promote the New Cooperative Medical System (NCMS) in rural areas after 2003. NCMS is a co-pay insurance system financed by the central government, local government, and individuals (Brown, de Brauw, and Du, 2009).

[40]The tuition fee for compulsory education (six years of primary school and three years of middle school) has been exempted in both rural and urban areas only since September 1, 2008.

these institutional features into account in the interpretation of our empirical results.[41]

4.2 The Summary Statistics

We now describe the main variables that are used in our empirical analysis. The summary statistics are reported in Table 1.

Early Health Shocks Our independent variable of interest (early health shocks, $e^H_{i,1}$) is defined as a dummy variable indicating whether the child suffered from a serious disease during ages 0-3. Table 1 (Panel A) shows that the prevalence rate in our sample is 9%. The most prevalent diseases are serious diarrhoea and calcium deficiency, as is the case for children in developing countries (Strauss and Thomas, 1998).[42] Table 2 in the appendix tabulates the distribution of serious diseases suffered during ages 0-3.[43]

We now address some potential concerns regarding the measurement of early health shocks as they are based on health histories constructed retrospectively. First, retrospective data may suffer from recall error, particularly, parents may report that the child who is currently sick was also sick in the past. The fixed-effects estimator may exacerbate this problem (Strauss and Thomas, 1998).[44] There are three reasons why we believe this to be less of a concern in our case: (a) the health history questions are answered together by the father, mother, and children (in the first part of the questionnaire); (b) given the young age of the twin sample, the recall period is not very long; (c) parents and children are also asked to specify the timing

[41]In addition to urban and rural, we also compare the results between the male and female subsamples. The results for the mixed-gender subsamples are only reported in the appendix because the sample size becomes much smaller in this case, as it only includes DZ twin pairs. Note that we do not distinguish between MZ and DZ twins in our estimation, given that the criterion to establish zigosity in our data is not based on DNA testing but on physical resemblance. Thus, it is subject to considerable error, which is likely to be correlated with parental behavior (e.g. parents may actually themselves attenuate pre-existing differences among twins). In any case, previous results in the literature do not point to the existence of marked differences in analyses based only on the MZ or DZ subsample, as, for example, in Black, Devereux, and Salvanes (2007).

[42]The complete list also includes asthma, fracture, attention deficit disorder, heart disease, serious hearing difficulties, whooping cough, stammer, and serious eyesight problems. Unfortunately, we cannot distinguish between mental and physical diseases because the former have low prevalence in our sample; see Currie and Stabile (2006) for an analysis of the effect of child mental health on human capital accumulation. Another interesting extension that we leave to a future occasion is to separate the effect of life-threatening shocks. This may well be a circumstance with infinite parental inequality aversion.

[43]We also defined our main independent variable as the number of serious diseases suffered during ages 0-3. The empirical results obtained using this alternative definition are almost identical to the ones reported in the paper and are available from the authors upon request.

[44]In general, the classical measurement error will bias the fixed-effects estimates towards zero. This is not the case in our study, because, as discussed in Section 5, our fixed-effects estimates are generally of a bigger magnitude than the corresponding OLS estimates.

and duration of each disease. This contextualization has the potential to increase recollection effort and further minimize recall error.

Second, respondents may use different thresholds so that some of the differences in the reported illnesses across households may simply reflect differences in the standards (Strauss and Thomas, 1998; Smith, 2009). For example, more educated households can both keep more accurate medical records and have higher standards. This is termed as reporting heterogeneity in the literature (Strauss and Thomas, 1998).[45] The problem of reporting heterogeneity may also exist in our case. Although the medical and economic environments are much better in urban areas than in rural areas as discussed above, Table 1 shows that the prevalence rate of early health shocks is 10% in urban areas, whereas it is only 8% in rural areas. The difference is statistically significant indicating that urban families are more likely to report early health shocks (rather than children in urban areas being more likely to suffer from them). However, these differences are unlikely to exist across twin siblings in the same family. Thus, our within-twin-pair fixed-effects estimation strategy will also avoid the bias arising from reporting heterogeneity.[46]

Parental Investments Our main dependent variables are the measures of the parental investments in children in the year before the survey $\left(I_{i,1}^{\kappa}\right)$. Due to the richness of our data, we are able to differentiate between investment in money (i.e., medical, education and clothing expenditures) and investment in time (i.e., minutes per day the parents spend tutoring each twin). Medical expenditures include money spent on medical treatments and on the purchase of medicine or health products;[47] educational expenditures include school tuition fees, money spent on the purchase of books and stationery, home tutors, and tutoring-class expenses. The summary statistics are shown in Table 1 (Panel B). There are several things that should be noted. First, the medical and educational expenditures on children constitute a substantial fraction of the family income: educational expenditures alone amount to ¥911.58/year, out

[45] The reporting heterogeneity can be regarded as a component of μ_τ in equation (35).

[46] Another interesting aspect of the twin design is that it overcomes the usual problem of the lack of an explicit reference group (or anchoring): it is natural for the parents to think of one twin as the reference point for the other. Curiously, Bago d'Uva, van Doorslaer, Lindeboom, and O'Donnell (2008) find that reporting heterogeneity does not seem to be a source of distortion for the measurement of health disparities in China.

[47] Grossman (2000) also measures medical care by personal medical expenditures on doctors, dentists, hospital care, prescribed and nonprescribed drugs, nonmedical practitioners, and medical appliances.

of a per capita family income of ¥3,030/year (Table 1, Panel H).[48] Second, there are significant differences between rural and urban households: not only do urban households spend, on average, twice the amount as rural households for all the three types of expenditures, but they also constitute a bigger share of the family income. This suggests that rural families may face a much tighter budget than families in urban areas. Third, parents in urban areas also spend, on average, more time tutoring their children, a statistic which can be partly rationalized by their higher level of education compared to that of the parents in rural areas. Finally, it is interesting that we do not find significant differences by gender.

Child Health As measures of child health $\left(\theta^H_{i,2}\right)$, we use anthropometric indicators (i.e., height, weight, and body mass index (BMI)),[49] general health status, and occurrence of visits to the hospital, which are all reported by both parents. The summary statistics in Table 1 (Panel C) show that the height and weight of Chinese child twins are about one standard deviation lower than those of US children of the same age and gender, with the differences being particularly pronounced in rural areas. In contrast, rural children appear less likely to go to the hospital than children in urban areas. This fact may be due to the higher medical costs or the tighter budgets faced by rural households, rather than being a reflection of better health conditions.

Child Academic and Schooling Performance As measures of academic performance $\left(\theta^C_{i,2}\right)$, we use both objective (exam transcripts) and subjective (self-reported evaluations in comparison with the class norm) measures in two different subjects: Literature and Mathematics.[50] Table 1 (Panel D) shows that urban children, on average, perform better than rural ones, and that girls perform better than boys in Literature. We also analyze several outcomes related to schooling performance, both recorded from transcripts (i.e., grade repetition, good student awards, and awards in contests) and reported by the parents (i.e., whether the parents have been interviewed by the teacher because of the poor performance of the child and whether the child is doing minor actions in class). Note that children in urban areas and girls in general perform better (Table 1, Panel E).

Child Noncognitive Skills Different from the administrative data commonly used in twin-based

[48] Unfortunately, our survey does not contain information on family's the total expenditures.
[49] The height, weight, and BMI are standardized by age and gender on the basis of US growth charts.
[50] Literature and Mathematics are compulsory courses from primary school to high school (from age 6 to 18).

analysis, our data are also rich in terms of noncognitive measures, which are categorical and reported by both parents (Table 1, Panel F). On the one hand, it is noted that children in urban areas are more likely to be reported by their parents as experiencing greater emotional instability, feeling more lonely, or anxious. On the other hand, girls are reported to have a stronger personality than boys.[51]

Parental Labor Supply and Expenditures Finally, we also analyze the effect of an early health shock on parental labor supply, measured as days worked per month, and on parental expenditures. We sum up the expenditures on several goods: cigarettes, alcohol, clothes, and cosmetics. Note that expenditures are separately recorded for both the mother and father. Panel G in Table 1 shows that both parents work longer hours in rural areas, whereas they have higher expenditures in urban areas.

Control Variables We include a rich set of control variables in all our empirical specifications: birth weight, gender, age, birth order,[52] number of siblings, mother's age, mother's years of schooling, per capita family income, binary indicators for household ownership of a washing machine, refrigerator, cell phone, whether the mother has a job in the public sector, and living in a rural area (of course, among these variables only birth weight and the gender dummy when required are included in the twins fixed-effects specifications). The summary statistics are reported in Table 1 (Panel H).

5 Results

5.1 Effects of an Early Health Shock on Parental Investments

We first present evidence in support of our identifying assumption of the randomness of the early health shocks. Table 2 (the first two columns) presents both OLS and within-twin-pair FE estimates

[51] We also analyze the effect of an early health shock on the parent-child relationship, both from the parents' (educational expectations and quality of the relationship) and the child's perspective (openness of the communication and time spent with the parents). As observed in Table 82 in the appendix, there are significant differences between the urban and the rural subsamples, that likely reflect different parenting styles. On the one hand, parents in urban areas have higher expectations regarding the educational achievement of their children. On the other hand, children in urban areas report that they spend more time with their parents.

[52] Interestingly, although we do not find any other evidence of gender discrimination, the proportion of males born at second birth (0.23) is significantly higher than that of females (0.16), and we observe that the mothers of female twins are significantly more educated (9.10) than those of males (8.70). We interpret this finding as evidence that more educated mothers are less likely to practice selective abortion.

of the determinants of early health shocks.[53] Clearly, both across and within households, the occurrence of an early health shock is unrelated to birth weight.[54]

We now turn to our main estimation results, starting with the effects of an early health shock on parental investments. Our main finding is that parents adopt a compensatory strategy when deciding how much to invest in health but use a reinforcement strategy with respect to investment in education in response to an early health shock affecting one of the twin children. The estimates are both statistically and economically significant. As shown in Table 2 (column 4), the gap in medical expenditures on average increases by ¥305 in favor of the sick twin, but the gap in educational expenditures increases by ¥186, on average, in favor of the healthy one.

To interpret these findings, we refer to our theoretical model. The key point is that, in our framework with multidimensional child endowments, the compensating or reinforcing nature of investment in health depends on both the price effect and the technological effect (equation (31)), whereas that of investment in education is unambiguously determined by the price effect (equation(32)). We first examine the effect of an early health shock on educational expenditures. The result of a reinforcing investment in education suggests that the price effect of an early health shock is negative. This finding implies that efficiency outweighs equality and that ρ is positive in the parental utility function.[55] We then examine the effect on health expenditures. The result of a compensating investment in health reflects the fact that the technological effect (the substitutability between health stock and investment in health) dominates the price effect.[56] Therefore, we observe that parents compensate and reinforce along different dimensions of the child's human

[53]Table 3 in the appendix presents the full OLS and FE results. It shows that there is a positive correlation between the level of education of the mother and the probability of reporting that the child has suffered from an early health shock. As discussed above, this reporting bias is swept out by the within-twin-pair FE estimator.

[54]However, why would an early health shock uncorrelated with birth weight differentially affect only one of the twins? One plausible explanation is the epigenetic effect: according to the Developmental Origins of Health and Disease (DOHaD) theory, small variations in prenatal experiences may affect the risk of disease in the absence of any effect on birth weight (Godfrey, Gluckman, and Hanson, 2010). In our case, what is critical to our identification strategy is the assumption that the first manifestation of this latent (or epigenetic) effect occurs with the health shock recorded in the data, thereby ruling out any previous parental response. This assumption is supported by the fact that, on average, 60% of the early health shocks affect the child within the first year of life and are not short-term episodes.

[55]Referring to equation (32), the negative estimate in the educational expenditure equation implies that $\partial\pi_i/\partial\theta^H_{i,1}$ is positive because $\partial\theta^H_{i,1}/\partial e^H_{i,1}$ is negative and that $\partial\pi_j/\partial\theta^H_{i,1}$ is opposite to the sign of $\partial\pi_i/\partial\theta^H_{i,1}$. The positive $\partial\pi_i/\partial\theta^H_{i,1}$ implies that ρ is positive and that efficiency outweighs equality when parents make investment decisions.

[56]Referring to equation (31), $\frac{\alpha_H}{\beta_I}\left(\frac{\partial\pi_i}{\partial\theta^H_{i,1}} - \frac{\partial\pi_j}{\partial\theta^H_{i,1}}\right)W$ is positive on the basis of the estimate in the educational expenditure equation. Therefore, the positive estimate in the health expenditures equation implies that $\frac{\alpha_H}{\beta_I}\left(\frac{\partial\pi_i}{\partial\theta^H_{i,1}} - \frac{\partial\pi_j}{\partial\theta^H_{i,1}}\right)W < \frac{\beta_\theta}{\beta_I}$, suggesting that the price effect is dominated by the technological effect.

capital at the same time.

These results have important implications. In the presence of parental responses, the reduced-form estimates of the effects of an early health shock cannot be purely interpreted as "biological" effects. They constitute either an upper or a lower bound on the true biological effect depending on whether parents adopt a reinforcing or compensatory strategy: this is something that we will not know unless we observe parental behavior. These results are also policy relevant. Parental responses should be taken into account when designing interventions aimed at remediating disadvantage, as parents can exacerbate or annihilate their effects by reallocating resources within the family. Moreover, compared with the within-twin-pair FE estimates, the OLS estimates (also reported in Table 2) systematically underestimate (in absolute value) the effects of early health shocks on parental investments.

The richness of our data allows us to investigate the effects of an early health shock not only on investment in money but also on investment in time. Interestingly, we find that parents spend the same amount of time on both twins,[57] a finding which may reflect the fact that parental time is a non-excludable public good within the household because the parents usually tutor the twins together.[58]

Finally, we find significant differences across subsamples (Table 3). On the one hand, the increase in medical expenditures in favor of the sick twin is not accompanied by a corresponding decrease in educational expenditures in rural areas. We rationalize this finding in light of the fact that the budget is already very tight in rural areas, and thus no changes in educational expenditures are possible. Instead, in urban areas, the extra educational resources allocated in favor of the healthy twin have almost the same monetary value as the amount redistributed to pay for the medical expenses of the sick twin. On the other hand, we also find significant differences by gender. The amount of money reallocated for both medical and educational expenditures in case of female twins is almost twice the amount allocated in case of male twins.

[57]Note that this question was answered by each twin separately.

[58]Price (2008) shows that most of the variation in the time spent with the child is driven by birth order and maternal employment, which do not vary within twin pairs.

5.2 Effects of an Early Health Shock on Child Outcomes

5.2.1 Child Health

We now examine the effects of an early health shock on child outcomes. We first examine its effects on health in Table 4. Overall, we find some evidence of a long-lasting effect on anthropometric measures. The twin child affected by the early insult is evaluated by the parents as being in worse health and is reported to have a greater occurrence of hospital visits. We now refer to the predictions of our theoretical model (equation (33)) as a guide to interpret the results. Despite the fact that parents have allocated more money as medical expenditures to the sick child, the negative effects of an early health shock are persistent. This finding implies that the direct medical damage (the first term in equation (33)) outweighs the positive intrahousehold resource allocation effect (the second term in equation (33)). Moreover, importantly, in the presence of compensatory parental responses concerning health expenditures,[59] reduced-form estimates *understate* (in absolute value) the biological effect. Given the difficulties of observing all the relevant inputs, we can only say that what we are estimating is a lower bound.

There are also substantial differences across subsamples (Table 4). An early health insult has a consistently negative effect on weight, BMI, and general health status but not on the occurrence of hospital visits in the rural sample. In contrast, an early health shock increases the occurrence of hospital visits in the urban sample and worsens the reported general health status, but it does not have a significantly negative effect on the anthropometric measures. We interpret this evidence by speculating that health shocks may have more long-lasting effects in rural areas where a tighter budget may not allow the parents to go to the hospital for the child to receive the necessary medical care every time it is required. This result has important implications. It suggests that, on the one hand, the negative health effects of an early health shock may be partly offset by compensating investments in families with adequate resources, as our theoretical model predicts. In other words, remediation is possible. On the other hand, the negative effects of an early health shock may persist throughout the life-cycle of children born in poor families because of a tight budget.[60] In the latter

[59]The second term on the right-hand side of equation (33) is positive on the basis of our estimates in the health expenditures equation (Table 2).

[60]This is consistent with the evidence reported in Condliffe and Link (2008) for the United States. Note that, in the richer urban areas, both the level of medical expenditures (Table 1) and the money allocated to the sick twin (Table 3) have a larger magnitude than in rural areas.

case, government subsidies or public health insurance might be crucial policy tools for preventing an early health shock from impairing the child's human capital formation. The gender differences are also noteworthy. Whereas an early health shock has a negative effect on the anthropometric measures only for females, it increases the occurrence of hospital visits only for males. This finding can be interpreted as evidence of greater vulnerability in terms of physical growth for females, and of greater susceptibility to disease for males, given that we do not find any gender differences in the reallocation of medical expenditures.

Finally, it is also interesting to compare the FE and the OLS estimates, which are reported in Table 4 and in Tables 10-12 in the appendix, respectively. We note that, for both the whole sample and the rural sample, OLS estimates underestimate the negative effects of an early health shock. However, for the urban sample, they overestimate them. To interpret these findings, we need to refer to our theoretical model once again. As discussed above, on the one hand, the FE estimator sweeps out the cross-household reporting heterogeneity. On the other hand, the effect of intrahousehold resource allocation is more important in driving the FE than the OLS estimates. Therefore, the difference between the OLS and the FE estimates depends on the relative importance of these factors. As our empirical evidence shows, to the extent the compensation in health via increased medical expenditures is stronger in urban than in rural areas (parents in urban areas allocate, on average, ¥130 more in medical expenditures to the insulted child than parents in rural areas, as shown in Table 3), the OLS estimates will be biased downward in the latter but upward in the former. The conceptual clarification that our theoretical model allows between OLS and FE estimates of the reduced-form effects of an early-life shock on late-life outcomes also has important implications in reconciling the contradictory empirical results present in the literature: although some studies find that, compared with within-family fixed-effects estimates, OLS estimates underestimate the negative effects of early-life health conditions, others find evidence of upward bias.

5.2.2 Other Child Outcomes

We then examine the effects of an early health shock on educational outcomes.[61] Table 5 shows that the twin affected by an early health insult has poorer academic achievement, both perceived

[61] In this case, we restrict our analysis to 95% of the sample who is still in school.

and actual. Table 6 shows that an early health insult also negatively affects the twin's schooling performance. Whereas these results come as no surprise, the point that we want to stress here is that we find these negative effects in the presence of parental reinforcing behavior (as noted in Section 5.1). Hence, reduced-form estimates *overstate* (in absolute value) the true biological effect. Given the difficulties of observing all the relevant inputs, we can only say that what we are estimating is an *upper* bound.[62]

We also uncover a significant gender difference. In the case of female twin pairs, the difference in academic achievements between the healthy and sick sisters is only perceived, not real. A significant difference also emerges between the rural and the urban subsamples. Whereas in rural areas we see the effects mainly operating through a problematic behavior in the classroom, in urban areas the long-lasting effects of early-life insults seem to affect mainly purely educational performance. This is consistent with the evidence reported earlier of a reduction in educational expenditures in the urban areas but not in the rural ones. Lastly, Table 7 shows that an early health insult consistently and negatively affects the child's personality in several different domains, with no significant differences between the rural and urban subsamples, but with the girls significantly more affected than the boys.[63]

Before moving on to the last section, we make several observations about the role that birth weight plays in our analysis, which appears to be more marginal than the pervasive and long-lasting consequences of the early health shock. First, we note that birth weight has an effect on parental investments (Tables 46-51 in the appendix) only in rural areas, where parents allocate more medical expenditures to children lighter at birth (Table 47 in the appendix). Second, among all outcomes studied (Tables 52-81 in the appendix), birth weight has only a strong and negative effect on physical growth (the anthropometric indicators; Tables 52-57 in the appendix), one of the

[62] Referring to equation (34), the second term on the right-hand side of this equation is negative based on our estimates in the educational expenditure equation (Table 2). Therefore, the reduced-form estimates overstate the true biological effect of an early health shock on the child's academic outcomes (the first term on the right-hand side of this equation).

[63] Finally, in Tables 76-81 in the appendix, we report the results on the effects of an early health shock on the relationship between parents and children. From the parental standpoint, parents consistently lower their expectations for the expected educational level of the child affected by the shock, and they also report a worsening relationship between them. The only exception to this pattern occurs in the rural sample, which can be explained in the context of a more traditional type of parent-child relationship, where parents have expectations and children have duties unaffected by changes in circumstances. From the child standpoint, instead, there is no change in the way the relationship with the parents is perceived compared with the healthy twin under a wide variety of common activities, ranging from playing to having dinner together. This is consistent with our previous result where we find evidence of no change in the time parents spend tutoring the child.

outcomes for which the early health shock has less of an impact, especially for males and in the urban areas. This suggests that, if parents do not respond to the difference in birth weight across twins (e.g., because they do not perceive a difference), these will work only through the biological channel, and birth weight will only be an indicator of physical fitness.[64]

5.3 Effects of an Early Health Shock on Parental Labor Supply and Expenditures

Lastly, we go beyond the within-twin-pair estimation framework to understand how money is reallocated within households by exploiting the richness of our data to investigate the effects of an early health shock on parental work and consumption patterns.[65] As these characteristics are invariant within twin pairs, we conduct the analysis at the household level. We analyze whether there are differences in parental labor supply and expenditures in case only one twin child is affected by the health shock compared with the case where none of them is.[66] The results are reported in Table 8. We highlight two main findings: in households where one twin child is affected by a health shock, the father is significantly less likely to spend money on goods for himself, whereas the mother is significantly more likely to work. Moreover, we note that these results are driven by different subsamples: mothers are more likely to work longer hours in households located in urban areas and in the presence of sons, whereas fathers are less likely to spend money on goods for themselves in rural areas and in the presence of daughters. These results can be explained in light of the fact that, in families with male twins, expenditures on non-children goods are already reduced to a minimum. This is due to the need for parents to save money to buy housing and stock wealth to help their sons to attract a mate, given the sex ratio imbalance occurring after the implementation of the "One-Child" policy as result of the preferences for sons (Wei and Zhang, 2009). We derive two main implications from these findings. First, we claim that they provide a

[64]Note that we can recast our findings in light of the recent literature on gene-environment correlation (rGE) and gene-environment interactions (GXE), according to which the observed phenotypic differences among twin pairs are a function of the complex interplay between genetic and environmental factors. Under the interpretation that the early health shock is a manifestation of an epigenetic effect, the differential parental responses can be considered an instance of gene-environment correlation (rGE - genes determine the selection into certain environments; in the current context, they trigger certain parental responses), whereas the phenotypic differences in health and other outcomes can be considered an instance of gene-environment interaction (GXE - parental behavior amplifies or reduces the genetic predisposition). See Conti and Heckman (2010) for a proposed application of gene-environment interaction models to twins data.

[65]See Pitt and Rosenzweig (1990) for an analysis of the effects of child health on intrafamily allocation of time.

[66]We also include the case where both twins are affected by a health shock as a separate category.

direct test of the separability assumption between parental consumption and the utility they derive from their children. Although this is a standard assumption adopted in the literature, it is strongly rejected in our data. Second, they imply that the within-twin-pair FE estimates of the effects of an early health shock on parental investments provide only a partial picture because they ignore the reallocation process arising through parental consumption. As such, the within-twin-pair FE estimates understate the overall negative effect of an early health shock at the household level.

6 Conclusions

In this paper, we have studied how early health shocks affect human capital formation. We have first formulated a theoretical model to understand how early health shocks affect child outcomes through parental responses. We have nested a dynamic model of human capability formation into a standard intrahousehold resource allocation framework. By introducing multidimensionality of child endowments, we have allowed parents to compensate and reinforce along different dimensions. We have then tested our main empirical predictions using the CCTS, which contains detailed information on child- and parent-specific expenditures. We have differentiated between investments in money and investments in time. On the one hand, we have found evidence of compensating investment in child health but of reinforcing investment in education. On the other hand, we have found no change in the time spent with the child. We have confirmed that an early health insult negatively affects the child under several different domains, ranging from later health, to cognition, to personality. We have also showed that, in presence of adequate resources, partial remediation may be possible, at least with respect to the child's physical growth. Our findings emphasize the importance of accounting for behavioral responses to early health shocks: parental responses should be taken into account when designing interventions to remediate disadvantage, as parents can exacerbate or annihilate their effects by reallocating resources within the family. They also suggest caution in interpreting reduced-form estimates as purely biological effects. In the presence of asymmetric parental responses under different dimensions of the child's human capital, reduced-form estimates cannot even be unequivocally interpreted as either lower- or upper-bounds of the biological effects.

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Table 1: Summary Statistics

	Whole	Rural	Urban	Difference	Male	Female	Difference
A. Main Independent Variables							
Early health shocks (dummy)	0.09	0.08	0.10	-0.02**	0.11	0.07	0.04***
Birth weight (kg)	2.46	2.48	2.43	0.04***	2.50	2.37	0.13***
Birth weight: <2 (dummy)	0.13	0.11	0.14	-0.03**	0.10	0.18	-0.08***
Birth weight: 2-2.5 (dummy)	0.36	0.35	0.37	-0.02	0.35	0.38	-0.03
Birth weight: 2.5-3 (dummy)	0.38	0.38	0.37	0.01	0.39	0.34	0.06***
Birth weight: 3- (dummy)	0.14	0.16	0.12	0.03***	0.16	0.10	0.05***
B. Investments							
Medical expenditures (¥/year)	225.76	150.16	310.69	-160.53***	238.32	254.70	-16.38
Education expenditures (¥/year)	911.58	630.41	1227.50	-597.09***	909.44	981.11	-71.67
Clothing expenditures (¥/year)	241.95	173.24	319.16	-145.92***	242.84	259.27	-16.43
Parents home tutor (minutes/day)	19.37	14.93	24.30	-9.36***	20.52	19.41	1.12
C. Health							
Height (cm)	137.35	133.37	141.83	-8.46***	137.74	136.84	0.90
Weight (kg)	33.60	32.07	35.30	-3.23***	34.26	32.87	1.39***
BMI	17.38	17.66	17.08	0.58***	17.57	17.20	0.37***
Height-for-age z-score	-1.05	-1.47	-0.59	-0.88***	-1.07	-1.01	-0.06
Weight-for-age z-score	-0.87	-1.03	-0.69	-0.34***	-0.79	-0.92	0.13***
BMI-for-age z-score	-0.31	-0.15	-0.50	0.35***	-0.19	-0.43	0.24***
Self reported general health status (GHS) (1: worst; 4: best)	2.92	2.91	2.93	-0.02	2.91	2.94	-0.02
Hospital visits (dummy)	0.33	0.30	0.36	-0.06***	0.33	0.34	-0.01
D. Academic performance							
Relative measures [1: lowest; 5: highest one-fifth in class]							
Literature	3.53	3.47	3.61	-0.14***	3.44	3.65	-0.21***
Mathematics	3.48	3.45	3.51	-0.06*	3.48	3.51	-0.03
Marks [1-100]							
Literature	81.95	78.89	85.30	-6.41***	81.18	83.59	-2.41***
Mathematics	80.89	78.54	83.48	-4.95***	81.46	81.39	0.07

The variables in Panel A, the expenditures in Panel B and the health measures in Panel C are reported by both parents; the amount of time the parents spend tutoring the child in Panel B and the relative measures of academic performance in Panel D are reported by each twin; the marks in Panel D are recorded from examination transcripts in the term before the survey. The "Difference" columns report the results of the t-test for the difference in the means in the two previous columns. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 1: Summary Statistics (ctd.)

	Whole	Rural	Urban	Difference	Male	Female	Difference
E. Schooling performance							
Good Student Awards (dummy)	0.24	0.18	0.31	-0.13***	0.21	0.29	-0.08***
Awards in contests (dummy)	0.07	0.03	0.11	-0.09***	0.07	0.08	-0.01
Grade repetition for poor performance (dummy)	0.04	0.06	0.03	0.02***	0.05	0.04	0.01
Parents interviewed for poor performance (dummy)	0.13	0.08	0.18	-0.10***	0.18	0.08	0.10***
Child doing minor actions in class	1.73	1.76	1.70	0.06**	1.89	1.59	0.30***
measured as 1: never; 2: seldom; 3: sometimes; 4: always							
F. Noncognitive skills							
Measured as 1: disagree; 2: agree; 3: strongly agree							
Always feel lonely	1.20	1.17	1.23	-0.05***	1.20	1.21	-0.01
Always feel anxious or fretful	1.28	1.26	1.31	-0.06***	1.38	1.23	0.15***
Easily distracted	1.59	1.52	1.66	-0.14***	1.66	1.55	0.11***
Always careless	1.94	1.96	1.91	0.05**	2.01	1.91	0.10***
Easily frightened	1.36	1.36	1.37	0.00	1.34	1.43	-0.09***
Emotionally instable	1.12	1.06	1.18	-0.12***	1.13	1.14	-0.01

The first three measures of schooling performance in Panel E are recorded from the official transcripts; the last two measures in the same Panel, and all the noncognitive skills measures in Panel F are reported by parents. The "Difference" columns report the results of the t-test for the difference in the means in the two previous columns. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 1: Summary Statistics (ctd.)

	Whole	Rural	Urban	Difference	Male	Female	Difference
G. Parental Labor Supply and Expenditures							
Father							
Labor supply (days/month)	25.50	26.18	24.65	1.53***	25.87	24.96	0.91***
Expenditures (¥/past 6 months)	700.38	536.58	886.55	-349.97***	686.88	725.62	-38.74***
Mother							
Labor supply (days/month)	25.32	26.03	24.34	1.69***	25.40	24.94	0.46**
Expenditures (¥/past 6 months)	283.93	169.66	412.33	-242.67***	261.83	348.22	-86.39***
H. Control variables							
Age	11.19	10.97	11.43	-0.46***	11.15	11.19	-0.05
Birth order (1: born at the second birth; 0: born at the first birth)	0.20	0.33	0.07	0.26***	0.23	0.16	0.06***
# siblings	2.24	2.39	2.08	0.30***	2.26	2.21	0.04**
Mother's age	36.84	36.49	37.24	-0.75***	36.55	36.53	0.01
Mother's schooling years	8.67	7.38	10.11	-2.73***	8.70	9.10	-0.40***
Per capital family income (¥1,000/year 2002)	3.03	2.46	3.68	-1.22***	3.10	3.04	0.05
Own washing machine (dummy)	0.65	0.47	0.85	-0.38***	0.66	0.69	-0.03
Own refrigerator (dummy)	0.38	0.14	0.65	-0.51***	0.39	0.41	-0.02
Own cell phone (dummy)	0.36	0.19	0.56	-0.37***	0.38	0.38	0.00
Mother's occupation (dummy: 1= Public sector)	0.08	0.02	0.15	-0.13***	0.09	0.10	-0.01
Rural indicator	0.53	1.00	0.00	0.00.	0.52	0.50	0.01
# Observations	2922	1326	1546		1082	1120	
# Pairs of twins	1461	688	773		541	560	

The variables in Panel H are reported by parents. The "Difference" columns report the results of the t-test for the difference in the means in the two previous columns. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 2: OLS and Within-Twin-Pair Fixed-Effects Estimates of the Determinants of Early Health Shocks and the Effects of Early Health Shocks on Parental Investments (Whole Sample)

	Dependent variables									
	Early health shock		Health		Education		Clothing		Parents home tutor	
	OLS	FE	OLS	FE	OLS	FE	OLS	FE	OLS	FE
Early health shocks			1.054***	1.351***	0.021	-0.204***	0.030	-0.058	0.784	-1.493
			[0.153]	[0.314]	[0.056]	[0.073]	[0.086]	[0.042]	[1.644]	[1.263]
Birth weight (kg): <2	0.040	0.010	0.440**	0.521**	-0.076	-0.015	-0.079	0.006	0.004	0.255
	[0.026]	[0.026]	[0.189]	[0.210]	[0.078]	[0.047]	[0.113]	[0.036]	[1.694]	[1.411]
Birth weight (kg): 2-2.5	0.010	0.000	0.255*	0.468***	0.054	0.016	-0.016	0.027	-1.860	0.257
	[0.019]	[0.021]	[0.150]	[0.163]	[0.060]	[0.026]	[0.090]	[0.030]	[1.315]	[1.194]
Birth weight (kg): 2.5-3	-0.010	-0.020	0.199	0.421***	-0.046	-0.013	-0.052	-0.004	-0.955	-0.319
	[0.018]	[0.018]	[0.143]	[0.149]	[0.059]	[0.023]	[0.087]	[0.020]	[1.243]	[0.993]
Gender (boy=1)	0.040***	0.020**	0.233**	0.086	-0.036	-0.024	-0.023	-0.028	1.394*	0.235
	[0.013]	[0.010]	[0.094]	[0.093]	[0.038]	[0.021]	[0.054]	[0.017]	[0.833]	[0.779]
Δ Expenditure			237.951	305.002	19.143	-185.962	7.259	-14.033		
# Observations	2922	2922	2922	2922	2922	2922	2902	2902	2922	2922
# pairs of twins		1461		1461		1461		1451		1461

Notes: Each entry comes from a separate regression. Robust standard errors, clustered at the household level, are in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variables of health, education, and clothing expenditures are in log form. The row "Δ Expenditure" reports the implied change in the level of expenditure.

Table 3: Within-Twin-Pair Fixed-Effects Estimates of the Effects of Early Health Shocks on Parental Investments (Subsamples)

	Health	Education	Clothing	Parents home tutor
Rural Sample				
Early health shocks	1.523***	-0.058	-0.120	-2.041
	[0.538]	[0.069]	[0.092]	[1.966]
Δ Expenditure	228.694	-36.564	-20.789	
# pairs of twins	773	773	773	764
Urban Sample				
Early health shocks	1.149***	-0.328***	-0.018	-0.962
	[0.374]	[0.116]	[0.021]	[1.678]
Δ Expenditure	356.983	-402.620	-5.745	
# pairs of twins	688	688	688	687
Male Sample				
Early health shocks	1.085**	-0.171**	-0.108	-2.393
	[0.426]	[0.074]	[0.091]	[2.565]
Δ Expenditure	258.577	-155.514	-26.227	
# pairs of twins	541	541	541	539
Female Sample				
Early health shocks	2.080***	-0.410**	-0.028	0.868
	[0.708]	[0.188]	[0.030]	[0.628]
Δ Expenditure	529.776	-402.255	-7.260	
# pairs of twins	560	560	560	556

Notes: Each entry comes from a separate regression. Robust standard errors are in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%. Birth weight is controlled for in each regression; gender has been controlled for in the estimations based on the rural and urban samples. The dependent variables of health, education, and clothing expenditures are in log form. The row "Δ Expenditure" reports the implied change in the level of expenditure.

Table 4: Within-Twin-Pair Fixed-Effects Estimates of the Effects of Early Health Shocks on Health

	Height (z-score)	Weight (z-score)	BMI (z-score)	Health Status	Hospital Visits
Whole Sample					
Early health shocks	-0.005	-0.270**	-0.204*	-0.449***	0.163***
	[0.102]	[0.115]	[0.121]	[0.111]	[0.051]
# pairs of twins	1423	1435	1411	1455	1451
Rural Sample					
Early health shocks	-0.114	-0.494***	-0.418***	-0.522***	0.085
	[0.165]	[0.154]	[0.121]	[0.164]	[0.060]
# pairs of twins	740	755	745	773	771
Urban Sample					
Early health shocks	0.079	-0.091	-0.040	-0.409***	0.221***
	[0.127]	[0.158]	[0.184]	[0.151]	[0.076]
# pairs of twins	683	680	666	682	680
Male Sample					
Early health shocks	0.038	-0.073	0.102	-0.441**	0.205**
	[0.100]	[0.186]	[0.157]	[0.186]	[0.084]
# pairs of twins	524	527	519	538	535
Female Sample					
Early health shocks	0.107	-0.251**	-0.355**	-0.327*	0.115
	[0.154]	[0.122]	[0.159]	[0.191]	[0.081]
# pairs of twins	548	553	544	558	558

Notes: Each entry comes from a separate regression. Robust standard errors are in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%. Birth weight is controlled for in each regression; gender has been controlled for in estimations based on whole, rural, and urban samples.

Table 5: Within-Twin-Pair Fixed-Effects Estimates of the Effects of Early Health Shocks on Academic Achievement

	Literature (self-reported)	Mathematics (self-reported)	Literature (exam record)	Mathematics (exam record)
Whole Sample				
Early health shocks	-0.345**	-0.529***	-5.158***	-5.384**
	[0.150]	[0.147]	[1.659]	[2.659]
# pairs of twins	1431	1425	1362	1343
Rural Sample				
Early health shocks	-0.186	-0.598***	-5.441**	-2.604
	[0.160]	[0.168]	[2.572]	[2.666]
# pairs of twins	759	757	711	705
Urban Sample				
Early health shocks	-0.511**	-0.510**	-4.632**	-7.330*
	[0.236]	[0.227]	[2.214]	[4.279]
# pairs of twins	672	668	651	638
Male Sample				
Early health shocks	-0.401*	-0.653***	-5.630**	-6.272*
	[0.242]	[0.229]	[2.527]	[3.718]
# pairs of twins	527	523	507	500
Female Sample				
Early health shocks	-0.461*	-0.457*	-2.020	-3.776
	[0.241]	[0.270]	[1.940]	[5.815]
# pairs of twins	551	549	519	511

Notes: Each entry comes from a separate regression. Robust standard errors are in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%. Birth weight is controlled for in each regression; gender has been controlled for in estimations based on whole, rural, and urban samples.

Table 6: Within-Twin-Pair Fixed-Effects Estimates of the Effects of Early Health Shocks on Schooling Performance

	Good Student Awards	Awards in Contests	Grade repetition	Parents interviewed	Minor actions in class
Whole Sample					
Early health shocks	-0.185***	-0.087**	0.109***	0.100*	0.279**
	[0.069]	[0.039]	[0.042]	[0.061]	[0.131]
# pairs of twins	1461	1461	1461	1459	1445
Rural Sample					
Early health shocks	-0.096	0.006	0.083	-0.039	0.396*
	[0.086]	[0.006]	[0.055]	[0.042]	[0.233]
# pairs of twins	773	773	773	771	766
Urban Sample					
Early health shocks	-0.236**	-0.163**	0.125**	0.197**	0.169
	[0.105]	[0.068]	[0.062]	[0.100]	[0.143]
# pairs of twins	688	688	688	688	679
Male Sample					
Early health shocks	-0.252**	-0.131*	0.127*	0.045	0.203
	[0.103]	[0.068]	[0.068]	[0.108]	[0.182]
# pairs of twins	541	541	541	541	532
Female Sample					
Early health shocks	-0.223*	-0.054	0.109	0.111	0.282
	[0.129]	[0.056]	[0.074]	[0.075]	[0.207]
# pairs of twins	560	560	560	559	554

Notes: Each entry comes from a separate regression. Robust standard errors are in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%. Birth weight is controlled for in each regression; gender has been controlled for in estimations based on whole, rural, and urban samples.

Table 7: Within-Twin-Pair Fixed-Effects Estimates of the Effects of Early Health Shocks on Noncognitive Skills

	Feel lonely	Anxious	Easily distracted	Careless	Easily Frightened	Emotional instability
Whole Sample						
Early health shocks	0.165***	0.121***	0.151***	0.142***	0.144***	0.112**
	[0.062]	[0.045]	[0.055]	[0.053]	[0.048]	[0.051]
# pairs of twins	1461	1461	1461	1461	1461	1455
Rural Sample						
Early health shocks	0.253***	0.071	0.148**	0.165**	0.092	0.044
	[0.089]	[0.056]	[0.071]	[0.075]	[0.057]	[0.074]
# pairs of twins	773	773	773	773	773	769
Urban Sample						
Early health shocks	0.099	0.160**	0.154*	0.125*	0.191***	0.163**
	[0.084]	[0.068]	[0.082]	[0.074]	[0.073]	[0.069]
# pairs of twins	688	688	688	688	688	686
Male Sample						
Early health shocks	0.040	0.093	0.036	0.035	0.117*	0.047
	[0.092]	[0.057]	[0.070]	[0.070]	[0.071]	[0.074]
# pairs of twins	541	541	541	541	541	539
Female Sample						
Early health shocks	0.394***	0.228**	0.279***	0.219**	0.282***	0.238**
	[0.113]	[0.099]	[0.105]	[0.098]	[0.106]	[0.103]
# pairs of twins	560	560	560	560	560	557

Notes: Each entry comes from a separate regression. Robust standard errors are in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%. Birth weight is controlled for in each regression; gender has been controlled for in estimations based on whole, rural, and urban samples.

Table 8: OLS Estimates of the Early Health Shocks on Parental Labor Supply and Expenditures

	Father		Mother	
	Work	Expenditure	Work	Expenditure
Whole Sample				
Early health shock (only one child)	-0.044	-140.393*	0.046*	-4.554
	[0.078]	[79.028]	[0.027]	[65.095]
# Observations	1163	1423	1048	1442
R-squared	0.017	0.200	0.026	0.207
Rural Sample				
Early health shock (only one child)	0.004	-133.164*	0.006	-12.947
	[0.050]	[70.516]	[0.040]	[46.779]
# Observations	646	757	608	763
R-squared	0.004	0.206	0.002	0.109
Urban Sample				
Early health shock (only one child)	-0.089	-140.071	0.087***	-5.265
	[0.146]	[128.382]	[0.033]	[109.298]
# Observations	517	666	440	679
R-squared	0.014	0.156	0.032	0.289
Male Sample				
Early health shock (only one child)	0.005	33.393	0.072*	74.990
	[0.045]	[134.589]	[0.039]	[116.180]
# Observations	417	524	386	536
R-squared	0.017	0.218	0.051	0.332
Female Sample				
Early health shock (only one child)	-0.122	-379.628***	-0.011	-106.805
	[0.217]	[99.651]	[0.048]	[101.787]
# Observations	452	545	405	553
R-squared	0.033	0.187	0.025	0.182

Notes: Each entry comes from a separate regression. Robust standard errors are in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%. Child's age, mother's years of schooling, and per capita family income are included as controls in each specification; rural has also been controlled for in estimations based on whole, male, and female samples.