
Reducing the Incidence of Low Birth Weight in Low-Income Countries Has Substantial Economic Benefits

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Reducing the incidence of low birth weight not only lowers infant mortality rates but also has multiple benefits over the life cycle. This study estimates the economic benefits of reducing the incidence of low birth weight in low-income countries, both through lower mortality rates and medical costs and through increased learning and productivity. The estimated economic benefits, under plausible assumptions, are fairly substantial, at about \$510 per infant moved from a low-birth-weight status. The estimated gains are primarily from increases in labor productivity (partially through more education) and secondarily from avoiding costs due to infant illness and death. Thus there may be many interventions to reduce the incidence of low birth weight that are warranted purely on the grounds of saving resources or increasing productivity.

Each year, some 11.7 million children in developing countries—16 percent of newborns—are born with low birth weight (weighing less than 2,500 g), most of them in low-income countries (UN SCN 2004). Many of these infants die young, contributing significantly to neonatal mortality. Many who survive infancy suffer cognitive and neurological impairment and are stunted as adults, all conditions that are associated with lower productivity in a range of educational, economic, and other activities. Low-birth-weight infants also may have increased risk of cardiovascular disease, diabetes, and hypertension later in life. For all these reasons, low birth weight appears to have serious economic costs.

Approach of the Current Analysis

This article synthesizes the relevant literature on low birth weight and, in a manner that is transparent and flexible to variations in core assumptions, provides the first

estimates of the total potential economic gains from reducing the incidence of low birth weight in low-income countries. Individual studies do not provide much insight into the potential overall gains from reducing the incidence of low birth weight, but this review combines the implications of several studies and some explicit assumptions to derive these estimates. The approach is general and can be applied to other health interventions that provide benefits through increased productivity and resource savings as well as through reduced illness and death.

This review differs from the Disease Control Priorities Project (Jamison and others 1993), which focuses on the relative cost-effectiveness of different health interventions but does not attempt to place benefits in a metric that allows comparison with other possible investments outside the health sector. The emphasis in this article is on estimating economic benefits in monetary terms. These benefits can, of course, be compared with the cost of obtaining them, as is done illustratively for a few promising programs—for example, an iron supplementation program in Nepal (Christian and others 2003).¹ However, even without experimental data on the cost of full-scale programs or in the absence of currently available low-cost technology, there is still value in knowing the potential benefits of new approaches to reducing low birth weight because such estimates can inform decisions about the value of efforts to spur research. For example, there are no fully effective vaccines for human immunodeficiency virus (HIV) or malaria, but estimates of the potential benefits are nevertheless useful for determining what resources should be devoted to research for vaccines. Similarly, although there are technologies for renewable solar energy, they are not yet low cost. Nevertheless, it is of value to know the breakeven point. The estimates provided here may likewise inform possible research on new techniques for reducing low birth weight.

To some extent this article parallels studies by Horton (1999) and Horton and Ross (2003). But although this study draws on the experience of the Disease Control Priorities Project and of Horton and colleagues, it differs in the subject for which benefits are calculated and in its emphasis on a method for varying core assumptions to accommodate diverse underlying conditions. In breaking down total benefits into components and their contribution to overall estimated gains, the study also points to where the gains to better information might be greatest.

This economic assessment of current information on the benefits of reducing the incidence of low birth weight in low-income countries is intended to clarify the economic case for the use of public resources for that purpose and to identify likely important research areas. It recognizes that not all returns are economic but that clarifying the economic returns will facilitate comparisons among alternatives. That should also shed light on how large the noneconomic returns must be to justify changing the priorities indicated by the economic returns.

The review first identifies the causes of low birth weight and its economic impacts. It then explores considerations involved in measuring the economic benefits of

interventions to reduce the incidence of low birth weight. This is followed by a discussion of the empirical information on the benefits of reducing the incidence of low birth weight. Lastly, some simulations are presented of the overall benefits of reducing the incidence of low birth weight, and their sensitivity to alternative assumptions is considered.

Causes of Low Birth Weight and Its Economic Impacts

Prematurity and intrauterine growth retardation are the two main causes of low birth weight, with prematurity relatively more important in developed countries and intrauterine growth retardation in developing countries (Villar and Belizán 1982). Proximate determinants of prematurity include multiple births, stress, anxiety and other psychological factors, high maternal blood pressure, acute infections, and hard physical work (Kramer 1998). Proximate determinants of intrauterine growth retardation include abnormally small or blocked placenta and factors in the maternal environment that prevent normal circulation across the placenta and thus cause poor nutrient and oxygen supplies to the fetus. Maternal undernutrition, anemia, malaria, and acute and chronic infections (such as sexually transmitted infections and urinary tract infections) all contribute to this risk (Allen and Gillespie 2001; Verhoeff and others 2001).

The economic impacts of low birth weight may occur at various stages of the life cycle. It is useful to distinguish among three broad life-cycle stages.

Impacts in the Neonatal Period and Infancy

Low birth weight is associated with higher risk of illness and death, impaired immune function, and poorer cognitive development. There are important differences between intrauterine growth retardation and prematurity in the extent to which low-birth-weight babies tend to catch-up on growth in childhood. Although premature low-birth-weight babies tend to catch-up gradually with normal-birth-weight babies, babies suffering from intrauterine growth retardation tend to remain somewhat below the means in anthropometric distributions as children and adults.

Wherever possible this review attempts to focus more on intrauterine growth retardation than on prematurity. However, because prematurity is more prevalent in developed countries, where data tend to be better and analyses more extensive, this analysis occasionally has to infer from experiences of prematurity.

Low birth weight results in two main economic costs in infancy: those associated with early death and those associated with additional requirements for medical care. Even in developed countries, the additional costs for survivors can be substantial. For example, healthcare in infancy accounts for 75 percent of the \$5.5–\$6 billion in

excess costs due to low birth weight in the United States (Lewit and others 1995). These healthcare costs differ according to the medical system, markets, and policies of a country. Costs during the neonatal period and infancy may be far less in low-income countries, where most births occur outside a clinical setting. But these lower medical costs associated with low birth weight come at the expense of higher mortality rates and worse outcomes for the survivors.

Impacts in Childhood

Children who are smaller than their peers because of prenatal nutritional deprivation risk many of the consequences that are noted for children with malnutrition in early life. Stunted children tend to start school later, progress through school less rapidly, have lower schooling attainment, and perform less well on cognitive achievement tests when they become older. Moreover, there is substantial evidence that the relationship between birth weight and cognitive function carries beyond the range of low birth weights into the range of normal birth weights (Matte and others 2001; Jefferis, Power, and Hertzman 2002; Richards and others 2002). Despite the absence of consensus on how much improvement there is in cognitive function as a child grows, many studies show that cognitive dysfunctions are moderated by social and economic factors (Jefferis, Power, and Hertzman 2002; Aylward 2003; Ment and others 2003). This underscores the call by Grantham-McGregor, Fernald, and Sethuraman (1999) for more studies of low birth weight in environments in which countervailing investments are not common, such as the low-income countries of interest here.

Low-birth-weight children require additional outpatient care and hospitalization during their childhood (Victora and others 1999). This has direct resource costs for healthcare services as well as lost time for uses including work and schooling for caregivers. As with health investments, increasing investments in education can mitigate a share of the long-term consequences of low birth weight for survivors. In developed countries, substantial resources are devoted to special education and social services (Petrrou, Sach, and Davidson 2001). Where an education system does not recognize or cannot accommodate the individual needs of students, however, these costs are observed less as up-front costs during childhood than as the costs of reduced productivity in adulthood.

Impacts in Adulthood

There are at least three likely effects of low birth weight on adult outcomes.

First, adults who were born small are likely to have lower earnings and productivity because of lower cognitive achievement or stature (Strauss and Thomas 1998).

Second, fetal undernutrition at critical periods may result in permanent changes in body structure and metabolism. Even without subsequent nutritional insults, these changes can lead to increased probabilities of chronic noninfectious diseases later in life. This hypothesis is bolstered by studies that track low-birth-weight infants into their adult years and document increased susceptibility to coronary heart disease, non-insulin-dependent diabetes, high blood pressure, obstructive lung disease, high blood cholesterol, and renal damage (Barker 1998).

The evidence for this fetal origins hypothesis is still being assessed. At least two other explanations for the association between low birth weight and adult diseases have been offered. Low birth weight may be an indicator of poor socioeconomic status, which may have a causal impact on adult disease probabilities through other variables such as poor nutrition later in life or higher rates of smoking. If so, low birth weight may be only a correlate and not a causal variable. Low birth weight may be due to a genetic predisposition to insulin resistance, tending to account for a higher predisposition to adult diabetes and coronary heart diseases that reflects genetics rather than aspects of the uterine environment that may be influenced by medical and nutritional interventions. Without evaluating the evidence supporting or disputing the fetal origins hypothesis, this review shows what the implications of some estimated impacts would be in an economic context.

Third, low birth weight may have long-term consequences through transmission of the nutritional shock to the next generation. To the degree that stunted mothers have a higher probability of having low-birth-weight children, the biological and economic consequences of low birth weight may be perpetuated across generations.

Considerations in Measuring the Economic Benefits of Reducing the Incidence of Low Birth Weight

The economic benefits of reducing the incidence of low birth weight must be valued at prices that reflect the true marginal resource costs of those benefits. This statement has several implications.

First, many policies that reduce the incidence of low birth weight have multiple possible benefits. It is important that all be included so that the benefits are not undervalued.

Second, the benefits may be increases in some desirable outcome, such as schooling attainment, cognitive skills, and labor productivity, or reductions in costs, such as medical care costs associated with low birth weight.

Third, for each benefit, the causal contribution of low birth weight must be assessed with proper controls for measurement problems, background variables, and behavioral choices.

Fourth, if the impacts are not estimated in direct monetary terms, they must be translated into appropriate monetary terms for the context so that they can be summed across all the benefits to obtain the total. If prices are not available or are very distorted, an alternative is to use the resource cost of the cheapest alternative means of attaining the same objective (Summers 1994; Knowles and Behrman 2003).

Fifth, one of the most controversial steps in aggregating benefits is valuing a reduction in mortality. One approach in the literature is to value a life in accordance with an individual's expected discounted lifetime earnings. This approach is flawed, in part because it does not net out the costs of investments in that individual or of his or her consumption. More vexing, this approach values the life of an individual roughly in proportion to the per capita income of the society in which the individual is born. The alternative used here does not attempt to put a figure on the value of a life but only on the expected savings of resources in the society in which the low-birth-weight baby is born. That is, the savings in reducing mortality are estimated in the costs of other investments undertaken to reduce mortality (Summers 1994). This approach is sufficiently transparent that the assumption can be altered to assess how different assumptions would affect the overall estimated returns.

Sixth, the impacts are likely to occur over time, with different time paths for the impacts from different programs. Therefore, to make benefits comparable across programs, the present discounted values of benefits are generally used. Such calculations recognize that it is better to obtain a given monetary impact sooner rather than later, so that the money can be reinvested to earn further productive returns. This means, for example, that it is better to have a benefit from reducing the incidence of low birth weight that occurs quickly (reduced neonatal medical costs, for example) than one of equal monetary value that occurs decades later (reduced medical costs of the same magnitude from cardiovascular disease or diabetes later in life).

Lastly, many of the potential benefits come from reducing government expenditures, such as those for healthcare. As raising revenue generally incurs administrative costs and deadweight costs to the economy from economic distortions, the full economic cost of the expenditures is higher than the nominal value. This needs to be considered when valuing the reduction in the incidence of low birth weight and when considering programs to address the issue.

Empirical Evidence on the Economic Benefits of Reducing the Incidence of Low Birth Weight

Information on the economic benefits from reducing low birth weight is found not only in the nutritional, epidemiological, and biomedical literatures, but also in the socioeconomic and demographic literatures. The ideal is experimental data from

randomized field designs that control for factors that determine both low birth weight and subsequent education, health, and productivity.

Although there are many randomized evaluations covering interventions that affect birth outcomes, only one such study was found in low-income countries, an experiment in Guatemala that also follows children into adulthood (Maluccio and others 2005).² Another set of studies tracks a cohort of children born at the end of the Dutch Hunger Winter—a short-term crisis caused by wartime rationing. Results from this natural experiment can be considered an outcome of an exogenous shock and thus considered to be relatively free of confounding factors. A similar natural shock was the famine in China between 1959 and 1961; recent research shows a doubling of rates of schizophrenia among the survivor cohort from that event (St. Clair and others 2005).

Additional information that controls for environmental factors is obtained from comparisons of twins (though the available studies are from developed countries). Although processes that lead to low birth weight among twins may be different from those among other children, in general weight differences in twins appear to reflect intrauterine resource competition.³ Results from experimental evidence, twins studies, and cross-sectional studies are in general agreement, especially on the impact of birth weight on productivity.

Moreover, many studies show that outcomes are affected by birth weight even in the range of normal births. Thus unlike studies focused on prematurity, results tracking children born small for gestational age may reflect one end of a continuum that extends from low-birth-weight outcomes that are relatively common in some low-income countries (particularly in South Asia) to outcomes in developed countries for which there are more data. However, this does not imply that socioeconomic factors are not also important. Indeed, even in studies showing that the resources available in developed countries explain a larger share of the variance in cognitive development than does birth weight, birth weight still has a persistent and significant effect (Jefferis, Power, and Hertzman 2002).

Nonetheless, because information on many aspects of these processes is imperfect, simulations are explored under alternative assumptions to see how robust the estimates are to changes in some critical assumptions. And in recognition that benefits are context specific and vary across countries, representative price and resource cost structures typical of low-income countries are used rather than estimates specific to any country. Finally, the focus on reducing the incidence of low birth weight is mainly on crossing a threshold birth weight of 2,500 g, although many of the benefits carry over a continuum; only at relatively high birth weights do the benefits from increasing birth weight decline substantially (and possibly become negative).

As noted, accounting for the timing of the benefits is critical. The base case uses an assumed discount rate of 5 percent, but because of uncertainty regarding the appropriate discount rate, conclusions are tested for sensitivity to assumed discount

Table 1. Estimates of Present Discounted Values of Seven Major Benefits of Moving One Infant Out of Low-Birth-Weight Status, at Different Discount Rates (U.S. Dollars)

<i>Benefits</i>	<i>Annual discount rate</i>		
	<i>3 percent</i>	5 percent	<i>10 percent</i>
1. Reduced infant mortality	95	99	89
2. Reduced neonatal care	42	42	42
3. Reduced costs of infant and child illness	36	35	34
4. Productivity gain from reduced stunting	152	85	25
5. Productivity gain from increased cognitive ability	367	205	60
6. Reduced costs of chronic diseases	49	15	1
7. Intergenerational benefits	92	35	6
Total	832	510	257
Share of total at 5 percent discount rate (percent)	163	100	50

Note: The 5 percent discount rate, shown in boldface in the table, is the base case estimate.

Source: Authors' analysis based on data and assumptions described in the text.

rates. Data in table 1 compare the present discounted value of seven benefits from moving one infant from a low-birth-weight status at discount rates of 3, 5, and 10 percent.

In addition to the discounting of benefits received in the future, the timing of benefits during the life cycle is important because the probabilities are less than 1 that survivors of infancy will survive to the life-cycle stage at which various benefits arise. Thus not all the potential benefits from reduced illness and increased productivity will be realized. For all but the first two benefits (which focus on survival through infancy), the estimated benefits are adjusted for survival to the relevant age using World Health Organization life tables for India (www.who.int/countries/ind/en/), the country with the largest number of low-birth-weight babies. These life tables imply, for example, that the probabilities of surviving are 0.88 for age 20, 0.82 for age 40, and 0.66 for age 60. Thus the expected benefits from effects that are realized only later in the life cycle—such as lower costs for postinfancy diseases, higher birth weights in the next generation, greater productivity, and less chronic disease—are lower than they would be if, all else being equal, survival probabilities were higher.⁴

The following sections describe the empirical evidence on seven major economic benefits from reducing the incidence of low birth weight (the benefits are numbered and keyed to the summary benefits in table 1).

Reducing Infant Mortality

Several studies provide estimates of the probability of excess infant mortality for low-birth-weight infants. For example, a review of 12 data sets, including two from India

and one from Guatemala, concludes that for infants born at term and weighing 2,000–2,499 g, the risk of neonatal death is 4 times that for infants weighing 2,500–2,999 g and 10 times that for infants weighing 3,000–3,499 g (Ashworth 1998). The risks of post-neonatal mortality are two and four times that of the other two groups. These studies did not control for socioeconomic variables, and a study that did so using data on twins to infer intrauterine resource competition—and, by inference, nutrition—found that an additional 400 g at birth in the United States led to a 14 percent decrease in mortality in the period between 28 days and 1 year for both fraternal and identical twins (Conley, Strully, and Bennett 2003). In contrast, in the first 28 days of life, an additional 400 g at birth led to a 27 percent decrease in the risk of mortality for fraternal twins compared with an 11 percent decrease for identical twins, implying a large role for genetic factors.

These risk ratios translate into fairly large differences in mortality rates, given the relatively high rates of low birth weight in many developing countries. The Indian and Guatemalan samples, for example, have neonatal mortality rates of 21–39 per 1,000 live births and post-neonatal mortality rates of 25.3–60.0 per 1,000 neonatal survivors, with low birth weight in these samples of 21.2–39.0 percent. The mid-points of these ranges and of the percentage of low-birth-weight babies and considering the four-times greater risk of neonatal death for full-term infants weighing 2,000–2,499 g at birth and the two-times greater risk of post-neonatal death as for full-term infants weighing 2,500–2,999 g imply a drop of about 0.078 in the probability of an infant death (neonatal or post-neonatal) for each birth in the 2,500–2,999 g range instead of in the 2,000–2,499 g range.⁵

It is difficult to place a value on a life saved. Using a conservative estimate based on an \$800 cost to save a life through measles immunization in the early 1990s (Summers 1994) and adjusting it for inflation in the next decade and for the distortion costs of raising these revenues yield an estimated alternative resource cost of saving an infant's life of about \$1,250. Because not every low-birth-weight child dies, this value is multiplied by the excess probability that a low-birth-weight child would die in infancy, giving an estimated monetary benefit of reducing infant mortality associated with low birth weight of about \$98. This benefit is obtained within a year or so of the assumed intervention occurring when the low-birth-weight baby is in the womb. Thus the discount rate does not greatly affect the present discounted value of this benefit (table 1, row 1).

Reducing the Additional Costs of Neonatal Medical Attention

The additional cost of neonatal medical care is the sum of extra hospital care and outpatient care required for low-birth-weight babies. Hospital care costs are the costs of a day of hospital stay times the number of additional days on average for babies born in hospitals and weighing less than 2,500 g. Under the assumption that

these costs are incurred only for babies born in hospitals, the contribution of this component to the total may be small, even though the costs are not discounted over many years, because the share of children born in hospitals is small in most developing countries.

No reports of studies could be found that indicate the average length of hospital stay for low-birth-weight newborns compared with normal-weight newborns in low-income countries. On the basis of experience in Bangladesh, hospitalization is assumed to be 1–2 days for a normal-weight newborn with a normal delivery and 5–7 days for a low-birth-weight baby weighing between 1,500 and 2,500.⁶ On the basis of a Tk2,000 per day cost at private hospitals, inclusive of medicine as the opportunity cost of care (government hospitals charge Tk200–300 plus medicine, but the cost of beds is subsidized), the extra direct hospital-related resource cost for a low-birth-weight newborn is \$155, taken at the midpoints of the difference in days and using an exchange rate of Tk58 per dollar.

To this must be added the distortion costs from raising government revenues to finance the hospitalization and the cost of time to the parents for the extended hospital stay. Assuming that the distortion costs are about 25 percent (\$39) of the hospitalization costs and that the time cost of the parents is \$15, the total extra resource cost for the longer hospitalization for a low-birth-weight baby is \$209. This is assumed to be incurred close enough to the intervention not to require discounting.

Most babies in low-income countries are born at home, not in hospitals. Although there may be some parallel costs for low-birth-weight babies born at home, they are likely to be much less than the costs of extra hospitalization. For the base estimates, therefore, 90 percent of babies are assumed to be born at home, and the additional resource costs for low-birth-weight babies born at home are estimated at 10 percent of that for low-birth-weight babies born in hospitals (table 1, row 2). Conservatively, the incremental costs of home care in the neonatal period are not considered. The methodology employed allows this—and any other component of the estimated benefits—to be varied to accommodate different conditions.

Reducing the Additional Costs of Subsequent Illnesses and Related Medical Care for Infants and Children

Several studies show a regular pattern of increased childhood illness for lower-birth-weight children, particularly in the first 2 years of life. For example, compared with normal-birth-weight children, low-birth-weight children 0–6 months old in Brazil have 33 percent more days with diarrhea, and low-birth-weight babies 0–59 months old in Papua New Guinea have 60 percent more (Ashworth 1998). In Brazil the increased days with diarrhea imply a doubling of the rate of hospitalization for dehydration and a 50 percent increase in hospitalization for pneumonia (Barros and

others 1992). Similar increases in pneumonia and acute respiratory disease are observed for many countries (Victora and others 1999).

Such increased illness has direct and immediate costs plus indirect costs due to associated stunting. In the absence of published estimates of the resource costs of such illnesses and related medical care among low-birth-weight children, the additional total direct resource costs for the first 2 years of life are estimated at \$40, at the center point of the end of the first year, with adjustment for the probability of surviving to 1 year old bringing the cost in the base case to \$35 (table 1, row 3).

Discounted Lifetime Productivity Gain Due to Decreased Stunting

The gain in lifetime productivity from increasing the birth weight of a low-birth-weight baby to a normal weight has two components. The first can be derived from an estimate of the impact of low birth weight on adult height and from an estimate of the difference in earnings attributable to low stature, under the assumption that the impact on earnings reflects the impact on productivity. The second component, discussed in the subsequent section, stems from the effect of stature on the timing and attainment level of schooling (Alderman, Hoddinott, and Kinsey forthcoming). For both components, the estimates incorporate the probability of survival through the working years of adulthood for normal-weight babies.

Long-term follow-up studies in the United Kingdom indicate a loss of 0.5 standard deviations in height for children weighing an average of 1,000 g less at birth than normal-birth-weight controls (Strauss 2000). A study of identical twins in the United States found that a difference of 1,000 g in birth weight led to a 1.6 cm (roughly 1 percent) difference in adult height (Behrman and Rosenzweig 2004). In a randomized experimental study tracking a cohort of Guatemalan children whose mothers received supplementation, a 1 standard deviation difference in birth weight led to a 1.8 cm difference in adult height for males and a 0.6 cm difference for females (Li and others 2003).

What do differences of this magnitude mean for productivity? An estimate of the direct impact of adult height on wages for urban Brazil found that a 1 percent increase in height leads to a 2–2.4 percent increase in wages or earnings (Thomas and Strauss 1997). Although the Brazilian study uses sophisticated methodology to account for labor selectivity and joint determination of health, the result is similar to others reported in the literature. Indeed, height is even a significant explanatory variable for wages in the United States (Strauss and Thomas 1998). Results such as these—though admittedly about stunting in general and not necessarily stunting due to low birth weight—are used to infer the impact on productivity through reduced stunting. Increasing the birth weight of a low-birth-weight infant to above 2,500 g results in an expected benefit of about 2.2 percent of assumed annual earnings of \$500 a year in constant prices over a work life from 15 to 60 years old (table 1, row 4).

Discounted Lifetime Productivity Gain Due to Increased Cognitive Ability

The indirect effect of height on wages mediated through schooling is likely to be even larger than the direct impact of height on wages. This indirect effect has been documented for preschool malnutrition. For example, a childhood shock that led to a 0.73 standard deviation decline in height in Zimbabwe resulted in a six-month delay in initiating enrollment and 0.8 years less of total schooling, leading to an estimated 14 percent reduction in lifetime earnings (Alderman, Hoddinott, and Kinsey forthcoming).

Learning may also be affected by the impairment of cognitive development that is associated with low birth weight, so reducing the incidence of low birth weight could also increase productivity through this channel. Two studies find that the cognitive impairment falls in a range of a 0.3–0.6 standard deviation decrease in intelligence quotient (IQ) (Sorensen and others 1997; Bhutta and others 2002). Extrapolation to the task at hand, however, is subject to several adjustments. These two studies investigate children whose birth weights reflect prematurity, whereas in low-income countries most low-birth-weight babies are a result of intrauterine growth retardation. Mental impairment may not be limited to extreme cases of low birth weight or to prematurity. One study found that intelligence scores continued to increase up to a birth weight of 4,200 g, with the difference between the low birth weight group and children born at 4,000 g being roughly 0.5 standard deviation of the score (Sorensen and others 1997). Another study comparing siblings with normal gestation found increases in IQ of similar magnitude with increases in birth weight (Matte and others 2001).

Next, the magnitude of impairment must be converted into an estimate of the impact on subsequent earnings. Two studies using the same data set but different measures of ability estimated the impact of IQ on earnings in the United States. One study shows that the logarithm of wages for men declined 0.05 with a 0.5 standard deviation decline in IQ, holding schooling constant (Altonji and Dunn 1996). This was slightly more than the impact of an additional year of postsecondary schooling. The other study modeled the influence of ability on schooling choice as well as on wage offers and found that a 0.5 standard deviation decline in cognitive ability led to a 8–12 percent decrease in wages (Cawley, Heckman, and Vytlačil 2001).

For Pakistan, a 0.5 standard deviation reduction in cognitive ability based on performance on Raven's matrices was found to result in a 6.5 percent reduction in wages (Alderman and others 1996). Similarly, for Kenya and Tanzania, Raven's scores influence schooling and learning conditional on years of school. Taking these pathways into account, a 0.5 standard deviation decline in ability would lead to declines in wages of 8 percent for Kenya and 5 percent for Tanzania (Boissiere, Knight, and Sabot 1985).⁷

Combined Productivity Gains from Decreased Stunting and Increased Cognitive Ability

An alternative approach to estimating the productivity gains from decreased incidence of low birth weight combines the fourth and fifth of the seven benefits considered in this article. It looks directly at individual earnings as a function of birth weight. Instead of summing the impact of low stature on wages and the impact of reduced cognitive function times an expectation of this type of impairment, the earnings of children with similar opportunities at birth but different birth weights can be compared. This approach, by drawing on a different set of studies using a different methodology, helps to narrow the plausible range of impact.

People 26 years old who were born small for gestational age (an average of 1,000 g less than the normal weight group) were found to earn 10 percent less than people of normal birth weights (Strauss 2000).⁸ Difference in cognitive ability on standard tests ranged from 0.13 to 0.37 standard deviations in follow-up measurements between the ages of 5 and 16. Even with a modest difference in measured cognitive ability and no difference in average years of schooling, wages differed as much (even more) as they did under the assumption of a 0.5 standard deviation difference in cognitive ability or as derived from wage equations that include cognitive ability. In the United States, a 1,000 g difference in the birth weight of identical twins results in an 18.6 percent difference in wages as adults (Behrman and Rosenzweig 2004). A similar study of siblings found a much larger negative relation between low birth weight and the probability of completing high school than that found in cross-sectional estimates, though the use of siblings may confound low-birth-weight and genetic effects (Conley and Bennett 2000). Norwegian twins indicate that the long-run effects of birth weight on earnings are significant and similar to those found in cross-section (Black, Devereux, and Salvanes 2005). Another study finds that birth weight is negatively associated with rates of unemployment (Kristensen, Bjerkedal, and Irgens 2004).

Overall, considering either the total impact of low birth weight on wages or the sum of the impacts due to stunting, impaired cognitive development, and reduced schooling, the earnings impact of moving an infant out of a low birth weight status can be bracketed between 5 and 10 percent a year. The base estimate uses 7.5 percent. Taken together with the 2.2 percent expected productivity benefit from reduced stunting, this implies a 5.3 percent expected productivity benefit from improved ability. Again, annual earnings or productivity are assumed to be \$500 in constant prices for a working life from 15 through 60 years old for those who survive to adulthood (see table 1, row 5).

Reduced Costs of Chronic Diseases Associated with Low Birth Weight

Numerous chronic illnesses are associated with fetal malnutrition, making it difficult to assign costs. Moreover, relatively few studies have traced the long-term

impacts. As mentioned, fetal malnutrition may affect adult health in ways that low birth weight does not, for example, by influencing gene expression. Moreover, what effect low birth weight has on chronic disease may depend on other deprivations in the individual's life, adding another dimension to any assumptions made. And, again because information is lacking on how many low birth weight children will survive to the ages at which chronic diseases are likely to strike, adjustments are made for survival probabilities using Indian life tables.

One study that attempts to calculate the costs of the impacts of low birth weight and of subsequent nutritional and dietary patterns on chronic disease considers the cost of diet-related chronic disease in two economies—China and Sri Lanka (Popkin, Horton, and Kim 2001). All diet-related factors were estimated to account for costs totaling 2.1 percent of GNP in 1995 in China and 0.3 percent in Sri Lanka. For both countries the costs were projected to rise appreciably over the next generation. The methodology used in these studies differs from that used here in at least two respects. First, the costs are estimates for the economy, not per low birth weight averted. Second, the average loss of earnings (assumed to be 10 years per adult death) is discounted only to the year of death, not from the year of the presumed interventions that might affect low birth weight, as is done here.

The basic estimates in the current study make two broad assumptions. First, the cost of lost productivity and increased medical care is assumed to be equivalent to 10 years of earnings in a low-income population (\$5,000) and to be experienced on average at age 60. Second, the probability of experiencing these chronic diseases is assumed to be reduced by 0.087 for moving a baby out of the low birth weight status.⁹

Reduction in Intergenerational Impacts

Since many women begin having children in their teens or early twenties, some of the costs for the second generation of low birth weight babies may occur before all of the direct costs for the earlier generation have been realized, such as the costs of chronic illnesses in adults who were themselves low birth weight babies. Of course, preventing such intergenerational impacts affects only women who survive to childbearing age.

Not much persuasive evidence was found on the impact of mother's low birth weight on the birth weight of her children. For the United States, in studies of identical twins, the significant positive correlation disappears if all endowments are controlled for (Behrman and Rosenzweig 2004). In low-income rural Guatemala an experimental design at the community level found evidence of an intergenerational effect for nutritional supplements (Ramakrishnan and others 1999). Therefore, benefits are estimated under several assumptions (see table 1, row 7). First, these effects are only for mothers who were low birth weight babies, not fathers, and thus apply to about half of low birth weight babies. Second, on average, these mothers have four children, born when the mother is 17, 20, 26, and 35. Third, for a mother who was a low-birth-weight baby, the

probability for each of her children of being low birth weight is 1 in 5. Fourth, this probability is reduced to 1 in 10 if the mother was not a low birth weight baby. And lastly, the benefits of reducing the incidence of low birth weight for the next generation of children over their life cycle are the same as the benefits for the mothers, but lagged in time and therefore discounted more, over three generations of children.¹⁰

Summary of Benefits from Moving One Infant Out of Low-Birth-Weight Status

The total estimate of the present discounted value (at the 5 percent basic discount rate) per infant born at normal weight rather than low birth weight is about \$510. In purely economic terms that means that it would be desirable to reduce the incidence of low birth weight infants in low-income populations as long as the true resource cost of doing so is less than \$510 per affected infant.

In these estimates the overall benefits are dominated by the benefits of increased productivity from reducing stunting and improving cognitive ability (working in part through the effects on schooling). These two benefits account for more than half (57 percent) of the total. While these benefits emerge only after considerable delay and are received only by those who survive to working ages, they persist over an individual's working life. Thus their effects are considerable even when discounted at 5 percent from the time of the intervention.

Though the estimated benefits from reduced infant mortality and reduced costs of neonatal care and infant and child illnesses are not huge, their contribution is appreciable because the benefits occur very early in the life cycle and are not discounted very much. In contrast, the present discounted value of the reduction in the costs of chronic diseases is fairly small (3 percent) because of the discounting and the survival probabilities, even though the constant dollar values per year are fairly large at the time they occur.

Sensitivity of Basic Estimates of the Benefits of Reducing the Incidence of Low Birth Weight to Selected Critical Assumptions

The illustrative estimates in table 1 are conditional on many assumptions and a few informed guesses. This section examines how sensitive the estimates are to some of these assumptions and guesses.

Discount Rates

The basic estimates use a real discount rate of 5 percent. Changing the discount rate to 10 percent results in an overall present discounted value of benefits half that obtained with the 5 percent discount rate. Changing it to 3 percent increases benefits by 163 percent (see table 1).

The present discounted values of all benefits (except reduced neonatal care, which is not discounted) decline as the discount rate increases, but at very different rates. The benefits that are realized early in the life cycle—reduced infant mortality, reduced neonatal care, and reduced costs of infant and child illness—become relatively more important, accounting for 20 percent of the present discounted value of total benefits at a discount rate of 3 percent, 33 percent at a discount rate of 5 percent, and 64 percent at a discount rate of 10 percent. Figure 1 shows a similar perspective on the differences in the shares of total estimated present discounted value attributable to individual benefits for six different discount rates. (The figure does not indicate that the totals change, only the changes in shares.)

Changes in Estimates of Individual Benefits

Benefits will vary with country-specific conditions. For example, a greater share of babies born in hospitals and higher costs of medical care will increase the benefit from reduced neonatal care, while higher average productivity will increase the benefits from productivity gains. To illustrate the implications of these uncertainties and the differences across countries, simulations were conducted starting with the base estimates with a 5 percent discount rate but increasing each of the seven benefits in turn by 50 percent (table 2). For example, the simulations show what would happen if the probability of infant mortality fell by 0.117 instead of by 0.078.

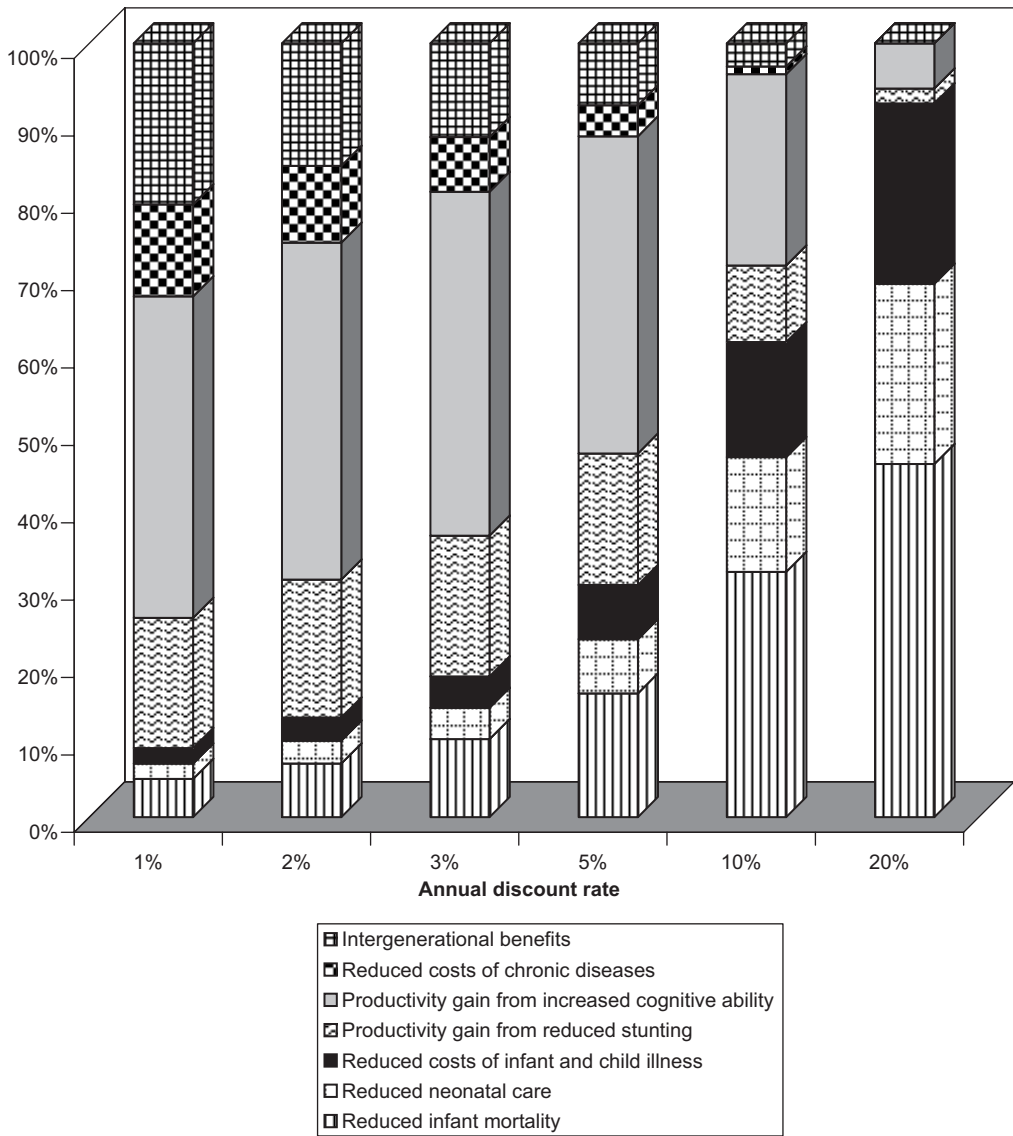
The total present discounted value of benefits increases from the base estimate of \$510 to \$517 for reduced chronic illnesses to \$612 for the productivity effects of increased cognitive ability. Thus under each of these alternatives, somewhat higher cost interventions would be warranted. These simulations also illustrate that it is much more important to pin down some of the benefits than others. With a 5 percent discount rate it would be more important to lessen the uncertainty about impacts on economic productivity and then on the costs of illness and death early in life than about the costs and probabilities of chronic diseases. With a higher discount rate, the value of improved estimates would shift somewhat toward events earlier in the life cycle, while with a lower discount rate the shift would be toward events later in the life cycle.

Any of the assumptions used in the estimates could be varied to explore the effects of variations in the core assumptions in a manner parallel to that illustrated here, including reducing rather than increasing assumed benefits.

Linking to Interventions Related to Low Birth Weight

One practical use of the benefits estimated here would be to adapt the cost structure to a particular environment and compare the expected discounted benefit with the cost of an intervention per low birth weight prevented. While this article does not

Figure 1. Composition of Total Present Discounted Values by Seven Classes of Benefits from Moving One Infant Out of Low Birth Weight Status, at Different Discount Rates



Source: Authors' analysis based on data and assumptions described in the text.

attempt to derive consensus estimates of the costs of different interventions, it is nonetheless useful to consider some illustrative examples.

Many interventions have been proposed to address low-birth-weight problems (Meriardi and others 2003; Steketee 2003; Alderman and Behrman 2004), including

Table 2. Impact of Increasing Each Benefit One at a Time by 50 Percent Relative to Estimates in Table 1, at 5 Percent Discount Rate (U.S. dollars)

<i>Benefits</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>
1. Reduced infant mortality	139	93	93	93	93	93	93
2. Reduced neonatal care	42	63	42	42	42	42	42
3. Reduced costs of infant and child illness	35	35	53	35	35	35	35
4. Productivity gain from reduced stunting	85	85	85	128	85	85	85
5. Productivity gain from increased cognitive ability	205	205	205	205	308	205	205
6. Reduced costs of chronic diseases	15	15	15	15	15	23	15
7. Intergenerational benefits	35	35	35	35	35	35	53
Total	556	531	528	552	612	517	527
Share of total in table 1 at 5 percent discount rate (percent)	109	104	103	108	120	101	103

Source: Authors' analysis based on data and assumptions described in the text.

antimicrobial treatments, antiparasitic treatments, insecticide-treated bednets, maternal health records to track gestational weight gain, iron and folate supplements, targeted food supplements, and social marketing regarding birth spacing and timing of marriage.

While some recommended interventions focus solely on low birth weight, some address other goals as well—for example, campaigns against smoking or consumption of other drugs during pregnancy. To assess such interventions, one would ideally sum the expected present discounted value of all anticipated outcomes. In reality, most lists of possible interventions provide little guidance on priorities, either for using scarce public resources for the general purpose of alleviating problems related to low birth weight or for deciding which interventions have relatively high returns in which situations. This lack of clearly defined priorities likely reduces the influence of advocates of using scarce public resources to alleviate problems related to low birth weight. And it also likely impedes agreement among advocates on how to use any additional public resources for treating low birth weight problems.

Under the assumptions used to construct the estimates in table 1, any intervention that costs less than \$510 per case of low birth weight averted in a low-income country is a suitable candidate in terms of a benefit to cost ratio greater than 1.¹¹ Rouse (2003) presents a brief review of the cost-effectiveness of interventions to prevent adverse pregnancy outcomes, including low birth weight. He indicates, for example, that it costs \$46 per case of low birth weight averted with treatments for asymptomatic sexually transmitted bacterial infections, where these are prevalent. Even taking into account the costs of raising revenue for such an intervention, costs of this magnitude are far lower than the benefits summarized in table 1.

As another example, consider an extensive field trial of supplementation with iron and folate in a community in Nepal where rates of low birth weight and anemia are

both high. Christian and others (2003) found that 11 women would need to be reached with the micronutrient supplements to prevent one case of low birth weight. While no cost data were provided in the published study, Christian and West (2003) in a personal communication estimated that the costs of the experimental program of \$64 per pregnant woman reached could be reduced to \$13 in an ongoing program. With just 1 in 11 births benefiting directly in terms of a case of low birth weight averted, the initial cost does not represent an economically efficient intervention. However, if at least one-third of the estimated cost reduction for an ongoing program can be realized, the intervention would be economically efficient. Moreover, economies of scope would allow the provision of vitamin A supplementation at little marginal cost and thus might reduce both infant and maternal mortality.

Concluding Comments

This review demonstrates that the economic benefits from reducing the incidence of low birth weight in low-income countries may be fairly substantial. Under plausible assumptions each infant moved out of low birth weight status would result in \$510 in benefits. Thus there may be many interventions that are warranted purely on the grounds of saving resources or increasing productivity. With a 5 percent discount rate, the gains are estimated to come primarily from increases in labor productivity (partly through more education), with the gains from avoiding costs due to infant illness and death second in importance. The beneficiaries of these gains are largely people who would otherwise be poor. If the appropriate discount rate is higher than 5 percent, then the relative gains from reduced illness and death in infancy would increase while those from increased productivity would decline.

In contrast, the estimated gains from reducing chronic diseases, a topic of considerable interest in recent years, are comparatively small for any reasonable discount rate. That is so because the gains—even if large when realized—occur decades after any resource-using interventions that might reduce the incidence of low birth weight.

Still, much remains unknown or poorly known. Better estimates are needed of the individual effects, particularly those that are relatively large for reasonable discount rates (those related directly to productivity and to early life-cycle benefits), and of the discount rates themselves. There would also be gains from understanding more about the impacts of incremental changes in birth weight rather than just the standard dichotomy of low birth weight (below 2,500 g) or not.

While improving birth weights clearly contributes to equity—low birth weight babies are concentrated among low-income households, and poor health is a facet of any multidimensional view of poverty—not enough is known about the efficiency rationale for public investments. Estimates that distinguish private and social gains

from reducing the incidence of low birth weight could help in assessing the efficiency case for public subsidies. Also helpful would be more information on the market failures that prevent private individuals from capturing all or some of the potential returns. A priori it would appear that the positive externalities from reducing the incidence of low birth weight—and therefore the potential efficiency gains—vary considerably across the impacts considered here. Reducing infant and childhood infectious diseases seems to have relatively high externalities. Similarly, large positive externalities are often claimed for learning, and so there should be gains to increasing cognitive skills. But despite such claims, little is known about the magnitudes of these possible externalities.

These and other improvements in knowledge would strengthen the informational basis for making policies related to low birth weight. The estimates presented here based on available information suggest that reducing the incidence of low birth weight in low-income countries might well provide substantial economic gains.

Notes

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1. This type of intervention has proven effective even among nonanemic African-American women in the United States (Cogswell and others 2003).

2. The study provides estimates of the intergenerational impacts of low birth weight. While there are preliminary estimates from the study that also indicate significant impacts from a nutritional intervention for a poor population 6–24 months old on earnings at 25–42 years old, the impact of low birth weight on this cohort has not yet been analyzed.

3. See Behrman and Rosenzweig (2004) for a discussion on whether estimates from twins can be generalized to broader populations.

4. This adjustment for survival probabilities was not used in a previous version of this study (Alderman and Behrman 2004), and thus the estimated benefits in the current study are slightly lower (about 10 percent) than without the adjustments.

5. The midpoint of the neonatal death rate (30.1) is assumed to be the weighted average of low birth weight and normal-birth-weight infants. All low birth weights are assumed to be in the 2,000–2,499 g range and all normal birth weights in the 2,500–2,999 g range. Given the fourfold greater risk of neonatal death for the low birth weight babies, this implies a neonatal mortality rate of 61.0 for low birth weight infants and 15.2 for normal-birth-weight infants, so the difference is 45.8 or a probability of 0.046. A parallel calculation for the twofold greater risk of post-neonatal death among neonatal survivors with an overall mortality rate at the midpoint of 42.7 and a midpoint of the birth weight range of 32.5 implies that the post-neonatal mortality rate is 64.4 for low birth weight infants and 32.2 for normal-birth-weight infants, so the difference is 32.2 or a probability of 0.032. Together these calculations

imply that a shift from low birth weight to normal-birth-weight status reduces the probability of mortality in such a population by about 0.078.

6. The authors are indebted to Dr Mohammed Shahjahan of the Micronutrient Initiative and former Medical Director of Save the Children Foundation's Children's Nutrition Unit in Dhaka for this information.

7. Additional results covering Chile, Colombia, and Ghana are reviewed in Alderman and Behrman (2004).

8. Small for gestational age is not identical to intrauterine growth retardation, but intrauterine growth retardation is often used as a proxy for small for gestational age when gestational age is not known precisely.

9. The reasoning behind this approximation is as follows. For the stereotypical low-income developing country, about 10 percent of adult deaths are considered to be due to these diseases under the assumption that the eventual share of deaths from these causes will be the same as the annual share of deaths. About 15 percent of the adult population is assumed to have been of low birth weight (much higher than in China and many low-income countries, but lower than in many low-income countries in South Asia and Sub-Saharan Africa), and the odds ratio of having these chronic diseases is twice as high for those who were low birth weight as for those who were not. Then let X be the probability of having these chronic diseases for normal-birth-weight babies (and $2X$ for low birth weight babies), where $X = 8.7$ percent is the solution to $10 \text{ percent} = 0.85X + 0.15(2X)$. Since the odds ratio for adults who were low birth weight babies is twice that for adults who were not, the reduction in the probability of having these chronic diseases by moving a baby from low birth weight to normal-birth-weight status is 0.087.

10. The impact of reduced schooling or lower cognitive ability on nutrition in the second generation is not included, although the impact of schooling on nutrition is well known, and recent evidence confirms the impact of cognitive ability as well (Rubalcava and Teruel 2004).

11. As costs and benefits occur in the same locality, exchange rates and purchasing power parity essentially net out in the estimates of benefit–cost ratios.

References

- Alderman, Harold, Jere Behrman, David Ross, and Richard Sabot. 1996. "The Returns to Endogenous Human Capital in Pakistan's Rural Wage Labor Market." *Oxford Bulletin of Economics and Statistics* 58(1):29–55.
- Alderman, Harold, John Hoddinott, and Bill Kinsey. Forthcoming. "Long Term Consequences of Early Childhood Malnutrition." *Oxford Economic Papers*.
- Alderman, Harold, and Jere Behrman. 2004. "Estimated Economic Benefits of Reducing Low Birth Weight in Low-Income Countries." HNP Discussion Paper. World Bank, Washington, D.C.
- Allen, Lindsay, and Stuart Gillespie. 2001. "What Works? A Review of Efficacy and Effectiveness of Nutrition Interventions." Nutrition and Development Series 5. Asian Development Bank, Manila.
- Altonji, Joseph, and Thomas Dunn. 1996. "The Effects of Family Characteristics on the Returns to Education." *Review of Economics and Statistics* 78(4):692–704.
- Ashworth, A. 1998. "Effects of Intrauterine Growth Retardation on Mortality and Morbidity in Infants in Young Children." *European Journal of Clinical Nutrition* 52(81):S34–42.
- Aylward, Glen. 2003. "Cognitive Function in Preterm Infants: No Simple Answers." *Journal of the American Medical Association* 289(6):747–50.
- Barker, D. J. P. 1998. *Mothers, Babies, and Health in Later Life*, 2nd ed. London: Churchill Livingstone.

- Barros, F. C., S. R. Huttly, C. G. Victora, B. R. Kirkwood, and J. P. Vaughan. 1992. "Comparisons of Causes and Consequences of Prematurity and Interuterine Growth Retardation: A Longitudinal Study in Southern Brazil." *Pediatrics* 90(2):238–44.
- Behrman, Jere, and Mark Rosenzweig. 2004. "The Returns to Birth Weight." *Review of Economics and Statistics* 86(2):586–601.
- Bhutta, Adnan, Mario Cleves, Patrick Casey, Mary Cradock, and K. J. Anand. 2002. "Cognitive and Behavioral Outcomes of School-Aged Children Who Were Born Preterm." *Journal of the American Medical Association* 288(6):728–37.
- Black, Sandra, Paul Devereux, and Kjell Salvanes. 2005. "From the Cradle to the Labor Market? The Effect of Birth Weight on Adult Outcomes." University of California, LA.
- Boissiere, Maurice, John B. Knight, and Richard H. Sabot. 1985. "Earnings, Schooling, Ability, and Cognitive Skills." *American Economic Review* 75(5):1016–30.
- Cawley, John, James Heckman, and Edward Vytlačil. 2001. "Three Observations on Wages and Measured Cognitive Ability." *Labor Economics* 8(4):419–42.
- Christian, Parul, Subarna Khatry, Joanne Katz, Elizabeth Pardhan, Steven LeClerq, Sharada Shrestha, Ramesh Adhikari, Alfred Sommer, and Keith West. 2003. "Effects of Alternative Maternal Micronutrient Supplements on Low Birth Weight in Rural Nepal: Double Blind Randomised Community Trial." *British Medical Journal* 326(7389):571–4.
- Cogswell, Mary E., Ibrahim Parvanta, Liza Ickes, Ray Yip, and Gary M. Brittenham. 2003. "Iron Supplementation during Pregnancy, Anemia, and Birth Weight: A Randomized Controlled Trial." *American Journal of Clinical Nutrition* 78(4):773–81.
- Conley, Dalton, Kate Strully, and Neil Bennett. 2003. "A Pound of Flesh or Just Proxy? Using Twin Differences to Estimate the Effects of Birth Weight on (Literal) Life Chances." NBER Working Paper 9901. National Bureau of Economic Research, Cambridge, MA.
- Conley, Dalton, and Neil G. Bennett. 2000. "Is Biology Destiny? Birth Weight and Life Chances." *American Sociological Review* 65(3):458–67.
- Grantham-McGregor, S., L. Fernald, and K. Sethuraman. 1999. "Effects of Health and Nutrition on Cognitive and Behavioural Development in Children in the First Three Years of Life. Part 1. Low Birth Weight, Breastfeeding, and Protein-Energy Malnutrition." *Food and Nutrition Bulletin* 20(1):53–75.
- Horton, Susan. 1999. "Opportunities for Investments in Nutrition in Low-Income Asia." *Asian Development Review* 17(1&2):246–73.
- Horton, Susan, and Jay Ross. 2003. "The Economics of Iron Deficiency." *Food Policy* 28(1):51–75.
- Jamison, D., H. Mosley, A. Measham, and J. Bobadilla, eds. 1993. *Disease Control Priorities in Developing Countries*. Oxford: Oxford University Press. Available online at www.fic.nih.gov/dcpp/dcp2.html.
- Jefferis, Barbara, Chris Power, and Clyde Hertzman. 2002. "Birth Weight, Childhood Socioeconomic Environment, and Cognitive Development in the 1958 British Birth Cohort Study." *British Medical Journal* 325(7359):305–8.
- Knowles, James, and Jere R. Behrman. 2003. "Assessing the Economic Returns to Investing in Youth in Developing Countries." World Bank, Human Development Network, Washington, D.C.
- Kramer, M. 1998. "Socioeconomic Determinants of Intrauterine Growth Retardation." *European Journal of Clinical Nutrition* 52(81):S29–33.
- Kristensen, Petter, Tor Bjerkedal, and Lorentz Irgens. 2004. "Birthweight and Work Participation in Adulthood." *International Journal of Epidemiology* 33(4):849–56.
- Lewit, E., L. Baker, H. Corman, and P. Shiono. 1995. "The Direct Costs of Low Birth Weight." *Future of Children* 5(1):35–56.

- Li, Haojie, Aryeh Stein, Huiman Barhhart, Usha Ramakrishnan, and Reynaldo Martorell. 2003. "Associations between Prenatal and Postnatal Growth and Adult Body Size and Composition." *American Journal of Clinical Nutrition* 77(6):1498–505.
- Maluccio, John A., John Hoddinott, Jere R. Behrman, Agnes Quisumbing, Reynaldo Martorell, and Aryeh D. Stein. 2005. "The Impact of an Experimental Nutritional Intervention in Childhood on Education among Guatemalan Adults." Philadelphia, Washington, D.C. and Atlanta: University of Pennsylvania, International Food Policy Research Institute and Emory University.
- Matte, T., M. Bresnahan, M. Begg, and E. Susser. 2001. "Influence of Variation in Birth Weight within Normal Range and within Sibships on IQ at Age 7 Years: Cohort Study." *British Medical Journal* 323(7308):310–4.
- Ment, Laura, Betty Vohr, Walther Allan, Karol Katz, Karen Schneider, Michael Westerveld, Charles Duncan, and Robert Makuch. 2003. "Change in Cognitive Function over Time in Very Low Birth Weight Infants." *Journal of the American Medical Association* 289(6):705–11.
- Merialdi, Mario, Guillermo Carroli, Jose Villar, Edgardo Abalos, Metin Gulmezoglu, Regina Kulier, and Mercedes de Onis. 2003. "Nutritional Interventions during Pregnancy for the Prevention or Treatment of Impaired Fetal Growth: An Overview of Randomized Controlled Trials." *Journal of Nutrition* 133(5):S1626–31.
- Petrou, Stavros, T. Sach, and L. Davidson. 2001. "The Long-term Costs of Preterm Birth and Low Birth Weight: Results of a Systematic Review." *Child Care, Health, and Development* 27(2):97–115.
- Popkin, Barry, Susan Horton, and Soowon Kim. 2001. "The Nutritional Transition and Diet-Related Chronic Disease in Asia: Implications for Prevention." FCND Discussion Paper 105. International Food Policy Research Institute, Washington, D.C.
- Ramakrishnan, U., R. Martorell, D. Schroeder, and R. Flores. 1999. "Intergenerational Effects on Linear Growth." *Journal of Nutrition* 129(2):544–9.
- Richards, M., R. Hardy, D. Kuh, and M. Wadsworth. 2002. "Birth Weight, Postnatal Growth, and Cognitive Function in a National UK Birth Cohort." *International Journal of Epidemiology* 31(2):342–8.
- Rouse, Dwight. 2003. "Potential Cost-Effectiveness of Nutrition Interventions to Prevent Adverse Pregnancy Outcomes in the Developing World." *Journal of Nutrition* 133(5):S1640–44.
- Rubalcava, Luis, and Graciela Teruel. 2004. "The Role of Maternal Schooling, Cognitive Ability, and Public Determinants on Child Health." *Economics and Human Biology* 2(3):439–56.
- Sorensen, H., S. Sabro, J. Olsen, K. Rothman, M. Gillman, and P. Fischer. 1997. "Birth Weight and Cognitive Function in Young Adult Life: Historical Cohort Study." *British Medical Journal* 315(7133):401–3.
- St. Clair, David, and others. 2005. "Rates of Adult Schizophrenia Following Prenatal Exposure to the Chinese Famine of 1959–1961." *Journal of the American Medical Association* 294(5):557–62.
- Steketee, Richard. 2003. "Pregnancy, Nutrition, and Parasitic Disease." *Journal of Nutrition* 133(5):S1661–67.
- Strauss, John, and Duncan Thomas. 1998. "Health, Nutrition, and Economic Development." *Journal of Economic Literature* 36(2):766–817.
- Strauss, Richard, S. 2000. "Adult Functional Outcome of Those Born Small for Gestational Age." *Journal of the American Medical Association* 283(5):625–32.
- Summers, Lawrence H. 1994. "Investing in All the People: Educating Women in Developing Countries." EDI Seminar Paper 45. World Bank, Economic Development Institute, Washington, D.C.
- Thomas, Duncan, and John Strauss. 1997. "Health and Wages: Evidence on Men and Women in Urban Brazil." *Journal of Econometrics* 77(1):159–87.
- UN SCN (United Nations System Sub-Committee on Nutrition). 2004. *5th Report on the World Nutrition Situation: Nutrition for Improved Development Outcomes*. New York.

- Verhoeff, F. H., B. J. Brabin, S. van Buuren, L. Chimsuku, P. Kazembe, J. M. Wit, and R. L. Broadhead. 2001. "An Analysis of Intra-uterine Growth Retardation in Rural Malawi." *European Journal of Clinical Nutrition* 55(8):682–9.
- Victora, Cesar, Betty Kirkwood, Ann Ashworth, Robert Black, Stephen Rogers, Sunil Sazawal, Harry Campbell, and Sandy Gore. 1999. "Potential Interventions for the Prevention of Childhood Pneumonia in Developing Countries: Improving Nutrition." *American Journal of Clinical Nutrition* 70(3):309–20.
- Villar, J., and J. M. Belizán. 1982. "The Relative Contribution of Prematurity and Fetal Growth Retardation to Low Birth Weight in Developing and Developed Societies." *American Journal of Obstetrics and Gynecology* 143(7):793–8.