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Fetal Origins and Parental Responses

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Abstract

How do parental investments respond to health endowments at birth? Recent studies have combined insights from an earlier theoretical literature on household resource allocation with improved identification strategies to capture causal effects of early life health shocks. We describe empirical challenges in identifying behavioral responses and how recent studies have sought to address these. We then discuss the emerging literature on "dynamic complementarities" in parental investments arising from the staged, developmental nature of capability production and how capabilities may have multiple dimensions. The bulk of the empirical evidence to date suggests that parental investments reinforce initial endowment differences.

I. Introduction

How parents respond to children's endowments has emerged as fertile ground for theoretically-minded and applied microeconomists alike. The burgeoning literature traces its origins to early work on intra-household resource allocation that was grounded in theory, e.g. Becker and Tomes (1976). The new phase of research on parental behavioral responses has been infused with insights from the "fetal origins" literature which has emphasized both the sizable long-term consequences of early childhood and credible research designs that utilize sharp identification strategies, or what we refer to as "design-based" studies. The literature has also been invigorated by contributions to our understanding of the staged, developmental nature of human capital production during childhood, summarized and formalized by Heckman (2007).

Understanding this behavioral response is of broad and compelling interest – what parents do when faced with endowment differences among their children is non-obvious, and something many of us can relate to as parents or children. For empirically minded economists, the literature maintains the virtues of design-based studies that emphasize credible causal inference. Behavioral responses are potentially as well identified as the reduced form effects documented in the "fetal origins" literature. Recent design-based papers have successfully exploited this opportunity to consider various investment behaviors as the dependent variable.

While earlier studies of fetal origins by economists utilized uncommon and severe historical events such as exposure to famine or infectious disease for identification, subsequent studies have succeeded in demonstrating that a broad spectrum of environmental influences has causal effects on later-life outcomes. There is now a consensus that the prenatal period is a key developmental window. One distinguishing feature of economics compared to other fields such as epidemiology is the central role of behavioral responses and the formal modeling thereof.[1] As the review below indicates, sometimes behavior seems to respond to endowment shocks and sometimes it does not. Overall, we see relatively limited evidence for compensatory responses by parents, particularly when design-based studies are considered (Table 1). That said, we are only beginning to understand whether the parental response is an important component to the later-life capabilities we care about most (e.g. health, cognitive ability, or productivity in adulthood). Thus, we sound a note of caution that, while responsive behavior may be of natural interest to economists, we should not be seduced by a surpassing interest in behavior *per se*. To maintain relevance outside of family economics, this interest should be scaled by behavior's importance to understanding developmental outcomes. For example, while it could be the case that parental investments serve to reinforce differences in capabilities that arise from prenatal health shocks, it might turn out that such behavior tends to only play a small role compared to the purely biological mechanisms set in motion by the initial shock itself.

Responsive behavior can be fruitfully analyzed with or without a full-blown structural model. Some recent research simply addresses the basic question of whether endowments cause behavioral responses among parents in a "reduced form" analysis. Yet even here there are formidable empirical challenges in identification, due to all of the standard concerns that confront researchers in applied microeconomics (e.g. appropriate longitudinal data, unobserved confounders, measurement error). Researchers have therefore employed a variety datasets and empirical comparisons, such as sibling models or natural experiments to try to overcome these challenges. Much of the empirical literature to date would fit into this category.

Pushing beyond the primitive question of whether parents respond to endowments, an added layer of richness comes from models allowing for "dynamic complementarities" in the production of human capital: the return to childhood investments increases with the baseline level of capability. This feature

[1] The preeminence of identification strategies also distinguishes economic analyses from those in epidemiology. Interestingly, earlier analyses in epidemiology featured a more design-based approach to observational data, e.g. Heider (1934) and Stein et al. (1975), than more recent epidemiological work.

could provide strong incentives for parents to reinforce endowment differences. We discuss how the empirical challenges of identifying such effects are more onerous: a second valid instrument would help. While there are a few studies that have attempted to address this need, we suspect that it may be a long-time before we have any kind of consensus.

Individual "capacity" clearly has multiple dimensions (e.g. health, cognitive abilities and non-cognitive abilities). Intriguingly, parental responses could differ across these dimensions. For example, it could be that parents might prefer to compensate for health endowments but reinforce cognitive ability endowments. The empirical challenges for credible identification of such models may be especially daunting. Interpreting the role of behavior may be nuanced for these reasons as well as ones specific to the topic at hand, e.g. how substitutable we think investments are across stages of development. A goal for future work is to try and integrate endowment shocks, responsive behavior, and developmental outcomes into a coherent whole, a point previously made by Bleakley (2010) and others.

This review article begins by defining and describing some of the key concepts and obstacles to estimation in section II. In section III we discuss a selection of recent empirical studies on parental responses that illustrate a range of methodological approaches. The first part of this section covers studies that mainly attempt to identify reduced-form effects. In the second part of section III, we highlight the recent literature on "dynamic complementarities". In section IV we discuss some very recent empirical work by Heckman and co-authors that has begun to consider multiple dimensions to endowments and investments and the implications of such models on parental responsiveness. Section V concludes.

II. Background

Definitions and concepts

In this section, we briefly review some basic concepts in the fetal/developmental origins literature that are used in the remainder of the review. For a more comprehensive and formal treatment, please see Heckman (2007) and Almond and Currie (2011).

It is common to refer to the stock of capacities at birth as the birth endowment. For the most part, studies have treated the birth endowment as unidimensional. As we discuss later, many recent studies have used birth weight as a measure of this endowment and such studies often have "health" in mind as the key dimension. An exogenous component of the birth endowment can be isolated by considering prenatal shocks. If postnatal investments in human capital are positively correlated with the shock, they are said to be *reinforcing*. They are considered *compensating* if the correlation is negative. One permutation which we will return to in section IV is if it matters whether we think there are multiple dimensions to human capital (e.g. health and cognitive ability) and whether the endowment shock and the investment responses refer to the same dimension.

It is tempting to think that whether parents reinforce or compensate within families in response to prenatal shocks would largely be driven by parental preferences, and, in particular, the degree to which parents have an aversion to inequality among their children. However, in an optimizing framework, one needs also to consider how readily responsive postnatal investments alter subsequent capacity stocks (e.g. health in adulthood). If substitutability between prenatal shocks and postnatal investments is high, then compensation is more likely. If the elasticity of substitution is very poor (e.g. Leontieff in prenatal and postnatal investments), reinforcement is more likely. In general, the more extreme the production technology, the less we learn about parental preference from the sign of the investment response (Almond & Currie, 2011). In this respect, basic formal modeling helps us interpret the design-based evidence. One interpretation of the results from design-based literature on fetal origins that finds large effects of prenatal shocks on long-term outcomes is that the elasticity of substitution between prenatal and postnatal periods is low. This may "stack the deck" toward reinforcement.

From the theoretical literature come core concepts increasingly explored in empirical studies of parental responsiveness to initial endowments. One important idea in developmental models is that the effect of an investment flow in human capital in a particular period of childhood may depend on the level or "stock" of human capital in the preceding period. If the return to investment is larger when the stock is higher in the preceding period, this is referred to as a *dynamic complementarity* (Heckman, 2007) or that "shills beget skills". In the presence of dynamic complementarities early in childhood, one might expect parents to be more likely to make reinforcing investments. A related concept, *self-productivity* (Heckman, 2007), by contrast, is about levels rather than investment flows and simply refers to the extent to which the level of human capital in one period depends on the level of human capital in the preceding period. More interestingly perhaps, this can include effects across dimensions of capacity (e.g. cognitive ability helps you form health).

Empirical Challenges

Practical obstacles to tracing out the myriad potential effect of endowment shocks provide useful context for the various empirical strategies utilized this far. First, ideally one wants to use a measure of the endowment at birth that is a meaningful indicator of health or human capital at birth that is easily observable to the parent.[2] Early studies on household allocation often did not have good measures of endowments and had to use a variety of indirect strategies to infer such endowments. Second, one would like the variation in the measure of endowments to reflect exogenous differences. For example, some of the differences in endowments at birth (e.g. birth weight) are driven by prenatal investments such as behaviors during pregnancy (e.g. nutrition, smoking, drinking, health examinations). A positive correlation between the endowment at birth and a postnatal investment could simply reflect the correlation between unobserved prenatal and postnatal investments rather than a behavioral response to the birth endowment. For example, prenatal investments may respond to child's sex, which may also

[2] It could be that the researcher observes something (e.g. birth weight) that is correlated with a better metric that parents observe and the researcher does not, but one would then like a sense of the relationship between the variables.

affect postnatal investments (Lhila and Simon, 2008; Hu and Schlosser, 2012; Bharadwaj and Nelson, forthcoming). Third, ideally one wants a measure of the parental post-natal investment that inherently reflects a behavioral response on the parent. Particularly worrying might be a parental "response" that is actually a mechanical effect of the initial treatment (more on this below).

Many early studies in the literature used completed years of education as a measure of parental investment. This can be problematic for various reasons, including that children may play an important role in deciding how much schooling they will actually complete and that education may be considered an outcome of the investment process. If one uses a measure of child endowments (e.g. test scores) that in part captures aspects of the child's personality (e.g. perseverance) then this can also induce a spurious correlation between endowments and subsequent investments.

In recent years the empirical literature on parental responses to child endowments has made important advances in at least two areas. First, recent studies have utilized better data to construct more direct measures of both children's health endowment and parental investments. For example, the more widespread use of natality data has provided researchers access to data such as birth weight and breast-feeding (at hospital discharge) and the Demographic and Health Surveys (DHS) to measure parental investments. Second, and perhaps more importantly, the literature has employed a variety of methodological approaches to deal with the challenge of how to credibly identify parental investment responses that are causally linked to the stock of human capital at birth. Stalwarts who take stock from design-based studies alone may find little evidence for compensatory response patterns.

III. Review of recent empirical studies

We organize studies by the basic types of methodological approaches used. As the Table 1 summary indicates, a variety of methodological approaches has been used and a variety of responses ranging from reinforcing, through zero, to compensatory have been found. Overall, we interpret the current state of the literature to suggest investments are frequently not compensatory and often reinforcing. This is consistent with a strongly developmental production function, which the design-based fetal origins literature likewise finds evidence for.

Family Fixed Effects

The fetal origins literature has spurred a resurgence of interest in investment allocations across children within the household. Datar et al. (2010) is among the first studies to directly measure both child endowments and parental investments. Specifically, they use the Children of the National Longitudinal Survey of Youth (CNLSY) data and use the birth weight of children as a proxy for endowment at birth. They use measures of breast-feeding initiation, well-baby visits, immunization and preschool attendance in order to capture postnatal investments by parents. Their main estimates rely on a family fixed effects estimator that relates the difference in parental investments among siblings to differences in birth weight. They find that children who are normal birth weight (≥ 2500 grams) are 5 to 11 percent more likely to receive parental investments compared to their low birth weight siblings. These results suggest that parents reinforce endowment differences rather than compensate for them.

As part of their analysis they also find that an increase in the number of low birth weight siblings that a child has leads to greater parental investments in that index child. One concern with their approach is that parental investments such as well care visits may increase when one has a low birth weight sibling simply because of the greater ease of access to care generated by the heightened attention given to the low birth weight sibling. Such an effect would imply a different mechanism for parental response than a deliberate decision on the part of parents to invest in the relatively advantaged child.[3]

A more general concern with studies that use family fixed effects models is that they rely on the assumption that there are no sibling-specific unobserved differences that could account for both their birth weight differences and their subsequent post-natal investments. Datar et al. (2010) attempt to address this

[3] The authors consider the possibility that the likelihood of breastfeeding may be reduced if a child is very low birth weight and is placed in a neonatal intensive care unit. They find similar effects when they drop very low birth weight children from the sample. However, the authors do not consider other health factors that could lead to a positive association between birth weight and breastfeeding. For example, children born prematurely may not be able to breastfeed initially.

concern by including a variety of sibling specific measures (e.g. family income, mother's age, mother's education, first month of prenatal care, smoking or alcohol use during pregnancy) that could account for a common pattern in sibling endowment differences and parental responses. As a robustness check, they also use only siblings born up to two years apart and find similar effects. Nevertheless one may still be concerned that there may be unobserved sibling specific factors that are correlated with both lower birth weight and lower parental investments that confound a causal interpretation even for siblings born within two years. We will return to this general issue below.

Hsin (2012) also uses a sibling model with fixed effects but uses data from the Child Development Supplement of the Panel Study of Income Dynamics (PSID-CDS). Like Datar et al. (2010), Hsin measures child endowments directly using birth weight. An important innovation is to analyze two sibling-specific, time–based measures of parental investment among children aged 12 or under. The first is the total amount of time that the mother spends with the child and the second is a measure of time spent with the child on activities that are directly related to human capital development. The latter measure includes time spent reading, playing, doing hobbies and doing homework together. Hsin reports that the maternal time spent with children is identical in only about 23 percent of the sibling pairs and in some cases the differences in maternal time are large.

The use of time-based measures of parental investment during childhood potentially presents some advantages over other measures of "investment" during the immediate postnatal period (e.g. breast-feeding) that could be directly related to birth weight for reasons unrelated to parental decision-making. On the other hand, sibling differences in maternal time could be highly age dependent and adjusting maternal time for age (as Hsin does) may not perfectly address confounding influences.

The results suggest an important role for mother's education in determining whether parents compensate or reinforce. Specifically, in a specification without maternal education, Hsin finds no statistically significant effect of log birth weight on maternal time investments. However, when she interacts log birth weight with maternal education she finds a statistically significant negative effect suggesting that more educated parents are more likely to compensate. Hsin plots a preferred set of estimates based on a specification that uses piece wise linear splines in mother's education for a sample of siblings under the age of 6. These results imply that while low educated mothers (less than 12 years of schooling) reinforce birth weight differences, better educated mothers compensate. She argues that in the aggregate the compensatory effects dominate.

As Almond and Currie (2011) note, several explanations might account for this relationship. It could be that the elasticity of substitution between consumption and human capital investment could be higher for families of lower socioeconomic status leading them to be more likely to reinforce a negative shock to the birth endowment. Alternatively, it could be that families of lower socioeconomic status are credit constrained and may be forced to shift resources to the better endowed child due to limited resources. Another possibility (not raised by Almond and Currie) is whether post-natal investments differ by education because of differences in prenatal investments by education level.[4] For example, better educated parents might make more prenatal investments than less educated parents and therefore may not have to respond as much after birth.

Interestingly, Datar et al. (2010) report finding no significant differences by maternal education in their CNLSY data (implemented by interacting birth weight variable with maternal education). However, Restrepo (2011) likewise uses the CNLSY but uses a different set of proxies for parental investment that are measured later in childhood, finds a very similar pattern of results as Hsin does with the PSID-CDS. This suggests the possibility that the time at which investments are measured may be important.

As mentioned above, a key assumption is that there are no unobserved sibling-specific effects that are correlated with both birth weight and the measure of parental investments. In light of Hsin's results, however, an alternative explanation based on unobservables would have to explain a negative correlation between birth weight and maternal time investments (during childhood) among highly educated mothers and a positive correlation between birth weight and maternal time investments among less educated

[4] We thank Prashant Bharadwaj for this suggestion.

mothers. One possible explanation could be that the *causal* responses by both less educated and better educated mothers are the same but that other unobserved factors vary by socioeconomic status.[5]

Aizer and Cunha (2012) also use a family fixed effects framework and provide some notable advances in measuring parental investments. The Collaborative Perinatal Project (NCPP) collected very detailed data on the characteristics of parents and children based on nearly 60,000 births in 11 cities that occurred between 1959 and 1965. To assess parental investments they use information derived from a psychologist's ratings of a mother's parenting behavior when her child is 8 months old along many dimensions (e.g. expressions of affection, handling of the child, management of the child, responsiveness to the needs of the child). Aizer and Cunha are motivated by research on "attachment theory" which suggests that when children develop strong bonds with parents it improves their neurological development, leads to a greater capacity to learn, and has been associated with improvements in measures of cognitive ability.

To measure endowments they use a rich set of measures taken at birth including birth weight, gestation length, body size, and head circumference. Following Rosenzweig and Wolpin (1988), they use a fixed effects model that includes a variety of covariates capturing several key aspects of prenatal parental investments: smoking during pregnancy, nutrition, and whether the mother was trying to conceive. They then construct a residual component that can be thought of as an endowment measure that is net of these key prenatal investments, using factor analysis on the residuals of the different endowment measures. With this approach they argue that they address measurement error and endogeneity. Using this method, they find that parenting behavior is positively associated with their measures of endowments suggesting that parents use post-natal investments to reinforce differences.

One possible concern with Aizer and Cunha's approach is that the measures of parenting behavior that they use could potentially simply reflect the personality that their children are born with and that

[5] For example, perhaps both groups truly compensate, but the observed correlation between endowments and parental responses is positive for less educated mothers due to unobserved sources of stress such as financial difficulties or family instability that affect both endowments and investments.

these innate personality differences could in turn, shape the quality of interactions parents have with children (see, e.g., Harris, 1998). The estimated effects could then reflect the correlation between the residual component of health endowments and personality. (We discuss Aizer and Cunha, 2012, further in the subsection below on dynamic complementarity).

Another study that considers parental responses to endowments and utilizes siblings for identification is Del Bono et al. (2012). They use data from the U.S. National Survey of Family Growth to estimate a structural dynamic model multi-stage model of parental investments during both the prenatal and postnatal period. For postnatal investments they only consider breast-feeding. The estimates of the structural parameters of their model appear to be consistent with a compensatory response by parents. Del Bono et al. employ a more complex model that returns multiple structural parameters relating parental responses to endowments and so it is difficult to directly compare their findings to the more "reduced form" estimates in the rest of the literature.

Twins

Comparing twins may narrow the potential scope for confounding influences: it is virtually impossible for parents to deliberately treat their twins differently during the *in utero* period. As part of a larger analysis,[6] Royer (2009) uses the Early Childhood Longitudinal Study, Birth Cohort (ECLS-B) which contains a sample of nearly 1500 twins, to study differential investment responses to twin differences in birth weight. Specifically, Royer examines whether neonatal intensive care use or the number of days in a hospital (which can be viewed as investment decisions made by health professionals) is related to birth weight and finds weak evidence of compensatory responses. She also reports finding no effects of birth weight differences on breast-feeding.

Building upon (i.e. borrowing) Royer's idea, Almond and Currie (2011) use the same ECLS-B sample to examine a host of measures that reflect parental investment responses slightly later in childhood

[6] The main analysis in Royer (2009) uses California natality files to study the short and long-term effects of birth weight differences among twins.

(available as the ECLS-B cohorts aged). They find few cases of differential parental behavior that are significant. They find that parents are more concerned about whether a low birth weight twin is ready for school. In some samples they also find differences in the timing of the introduction of solid food. They find no differences, however, in whether parents reprimand, praise, caress or otherwise behave differently among their twin children.

While the use of data on twins rather than siblings helps address the concern about sibling-specific unobserved factors, it is not a panacea. On the one hand, even twin endowment differences may come bundled across dimensions (see Section IV below on multi-dimensional capacity). On the other hand, postnatal allocation decisions for twins may not generalize well. In particular, one might be concerned that it is simply very costly to implement favoritism among twin children and it therefore may be much more difficult to identify instances of reinforcing or compensating behavior.

Bharadwaj, Eberhard and Neilson (2011) may be especially interesting in this light because it considers investments in twins versus non-twin siblings. Their main analysis examines the effect of birth weight on test scores using the universe of births in Chile and compares estimates derived from a twins estimator and a siblings estimator. Using repeated tests scores on the same children from grades 1 through 8, they find that the twins estimates are remarkably stable over time but that the sibling estimate gradually declines. They conjecture that an explanation for this finding could be that parents may compensate for endowment differences between siblings but not between twins. Using survey data on parental investments they indeed find: 1) that parental investments are negatively related to birth weight among siblings suggesting compensating behavior on the part of parents and; 2) no statistically significant effect of birth weight on parental investment measures among twin pairs. The latter result is consistent with the notion that parents may not be able to differentially invest among twins.

Research Designs in Observational Data

As mentioned in the introduction, the design-based literature in fetal origins has until fairly recently ignored parental responses (often for data reasons). A number of recent empirical papers have made use of the insight that econometrically we are still on *terra firma* so long as behavior is the dependent variable together with some richer datasets. (Including endogenous behavior as a regression control, by contrast, can introduce bias.) This has yielded some new and credible estimates on parental behavior.

Kelly (2011) uses the geographic variation in the spread of the 1957 influenza epidemic across the U.K. to identify the effects of prenatal exposure to influenza on birth weight and on children's test scores. The study uses the National Child Development Survey (NCDS) which follows a large sample of children who were born in one week in March of 1958 and who were potentially exposed to the Asian flu pandemic *in utero*. The epidemic struck England between September and November of 1957. Kelly finds that only mothers with certain characteristics (those who smoked during pregnancy or were of short stature) had lower birth weight children as a result of flu exposure. In contrast lower childhood test scores were found for those with exposure to the virus irrespective of maternal characteristics. The study explicitly acknowledges the possibility that responsive behavior on the part of parents could constitute part of the reduced form effect that is identified. To address this, Kelly uses two approaches. First, Kelly use parental investment measures as a dependent variable. Second the parental investment measures are interacted with the exposure measure. Kelly reports that in neither case is there evidence that postnatal parental investments responded to the epidemic. [7]

Bharadwaj, Loken and Neilson (2012) use administrative data from Chile and Norway to implement a regression discontinuity (R-D) design. Infants who weigh under 1500 grams are classified as very low birth weight (VLBW), and are often provided access to special medical treatments (e.g. surfecant) after birth. Bharadwaj, Loken and Neilson show that infants who are just below the cutoff not only received greater access to medical care after birth but also experienced improved test scores and

[7] While the measures of investment and the detail results are not reported in Kelly (2011), in private communication Kelly reports using measures such as time spent reading to children, time spent on outings with a child and teacher assessments of parental interest in the child's education. Kelly also suggests that while her effects were statistically insignificant, and of mixed sign, her data may not have had sufficient power to detect effects.

higher grades in childhood compared to those whose birth weight is just above the VLBW cutoff. Like Kelly, Bharadwaj, Loken and Neilson explicitly consider the extent to which these effects may be driven by parental responses by using a variety of measures of parental investment as dependent variables. They find no evidence of differences around the VLBW cutoff in the quality of schools attended, the time spent by parents reading to children, whether the child was enrolled in child care by age 5, or whether the mother returned to work after child birth. It remains an open question to what extent other aspects of neonatal care or higher birth weight infants show corresponding effects.

Tropical disease has also been used by a number of studies to demonstrate long-term effects of health impairments early in life (e.g., Bleakley, 2007 and Barreca, 2010). In a recent study set in Mexico, Venkataramani (2012) links malaria eradication in one's year of birth to a number of outcomes including improved cognitive test scores measured in adulthood. Venkataramani addresses the potential for parental investment responses to mediate these effects by examining the timing of schooling investments. He argues that given a positive endowment shock, a standard human capital model would predict that children would likely start school at an earlier age on average. This is because parents who would have otherwise delayed school entry (because the marginal returns to schooling did not yet outweigh the marginal costs to schooling) may now find that with the improved learning capacity of their children due to malaria eradication, it would make sense to have children start school at an earlier age. Given that there are few outside opportunities to schooling in the labor market for young children (that could also benefit from a positive shock), this is a relatively unambiguous prediction.

On the other hand, Venkataramani argues that it is ambiguous whether an endowment shock would affect the age at which children *leave* school when they are older. This is because at later ages it is more likely that improved cognitive abilities could confer advantages both for learning and outside options in the labor market. At later ages the endowment shock could lower the marginal costs by more than it improves the marginal benefits of education. Indeed, Venkataramani finds that malaria eradication appears to both lower the age at which children start school and the age at which they finish school.

Since the age of school entry is likely a decision made by parents, this provides evidence that parents reinforce endowment shocks. However, this is the only measure of parental investment that can be linked to the malaria shock.

Adhvaryu and Nyshadham (2012) present perhaps the most compelling and intriguing evidence thus far on parental responses. They build on previous work by Field et al. (2009) who showed that a large scale iodine supplementation program for women of child-bearing age in Tanzania led to increases in educational attainment among children who were exposed to the program *in utero*. Medical studies have shown that iodine deficiency early in pregnancy can inhibit normal neurological development. Adhvaryu and Nyshadham follow up on this prior work by examining how parental investments responded to the plausibly exogenous improvement in the cognitive endowment of children. Specifically they use data from the 1999 round of the Tanzania Demographic and Health Surveys (DHS) containing a rich set of measures of post-natal parental investments including the duration of breast-feeding, and vaccinations among children under the age of 5.

They find that children are more likely to be breastfed and are more likely to be immunized if they were exposed to the iodine supplementation program. Further, they find that there are spillover effects on siblings. Controlling for one's own exposure, parental investments are larger if one has siblings that were exposed to the iodine supplementation program. One threat to the research design is if there were other aspects of the iodine supplementation program (e.g. health information) that might have direct effects on the likelihood of women undertaking investments. Adhvaryu and Nyshadham cite prior evidence in the literature suggesting that no such other aspects of the program existed. They further show that the program did not appear to directly affect measures of neonatal investment or measures of the health endowment at birth as measured by birth weight or perceived size at birth.

The results suggest that while parents invest more in a child with higher cognitive endowments (i.e. reinforce), they may also invest more in his or her siblings. This implies that studies that rely on family models to identify sibling differences may be missing an important aspect of household allocation decisions and underestimating the total effect on parental investments.[8] Nevertheless, an appealing feature of this study is that it arguably considers a specific treatment that is known to affect cognitive ability but is not strongly associated with health more generally. This stands in contrast to studies that have relied on birth weight –which may not serve as a useful indicator for whether there has been an impairment to cognitive function.[9] To the extent the core question is how parental investments specifically relate to cognitive endowments, this may advantageous. In addition, they use key measures of post-natal parental investments that should occur fairly quickly after birth. Finally, the data allow them to take account of other observable measures of the health endowment that likely reflect prenatal investments as well as measures of neonatal investments.

Random Assignment

Thus far, we have not encountered any studies that use randomized control trials (RCT) to identify parental responses to birth endowments. We expect this to change. For example, Li et al. (2009) analyze the effects of a double blind RCT that provided multi-micronutrient supplementation to several thousand pregnant women in rural China on measures of offspring mental and psychomotor development at up to age 1. Similarly, Vaidya et al. (2008) implemented an RCT in Nepal to identify the effects of iron or folic acid supplementation during the prenatal period on various measures of childhood size, illness and blood pressure. At some cost, both studies could follow-up with both the treatment and control groups to assess parental responsive behaviors. As in development economics, it may be useful for researchers interested in fetal origins to become more engaged in RCTs of the kind that have been

[8] This parallels the criticism that Gluckman and Hanson (2005, p101) has made of twin studies in the fetal origins literature that have relied on birth weight differences to measure fetal injury and which have not found differences in hypertension later in life because these studies failed to understand that in some cases both fetuses are affected by the fetal environment even if this is not reflected in birth weight differences.

[9] Almond and Mazumder (2011) and Kelly (2011) also argue that birth weight may not capture biological adaptive responses that affect latent health or cognition.

traditionally used by the scientific community in order to better understand how parental behaviors are affected by random treatments during the prenatal period.[10]

Indirect evidence

Finally, some research has produced indirect evidence on whether parents reinforce or compensate for prenatal endowments. One approach is to compare simple OLS estimates which rely on cross-sectional variation to family fixed effects model which only use within family variation. If family differences among siblings are reinforced (compensated) then under some assumptions the fixed effects estimates would be larger (smaller) than the OLS estimates. Almond, Edlund, and Palme (2009) study the effects of exposure to radioactive fallout from the Chernobyl episode on the educational outcomes of Swedish students who were exposed *in utero*. They find that their estimates are somewhat larger when they include family fixed effects than when they use OLS. This leads them to conclude that "to the extent that parents responded to the cognitive endowment, such responses may have been reinforcing."[11]

Dynamic Complementarities

Dynamic complementarities exist when the return to developmental investments in capability is increasing in the baseline stock of that capability. In a multidimensional world, it could be that subsequent investments have a higher return when, for example, either the cognitive or the non-cognitive

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[10] A relevant study that examines parental responses to an early life intervention but not to birth endowments is by Gelber and Isen (2011). They use used randomized access to Head Start programs to evaluate the effects of program access on parental investments. They find that there are positive effects of the program on many measures of parental involvement in children's learning activities, some of which persist even after the program has ended. Their results are consistent with the possibility that parents are more involved with their children because such investments are complementary with improvement in cognitive or non-cognitive skills induced by Head Start. However, they cannot conclusively rule out whether the greater involvement by parents is simply due to the fact that parental involvement itself is a key feature of the Head Start program.

[11] Black et al. (2010) study how an increased in the quantity of children in a family affects tests scores of already born children. As part of a robustness check on their analysis they conduct an exercise that suggests that parents may compensate for birth endowments. Specifically, in one of their approaches they estimate that the IQ scores of existing children decline when parents give birth to twins --which may constitute an unexpected increase in family size. Since twins are typically born at a low birth weight, there is a concern that parents may have reallocated resources in favor of the existing higher birth weight children, thereby understating the true effect of family size increases on IQ scores. Black et al., however, find that when they control for the birth weight of the twins that instead the effects on the IQ scores of the first child older disappear. They conclude that their finding is "consistent with compensatory investment behavior by parents."

baseline is higher.[12] Dynamic complementarities are one theoretical channel by which subsequent investments might optimally reinforce previous stocks (and previous shocks to those stocks). There is clearly much interest in this channel in the emerging literature.

That said, we think making a water tight empirical case for dynamic complementarities is more challenging than simply demonstrating that investments respond to shocks: familiar identification strategies in fetal origins literature are sufficient for the latter but not the former. Causal inference on dynamic complementarities requires: a) exogenous variation in the baseline stock, and; b) exogenous variation in subsequent investment (or its return, see below). One can then trace the effects of the interaction on the return. In an observational setting, this may be asking for "lightning to strike" twice: two identification strategies affecting the same cohort but at adjacent developmental stages. Clearly, this is a tall order.

In general, empirical studies (struggle to) feature at most one identification strategy. Even if that individual identification strategy is valid, familiar issues like omitted variables bias creep back in to undermine inference on the existence of dynamic complementarities. As a case in point, Aizer and Cunha (2012) use an "exogenous increase in preschool availability to identify…complementarities with early stocks of human capital" which they conclude provides "strong evidence of complementarity between investments and early human capital." This inference is drawn from the finding that those with higher Bailey test scores at month 8 benefit more from (arguably exogenous) variation in subsequent investments. However, missing is an explicit reason why *only* the Bailey test score is different at month 8 and not other characteristics of the child. Alternative factors that are not held constant could affect the return to subsequent Head Start investment.

More formally, Heckman (2007) defines the technology of capability production *f* when the child is *t* years old:

[12] Heckman (2007) considers uni-dimensional investments that affect multi-dimensional capabilities. Cunha, Heckman, and Schennach (2010) differentiate between investments in cognitive versus non cognitive skills, and define the related concept of "direct complementarity".

$$\theta_{t+1} = ft(h, \theta_t, I_t)$$

where θ_{t+1} is a vector of capabilities, h denotes parental capabilities, and I_t investments when the child is t years old. Dynamic complementarities posit that:

$$\frac{\delta^2 ft(h, \theta_t, I_t)}{\delta\theta_t \delta I_t} > 0$$

While Aizer and Cunha (2011) claim an exogenous change in I_t with Head Start, there is no corresponding natural experiment in θ_t. Absent this, variation in θ_t can be correlated with other factors that affect the return to I_t. Across families (a comparison Aizer and Cunha (2012) carefully avoid making), this could include unobserved aspects of h that are correlated with θ_t and affect the return to investment (e.g. confounding from parental "concern"). Still, the multidimensional conception of capacity makes the "single experiment" evidence of Aizer and Cunha (2012) more difficult to interpret. For example, assume θ_t has a cognitive and health dimension, where Bailey captures the former. Likewise, assume Head Start constitutes and investment in cognitive skill. Health is plausibly correlated with both the Bailey score and the return to cognitive investments, yielding the appearance of dynamic complementarities, or that "skills beget skills". But in reality, the relationship between Bailey score and return to Head Start may be driven by differences in health. Nor does inclusion of family fixed effects provide a solution, as sibling differences also come bundled. And indeed, Aizer and Cunha (2012) find that non-cognitive skills at month 8 ("advanced social and emotional development") likewise seem to raise the return to Head Start. Once we have opened the multidimensional "box", when have we captured all the relevant, correlated dimensions of capability that alter the return on investment? Absent a two-pronged identification strategy for a specific θ_t and I_t,, we are quickly back in the familiar territory of omitted variables bias. It is then difficult to know whether inclusion of additional regression controls that one happens to observe (like family identifiers or various imperfect measures of health) reduces or increases bias (see, e.g. Clarke, 2005)

That said, we don't view dynamic complementarities as a "fundamentally unidentified question" (Angrist and Pischke, 2009). One could imagine a controlled intervention with two distinct treatment arms targeting adjacent developmental ages for the same cohort. Clearly, such an intervention would require longitudinal data on an especially large sample. Absent researcher manipulation, it seems those analyzing observational data will need to get especially lucky. A recent attempt in this spirit is by Bhalotra and Venkataramani (2012a), who overlay the diffusion of sulfa drugs among children with racial segregation to consider long-term effects on schooling, income, and disability. The basic argument is that returns to investment differed starkly by race and place, and this variation constitutes a second instrument in addition to sulfa. Likewise, Bhalotra and Venkataramani (2012b) consider gender differences in the comparative advantage for brain- versus brawn-intensive occupations in Mexico, and lay this on top of a sanitation investment that reduced early childhood diarrhea for boys and girls by similar amounts. Reinforcement is stronger among Whites in the US following sulfa and girls in Mexico following sanitation because return to that investment was higher.

Overall, the evidence for dynamic complementarities is mainly descriptive at present. A few studies (Chay et al., 2009; Heckman et al., 2010; Kelly, 2011) have found larger treatment effects at higher capacity levels using quantile estimators, which is consistent with the existence of dynamic complementarities, but no "smoking gun". Again, there are other channels besides dynamic complementarities that could explain these patterns and these three studies are commendably circumspect in invoking the dynamic complementarity story – it's not their *raison d'etre*. The descriptive evidence that exists is an invitation to sharpen empirical tests, much as early descriptive evidence on fetal origins (e.g. Currie and Hyson, 1999) provoked stronger (generally corroborative) analyses. Eventually we might understand whether dynamic complementarities are an important motivating factor behind responsive parental investments and fetal origins effects more generally.

Summary of Evidence

Table 1 summarizes evidence from the recent empirical literature.[13] We roughly categorize studies into one of four categories: 1) those that find either no effects or small effects on parental responses; 2) those that find evidence of compensating behavior; 3) those that find evidence of reinforcing behavior; and 4) those that find mixed evidence in favor of both compensating and reinforcing behavior.

We have placed a total of four studies in the first category that finds no effects. Of these, two are based on twins comparisons and one is based on a regression discontinuity involving comparisons of very small infants. For reasons mentioned above, their interpretation might be qualified. We have found only three recent studies that find evidence consistent with compensatory investments, our second category. In one of the studies, that by Black et al. (2010), the issue of parental responsiveness was not really a focal point; the evidence is more indirect and was simply presented as a robustness check. For our third category, those that find only evidence of reinforcement we have placed a total of seven studies, three of which use family fixed effects. Finally, an additional five studies find evidence of both compensating and reinforcing behavior.

Overall, the balance of the evidence seems to be tipped towards finding that parental investments are reinforcing. To the extent that compensating behavior occurs, some of the evidence suggests it takes place more for higher SES families. There is evidence from two developing countries (China and Ethiopia) of compensating behavior along the health dimension but reinforcing behavior along the cognitive dimension. Although many studies seem to find unambiguous evidence of reinforcement, given the nascent stage of the literature, we do not wish to push this conclusion too far. If biology is doing the "heavy lifting" in terms of outcomes, these investments may still not be of first order importance.

IV. Multi-dimensional capability and investment

[13] We chose to limit the evidence to studies from the past 3 or 4 years that have generally used better measures of both endowments and investments. The one exception is Ayalew (2005) which though published in 2005 is unique in that it considers multiple dimensions of investments. We have also omitted studies that look at parental responses to measures of skill observed well after birth (e.g. test scores) or to post-natal interventions.

The early modeling of human capacity formation featured a multi-dimensional conception of capacity. For example, capacity could include dimensions of health, cognitive skills, and non-cognitive skills. In general, recent empirical work on parental investments response to endowment shocks has glossed over this potential multi-dimensionality in investments and capacity.

An exception to this empirical literature distinguishes between health *H* and other skills *C* (Conti, Heckman, Yi, Zhang, 2011). The formation of health at a given developmental stage may be intertwined with the accumulated stock of other skills, and vice versa. Thus, we could have a health production technology like:

$$\theta_2^H = (\theta_{t,1}^C)^\gamma [\beta_\theta \theta_1^H + \beta_I I_1^H]^{1-\gamma}$$

Higher stocks of cognitive skills at the end of period 1 aid in the formation of health through health investments *I*.[14] These production technologies are nested within a convention intra-household resource allocation framework. An empirical prediction of their model is that when a shock to early childhood health occurs to one child, it may be optimal for parents to compensate (help offset) the shock to that child's health but reinforce (exacerbate) the shock in terms of subsequent cognitive investments. Conti et al. find support for this model in an analysis of data on Chinese twins, where direct parental investment measures are observed. The intertwining of cognitive and health dimensions in the production of subsequent capacities means, essentially, that optimal parental responses may be heterogeneous and somewhat nuanced. For this reason, it becomes difficult to interpret estimates of "fetal origins" effects from the "reduced form" literature as providing a lower or upper bound on biological effects (effects absent responsive behavior).

Conti et al. sound an articulate and worthwhile note of caution on the interpretation of empirical studies related to the multi-dimensionality of capacity and its formation. This multi-dimensionality may

[14] While the production function above assumes a Cobb-Douglas relationship across health and cognitive dimensions, Conti et al. (2011) show that a more general CES production function yields similar predictions.

help explain why the literature has "yet to achieve a consensus" (Conti et al.) on whether parental investments tend to be reinforcing or compensating – it may depend on the dimension considered. Even with a natural experiment, it is useful highlight the challenge of identify the parameters of the production technology above – e.g. what's the Cobb-Douglas elasticity of substitution between health and other skills? Assume the natural experiment provides an exogenous shock to $\theta^{H}{}_{2}$. Even if we assume no investment response and a symmetric production function for cognitive ability:

$$\theta_2^C = \left(\theta_{t,1}^H\right)^{\gamma}\left[\beta_\theta \theta_1^C + \beta_I I_1^C\right]^{1-\gamma}$$

the observed response of health and cognitive capacity to this (unidimensional) shock is a function of the parameters γ, β_θ, and β_I. Empirically, we only have two damage estimates ($\partial\theta_2^H/\partial\theta_1^H$, $\partial\theta_2^C/\partial\theta_1^H$) and three parameters. Moreover, this presumes we observe the capabilities and investments (which in practice is a challenge to marry to a shock) and have further made the simplifying assumption that the technology by which investments in period 1 build on previous levels of that skill is the same for *H* and *C* (perfect substitutability with identical coefficient β_I). As before, we would like some more exogenous variation beyond the exogenous shock to $\theta^{H}{}_{2}$ to help identify the parameters.[15]

The ambiguity may be greater still if we consider non-health shocks. Conti et al. assume the birth weight difference within twin pairs has an immediate effect on the early health endowment but not on the cognitive endowment (their equations 1 and 2). Leaving aside the merit of this assumption, consider an alternative shock that had a purely cognitive initial effect, such as that characterized by Almond, Edlund, and Palme (2009) with ionizing radiation or Advaryu and Nyshadham (2012) with iodine supplementation. Since the Conti et al. model is symmetric with respect to cognitive and health dimensions, we could use it to interpret a purely cognitive shock but swapping the dimension labels of "cognitive" versus "health". In this "photo negative" framework, we would now expect compensation

[15] If the same natural experiment affects some cohorts in period 1 of their lives and others in period 2 (i.e., a shock to $I_2^{H)}$, this may provide additional traction on estimating parameters (Almond and Currie, 2011).

along the educational dimension and reinforcement along the health dimension to be optimal for the parent – i.e. the opposite of the Conti et al. empirical finding.

Indeed, theoretical ambiguity in whether to compensate versus reinforce along different dimensions of capacity may exist even when there are no production synergies between cognitive and non-cognitive skills. We can simplify the Conti et al. (2011) framework by assuming just one child and taking health out of the production function for cognitive capacity and vice versa. Now, the level of cognitive capacity does not affect the productivity of investments in health in producing next period's health (and vice versa). Instead, we can allow for differing "own" production technologies by which health investments generate health and cognitive investments generate cognitive ability.[16] Arbitrarily, we could assume a relatively developmental production technology for cognitive ability:

$$\theta_C = B[\gamma_C(\bar{I}_{1C} + (1-\beta)\mu)^{\phi} + (1-\gamma_C)I_{2C}^{\phi}]^{1/\phi}$$

And a non-developmental production technology for health:

$$\theta_H = \gamma_1(\bar{I}_{1H} + \beta\mu) + \gamma_2 I_{2H}$$

When ß=1, we have a pure health shock. Using a Cobb-Douglas child quality function like Conti et al.'s equation 18, we should compensate the health shock. If the health shock is positive, it's optimal to use that bounty to invest in the cognitive dimension, thereby reinforcing the positive health shock in the child with additional cognitive investments. The difference in the elasticities of substitution across the two production functions drives the asymmetric investment response. As we do not yet have a well-identified sense of what these elasticities of substitution are for differing dimensions of capacity, reinforcement versus compensating strategies may be an artifact of these differences rather than a capacity intertwining like that depicted in Conti et al. equation 19.

[16] Analogous to $\phi_C \neq \phi_N$ in Cunha, Heckman, and Schennach (2010), who note that it is "implausible" that a "common elasticity of substitution governs the productivity of inputs in producing both cognitive and noncognitive skills".

As in the Conti et al. framework, the situation above is reversed when ß=0 and we have a purely cognitive shock. It is now optimal to increase health investments in response to an increase in the (cognitive) endowment, and reduce cognitive investments. Moreover, it is difficult to know at what value of ß our investment strategy flips. Even in this simple model, the intermediate "no investment response" value of ß is a non-obvious function of the production technology parameters. Even in the design-based literature, the early-life shocks often come bundled (affecting multiple dimensions at the same time), so it may be inappropriate to assume a unidimensional shock and trace the multidimensional investment response: it may instead be the multidimensionality of the initial shocks that drives the multidimensional response.

To summarize, allowing for different dimensions of capability and investment makes the exercise of interpreting empirical evidence more challenging and nuanced. In light of the discussion above, future empirical work should consider along what dimensions an initial shock strikes (e.g. what's ß?) and the potential for multidimensional impacts later in life and the correspondence between these dimensions over time. More challenging from a data perspective is to also consider the response of different dimensions of parental response. At this early stage, it is difficult to know whether the multidimensional nature of human capacity formation is mainly of conceptual interest or that heterogeneity across dimensions is indeed empirically important. Future work in the design-based tradition can help shed light on this question that arose from innovations in the theoretical literature. In the meantime, the basic point of Conti et al. goes through: we should exercise caution in interpreting fetal origins effects as upper versus lower bounds, particularly when within-family estimates are considered.

Does the Bumble Bee Fly?

Bleakley (2010), channeling 1960s work on human capital formation, sounds a sobering note on the interpretation of analyses of parental investments and their optimized response to early-life shocks. His focus is on parental investments in education, but speaks more generally to inputs in the production adult capacity, income, etc. One can decompose the response of capacity due to a health shock into that attributable to the direct effect of health on capacity/income, and that operating through investments. At the optimal level of investments, the marginal return should be zero (i.e., the envelope theorem). While this need not imply that the change in investments due to an early-life shock is zero, Bleakley argues their effect on "what matters" may be zero at their optimal level.

Bleakley's point underscores the need for new studies that can assess not just the response of investments but their effect on later-life capacity. Bleakley also highlights the point that the inframarginal return on investment may change with an endowment shock: the quality of given level of investments improves even if the effect of the last unit of investment is zero. Again, a "lightening strikes twice" design would be a good starting point for testing this hypothesis. For the moment, we are left to explain why investments to the extent they do respond empirically to endowment shocks, more often than not seem to go in the reinforcing direction.[17] Bleakley also discusses potential endogenous response in the child's opportunity cost of schooling, whereas the childhood investments we have in mind typically occur before such options become important.

Even with the envelope theorem in mind, investments may still have first order effects on things we care about. To the extent there are externalities to childhood investments (as is often invoked with education), then parental decision makers are not investing the optimal amount insofar as society at large is concerned and the optimized marginal investment consequential. Uncertainty in the returns to childhood investments or a divergence in whose utility is being optimized through investments (parents or kids?) could likewise lead to sub-optimal investment levels and thereby magnify the effect of parental investment decisions. Nevertheless, it is worth reiterating the overarching point that investments are a means to an end: we should seek to integrate consideration of investment response with the response of later-life outcomes that enter directly into utility.

[17] In Bleakley's model $b_{ee}<0$: the marginal benefit of (schooling) investment falls with more investment.

V. Conclusion

How parents respond to endowment shocks is a subject of inherent interest made more so by the confluence of researchers and researcher styles working on it. The topic invites a balanced approach of theoretically-informed and designed based analyses. We expect this area to be focus of continued research attention because the nature of the behavioral response and its importance to long-term effects is still being debated. How much of putative fetal origins effects are parents "piling on" with subsequent investments? Indeed, the current scorecard seems to tilt against compensatory investments. Given the lens it provides on behavior and parent-child interactions, those well outside the "fetal origins" camp can follow developments and any regularities uncovered with interest. Finally, learning more about this area may help inform appropriate individual and policy responses to fetal origins: how to harness the critical developmental window to make more cost-effective investments.

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Table 1: Summary of Empirical Studies on Parental Responses to Endowments

Study	*Country*	*Methodology*
1. No Effects or small effects		
Bharadwaj, Loken and Neilson (2012)	Chile, Norway births	Regression Discontinuity at 1500 Grams
Royer (2009)	US	Twins
Almond and Currie (2011)	US	Twins
Kelly (2011)	UK	Flu Exposure in Utero
2. Compensating Responses		
Black et al. (2010)	Norway	Indirect, Family Size Effects
Del Bono et al. (2012)	US	Structural Model with fmaily fixed effects
Bharadwaj, Eberhard and Neilson (2011)*	Chile	Family Fixed Effects
3. Reinforcing Responses		
Aizer and Cunha (2012)	US	Family Fixed Effects
Adhvaryu and Nyshadham (2012)	Tanzania	Iodine Supplementation in Utero
Venkataramani (2012)	Mexico	Malaria Eradication
Bhalotra and Venkataramani (2012)	US	Access to Sulfa Drugs in Infancy
Datar et al (2010)	US	Family Fixed Effects
Almond, Edlund and Palme (2009)	Sweden	Exposure to Radiation in Utero
Rosenzweig and Zhang (2009)	China	Family Fixed Effects
4. Evidence of Both Compensating and Reinforcing Responses		
Conti, Heckman, Yi and Zhang (2011)	China	Twins, Multiple Dimensions
Restrepo (2012)	US	Family Fixed Effects
Parman (2012)	US	Flu Exposure in Utero
Hsin (2012)	US	Family Fixed Effects
Ayalew (2005)	Ethiopia	Family Fixed Effects

*The study finds evidence of compensating investments among siblings but no effects among twins

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