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The Technology of Birth: Is It Worth It?

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Executive Summary

We evaluate the costs and benefits of increased medical spending for low-birthweight infants. Lifetime spending on low-birthweight babies increased by roughly $40,000 per birth between 1950 and 1990. The health improvements resulting from this have been substantial. Infant mortality rates fell by 72 percent over this time period, largely due to improved care for premature births. Considering both length and quality of life, we estimate the rate of return for care of low-birthweight infants at over 500 percent. Although prenatal care and influenza shots are more cost-effective than neonatal care, it is significantly more cost-effective than other recent innovations, such as coronary artery bypass surgery, treatment of severe hypertension, or routine Pap smears for women aged 20 to 74. We conclude that the answer to the question posed in this paper is a resounding yes.

I. Introduction

Is medical technology worth it? Perhaps no question is as central in evaluating the medical care system as this one. We know, on the one hand, that medical technology is quite costly. The average person in 1996 spent $3,759 on medical care per year; a half century ago, the amount was $3,200 less (in real terms).[1] Most of this enormous increase—4 percent per year—is a result of medical technology changes (Newhouse 1992). We also know that people live longer and enjoy better health than they used to. Half a century ago, life expectancy at birth was sixty-eight years; today it is near eighty years. Also, chronic disability rates are falling (Manton et al. 1997; Costa 1998). Thus, it seems like medical technology changes may well be worth it.

But combining these facts is difficult. People are healthier for many reasons. Medical technology is certainly one factor. But incomes have improved, and higher-income people have historically lived longer than poor people have. Smoking rates have declined, which will also improve health. And public health improvements such as alcohol restrictions or healthy eating messages have changed individual behavior. How can we tell to what extent medical technology contributes to better health?

In this article, we evaluate the costs and benefits of medical technology changes for one particular type of medical technology—care for low-birthweight infants. We focus on low-birthweight infants for several reasons. First, low birthweight is extremely expensive. A neonatal intensive care unit can cost up to $2,200 per day and as much as $131,000 per infant in 1996 dollars.[2] When something costs so much, it is natural to evaluate what the spending buys, particularly in light of the enormous uncertainty about the value of this care. It is a common—although not wholly correct—perception that many children saved at very low birthweight live substantially reduced lives: they experience higher rates of cerebral palsy, deafness, blindness, epilepsy, chronic lung disease, learning disabilities, and attention deficit disorder than normal birthweight infants (Paneth 1995, Lewit et al. 1995). Aside from their own personal suffering, these infants impose a large burden on their family and society.

Second, technology for low-birthweight infants has expanded tremendously. In the first half of the twentieth century, the technology to treat preterm infants consisted primarily of the incubator; the first nursery to have such technology opened in 1922.[3] Ventilators for premature infants were developed in the 1960s. Today, a sophisticated neonatal intensive care unit houses infants in an incubator where the sickest infants breathe with the assistance of a ventilator (better than the 1960 version). Other technologies available to sick infants include phototherapy and exchange blood transfusions for jaundice; intravenous hyperalimentation (the provision of nutrition to critically ill infants); and machines to monitor blood gases, heart rate and rhythm, breathing rate, and blood pressure. Infants sometimes receive diagnostic techniques such as CT scans and cardiac catheterization. Intravenous tubes deliver medication and fluids to these infants. The staff involved in a neonatal nursery can include up to fifty neonatal nurses, as many as ten physicians and one to two social workers.

This innovation in neonatal care has come at a cost. In 1949, spending for low-birthweight infants likely averaged less than for normal birthweight infants because nothing major could be done for them and death was relatively cheap. Today, costs for low-birthweight infants substantially exceed those for normal birthweight infants—by ten to twenty times. As a result of this technological change, the cost of infant care has increased substantially and more rapidly than the cost of health services on average. Our earlier work (Cutler and Meara 1998) shows that spending for infants increased by 4.2 percentage points per year more rapidly than spending for the average middle-aged adult in the past forty years. The vast bulk of this differential spending increase appears attributable to the costs of caring for premature infants.

The third reason for studying neonatal care is that it is possible to know in some detail the effect of medical technology on outcomes. Conditional on birthweight, essentially all changes in neonatal survival are due to increasing technology. By focusing on birthweight-specific survival, we can therefore construct an extremely accurate estimate of the effect of medical technology changes on outcomes. This accuracy is in contrast to many other conditions, for example, in the elderly, where it is difficult to separate the effects of medical care on outcomes from the effects of public health measures, behavioral changes, or socioeconomic status.

We review available literature on the care of low-birthweight infants and examine both national vital statistics data and data on low-birthweight infants in Massachusetts to understand the costs and benefits of medical technology changes. We estimate that low-birthweight infants cost about $39,000 more per birth in 1990 than in 1960. As a result of this spending, an additional 12 percent of low-birthweight infants survive, at what will likely be a reasonably healthy—if not disability-free—life.

We evaluate this social trade-off in several ways. First, we attach a value to additional years of life and estimate the rate of return to spending on low-birthweight infants. Using a consensus estimate from the literature (a year of life in perfect health is worth $100,000; see Cutler and Richardson 1997, 1998, 1999), we find a striking rate of return to increased medical spending on low-birthweight infants—510 percent.

We also compare this return to estimates for other medical interventions. We find that the benefits from this care compare favorably to other types of medical spending, for example, coronary artery bypass surgery in the elderly. Estimates of enhanced prenatal care suggest a potentially greater efficacy of that intervention—in some cases, cost reductions—but such gains may not always be achievable. In total, our calculations suggest a clear bottom line: while we spend a lot more on care for low-birthweight infants than we used to, we receive a lot more in return.

One should distinguish our estimates of the return to increased spending over time from recent analyses that estimate the return to increased spending across regions (see, for example, Skinner and Wennberg in this volume). It is possible that increased spending over time is worth it, while additional spending at a point in time delivers little measurable benefit. In our analysis, we are measuring the average gain to society of spending on new technologies for critically ill neonates. In cross-sectional analyses, authors estimate how the marginal benefit of intensive medical treatment changes as that treatment is applied to additional individuals. For example, our findings suggest that the introduction of neonatal intensive care has yielded high returns, but this result is consistent with a case where expanding intensive care for newborns is not worth it.

In the next section, we begin by discussing how one can estimate the rate of return to medical technology. In the third section, we discuss changes in outcomes for low-birthweight infants over time and the medical changes that have likely led to this increased survival. The fourth and fifth sections estimate the costs and benefits of this technology. These estimates are combined into a rate of return calculation in Section VI. The last section presents our conclusions.

II. Evaluating the Worth of Medical Technology

Before discussing the specifics of care for premature infants, we detail the more general problem of estimating the costs and benefits of medical technology changes. Changes in medical technology affect the cost of medical care and the benefits that the medical care provides. Table 2.1 details the costs and benefits of general changes in medical treatments.

The first cost is the cost of the initial treatment itself—in the case of premature infants, the cost during the birth episode.[4] In addition, downstream costs are provided over the person's remaining life. In the case of care for low-birthweight infants, these costs may be large if the children saved at birth are at increased risk of future physical and developmental complications. In other circumstances, for example, in analyzing preventive medications, there might be downstream savings from incurring costs up front.

Table 2.1
Analysis of medical technology changes

Costs	Benefits
Birth costs	Value of being alive
Subsequent medical costs	
Costs of living	

A third cost includes the normal costs of sustaining a person over her or his lifetime—food, clothing, shelter, etc. These costs are relevant for interventions that extend life. Even though these costs are not medical, they need to be included in calculating the costs of a medical intervention that prolongs life because saving a low-birthweight infant commits society to these future costs. Similarly, the benefits a person provides to society should also be included in the valuation of medical spending (Meltzer, 1997).

Using a discount rate r, we express the present value of the cost of saving low-birthweight infants as:

$$PDV\ (\text{cost}) = \sum_{t=0} (1+r)^{-t} M_t + \sum_{t=0} (1+r)^{-t} L_t \tag{2.1}$$

where we have separated the medical (M) and nonmedical (L) costs for reasons that will be clear shortly.

The benefits of medical care are the increase in quality-adjusted life that it affords and the fact that it keeps people who will provide more to society alive longer. There may also be some spillovers of medical technology to other fields, but these spillover benefits are difficult to evaluate.[5] We denote the contribution an individual will make to society in year t as w_t, with present value defined as above.

To quantify the health benefits of medical technology, we use a framework of *health capital* (Grossman 1972; Cutler and Richardson 1997, 1998, 1999). We assume that years of life can be measured on a quality-adjusted scale. The lowest quality of life is death, which we define as quality of zero. We define perfect health as quality of one. Living with various conditions falls between death and perfect health. We denote the expected quality of life for a person in year t as q_t. The (discounted) value of quality-adjusted life years is:

$$\text{QALYs} = \sum_{t=0} (1+r)^{-t} q_t \tag{2.2}$$

The cost-effectiveness ratio is typically defined as the increment to quality of life from a given amount of medical spending:

$$\text{Cost-effectiveness} = \Delta(\text{QALY}) \,/\, \Delta(\text{medical spending}) \qquad (2.3)$$

Using only medical spending, and not total spending, is not appropriate theoretically. But it is an approximation to a rate of return calculation for medical care in this case.

To see this approximation we need to form the net benefits of medical treatment changes—the dollar value of health benefits minus their cost. Such a calculation requires valuing the health improvement from medical care in dollars. We denote the value of a year in perfect health as *V*. It is important to note that *V* is the social value of life. This variable does not include what a person will earn—that amount is included separately.[6] We express the net benefits as:

$$\begin{aligned}\text{Net benefit} &= \sum_{t=0} (1+r)^{-t} V q_t \\ &\quad - \left[\sum_{t=0} (1+r)^{-t} M_t + \sum_{t=0} (1+r)^{-t} (L_t - w_t) \right] \qquad (2.4)\end{aligned}$$

The last term in equation (2.4) is the net contribution of an individual to society—the value of what they contribute minus what they consume. Using the life-cycle model as a rough approximation, we assume that, for infants without severe problems, this term is equal to zero—infants will consume as much as they produce over the course of their lives.[7] For infants with severe health problems, the second term in equation (2.4) will be positive on net. Therefore, we include nonmedical costs in our rate of return calculation.

We can then estimate the rate of return to medical technology using the health benefits and costs (current and future) of that technology:

$$\text{Rate of return} = \frac{\sum_{t=0} (1+r)^{-t} V q_t}{\sum_{t=0} (1+r)^{-t} (M_t + L_t - w_t)} - 1 \qquad (2.5)$$

For individuals without severe health problems or disabilities, we assume that the $L_t - w_t$ terms cancel each other and the denominator is simply medical spending. For people with disabilities, we assume that there are additional costs of living that we account for separately.

To implement this equation, we need to measure several items: the current and future medical costs for treatment of the condition under consideration, *M*; the quality of life resulting from medical treatments q; the value of a year of life to society, V; the net costs of living for disabled individuals, $L - w$; and the discount rate, r. We discuss below in some depth how we figure each of these variables for low-birthweight infants. We start by analyzing trends in infant survival and the role of medical technology in those trends.

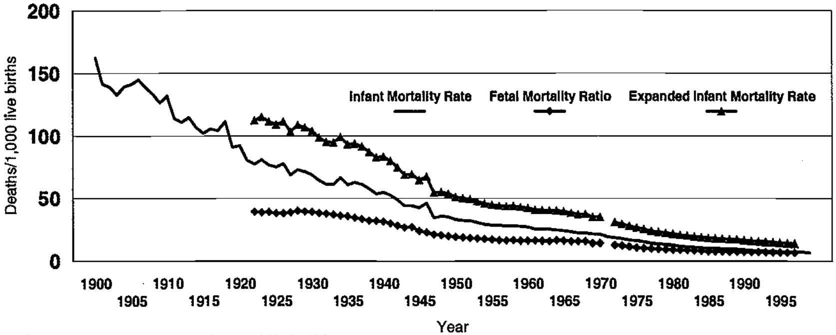
III. Birthweight and Survival

Infant mortality has declined dramatically this century. Figure 2.1 shows trends in infant mortality—death in the first year of life—in the twentieth century.[8] In 1900, infant mortality was 16 percent. The magnitude of this number is staggering; it implies, for example, that half of women finishing their childbearing years at the turn of the century bore a child who died in infancy. By 1996, infant mortality was about 1 percent, a nearly 95 percent decline. In 1996, only 2 percent of women finishing childbearing age currently have had a baby die during infancy.[9]

In fact, even these figures may underestimate the change in infant survival. Neonatal intensive care changes the distribution of pregnancy outcomes between fetal deaths and live births. Aggressive medical intervention implies that some babies who might have been counted as fetal deaths now survive, are counted as live births, but die before one year of age. Adding these infant deaths to total infant deaths will overstate the infant mortality rate, and especially so in later years. To adjust for this, figure 2.1 shows an expanded infant mortality rate equal to the number of fetal deaths plus infant deaths per 1,000 births plus fetal deaths. Expanded infant mortality is declining at roughly the same rate as infant mortality. Thus, the magnitude of the underestimation of gains in infant health is small.

Figures 2.2 and 2.3 highlight how gains in infant health differ by decade. Infant mortality declined by seven or eight deaths per thousand in the 1950s, 1960s, and 1970s. Gains in infant health continued throughout the 1980s and 1990s but at a slower pace. Figure 2.3 reveals that the 1970s is the decade with the most rapid percentage decline in both infant and fetal deaths.

Changes in infant mortality can result from many factors, and medical care for low-birthweight infants is only one. Medical care in the prenatal period may also increase infant survival, for example, by increasing maternal weight gain or ensuring an adequate diet. Public health measures such as clean water and sanitation, economic variables



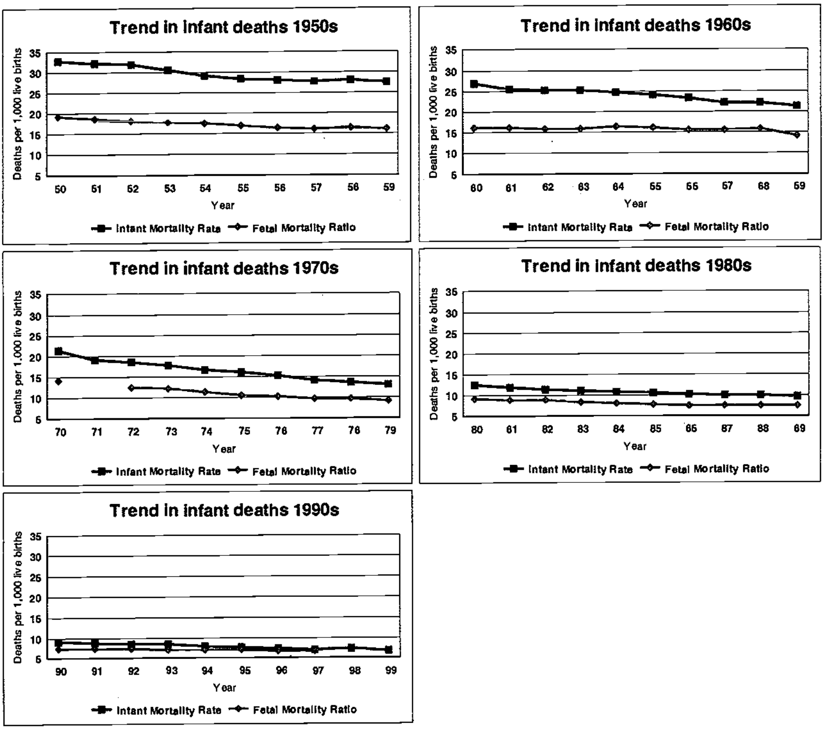
Infant mortality rate = Deaths <1 year of age per 1,000 live births
Fetal mortality ratio = Fetal deaths per 1,000 live births
Expanded infant mortality = (Infant+Fetal Deaths)/(1000 Live Births+Fetal Deaths)

Figure 2.1
Infant mortality rates and fetal mortality ratios since 1900

such as income and education, and behavioral variables such as smoking and drinking will also affect infant health.

In the case of neonatal mortality, or death within the first twenty-eight days of life, there is a natural way to control for these factors. Conditional on birthweight, the overwhelming factor influencing survival for low-birthweight babies is medical care in the immediate postbirth period (Paneth 1995, Williams and Chen 1982). In essence, infant health is a condition for which there are accurate risk adjusters—the birthweight and gestational age of the infant. Table 2.2 illustrates how birthweight allows one to adjust for nonmedical factors by showing simple linear probability models of neonatal mortality on nonmedical factors. Factors such as education, maternal race, smoking, and marital status have a strong relationship with neonatal mortality, as shown in the first two columns. However, conditional on birth weight, these factors diminish greatly in importance and become statistically insignificant in many cases. A comparison of R^2 values in these two regressions supports the notion that any nonmedical factor affecting neonatal mortality is reflected in birthweight. The R^2 on the regression without birthweight is .03 compared with an R^2 of .325 when controlling for birthweight.

Thus, the effects of medical care on infant health can be isolated by making survival conditional on birthweight. Figures 2.4 and 2.5 and tables 2.3 and 2.4 display trends in birthweight-specific neonatal mortality over time; background on the birthweight distribution over time for the United States and Massachusetts is shown in tables 2.5 and 2.6, respectively. Table 2.3 and figure 2.4 show national data on



Infant mortality rate = Deaths < 1 year of age per 1,000 live births
Fetal Mortality ratio = Fetal deaths per 1,000 live births
Data on infant deaths not available in 1971.

Figure 2.2
Trends in infant deaths by decade, 1950–99
Note: Data on infant deaths not available in 1971. Vertical axis in each graph equals "number of infant deaths per 1,000 live births."

birthweight-specific infant mortality rates from 1950, 1960, 1985, and 1990. Table 2.4 and figure 2.5 show Massachusetts vital statistics data for various years between 1972 and 1994. In both cases, the data omit fetal death rates, thus biasing toward zero the estimated decline in infant mortality rates at the lowest birthweights.

Figure 2.4 and table 2.3 show a remarkable change. The largest declines in infant mortality are for low-birthweight infants. Between 1950 and 1990, infant mortality rates for very low birthweight infants (<1500 grams) fell almost 2 percentage points per year, or 42 percent in total. Mortality for low-birthweight infants (1500–2500 grams) declined much more slowly, by about one-third percentage point each year, or

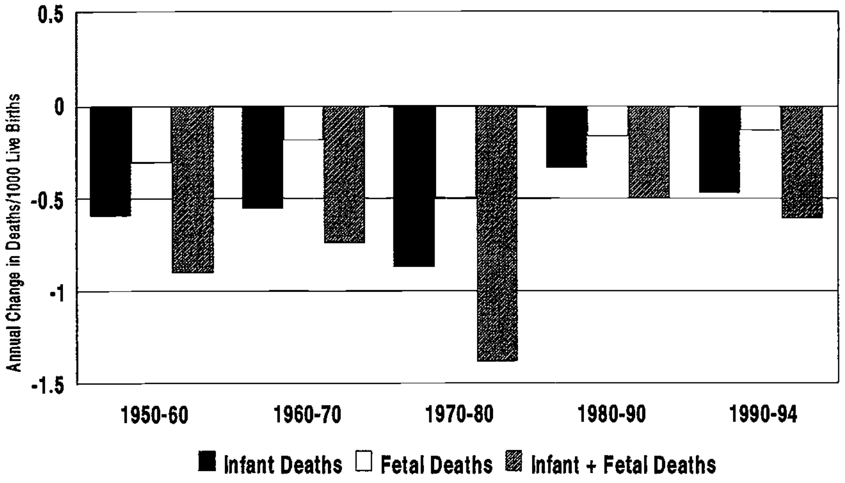


Figure 2.3
Annual changes in deaths per 1,000 live births

7.5 percentage points in total. Mortality for normal birthweight infants fell the least, about 1 percentage point over the period. The Massachusetts data in figure 2.5 and table 2.4 show rapid declines in mortality among the lightest infants during the period from 1972–94.

The figures suggest that changes in survival rates are an important source of improved infant mortality. We can make this formal using a simple decomposition. The neonatal mortality rate is the weighted average of mortality rates for infants in each birthweight group k:

$$P[\text{neonatal death}]_t = \sum_{k=1}^{K} P\,[\text{weight} \in \text{group } k]^{*}\, P[\text{death} \mid k] \qquad (2.6)$$

Changes in neonatal mortality rates can thus be divided into changes in the birthweight distribution and changes in survival conditional on birthweight[10]:

$$\Delta P[\text{neonatal death}] = \sum_{k=1}^{K} \Delta P[\text{weight} \in \text{group } k]^{*}\, \overline{P[\text{death} \mid k]} + \overline{P[\text{weight} \in \text{group } k]}^{*}\, \Delta P[\text{death} \mid k] \qquad (2.7)$$

The first term in equation (2.7) is the change in neonatal deaths due to changes in the birthweight distribution. The second term is the change due to trends in birthweight-specific neonatal death rates, which can be broken out by birthweight.

Table 2.2
The probability of neonatal death and birthweight, U.S. Vital Statistics 1990

	Coefficient	Standard error	Coefficient	Standard error
Mother's age	−0.0007[a]	0.0001	−0.0003[a]	0.0001
Mother's age squared	1.3e-05[a]	1.2e-06	4.1e-06[a]	9.7e-07
Other nonwhite mother	−0.00035	0.0002	−0.0004[a]	0.00020
Black mother	0.0051[a]	0.0001	−0.0007[a]	0.0001
Mother's education				
Some high school	−0.00016	0.0002	−0.0002	0.0002
High school degree	−0.0004	0.0002	−0.0000	0.0002
Some college	−0.0004	0.00024	−0.0002	0.0002
College degree and/or postgraduate work	−0.0007[a]	0.0002	−0.0002	0.0002
Education not stated	0.0031[a]	0.0003	0.0018[a]	0.0003
Single mother?	0.0013[a]	0.0001	−0.0001	0.0001
Prenatal care in second trimester	−0.00161[a]	0.0001	−0.0002[a]	0.0001
Prenatal care in third trimester	−0.00353[a]	0.0002	−0.0001	0.0002
No prenatal care	0.02279[a]	0.0003	0.0037[a]	0.0003
Unknown prenatal care	0.01213[a]	0.0003	0.0025[a]	0.0003
Used alcohol during pregnancy?	0.0008[a]	0.0002	−0.0007[a]	0.0002
Used tobacco during pregnancy?	0.00067[a]	0.0001	−0.0009[a]	0.0001
Birthweight dummies:				
500–999 g			−0.5191[a]	0.0011
1,000–1,499 g			−0.8175[a]	0.0011
1,500–1,999 g			−0.8581[a]	0.0010
2,000–2,499 g			−0.8762[a]	0.0010
2,500–2,999 g			−0.8820[a]	0.0010
3,000–3,499 g			−0.8833[a]	0.0010
3,500–3,999 g			−0.8838[a]	0.0010
4,000–4,499 g			−0.8835[a]	0.0010
5,000–8,165 g			−0.8796[a]	0.0013
Unknown			−0.6240[a]	0.0014
R-squared	0.003		0.325	
Observations	2,982,529		2,982,529	

[a] Indicates p-value < .05.

Dependent variable = 1 if baby died within 28 days of birth. The omitted categories for race, education, prenatal care, and birthweight are: white, 0–8 years education, prenatal care in first trimester, and 0–500 grams, respectively.

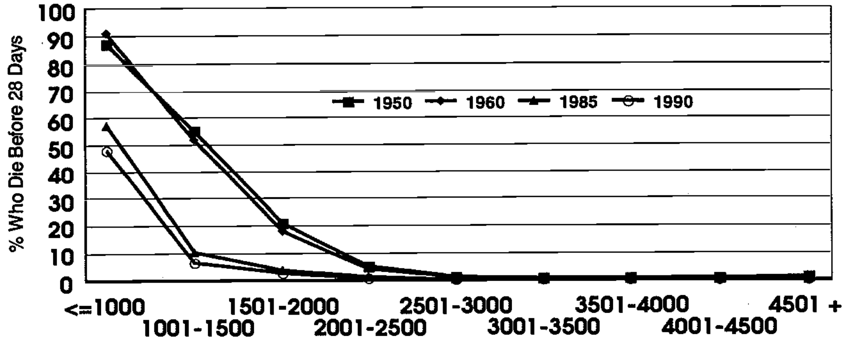


Figure 2.4
Percentage of infants who die within 28 days of birth, United States vital statistics

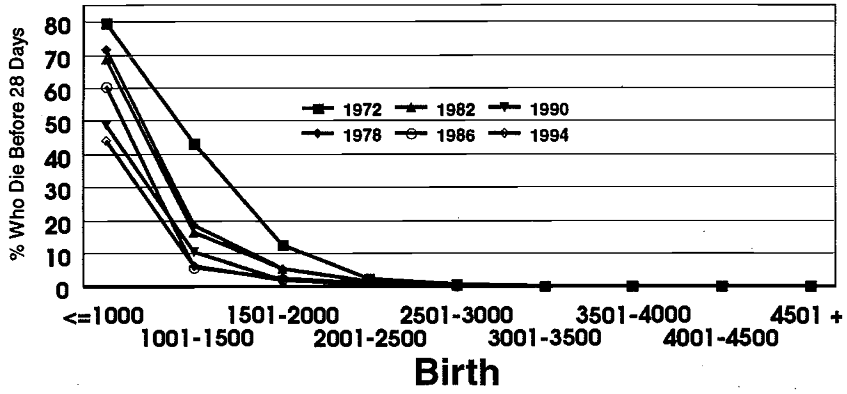


Figure 2.5
Percentage of infants who die within 28 days of birth, Massachusetts vital statistics

Table 2.3
Neonatal deaths in the United States per 100 live births, 1950–90

	1950	1960	1985	1990	Annual percentage change
<1,000 g	87.2	91.3	57.2	48.3	−1.5
1,000–1,499 g	55.1	52.2	10.5	6.7	−5.3
1,500–1,999 g	21.1	18.1	3.4	2.7	−5.2
2,000–2,499 g	5.0	4.1	1.1	0.8	−4.5
2,500–2,999 g	1.3	1.0	0.3	0.2	−4.1
3,000–3,499 g	0.7	0.5	0.2	0.1	−4.4
3,500–3,999 g	0.6	0.4	0.1	0.1	−4.9
4,000–4,499 g	0.8	0.4	0.1	0.1	−5.7
4,500+ g	1.4	0.9	0.3	0.2	−5.4

Sources: 1950–60 data from "A Study of Infant Mortality from Linked Records: Comparison of Neonatal Mortality from Two Cohort Studies, United States, January–March 1950 and 1960." 1985 data from: U.S. Vital Statistics "Linked Birth-Death Files 1985," Chapter 6, table 4. 1990 data based on authors' calculations using linked birth-death files.

Table 2.4
Neonatal deaths per 100 live births in Massachusetts, 1972–94

	1972	1978	1982	1986	1990	1994	Annual percentage change
<1,000 g	79.8	71.7	68.4	60.3	48.7	44.3	−2.7
1,000–1,499 g	43.4	18.4	16.4	5.9	10.4	6.1	−8.9
1,500–1,999 g	12.5	5.4	5.2	2.5	1.8	2.0	−8.4
2,000–2,499 g	2.3	1.5	1.3	1.2	1.0	0.7	−5.4
2,500–2,999 g	0.5	0.4	0.3	0.3	0.2	0.2	−4.2
3,000–3,499 g	0.2	0.1	0.2	0.1	0.1	0.1	−6.5
3,500–3,999 g	0.2	0.1	0.1	0.1	0.1	0.1	−5.9
4,000–4,499 g	0.1	0.1	0.1	0.1	0.1	0.0	−8.7
4,500+ g	0.2	0.2	0.2	0.4	0.1	0.2	−0.1

Sources: Based on authors' calculations using Massachusetts vital statistics data.

Table 2.5
The birthweight distribution in the United States, 1950–1990

	Birthweight distribution (percentage)				Annual percentage change
	1950	1960	1985	1990	
<1,000 g	0.50	0.60	0.60	0.60	0.5
1,000–1,499 g	0.6	0.7	0.6	0.6	0.0
1,500–1,999 g	1.4	1.5	1.3	1.3	−0.2
2,000–2,499 g	4.9	5.1	4.2	4.4	−0.3
2,500–2,999 g	18.1	18.5	15.9	16.1	−0.3
3,000–3,499 g	37.7	38.0	36.7	36.8	−0.1
3,500–3,999 g	27.1	26.8	30.0	29.3	0.2
4,000–4,499 g	7.7	7.5	9.2	9.0	0.4
4,500+ g	2.1	1.5	1.9	1.8	−0.4

Sources: 1950–60 data from "A Study of Infant Mortality from Linked Records: Comparison of Neonatal Mortality from Two Cohort Studies, United States, January–March 1950 and 1960." 1985 data from U.S. Vital Statistics "Linked Birth-Death Files 1985," Chapter 6, table 4. 1990 data based on authors' calculations using linked birth-death files.

Table 2.6
The birthweight distribution in Massachussets, 1972–1994

	Birthweight distribution (percentage)						Annual percentage change
	1972	1978	1982	1986	1990	1994	
≤1,000 g	0.41	0.39	0.42	0.39	0.43	0.44	0.3
1,001–1,500 g	0.4	0.4	0.5	0.4	0.4	0.4	−0.3
1,501–2,000 g	1.1	1.0	0.8	0.9	0.8	0.9	−0.9
2,001–2,500 g	4.2	3.7	3.3	3.1	3.0	3.2	−1.3
2,501–3,000 g	18.3	16.0	14.8	14.2	14.1	14.0	−1.2
3,001–3,500 g	40.0	38.4	37.5	36.0	36.2	36.2	−0.5
3,501–4,000 g	27.1	29.6	31.3	32.1	32.1	32.1	0.8
4,001–4,500 g	7.2	8.7	9.5	10.6	10.9	10.9	1.9
4,501+ g	1.4	1.8	2.0	2.3	2.1	2.0	1.6

Sources: Based on authors' calculations using Massachussets vital statistics data.

Table 2.7
Explaining improvements in neonatal mortality

Measure	United States 1950–90 (percentage)	Massachusetts, 1972–94 (percentage)
Annual change in infant mortality	−3.1	−5.0
Contribution of:		
Change in birthweight distribution	−4.2	4.5
Birthweight-specific survival	107.1	95.4
<1,500 g	35.2	43.3
1,500–2,500 g	31.3	23.9
2,501+ g	40.6	28.1

Table 2.7 shows the relative importance of these two factors in the national and Massachusetts data. As table 2.7 shows, 35 percent of the improvement in national neonatal mortality since 1950 have resulted from reductions in mortality for very low birthweight infants (<1500 g). This improvement is despite the fact that these infants account for just over 1 percent of births. Another 31 percent results from reductions in mortality for other low-birthweight infants (1500–2500 g), who account for only 5.5 percent of births. Thus, two-thirds of the national and Massachusetts reduction in neonatal mortality results from improved survival for the 7 percent lowest birthweight infants. Most of the remainder results from reductions in mortality for the 93 percent of infants born of normal birthweight (>2500 g). Changes in the distribution of births by birthweight over time would actually have increased infant mortality, although this conjecture is somewhat misleading because some formerly fetal deaths are almost certainly now classified as infant mortality at low birthweights.

It is clear that medical technology has been important for improving infant health. Examining neonatal deaths highlights the role of technology because almost all neonatal deaths occur within the hospital, and most of these deaths happen within twenty-four hours of birth.

The Technology of Birth

The improvement in birthweight-specific survival is consistent with the diffusion of technologies for these babies. Table 2.8 outlines some of the major developments in newborn medicine over time. Before 1960, there was little medical treatment for preterm infants. In the 1960s, the first modern neonatal intensive care units began as physicians started to

Table 2.8
Timeline for the history of care for critically ill newborns

1878	First incubator developed in France for regulating temperature of newborn environment.
1922	Julius Hess opened the first fully developed, preterm nursery (incubator station) at Sarah Lawrence Children's Hospital (affiliated with Michael Reese in Chicago).
1960s	First NICUs started. Early attempts at modifying ventilators for tiny infants began. Other innovations to maintain temperature and nutrition of preterm infants. For term babies, obstetric monitoring began in the 1960s.
1970s	There were major improvements in ventilators for preterm infants. Neonatal-perinatal medicine became a board-certified subspecialty of pediatrics in 1975. By 1976, over 125 NICUs existed in North America. By the end of 1970s, the edge of viability was at 1,000 grams, 28–29 weeks. By 1979, the probability that an infant would die in the first year of life given a birth weight of 1,000 grams was .9.
1980s	Major innovations in the late 1980s include: antenatal corticosteroid treatments to speed maturation; tocolytics, or medication for delaying preterm delivery (can be combined with corticosteroids for accelerating antenatal development); high-speed ventilation to deliver more frequent, smaller puffs of air. Clinical trials of surfactant to treat infants with respiratory distress syndrome began.
1990s	Surfactant use approved by FDA. Broader use of corticosteroids, Proliferation of high-frequency ventilation. Pharmaceutical treatments to treat open patent ductus arteriosus. Babies who need surgery to correct defects get the surgery faster due to better coordination between OB/gyn and neonatology and subspecialties. By 1995, over 700 NICUs in North America. By 1999, the edge of viability is at 23–24 weeks (600–700 g). The probability that an infant would die in the first year of life given a birth weight of 1,000 grams was .1.

See Anspach (1997) and Baker (1996) for details on history of neonatal care.

adapt ventilators for use on preterm infants. One of the leading causes of infant death is respiratory distress syndrome (RDS), a consequence of being born too early and having poorly developed lungs. Although recent innovations such as the use of surfactant have greatly reduced the consequences of RDS, various deficits relating to poor respiratory development are still a central part of neonatal intensive care.

The machine that is most visible and probably also most important in recent gains in neonatal mortality is the ventilator. The major innovation of the 1970s was the refinement of ventilators so that they would not damage a tiny infant's fragile lungs. State-of-the art ventilators now use high-speed ventilation to fill the infants' lungs with rapid short puffs of air that pose fewer risks to the undeveloped lung.

Recently, new pharmaceuticals have triggered impressive gains in health for tiny infants. Surfactant is used to treat respiratory distress syndrome and is believed to have contributed to declines since 1990 in death and morbidity for the lightest infants (Stevenson et al. 1998; Schoendorf and Kiely 1997). Prenatal steroids are used to speed development of the fetus when the fetus is in danger of being premature. There are now pharmaceuticals that treat infants with *patent ductus arteriosus*, a condition in which the structure that allows blood to bypass the lungs of the fetus does not close naturally after birth. Previously, infants with a severe case of *patent ductus arteriosus* faced heart surgery; many can now be treated medically.

Other less visible but important innovations include the development of improved monitoring both before and after birth and improved coordination among personnel. One example of improved monitoring is the development of technology to perform blood tests and related lab tests using incredibly small samples of blood. The tiniest babies have only a few tablespoons of blood in total, so standard blood tests would be impossible for these infants. In addition, there is more coordination between neonatologists and obstetricians, so women at risk for low-birthweight births take appropriate pharmaceuticals as soon as possible to speed the development of the fetus.

Health Consequences of Low Birthweight

Perhaps the most controversial issue in the technology of birth is the question of quality of life for infants saved by neonatal technology. Horror stories abound of light infants saved at birth but without a semblance of a normal life. In fact, the situation is far better than the horror stories suggest. A rough summary of the literature[11] is that at the margin of viability, developmental problems are substantial: roughly one-third of infants will have serious disability, one-third of infants will have moderate disability, and one-third will not be disabled. As mortality rates at any birthweight fall, health of survivors typically improves. Babies born at birthweights that formerly had substantial problems have many fewer problems now than in the past.

Table 2.9 shows evidence on developmental problems by birthweight for births in about 1960 and about 1990. As table 2.10 shows, in 1960, the margin of viability was near 1500 g, while in 1990 the margin of viability was under 1000 g.

Estimates around 1950 reported that for infants born under 1500 grams, only one-third would be free of handicap and with IQs in the

Table 2.9
Health problems and costs by birthweight, 1960 and 1990

	Pr (Problems)		Average costs at birth		Annual costs | problems (without special education)	
	1960	1990	1960	1990	1960	1990
Pr(problems) by birthweight						
<1,000 g	0.68	0.66	$0	$67,766		
1,000–1,499 g	0.68	0.28	0	56,557		
1,500–2,499 g	0.23	0.23	0	11,048		
2,500+ g	0.01	0.01	0	2,099		
All birthweights	0.033	0.028	$0	$3,330	$4,136 ($2,959)	$8,271 ($5,919)

See article for a description of the source for rates and costs of disability.

normal range (Lubchenco et al. 1963). Common handicaps for low-birthweight infants included (and still include) cerebral palsy; blindness; mental retardation; and other neurosensory, behavioral, or learning disabilities. Since there was little technological advance (and little mortality improvement) for these infants between 1950 and 1960, we assume this applies to 1960 as well. Table 2.10 shows our estimate that two-thirds of all infants under 1500 grams had developmental problems in that year. These early estimates do not separate health outcomes for infants under 1000 grams because so few survived to leave the hospital. Estimates for heavier infants come from Shapiro et al. 1983. In their analysis, 23 percent of infants weighing 1500 to 2500 grams had some form of impairment ranging from mild to severe. Developmental problem rates for normal birthweight infants were low; we estimate these at 1 percent, roughly the rate of disability in 1990.

Among infants born under 750 grams between 1990 and 1992, Hack et al. (1996) document a 31 percent chance of severe problems including mental retardation, cerebral palsy, blindness, deafness, or some combination of these problems. This finding is consistent with the notion that infants at the edge of viability have equal chances of severe problems, moderate disability, and no problems. Therefore, we assume that the probability of problems for infants under 1000 grams is 66 percent in 1990. Hack's results focus on babies born under 750 grams, so we are probably overstating the disability rates in this group.

Estimates for infants weighing 1500 to 2500 g are based on Hack et al. (1995), who review other literature suggesting that infants born in 1984 weighing 1000 to 1499 grams had a 14 percent chance of neuromotor impairment, 0.3 percent chance of blindness, 12 percent chance of squint, and 1.4 percent chance of deafness. An upper-bound estimate on the probability of impairment is the sum of these probabilities, or 28 percent. Compared with a 68 percent chance of impairments in 1960, there has been a clear improvement not only in mortality rates, but also in morbidity for infants born weighing 1000 to 1500 grams. Hack also reports that infants born 1500 to 1749 grams had an 11 percent chance of neuromotor impairment, 1.2 percent chance of blindness, 9 percent chance of squint, and 2 percent chance of deafness. An upper-bound estimate on their probability of impairment, the sum of these probabilities, is 23 percent. We use these numbers for infants in the 1500 to 2500 gram weight range in the absence of estimates for the entire range. These figures will overestimate rates of problems because they focus on the lower part of that birthweight range and because they are based on births in 1984 rather than 1990.

The rates of problems or disability reported reflect all impairments and disabilities, regardless of severity. Based on the literature, the rate of severe disability is, at most, about half as large as the rates reported here. The remaining disabled infants suffer relatively mild disability, ranging from mild visual and hearing impairments to mild learning disabilities.

To test these conclusions in more detail, we examined data from the National Health Interview Survey Child Health Supplements in 1981 and 1988.[12] The Child Health Supplements are part of the health interview surveys designed to measure the extent of illness, its effects on disability and chronic impairments, and the kinds of health services people receive. This Child Health Supplement focuses on noninstitutionalized children under eighteen years of age. It includes questions on biological parental information, the child's general health status, school, development, learning, behavior, and health services.

Table 2.10 shows age-adjusted outcomes by birthweight in 1981 and 1988 for several indicators of child health and well-being: whether health status is reported as excellent, whether the child has moderate or severe activity limitation, the average number of short-stay hospital days in the last twelve months, the number of hospital episodes and doctor visits in the last twelve months, the number of behavior

Table 2.10
Age-adjusted measures of child health by birthweight: Sample of noninstitutionalized children aged zero to seventeen from Health Interview Surveys, 1981 and 1988 Child Health Supplements

Outcome	1981	1988	Percentage change, 1981–88	*t*-stat
Percentage SRHS = Excellent				
<1,500 g	70.4%	70.8%	0.6	0.08
1,501–2,500 g	70.6	70.7	0.1	0.03
2,501–4,500 g	70.6	71.2	0.8	1.59
> 4,500 g	70.6	71.5	1.3	0.37
Percentage with activity limitation	In major activity	In usual activity		
<1,500 g	5.0%	14.0%	NA	
1,501–2,500 g	5.5	8.8	NA	
2,501–4,500 g	1.7	3.9	NA	
> 4,500 g	3.4	5.2	NA	
Number of short-stay hospital days in last 12 months				
<1,500 g	0.310	0.285	−8.5	0.05
1,501–2,500 g	0.293	0.268	−8.8	0.23
2,501–4,500 g	0.327	0.333	1.7	0.49
> 4,500 g	0.347	0.298	−15.0	0.95
Number of short-stay hospital episodes in last 12 months				
<1,500 g	0.053	0.055	2.7	0.52
1,501–2,500 g	0.055	0.052	−6.7	2.10
2,501–4,500 g	0.060	0.060	0.6	1.78
> 4,500 g	0.061	0.055	−9.8	4.50
Number of doctor visits in last 12 months				
<1,500 g	2.82	3.08	8.5	0.06
1,501–2,500 g	2.88	2.95	2.7	0.04
2,501–4,500 g	3.05	3.10	1.7	0.27
> 4,500 g	3.00	2.94	−2.2	0.06
Number of behavior problems on 32-point behavior index				
<1,500 g	0.74	0.74	1.0	0.03
1,501–2,500 g	0.77	0.80	3.0	0.11
2,501–4,500 g	0.73	0.72	−2.4	0.98
> 4,500 g	0.81	0.79	−2.4	0.15
Percentage repeated grade in school				
<1,500 g	10.7%	8.6%	−21.6	2.94
1,501–2,500 g	10.5	9.7	−7.9	1.62
2,501–4,500 g	9.6	9.0	−6.5	12.02
> 4,500 g	11.0	9.9	−10.5	4.42

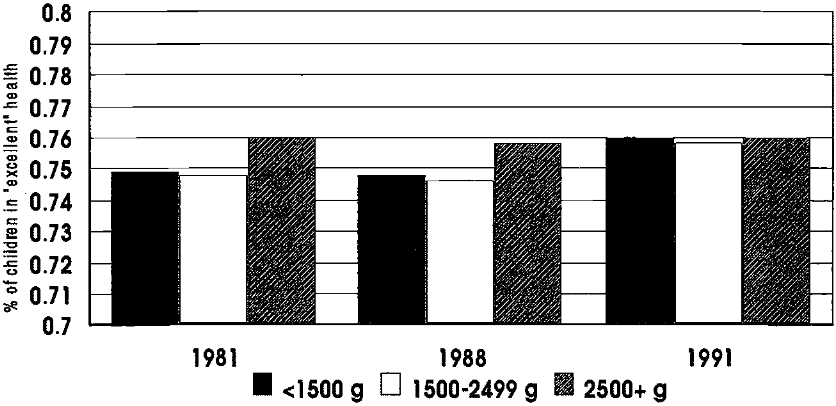


Figure 2.6
Change in general health status by birthweight, 1981–91
Source: 1981 and 1988 data from the National Health Interview Survey Child Health Supplements. 1991 data from the National Maternal and Infant Health Survey Follow-up. Data are weighted to reflect population and age-adjusted by age in months to correct for differences in age distribution across samples.

problems on a 32-point behavior problem index, and the percentage of children who repeated a grade.

Children weighing less than 1500 grams at birth are remarkably similar to normal birthweight children in all aspects except activity limitation. In both years, about 70 percent of children, regardless of birthweight, are reported as being in excellent health. In cases where outcomes are comparable across years, low-birthweight infants have either improved outcomes or have experienced little change. Only doctor visits increased over the 1981 to 1988 period, and this shift likely reflects the change from inpatient to outpatient care for these children. The similarity of health for lighter and heavier infants at birth refutes the idea that, as we push the edge of viability toward lower birthweights, we are saving children who will lead severely limited lives.

Figure 2.6 shows a similar pattern in the share of children aged two to four years who are reported to be in excellent health in 1981, 1988, and 1991. The 1981 and 1988 data are from the Child Health Supplements described above, and the 1991 data come from the follow-up to the 1988 National Maternal and Infant Health survey. There are few differences across birthweight groups. Nearly three-quarters of two- to four-year-olds are rated as being in excellent health regardless of their birthweight. And the share in excellent health rises slightly over this period for all birthweight groups.

Improving health for babies at the same birthweight is consistent with the diffusion of new technologies, such as the refinement of ventilation techniques or the advent of surfactant to treat respiratory distress syndrome. In part, these technologies reduce mortality by speeding infant development. The same increase in development reduces future disability. In our analysis of the costs and benefits of care for low-birthweight infants, therefore, we assume that roughly two-thirds of infants at the edge of viability have developmental problems, but this figure falls rapidly at birthweights where survival is nearly 100 percent.

IV. The Costs of Medical Innovation for Newborns

The innovations in neonatal care have been large but not without cost. Little was spent on the typical birth in 1960 because many women gave birth at home and seriously ill infants died shortly after birth. In contrast, the average length of hospital stay for infants born today with the diagnosis "preterm or small for gestational age" is about twenty-three days. Infants under 1500 g have an average length of stay of almost forty days (Rogowski 1998).

Many studies estimate the birth costs for infants at different birthweights; table 2.11 presents a summary. The literature is not uniform on the weight of the infants being considered. In older studies, viability at higher weights was a more important issue, and costs considered heavier infants. More recent studies focus on the lightest infants, where viability is currently the most difficult. The costs for the lightest infants (those weighing less than 1000 grams at birth) range from $35,000 to about $68,000. Infants between 1000 and 1500 grams incur hospital costs near $56,000, based on the only estimate that separates costs for this group. The costs for the remaining infants under 2500 grams were much lower, with costs in the $11,000 range. Table 2.11 shows a summary of the costs by birthweight that we will use for our cost-benefit analysis.

We also need to estimate the subsequent costs for caring for low-birthweight infants with developmental difficulties. We assume that given disability, an individual will incur three major costs: medical, benefit payments, and costs of special education. Estimates of medical costs are based on the 1990 average Medicaid payment for disabled Medicaid recipients, and they total $6,594. The average Social Security

Table 2.11
Costs of care at birth by birthweight (in 1990 $)

Medical costs	Study	Country	Birth cohort	Birthweight	Medical costs per live birth
	Boyle et al. 1983	Canada	1973–76	<1,500 g	$28,725
	Office of Technology Assessment 1988	United States	1970s	<2,500 g	6,850
	Pomerance et al. 1978	United States	1970	<1,000 g	44,874
	Lewit et al. 1988	United States	1988	<1,000 g	35,354
				1,000–2,499	11,048[a]
				≥2,500 g	2,099[a]
	Rogowski 1998	United States	1986–87	<1,500 g	61,668
				<1,000 g	67,766[a]
				1,000–1,499 g	56,557[a]

Estimates include direct medical costs associated with hospital admission at time of birth until discharge.
[a] Indicates cost estimates used to compute costs of birth by birthweight.

Administration payment for a disabled child is $4,167. Finally, Lewit et al. (1995) estimate that the additional cost of special education is $4,728. Not all of these costs will persist forever; for example, special education costs occur only during school attendance. We include special education costs for ages five through twenty. In 1990, therefore, the subsequent costs for school-age children with severe disabilities is about $15,000 per year. About half of the children with health problems are not severely disabled. They may suffer more minor disorders such as hearing impairment that requires the use of a hearing aid. We do not expect these children to require resources of $15,000 per year. We assume that, for these individuals, the cost of disability is one-tenth as large as for severely disabled children. Therefore, we use $8,271 as the average annual spending for children with problems in 1990. These costs have increased over time. To account for the increase, we assume that costs in 1960 were half of their real value in 1990. Our estimate of costs for impaired children in 1960 is therefore about $4,136.

V. Valuing the Benefits of Neonatal Care

The benefits of improved care for low-birthweight infants involves both mortality and morbidity changes. We take life expectancy estimates from period life tables from the Social Security Administration (Bell et al. 1992). To generate life tables by birthweight, we use birthweight-specific infant mortality rates and assume that, based on survival to age one, subsequent mortality rates equal those of the average child within the population.[13] Details of the procedure used to compute life expectancy are included in Appendix 2.1.

Life expectancy grew dramatically for the lightest infants from 1960 to 1990. In 1960, an infant born under 1000 grams was expected to live 6.5 years. In 1990, that number was 38.2. Babies born at 1000 to 1500 grams were expected to live until age 36 in 1960 but now are expected to live until age 73. The gains were smaller but nontrivial for heavier infants over this period, increasing from 71 to 79 years for infants weighing 1500 to 2500 grams and from 77 to 80 years for infants above 2500 grams. By 1990, all infants over 1500 grams could expect to live 79 to 80 years.

Quality of life is more difficult to estimate. Ideally, one might estimate the quality of life for each of the complications low-birthweight infants face using a methodology such as that suggested by Cutler and Richardson (1997, 1998, 1999). We intend to pursue this in subsequent work. As a starting point, we use results on quality of life already published in Cutler and Richardson. In their work, they show that in 1990, Quality Adjusted Life Years (QALYs) for even the most severe conditions studied, such as cancer, diabetes, heart disease, and paralysis, are in the range of .65 to .75. Therefore we use a QALY of .65 for severely disabled children, .75 for moderately disabled children, and .95 for low-birthweight children who are considered normal. We assume that half the children who are disabled have a serious disability and half have a moderate disability. Finally, we assume that infants born at a normal birthweight have a quality of life of .96, reflecting the absence of serious disability in this group. Table 2.12 shows the implied quality-adjusted life expectancy by birthweight in 1960 and 1990. Quality-adjusted life expectancy has increased as much or more than expected years of life.

To form cost-effectiveness ratios, this information is all we need. To estimate a rate of return to medical care, however, we need to value these health changes in dollars. The economics literature has attempted to measure the value of life in several ways (see Viscusi 1993 or Tolley et al. 1994 for reviews). One type of measurement is contingent valuation—asking people in surveys at what dollar amount they value life. A second method is the compensating differentials framework—infer-

Table 2.12
Cost benefit calculation assuming discount rate = 0.03

	Birthweight			
	<1,000	1,000–1,499	1,500–2,499	≥2,500
1960				
Life expectancy ∣ birth	6.5	35.9	71	77.3
QALY	0.78	0.78	0.89	0.96
Pr (problems)	0.68	0.68	0.23	0.01
Value of life	$465,180	$1,741,128	$2,688,515	$2,949,694
Total costs	16,871	57,440	24,180	1,093
1990				
Life expectancy ∣ birth	38.2	73.1	78.8	80.3
QALY	0.78	0.88	0.89	0.96
Pr (problems)	0.66	0.28	0.23	0.01
Value of life	$1,801,663	$2,673,145	$2,765,862	$2,978,061
Total costs	166,861	104,517	50,861	3,834

Rate of return calculation for low-birthweight infants, 1960–90

	<1,000	1,000–1,499	1,500–2,499	≥2,500 g	All low-birthweight infants
Change in costs	$ 149,991	$47,077	$26,681	$2,742	$39,042
Change in value	1,336,484	932,017	77,347	28,367	238,248
Rate of return	791%	1880%	190%	935%	510%
10% discount rate	408	270	3	7	46
0% discount rate	1,084	3,172	924	6,037	1,022

Refer to the article for descriptions of calculations and definitions of terms.

ring the value of life from how much people have to be paid to work in risky jobs or how much people are willing to pay for safety measures. While any concept like the value of life is difficult to measure, the preponderance of the evidence is in a fairly tight range. Most studies find a value of life of about $75,000 to $150,000 per year, or about $3 million to $7 million for a middle-age person. We use the $100,000 figure in our analysis; for those who prefer a different number, our estimates of the benefits of medical technology can be multiplied by the ratio of the preferred number to 100,000, and a new estimate of the rate of return on technology can be calculated. For reasons discussed above, we do not vary this estimate across people or ages.

The final requirement is a discount rate, *r*, which is also a venerable economic issue. Arguments for several discount rates have been presented, ranging from 0 (life should not be discounted) to 20 percent or more (to justify risky behavior). As a rough consensus of the economic literature, we use a discount rate of 3 percent in our central estimate. We present sensitivity results to alternative discount rates of 0 and 10 percent. Although discount rates affect the magnitude of returns to increased spending on low-birthweight infants, these changes will not alter our conclusions.

VI. Cost-Benefit Analysis

The last rows of table 2.12 show the cost-benefit calculation, in 1990 dollars. The net benefit for all birthweights is high. Among the lightest infants, costs increased by nearly $150,000 per infant between 1960 and 1990. About 40 percent of this amount is the cost of the birth; the remainder is the future costs for the increased share of surviving infants with developmental problems. But the benefit of care for this group is high. We estimate a benefit to this group of thirty additional years of life, or $1.3 million of quality-adjusted life. The rate of return for babies born under 1000 grams, shown in the last row of the table, is 791 percent.

For infants born between 1000 and 1500 grams, we estimate that lifetime costs grew by $47,000. We estimate that the birth costs of these infants was nearly $70,000 higher in 1990 than in 1960, but the share of infants with developmental problems fell by 40 percent. The benefits to these infants of improved survival and quality of life is nearly $1 million per infant. The return to spending on these infants is a stunning 1880 percent.

For infants weighing 1500 to 2499 grams, the change in net benefits of care are smaller. Birth costs increased by only $11,000 per child, and developmental problems are relatively low. Thus, total costs for these infants rose by $27,000. These infants lived an additional seven years of quality-adjusted life, however, for a gain of over $75,000. The rate of return is 190 percent.

The next column shows an extremely high rate of return for increased technology for normal birthweight infants—over 930 percent. But this estimate is somewhat misleading. Both cost increases and benefit changes are low for this group. The net benefit of improved care is not particularly large.

The final column of the table shows the estimated return for all low-birthweight infants. Our estimated return is 510 percent. Using a

Table 2.13
Cost effectiveness: costs per QALY for selected medical interventions

	Birthweight				
Intervention	<1,000	1,000–1,500	1,500–2,500	>2,500	All weights <2,500 g
Neonatal care	$6,101	$1,290	$3,833	$955	$3,726

Compared with other interventions

Prenatal care	Cost savings[a]
Influenza vaccination age <3 years	$1,745
Neonatal care for all low-birthweight infants	3,726
Pap smear every 3 years, ages 20–74	17,000
Treatment of severe hypertension	17,000
Coronary artery bypass	$33,600–$48,300

Source: Cost-effectiveness numbers (except for prenatal and neonatal care) based on those reported in Meltzer 1997.

[a] Prenatal care estimates based on the following: OTA 1988 reports that prenatal care costs $380 ($453 in 1990 dollars) and reduces p(low birthweight) by 50%. Given a rate of low birthweight of 7%, this figure implies a 3.5 percentage point reduction in low birthweight, or an additional QALE of .27 for each newborn whose mother received prenatal care. Given the prevented cases of low birthweight, this figure reduces expected costs for a given child, and so the net cost savings resulting from prenatal care is $4,214.

higher discount rate reduces the rate of return to 46 percent (because the value of life in the future is discounted). Among very low birthweight infants, however, returns still exceed 400 percent. The clear conclusion is that, while care for low-birthweight infants has cost a lot, it has brought even more in the way of benefits.

One can also judge this technology by how it compares to other medical interventions. Table 2.13 shows cost-effectiveness ratios for various medical interventions. Our estimates in table 2.12 imply a cost per QALY of $3,700 (assuming a 3 percent discount rate).

Based on estimates presented in a U.S. Congress Office of Technology Assessment (OTA) Report (1988), prenatal care still appears to be much more cost-effective than neonatal care. The OTA estimates that prenatal care actually saves money. However, these estimates of the impact of prenatal care should be interpreted with caution. Recent estimates of the effect of Medicaid expansions on infant survival estimate small effects of Medicaid eligibility on low birthweight (Currie and Gruber, 1996). The estimates are sufficiently small that prenatal care would not pay for itself. The difference between the theoretical and actual impacts of insurance eligibility on costs may result from inadequate take-up of prenatal care when offered. Enhanced prenatal care services will improve outcomes only if women use these services correctly. Because many women do not use them appropriately (Piper et al. 1990), the theoretical benefits are generally not achieved.

Influenza vaccinations in low-risk populations yield cost effectiveness ratios of about $1,700 per QALY, lower than what we estimate. The treatment of severe hypertension yields a cost effectiveness ratio of $17,000. Similarly, regular Pap smears every three years yields a ratio of $17,000 per QALY. Finally, coronary artery bypass surgery costs approximately $34,000 to $48,000 dollars per QALY, depending on the exact procedure. Relative to other medical interventions, intensive care for low-birthweight infants fares well.

One issue not captured in our analysis thus far is the controversial question about what the loss is from death of very low weight infants. One may judge our estimates of the benefits of this care as too high because the children who do not survive are more or less "replaceable." It seems clear that families are less upset by the death of a very premature infant than by the death of a normal birthweight infant. But how can this be quantified?[14] And are all children really replaceable? For some women who are delaying childbearing or seeking fertility treatments, or who, because of careers, face high opportunity costs of childbearing, the "replacement" costs may be high.

One way to gain a lower-bound estimate of returns to intensive care is to assume that society places no value on saving the life of a premature infant. Instead, assume that society values only improvements in the quality of life for those infants who survive without the technology advances of the past thirty years. In other words, assume replacement costs are zero. We performed a cost-benefit analysis similar to that shown in table 2.12, but we assumed that no gains were made in neonatal mortality among low-birthweight infants since 1960. Under this assumption, gains come in the form of increased QALYs and the decreased cost associated with a reduction in severe problems. Without gains in survival for low-birthweight infants, we calculate negative returns to increased spending on neonatal care. The gains do not seem great enough to outweigh the costs. Costs rose by about $38,000 over the last thirty years, but the health benefits rose by only $21,000.[15] The issue of replacement cost is important for future research.

VII. Conclusions

Medical spending for infants has grown explosively over the last several decades. It is natural to question what we buy with the additional spending. In the case of infant survival, we can answer relatively clearly: spending an additional $40,000 per low-birthweight infant has increased survival by 11.8 years on average, or 10.5 quality-adjusted years.

Our estimated rate of return to increased spending on low-birthweight infants is enormous—over 500 percent. Put another way, the cost per year of quality-adjusted life is about $3,700. This figure is low even at high discount rates. While the cost-effectiveness of certain other medical interventions such as prenatal care or influenza shots for infants may be greater than that for neonatal intensive care, this intervention compares favorably with many highly valued medical interventions such as preventive care for cervical cancer and coronary artery bypass surgery.

Because neonatal intensive care provides one of the few examples where we can accurately estimate the returns to medical spending, our results are encouraging. In the case of newborns, medical spending for aggressive care at birth is worth it.

Notes

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1. Statistical Abstract of the United States, 1972 and Health United States, 1998.

2. Based on average length of stay and inpatient charges for infants diagnosed as "short gestation, low-birthweight, and fetal growth retardation." These conditions account for 24,555 or 0.6 percent of newborn admissions, so it includes less than 10 percent of all low-birthweight infants. See *Statistics from the HCUP-3 Nationwide Inpatient Sample for 1994: Principal Diagnoses* for details. This publication can be viewed at *http://www.ahcpr.gov/data/hcup/94DCCHPR.htm#218*. See Anspach 1997, p. 246, for estimates of direct costs for very low birthweight infants.

3. The first incubator was developed in 1880 as a warming chamber for premature infants in France.

4. Assuming no care related to the premature birth was provided to the mother while she was pregnant.

5. Other sometimes-claimed benefits should not be considered. For example, some have claimed that additional jobs in the medical care field are a benefit of spending on medical care. But this benefit assumes that some people would not be employed but for the medical care spending. Since money spent on medical care would be spent elsewhere if not on medical services, the jobs created by additional medical spending would have been created in other parts of the economy. Thus, the impact of medical spending on overall employment is negligible.

6. In economic terms, we are not using a willingness-to-pay framework.

7. Meltzer (1997) shows that individuals who are saved at age twenty-five have a negative net resource use. He does not show calculations for the net resource use of individuals under twenty-five.

8. Infant mortality rates express the number of deaths before age one per 1,000 live births. Neonatal mortality refers to death within twenty-eight days of birth and fetal death refers to the death of the fetus. Fetal deaths are typically recorded only for gestations of at least twenty weeks.

9. The percentage of women starting childbearing in year t who see an infant die by the end of childbearing is estimated with the following equation:

$$1 - Pr[\text{all children born survive the first year}] = 1 - (\text{death rate})_t^{(\text{fertility rate})t*(\text{thirty years of childbearing})}$$

This equation assumes that all women have the average number of children and that death rates are constant throughout childbearing years.

10. This computation is an approximation; there is also an interaction term, which we ignore: $\Delta P[\text{neonatal death}]_{'60-'90} = \sum_{k=1}^{K} \Delta P[\text{weight} \in \text{group } k]_{'60-'90} * P[\text{death} \mid k]_{'60} + P[\text{weight} \in \text{group } k]_{'60} * \Delta P[\text{death} \mid k]_{'60-'90} + \Delta P[\text{weight} \in \text{group } k]_{'60-'90} * \Delta P[\text{death} \mid k]_{'60-'90}$.

11. We are particularly grateful to Dr. Steven Ringer for discussing this subject with us.

12. These data end in 1988, but recent evaluations of morbidity in infants through 1994 show a trend toward lower morbidity for several clinical indicators (Stevenson et al. 1998).

13. The number of deaths for low-birthweight infants after age one is too small to estimate subsequent mortality by birthweight. Such mortality rates would also be contaminated by differences in socioeconomic status of low and normal birthweight babies. One sensitivity test for this estimate is to assume death at age fifty for all low-birthweight births. Making this change does not substantially affect our results.

14. An interesting thought experiment is to imagine how a couple at twenty-two to twenty-five weeks of pregnancy might respond to the following scenario: "You have just given birth to an extremely low-birthweight infant. You may choose between aggressive care for your preterm infant or you may receive the cash equivalent of the Present Discounted Value (PDV) of all current and future costs for the child, about $150,000 to $200,000, for use on your next child." How many parents would accept the money?

15. This estimate is particularly conservative because we based estimates of the disability improvement and QALY improvement on conservative estimates taken from previous literature.

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Appendix 1a:
The birthweight distribution in the United States, 1950–1990

	Birthweight distribution (percentage)				Annual % Change
	1950	1960	1985	1990	
<1,000 g	0.50%	0.60%	0.60%	0.60%	0.5%
1,000–1,499 g	0.6	0.7	0.6	0.6	0.0%
1,500–1,999 g	1.4	1.5	1.3	1.3	−0.2%
2,000–2,499 g	4.9	5.1	4.2	4.4	−0.3%
2,500–2,999 g	18.1	18.5	15.9	16.1	−0.3%
3,000–3,499 g	37.7	38.0	36.7	36.8	−0.1%
3,500–3,999 g	27.1	26.8	30.0	29.3	0.2%
4,000–4,499 g	7.7	7.5	9.2	9.0	0.4%
4,500 + g	2.1	1.5	1.9	1.8	−0.4%

Sources: 1950–60 data from "A Study of Infant Mortality from Linked Records: Comparison of Neonatal Mortality from Two Cohort Studies, United States, January–March 1950 and 1960." 1985 data from: U.S. Vital Statistics "Linked Birth-Death Files 1985," Chapter 6, table 4. 1990 data based on authors' calculations using linked birth-death files.

Appendix 1b:
The birthweight distribution in Massachusetts, 1972–1994

	Birthweight distribution (percentage)						Annual % Change
	1972	1978	1982	1986	1990	1994	
≤1,000 g	0.41%	0.39%	0.42%	0.39%	0.43%	0.44%	0.3%
1,001–1,500 g	0.4	0.4	0.5	0.4	0.4	0.4	−0.3%
1,501–2,000 g	1.1	1.0	0.8	0.9	0.8	0.9	−0.9%
2,001–2,500 g	4.2	3.7	3.3	3.1	3.0	3.2	−1.3%
2,501–3,000 g	18.3	16.0	14.8	14.2	14.1	14.0	−1.2%
3,001–3,500 g	40.0	38.4	37.5	36.0	36.2	36.2	−0.5%
3,501–4,000 g	27.1	29.6	31.3	32.1	32.1	32.1	0.8%
4,001–4,500 g	7.2	8.7	9.5	10.6	10.9	10.9	1.9%
4,501 + g	1.4	1.8	2.0	2.3	2.1	2.0	1.6%

Sources: Based on authors' calculations using Massachusetts vital statistics data.

Appendix 2.1: Estimating Life Expectancy by Birthweight

Traditional cohort life tables are computed as follows:

$\dot{e}_x$ = life expectancy = $\dfrac{T_x}{L_x}$ $\qquad x = 1, 2, 3, 4$

T_x = total life years lived by cohort at age $x = L_x + L_{x+1} + L_{x+2} + \cdots + L_{119}$ $\qquad x = 0, 1, 2, 3, \ldots 119$

L_x = expected life years lived at age x by cohort $= l_x - .5 \cdot d_x$ $\qquad x = 1, 2, 3, 4$

L_0 = expected life years lived in first year of life by cohort $= l_0 - {}_1f_0 \cdot d_0$

${}_1f_0$ = separation factor, or average fraction of a year not lived by those who die in first year

l_x = number of individuals in cohort at age $x = l_{x\text{-}1} \cdot (1 - {}_1q_{x\text{-}1})$ $\qquad x = 1, 2, 3, 4$

d_x = number of deaths in cohort at age $x = l_x \cdot {}_1q_x$ $\qquad x = 1, 2, 3, 4$

${}_1q_x$ = one-year probability of death at age x

l_0 = number of individuals in cohort at age 0 = 100,000

For each birthweight group within each sex, the value of ${}_1q_0$, or the average probability of death before age one, was replaced with the actual probability of death within that birthweight group. Then values of ${}_1f_0$ were replaced in each gender-cohort-birthweight group such that the weighted average of life expectancy by birthweight group and gender would equal that of the population in that cohort. For example, in 1960, the actual male distribution of infant deaths by age at death (<7 days, 7–27, 28–365) was multiplied by the fraction of the year not lived for infants who died at a given age. Male infants who died before 7 days were assumed to have not lived for .9969 of the first year. Those dying between 7 and 27 days did not live .9795 of the first year, and those dying from day 28 to 365 were assumed to have not lived for .6055 of the first year. The values of "fraction of year not lived" by gender, cohort, and age at death are shown in table 2.14.

Table 2.14
Fraction of year not lived

	1960		1990	
	Male	Female	Male	Female
Under 7 days[a]	0.9969	0.9964	0.9969	0.9964
7–28 days[b]	0.9795	0.9780	0.9794	0.9780
28–365 days[c]	0.6055	0.5945	0.7726	0.8301

[a] For males(females), this figure assumes a 95(90) percent chance of death at age 1 day and 5(10) percent chance of death at 3.5 days.

[b] For males(females), this figure assumes a 95(90) percent chance of death at age 7 days and 5(10) percent chance of death at age 17 days.

[c] This value was selected so that, given the values used above, the weighted average life expectancy over gender and birthweight groups would equal the life expectancy shown in published cohort life tables.