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THE TECHNOLOGY OF BIRTH:
IS IT WORTH IT?

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The Technology of Birth: Is it Worth it?
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ABSTRACT

We evaluate the costs and benefits of increased medical spending for low birth weight infants. Lifetime spending on low birth weight 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 birth weight infants at over 500 percent. Although prenatal care and influenza shots are more cost effective than neonatal care, this 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 20-74. We conclude that the answer to the question posed in this paper is a resounding "Yes."

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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 – four percent per year – is a result of medical technology changes (Newhouse, 1992). We also know that people live longer and in better health than they used to. Half a century ago, life expectancy at birth was 68 years; today it is near 80 years. Further, 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 what the contribution of medical technology is to better health?

In this paper, we evaluate the costs and benefits of medical technology changes for one particular type of medical technology – care for low birth weight infants. We focus on low birth weight infants for several reasons. First, low birth weight is extremely expensive. A neonatal intensive care unit can cost up to $2,200 per day, and as much as

[1] Statistical Abstract of the United States, 1972 & Health United States, 1998.

$131,000 per infant in 1996 dollars.[2] When something costs so much, it is natural to evaluate what the spending buys.

This is particularly true 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 birth weight 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 birth weight 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 birth weight infants has expanded tremendously. In the first half of the 20th century, the technology to treat pre-term 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 hyper-alimentation (the provision of nutrition to critically ill infants), 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

[2]Based on average length of stay and inpatient charges for infants diagnosed as "short gestation, low birth weight, and fetal growth retardation." These account for 24,555 or .6 percent of newborn admissions, so it includes less than 10 percent of all low birth weight 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 birth weight infants.

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

these infants. The staff involved in a neonatal nursery can include up to 50 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 birth weight infants likely averaged less than for normal birth weight infants, since nothing major could be done for them and death was relatively cheap. Today, costs for low birth weight infants substantially exceed those for normal birth weight infants – by 10 to 20 times. As a result of this technological change, the cost of infant care has increased substantially 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 40 years. The vast bulk of this differential spending increase appears attributable to the costs of 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 birth weight, essentially all changes in neonatal survival are due to increasing technology. By focusing on birth weight-specific survival, we can therefore construct an extremely accurate estimate of the effect of medical technology changes on outcomes. This 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 birth weight infants, and examine both national vital statistics data and data on low birth weight infants in Massachusetts to understand the costs and benefits of medical technology changes. We estimate that low birth weight 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 birth weight infants survive, at what will likely be a reasonable -- if not disability free -- life.

We evaluate this social tradeoff in several ways. First, we attach a value to additional years of life and estimate the rate of return to spending on low birth weight infants. Using a consensus estimate from the literature (a year of life in perfect health is worth $100,000; see Cutler and Richardson, 1987, 1988, 1989), we find a striking rate of return to increased medical spending on low birth weight 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 birth weight infants than we used to, we get 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 we apply that treatment 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.

We begin in the next section by discussing how one can estimate the rate of return to medical technology. In the second section, we discuss changes in outcomes for low birth weight infants over time and the medical changes that have likely led to this increased survival. The third and fourth sections estimate the benefits and costs of this technology. These are combined into a rate of return calculation in section 5. The last section concludes.

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 care provides. Table 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, there are downstream costs provided over the person's remaining life. In the case of care for low birth weight 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.

A third cost is the normal cost of sustaining a person over their lifetime– food, clothing, shelter, etc. These costs are relevant for interventions that extend life. Even

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

though these costs are not medical, they need to be included in calculating the costs of a medical intervention that prolongs life, since saving a low birth weight 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 birth weight infants as:

$$PDV(Cost) = \sum_{t=0}(1+r)^{-t} M_t \quad + \quad \sum_{t=0}(1+r)^{-t} L_t \tag{1}$$

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

The benefit of medical care is the increase in quality-adjusted life it affords and the fact that it keeps people alive longer, who will provide more to society. There may also be some spillovers of medical technology to other fields, but these 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

[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 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 in 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.

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:

$$QALYs \quad = \quad \sum_{t=0} (1+r)^{-t} \; q_t \qquad (2)$$

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

$$\textit{Cost-effectiveness} \quad = \quad)\,(QALY) \,/\,)\,(\textit{Medical Spending}) \qquad (3)$$

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

To see this, we need to form the net benefits of medical treatment changes – the dollar value of health benefits net of 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 is not what a person will earn – that amount is included separately.[6]

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

We express the net benefits as:

$$Net\ Benefit\ =\ \sum_{t=0}(1+r)^{-t}\,Vq_t\ \ -\ \left[\ \sum_{t=0}(1+r)^{-t}\ M_t\ \ +\ \ \sum_{t=0}(1+r)^{-t}\,(L_t-w_t)\right] \qquad (4)$$

The last term in [.] is the net contribution of an individual to society – the value of what they contribute less what they consume. Using the life cycle model as a rough approximation, we assume that for infants without severe problems, this term is zero – infants will consume as much as they produce over the course of their life.[7] For infants with severe health problems, the second term in [.] will be positive on net. We therefore include non-medical 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:

$$Rate\,of\ \ Return\ =\ \frac{\sum_{t=0}(1+r)^{-t}\,Vq_t}{\sum_{t=0}(1+r)^{-t}\left(M_t+L_t-w_t\right)}\ \ -\ \ 1 \qquad (5)$$

For individuals without severe health problems or disability, we assume that the L_t-w_t terms cancel out 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.

[7] Meltzer shows that individuals who are saved at age 25 have negative net resource use. He does not show calculations for net resource use of individuals under 25.

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 how we form each of these for low birth weight infants in some depth below. We start by analyzing trends in infant survival and the role of medical technology in those trends.

III. Birth Weight and Survival

Infant mortality has declined dramatically this century. Figure 1 shows trends in infant mortality -- death in the first year of life -- in the 20th century.[8] In 1900, infant mortality was 16 percent. The magnitude of this number is staggering; it implies, for example, that half of woman finishing their childbearing years at the turn of the century had a child die 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

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[8] Infant mortality rates express the number of deaths before age one per 1,000 live births. Neonatal mortality refers to death within 28 days of birth and fetal death refers to the death of the fetus. Fetal deaths are typically recorded only for gestations of at least 20 weeks.

[9] The percent of women starting childbearing in year t who see an infant die by the end of child bearing is estimated with the following equation:

$$1 - \Pr[\text{All children born survive the } 1^{st} \text{ year}] = 1 - (\text{death rate})_t^{(\text{fertility rate})t*(30 \text{ years of child bearing})}.$$

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

before 1 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 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 underestimate of gains in infant health is small.

Figures 2 and 3 highlight how gains in infant health differ by decade. Infant mortality declined by 7 or 8 deaths per thousand in the 1950s, 1960s, and 1970s. Gains in infant health continue throughout the 1980s and 1990s, but at a slower pace. Figure 3 reveals the 1970s as the decade with the most rapid percentage decline in both infant and fetal deaths.

Changes in infant mortality can result from many factors, of which medical care for low birth weight 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 water and sanitation, economic variables 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 28 days of life, there is a natural way to control for these factors. Conditional on birth weight, the overwhelming factor influencing survival for low birth weight babies is medical care in the immediate post-birth period (Paneth et al. 1995, Williams and Chen 1982). In essence, infant health is a condition for which there are very good risk adjusters – the birth weight and gestational age of the infant. Table 2 illustrates how birth weight allows one to adjust for non-medical factors by showing simple linear probability models of neonatal mortality on non-medical 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 non-medical factor impacting neonatal mortality is reflected in birth weight. The R^2 on the regression without birth weight is .03 compared with an R^2 of .325 when controlling for birth weight.

Thus, the effects of medical care on infant health can be isolated by conditioning survival on birth weight. Figure 4 and Tables 3a and 3b display trends in birth weight-specific neonatal mortality over time; background on the birth weight distribution over time is shown in appendix 1. Table 3a and the top of figure 4 show national data on birth weight-specific infant mortality rates from 1950, 1960, 1985, and 1990. Table 3b and the lower panel of the figure show Massachusetts Vital Statistics data for various years between 1972 and 1994. In both cases, the data omit fetal death rates, thus biasing towards zero the estimated decline in infant mortality rates at the lowest birth weights.

The figure and table show a remarkable change. The largest declines in infant mortality are for low birth weight infants. Between 1950 and 1990, infant mortality rates for very low birth weight infants (<1500 grams) fell almost 2 percentage points per year, or 42 percent in total. Mortality for low birth weight infants (1500-2500 grams) declined much more slowly, by about 1/3 percentage point each year, or 7.5 percent in total. Mortality for normal birth weight infants fell the least, about 1 percentage point over the period. The Massachusetts data show very 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 at each birth weight:

$$P\left[Neonatal\ \ Death\right]_t = \sum_{k=1}^{K} P\left[Weight \in group\ k\right] * P\left[Death \mid k\right] \tag{7}$$

Changes in neonatal mortality rates can thus be decomposed into changes in the birth weight distribution, and changes in survival conditional on birth weight:[10]

$$\begin{aligned} \Delta P\left[Neonatal\ Death\right] = \sum_{k=1}^{K} \Delta P[Weight \in group\ k] * \overline{P\left[Death \mid k\right]} + \\ \overline{P[Weight \in group\ k]} * \Delta P\left[Death \mid k\right] \end{aligned} \tag{8}$$

The first term in equation (8) is the change in neonatal deaths due to changes in the birth weight distribution. The second term is the change due to trends in birth weight-specific neonatal death rates, which can be broken out by birth weight.

Table 4 shows the relative importance of these two factors in the national and Massachusetts data. As table 4 shows, 35 percent of the improvement in national

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[10] This is an approximation; there is also an interaction term, which we ignore.

$$\Delta P\left[Neonatal\ \ Death\right]_{60-'90} = \sum_{k=1}^{K} \Delta P[Weight \in group\ k]_{'60-'90} * P\left[Death \mid k\right]_{60} +$$
$$P[Weight \in group\ k]_{'60} * \Delta P\left[Death \mid k\right]_{60-'90} + \ \Delta P[Weight \in group\ k]_{'60-'90} * \Delta P\left[Death \mid k\right]_{60-'90}.$$

neonatal mortality since 1950 have resulted from reductions in mortality for very low birth weight infants (<1500 g). This 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 birth weight infants (1500 g to 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 birth weight infants. Most of the remainder results from reductions in mortality for the 93 percent of infants born of normal birth weight (>2500 g). Changes in the distribution of births by birth weight over time would actually have increased infant mortality, although this is somewhat misleading since some formerly fetal deaths are almost certainly now classified as infant mortality at low birth weights.

It is clear that medical technology has been very 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 happen within 24 hours of birth.

A. The Technology of Birth

The improvement in birth weight-specific survival is consistent with the diffusion of technologies for these babies. Table 5 outlines some of the major developments in newborn medicine over time. Before 1960, there was little medical treatment for pre-term infants. In the 1960s the first modern neonatal intensive care units began as physicians started to adapt ventilators for use on pre-term 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 the 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 a major part 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 up development of the fetus when the fetus is in danger of being premature. There are now pharmaceuticals that treat infants with a *patent ductus arteriosus,* a condition when 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; now, many can be treated medically.

Other less visible, but important innovations include the development of improved monitoring both before and after birth and improved personnel. One example of improved monitoring technology 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 birth weight births take appropriate pharmaceuticals as soon as possible to speed the development of the infant.

B. Health Consequences of Low Birth Weight

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 in any birth weight fall, health of survivors typically improves. Babies born at birth weights that formerly had substantial problems have many fewer problems now than in the past.

Table 7 shows evidence on developmental problems by birth weight for births in about 1960 and about 1990. As table 3 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 normal range (Lubchenco 1963). Common handicaps for low birth weight 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 7 shows our estimate that two-thirds of all infants under 1500 grams had developmental problems in that year. These early estimates do not separate out 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 1500-2500 grams had some form of impairment ranging from mild to severe. Developmental problem rates for normal birth weight infants were low; we proxy these at 1 percent, roughly the rate of disability in 1990.

Among infants born under 750 grams between 1990 and 1992, Hack (1996) documents a 31 percent chance of severe problems including mental retardation, cerebral palsy, blindness, deafness, or some combination of these. This 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. Given that Hack's results focus on babies born under 750 grams, 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, a 0.3 percent chance of blindness, a 12 percent chance of squint, and a 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 morbidity for infants born weighing 1000-1500 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

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

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 will over-estimate rates of problems because they focus on the lower part of that birth weight 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 that are 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 non-institutionalized children under 18 years of age. It includes questions on biological parental information, the child's general health status, school, development, learning, behavior, and health services.

Table 8 shows age-adjusted outcomes by birth weight 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 12 months, the number of hospital episodes

[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. 1999).

and doctor visits in the last 12 months, the number of behavior problems on a 32 point behavior problem index, and the percent of children who repeated a grade.

Children born weighing less than 1500 grams are remarkably similar to normal birth weight children in all aspects except activity limitation. In both years, about 70 percent of children, regardless of birth weight, report being in excellent health. In cases where outcomes are comparable across years, low birth-weight infants have either improved outcomes or experienced little change. Only doctor visits “worsened” over the 1981 to 1988 period, and this likely reflects the shift from inpatient to outpatient care for these children.

The similarity of health for lighter and heavier births refutes the idea that as we push the edge of viability toward lower birth weights, we are saving children who will lead severely limited lives.

Figure 5 shows a similar pattern by showing the share of children aged 2 to 4 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 birth weight groups. Nearly three quarters of two to four year olds are rated as being in excellent health regardless of their birth weight. And the share in excellent health rises slightly over this period for all birth weight groups.

Improving health for babies at the same birth weight 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 birth weight infants, therefore, we assume that roughly two-thirds of infants at the edge of viability have developmental problems, but this falls rapidly at birth weights 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. Very little was spent on the typical birth in 1960 since many women gave birth at home and seriously ill infants died shortly after birth. In contrast, today the average length of hospital stay for infants born with the diagnosis "pre-term or small for gestational age" is about 23 days. Infants under 1500 g have an average length of stay near 40 days (Rogowski 1998).

There have been many studies estimating the birth costs for infants at different birth weights. Table 6 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 breaks out costs for this group. The remaining infants under 2500 grams are much cheaper, with costs in the $11,000 dollar range. Table 6 shows a summary of the costs by birth weight we will use for our cost-benefit analysis.

We also need to estimate the subsequent costs for caring for low birth weight 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 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 ages. We include special education costs for ages 5 through 20. In 1990, therefore, the subsequent costs for school-aged 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 1/10 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 this, 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 birth weight births 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 birth weight, we use birth weight-specific infant mortality rate and assume that conditioning 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.

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 1000-1500 grams were expected to live until age 36 in 1960, but now are expected to live until age 73. The gains were smaller, but non-trivial 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 79-80 years.

Quality of life is more difficult to estimate. Ideally, one might estimate quality of life for each of the complications low birth weight 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 already published results on quality of life, in Cutler and Richardson. In their work, they show that in 1990, QALYs for even the most severe conditions studied such as cancer, diabetes, heart disease, and paralysis, are in the range of .65 to .75. We therefore use a QALY of .65 for severely disabled children, .75 for moderately disabled children and .95 for low birth weight children who are considered normal. We assume that half the children who are disabled have a serious

[13] The number of deaths for low birth weight infants after age 1 is too small to estimate subsequent mortality by birth weight. Such mortality rates would also be contaminated by differences in socioeconomic status of low and normal birth weight babies. One sensitivity test for this estimate is to assume death at age 50 for all low birth weight births. Making this change does not substantially affect our results.

disability and half have a moderate disability. Finally, we assume that infants born of normal birth weight have a quality of life of .99, reflecting the absence of serious disability in this group.

Table 9 shows the implied quality-adjusted life expectancy by birth weight 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 is all the information 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 how much they value life at. A second method is the compensating differentials framework – inferring 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 as difficult as the value of life is problematic 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 to $7 million for a middle-aged 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 to 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. This too is a venerable economic issue. Arguments for a number of 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 birth weight infants, these will not alter our conclusions.

VI. Cost-benefit Analysis

The last rows of table 9 show the cost-benefit calculation, in 1990 dollars. The net benefit for all birth weights 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 30 additional years of life, or 1.3 million dollars 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 of 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 7 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 birth weight 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 birth weight infants together. Our estimated return is 510 percent. Using a higher discount rate reduces the rate of return to 46 percent (because the value of life in the future is discounted). However, among very low birth weight infants, returns still exceed 400 percent. The clear conclusion is that while care for low birth weight infants has cost a lot, it has brought even more in the way of benefits.

One might alternatively judge this technology by how it compares to other medical interventions. Table 10 shows cost-effectiveness ratios for various medical interventions. Our estimates in table9 imply a cost per QALY of $3,700 (assuming a 3 percent discount rate).

Based on estimates presented in an Office of Technology Assessment 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 very small effects of Medicaid eligibility on low birth weight (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 only improve outcomes if women use these services in the right way. Since many women do not use them appropriately (Piper et al. 1995), 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 3 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 birth weight 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 birth weight infant. But how can this be quantified?[14] And are all children really replaceable? For some women who are increasingly delaying childbearing, seeking fertility treatments, or who because of careers face high opportunity costs of childbearing, the "replacement" costs may be high.

[14] An interesting thought experiment is to imagine how a couple at 22-25 weeks of pregnancy might respond to the following scenario: "You have just given birth to an extremely low birth weight infant. You may choose between aggressive care for your pre-term infant or you may receive the cash equivalent of the PDV of all current and future costs for the child, about 150 to 200 thousand dollars, for use on your next child." How many parents would accept the money?

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 30 years. In other words, assume replacement costs are zero. We performed a cost-benefit analysis similar to that shown in table 9, but assuming that no gains were made in neonatal mortality among low birth weight 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 birth weight infants, we calculate negative returns to increased spending on neonatal care. The gains do not seem great enough to outweigh the costs. Costs rise by about $38,000 over the last 30 years, but the health benefits rise by only $21,000.[15] The issue of replacement cost is an important issue for future research.

VII. Conclusions

Medical spending growth for infants has been explosive 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 birth weight 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 birth weight 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

[15] This estimate is particularly conservative because we based estimates of the disability

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, on average, medical spending for aggressive care at birth is worth it.

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Appendix 1a: The Birth Weight Distribution in the U.S. 1950-1990

	Birth Weight Distribution (percentage)				Annual
	1950	1960	1985	1990	% Change
<1000 g	0.50%	0.60%	0.60%	0.60%	0.5%
1000-1499g	0.6	0.7	0.6	0.6	0.0%
1500-1999 g	1.4	1.5	1.3	1.3	-0.2%
2000-2499 g	4.9	5.1	4.2	4.4	-0.3%
2500-2999 g	18.1	18.5	15.9	16.1	-0.3%
3000-3499 g	37.7	38.0	36.7	36.8	-0.1%
3500-3999	27.1	26.8	30.0	29.3	0.2%
4000-4499 g	7.7	7.5	9.2	9.0	0.4%
4500 + 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 Birth Weight Distribution in Massachussets, 1972-1994

	Birth Weight Distribution (percentage)						Annual
	1972	1978	1982	1986	1990	1994	% Change
<=1000 g	0.41%	0.39%	0.42%	0.39%	0.43%	0.44%	0.3%
1001-1500g	0.4	0.4	0.5	0.4	0.4	0.4	-0.3%
1501-2000 g	1.1	1.0	0.8	0.9	0.8	0.9	-0.9%
2001-2500 g	4.2	3.7	3.3	3.1	3.0	3.2	-1.3%
2501-3000 g	18.3	16.0	14.8	14.2	14.1	14.0	-1.2%
3001-3500 g	40.0	38.4	37.5	36.0	36.2	36.2	-0.5%
3501-4000 g	27.1	29.6	31.3	32.1	32.1	32.1	0.8%
4001-4500 g	7.2	8.7	9.5	10.6	10.9	10.9	1.9%
4501 + 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

Appendix 2: Estimating Life Expectancy by Birth Weight

Traditional cohort life tables are computed as follows:

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

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

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

$$L_0 = \mathit{expected\ life\ years\ lived\ in\ 1^{st}\ year\ of\ life\ by\ cohort} = l_0 - {}_1f_0 \cdot d_0$$

$${}_1f_0 = \mathit{separation\ factor, or\ average\ fraction\ of\ a\ year\ not\ lived}$$
$$\mathit{by\ those\ who\ die\ in\ 1^{st}\ year}$$

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

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

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

$$l_0 = \#\ \mathit{of\ individuals\ in\ cohort\ at\ age\ 0} = 100{,}000$$

For each birth weight 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 birth weight group. Then, values of ${}_1f_0$ were replaced in each gender-cohort-birth weight group such that the weighted average of life expectancy by birth weight group and gender would equal that of the population in that cohort. So 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 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 age

28-365 were assumed to not live for .6055 of the first year. The values of "fraction of year not lived" for by gender, cohort, and age at death used are shown in the table below.

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 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 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 birth weight groups would equal the life expectancy shown in published cohort life tables.

Table 1: Analysis of Medical Technology Changes

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

Table 2: The probability of neonatal death and birth weight, U.S. Vital Statistics 1990

	Coefficient	Standard Error	Coefficient	Standard Error
Mother's age	-0.0007*	0.0001	-0.0003*	0.0001
Mother's age squared	1.3e-05*	1.2e-06	4.1e-06*	9.7e-07
Other non-white mother	-0.00035	0.0002	-0.0004*	0.00020
Black mother	0.0051*	0.0001	-0.0007*	0.0001
Mother's education				
Some HS	-0.00016	0.0002	-0.0002	0.0002
HS Degree	-0.0004	0.0002	-0.0000	0.0002
Some College	-0.0004	.00024	-0.0002	0.0002
College Degree+	-0.0007*	0.0002	-0.0002	0.0002
Education not stated	0.0031*	0.0003	0.0018*	0.0003
Single mother?	0.0013*	0.0001	-0.0001	0.0001
Prenatal care in 2nd trimester	-0.00161*	0.0001	-0.0002*	0.0001
Prenatal care in 3rd trimester	-0.00353*	0.0002	-0.0001	0.0002
No prenatal care	0.02279*	0.0003	0.0037*	0.0003
Unknown prenatal care	0.01213*	0.0003	0.0025*	0.0003
Used alcohol during pregnancy?	0.0008*	0.0002	-0.0007*	0.0002
Used tobacco during pregnancy?	0.00067*	0.0001	-0.0009*	0.0001
Birth weight dummies:				
500-999 g			-0.5191*	0.0011
1000-1499 g			-0.8175*	0.0011
1500-1999 g			-0.8581*	0.0010
2000-2499 g			-0.8762*	0.0010
2500-2999 g			-0.8820*	0.0010
3000-3499 g			-0.8833*	0.0010
3500-3999 g			-0.8838*	0.0010
4000-4499 g			-0.8835*	0.0010
5000-8165 g			-0.8796*	0.0013
Unknown			-0.6240*	0.0014
R-squared	0.003		0.325	
Observations	2,982,529		2,982,529	

* indicates p-value < .05.
Dependent variable = 1 if baby died within 28 days of birth. The omitted categories for race, education, prenatal care, and birth weight are: White, 0-8 years education, prenatal care in first trimester, and 0-500 grams respectively.

Table 3a: Neonatal Deaths in the U.S. per 100 Live Births, 1950-90

	1950	1960	1985	1990	Annual % Δ
<1000 g	87.2	91.3	57.2	48.3	-1.5%
1000-1499 g	55.1	52.2	10.5	6.7	-5.3
1500 1999 g	21.1	18.1	3.4	2.7	-5.2
2000 2499 g	5.0	4.1	1.1	0.8	-4.5
2500-2999 g	1.3	1.0	0.3	0.2	-4.1
3000-3499 g	0.7	0.5	0.2	0.1	-4.4
3500-3999 g	0.6	0.4	0.1	0.1	-4.9
4000-4499 g	0.8	0.4	0.1	0.1	-5.7
4500+ 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 3b: Neonatal Deaths per 100 Live Births in Massachusetts, 1972-94

	1972	1978	1982	1986	1990	1994	Annual % Δ
<1000 g	79.8	71.7	68.4	60.3	48.7	44.3	-2.7%
1000-1499 g	43.4	18.4	16.4	5.9	10.4	6.1	-8.9
1500 1999 g	12.5	5.4	5.2	2.5	1.8	2.0	-8.4
2000 2499 g	2.3	1.5	1.3	1.2	1.0	0.7	-5.4
2500-2999 g	0.5	0.4	0.3	0.3	0.2	0.2	-4.2
3000-3499 g	0.2	0.1	0.2	0.1	0.1	0.1	-6.5
3500-3999 g	0.2	0.1	0.1	0.1	0.1	0.1	-5.9
4000-4499 g	0.1	0.1	0.1	0.1	0.1	0.0	-8.7
4500+ g	0.2	0.2	0.2	0.4	0.1	0.2	-0.1

Sources: Based on Authors' Calculations using Massachussets Vital Statistics Data

Table 4: Explaining Improvements in Infant Mortality

Measure	U.S. 1950-90	Massachusetts 1972-94
Annual change in infant mortality	-3.1%	-5.0%
Contribution of:		
Change in birth weight distribution	-4.2%	4.5%
Birth weight-specific survival	107.1%	95.4%
<1500 g	35.2%	43.3%
1500-2500 g	31.3	23.9
2501+ g	40.6	28.1

Table 5: 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 pre-term 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 & nutrition of pre-term infants. For term babies, obstetric monitoring began in the 1960s.
1970s	There were major improvements in ventilators for pre-term 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 >70s, the edge of viability was at 1000 grams, 28-29 weeks By 1979, Prob[Death | bw=1000 g] ~ .90
1980s	Major innovations in the late 1980s include: Antenatal corticosteroid treatments to speed up maturation; tocolytics, or medication for delaying pre-term delivery (this 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 sub-specialties. By 1995, over 700 NICUs in North America. By 1999, the edge of viability is at 23-24 weeks (600-700 g). P[Death | weight=1000 g]=.10.

Table 6: Costs of Care for Low Birth Weight Births (in 1990 $)

Medical Costs	Study	Country	Birth Cohort	Birth Weight	Medical Costs per Live Birth
	Boyle et al. 1983	Canada	1973-76	< 1500 g	$28,725
	Office of Technology Assessment 1988	U.S.	1970's	< 2500 g	6,850
	Pomerance et al. 1978	U.S.	1970	< 1000 g	44,874
	Lewit et al. 1988	U.S.	1988	<1000 g	35,354
				1000-2499	11,048
				>=2500 g	2,099
	Rogowski 1998	U.S.	1986-87	< 1500 g	61,668
				<1000 g	67,766
				1000-1499 g	56,557

Table 7: Health Problems and Costs by Birth Weight, 1960 &1990

	Pr[Problems]		Average costs at birth		Annual Costs | Problems (without special ed.)	
	1960	1990	1960	1990	1960	1990
Pr[Problems] by birth weight						
< 1000 g	0.68	0.66	$0	$67,766		
1000-1499 g	0.68	0.28	0	56,557		
1500-2499 g	0.23	0.23	0	11,048		
2500+	0.01	0.01	0	2,099		
All Birth weights	0.033	0.028	$0	$3,330	$4136	$8,271
					($2,959)	($5,919)

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

Table 8: Age-adjusted measures of child health by birth weight
Sample of non-institutionalized children aged 0-17 from Health Interview Surveys, 1981 and 1988 Child Health Supplements

Outcome	1981	1988	% Δ 1981-88	t-stat
% SRHS=Excellent?				
< 1500 g	70.4%	70.8%	0.6	0.08
1501-2500 g	70.6	70.7	0.1	0.03
2501-4500 g	70.6	71.2	0.8	1.59
> 4500 g	70.6	71.5	1.3	0.37
% With Activity Limitation	in major activity	in usual activity		
< 1500 g	5.0%	14.0%	NA	
1501-2500 g	5.5	8.8	NA	
2501-4500 g	1.7	3.9	NA	
> 4500 g	3.4	5.2	NA	
# of Short-stay hospital days in last 12 months				
< 1500 g	0.310	0.285	-8.5	0.05
1501-2500 g	0.293	0.268	-8.8	0.23
2501-4500 g	0.327	0.333	1.7	0.49
> 4500 g	0.347	0.298	-15.0	0.95
# of Short-stay hospital episodes in last 12 months				
< 1500 g	0.053	0.055	2.7	0.52
1501-2500 g	0.055	0.052	-6.7	2.10
2501-4500 g	0.060	0.060	0.6	1.78
> 4500 g	0.061	0.055	-9.8	4.50
# of Doctor Visits in last 12 months				
< 1500 g	2.82	3.08	8.5	0.06
1501-2500 g	2.88	2.95	2.7	0.04
2501-4500 g	3.05	3.10	1.7	0.27
> 4500 g	3.00	2.94	-2.2	0.06
# of behavior problems on 32 point behavior index				
< 1500 g	0.74	0.74	1.0	0.03
1501-2500 g	0.77	0.80	3.0	0.11
2501-4500 g	0.73	0.72	-2.4	0.98
> 4500 g	0.81	0.79	-2.4	0.15
% Repeated Grade in School?				
< 1500 g	10.7%	8.6%	-21.6	2.94
1501-2500 g	10.5	9.7	-7.9	1.62
2501-4500 g	9.6	9.0	-6.5	12.02
> 4500 g	11.0	9.9	-10.5	4.42

Table 9: Cost Benefit Calculation Assuming Discount Rate = 0.03

		Birthweight				
		<1000	1000-1499	1500-2499	>=2500	
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 Birth Weight Infants						
		<1000	1000-1499	1500-2499	>= 2500 g	All lbw infants
1960-90	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%**
	[10,0% discount rates]	**[408, 1084]**	**[270, 3172]**	**[3, 924]**	**[7, 6037]**	**[46, 1022]**

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

Table 10: Cost effectiveness: Costs per QALY for selected medical interventions

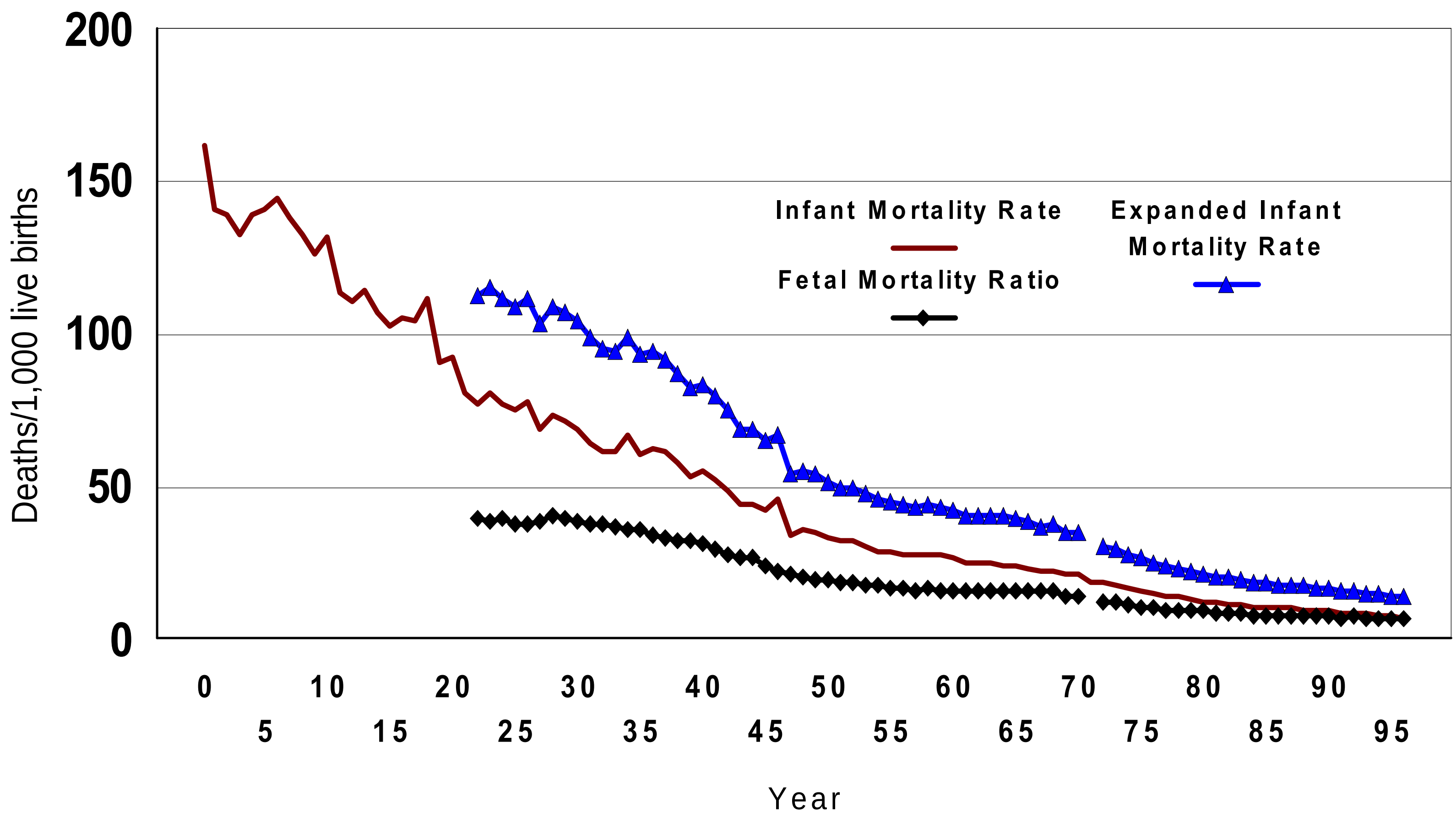
	Birth weight				
Intervention	<1000	1000-1500	1500-2500	>2500	All Weights < 2500 g
Neonatal Care	$6,101	$1,290	$3,833	$955	$3,726

Compared with other interventions	
Prenatal Care	Cost savings**
Influenza vaccination age < 3 years	$1,745
Neonatal Care for All LBW 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.

** Prenatal Care estimates based on the following: OTA, 1988 reports that prenatal care costs $380 ($453 in '90 $) and reduces p(LBW) by 50 %. Given a rate of LBW of 7%, this implies a 3.5 percentage point reduction in low birth weight, or an additional QALE of .27 for each newborn whose mother received prenatal care. Given the prevented cases of low birth weight, this reduces expected costs for a given child and so the net cost savings due to prenatal care is $4,214.

Figure 1: Infant mortality rates and fetal mortality ratios since 1900



Note: Expanded Infant Mortality = (Infant+Fetal Deaths)/(1000 Live Births+Fetal Deaths)

Fig. 2: Trends in Infant Deaths by Decade, 1950-95

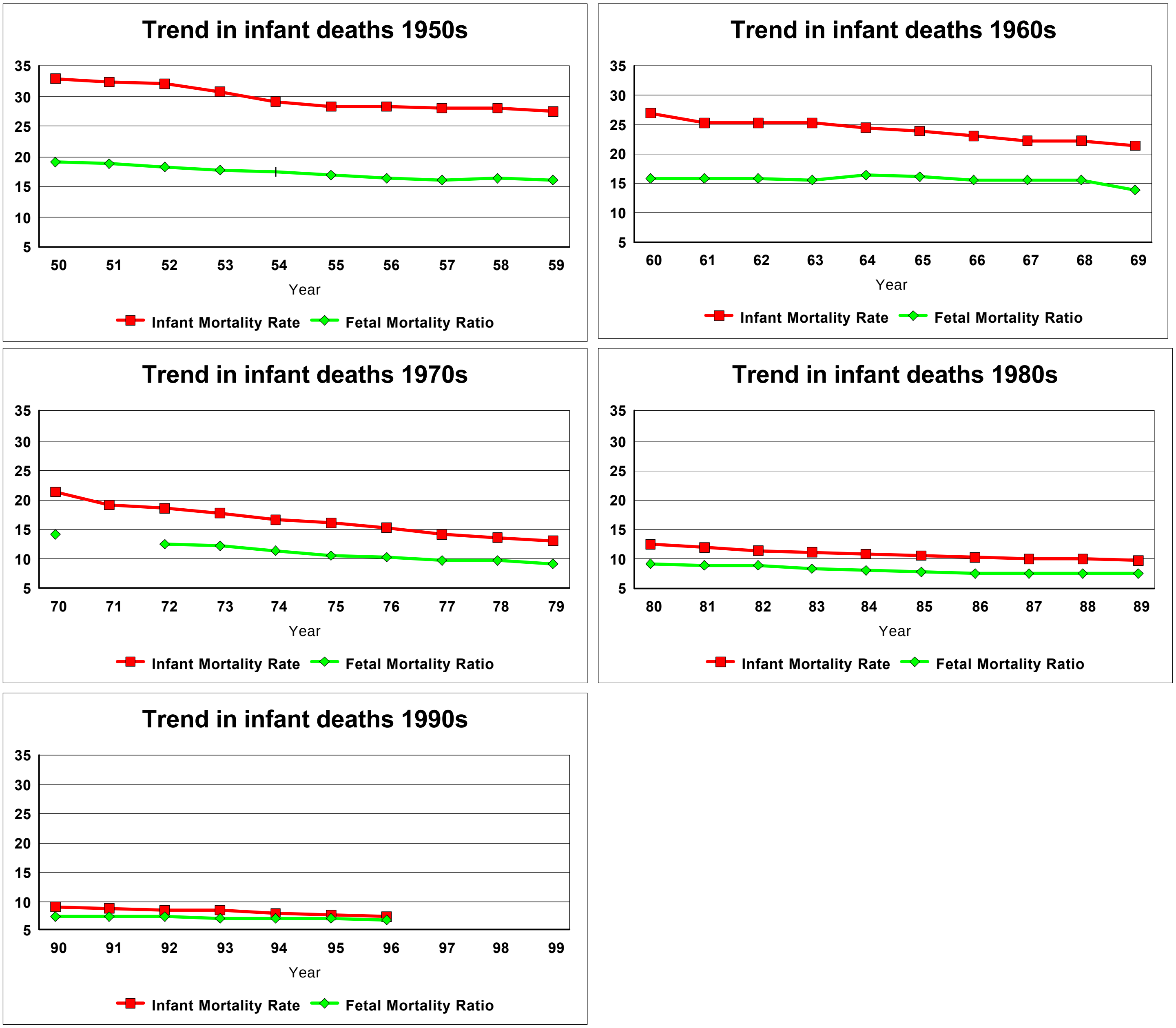
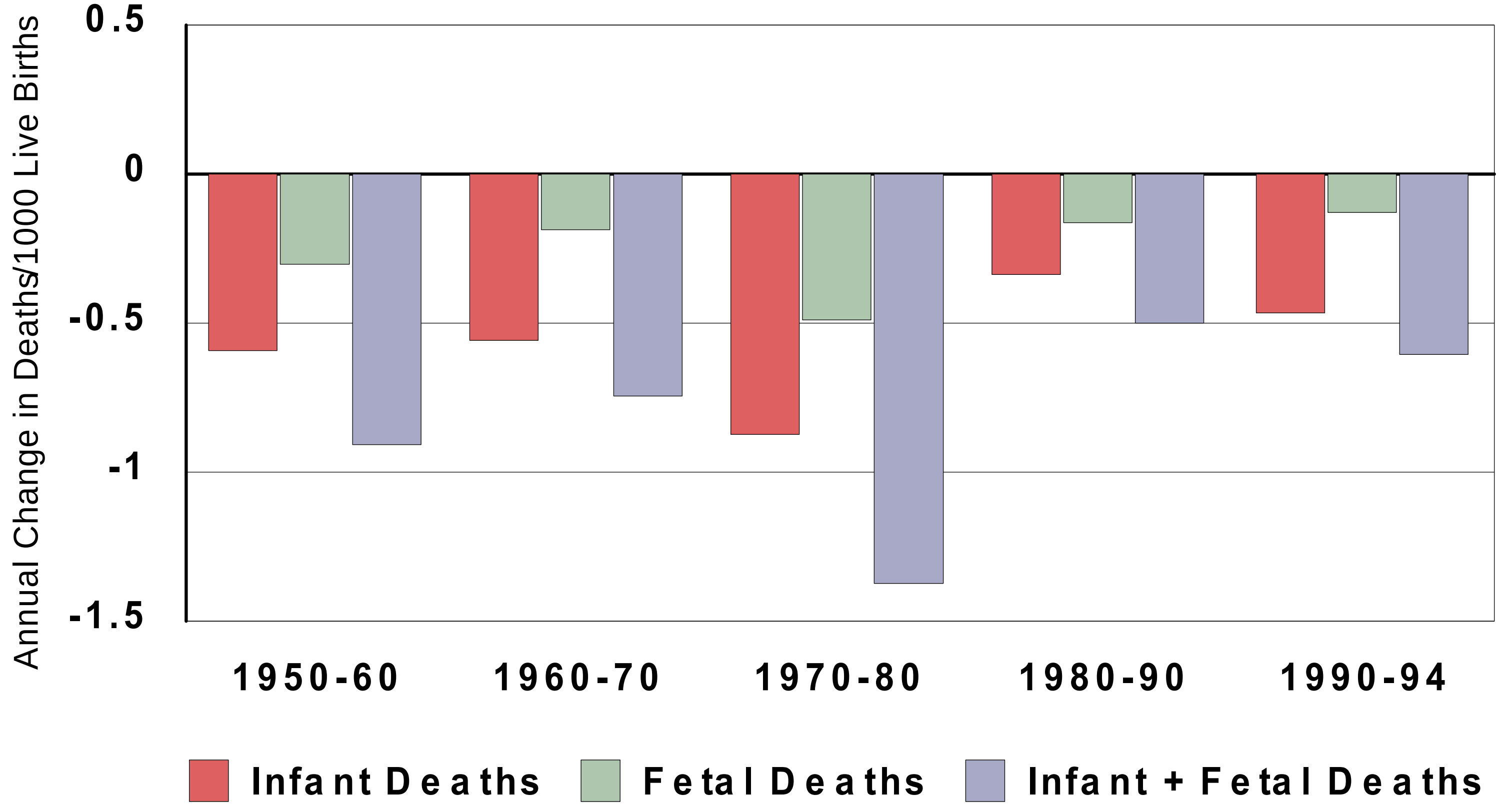


Fig. 3 Annual Changes in Deaths/1000 Live Births



Note: Infant Mortality Rate = Deaths < 1 year of age per 1,000 live births
Fetal Mortality Ratio = Fetal Deaths per 1,000 live births

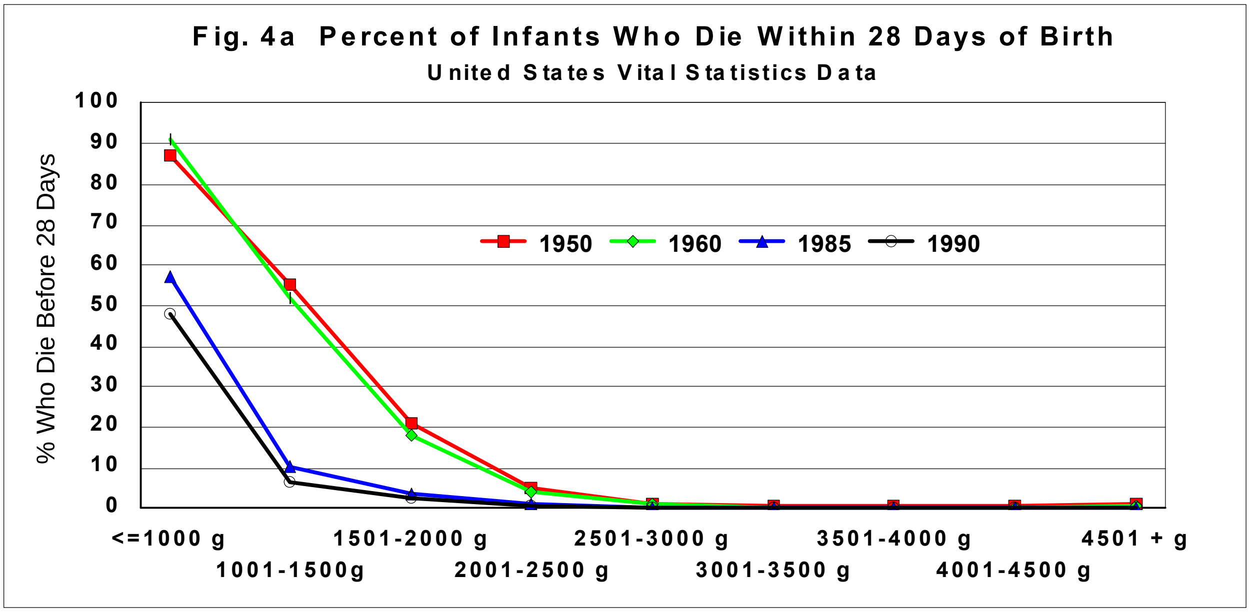


Fig. 4a Percent of Infants Who Die Within 28 Days of Birth
United States Vital Statistics Data
% Who Die Before 28 Days
100
90
80
70
60
50
40
30
20
10
0
1950
1960
1985
1990
<=1000 g
1001-1500g
1501-2000 g
2001-2500 g
2501-3000 g
3001-3500 g
3501-4000 g
4001-4500 g
4501 + g

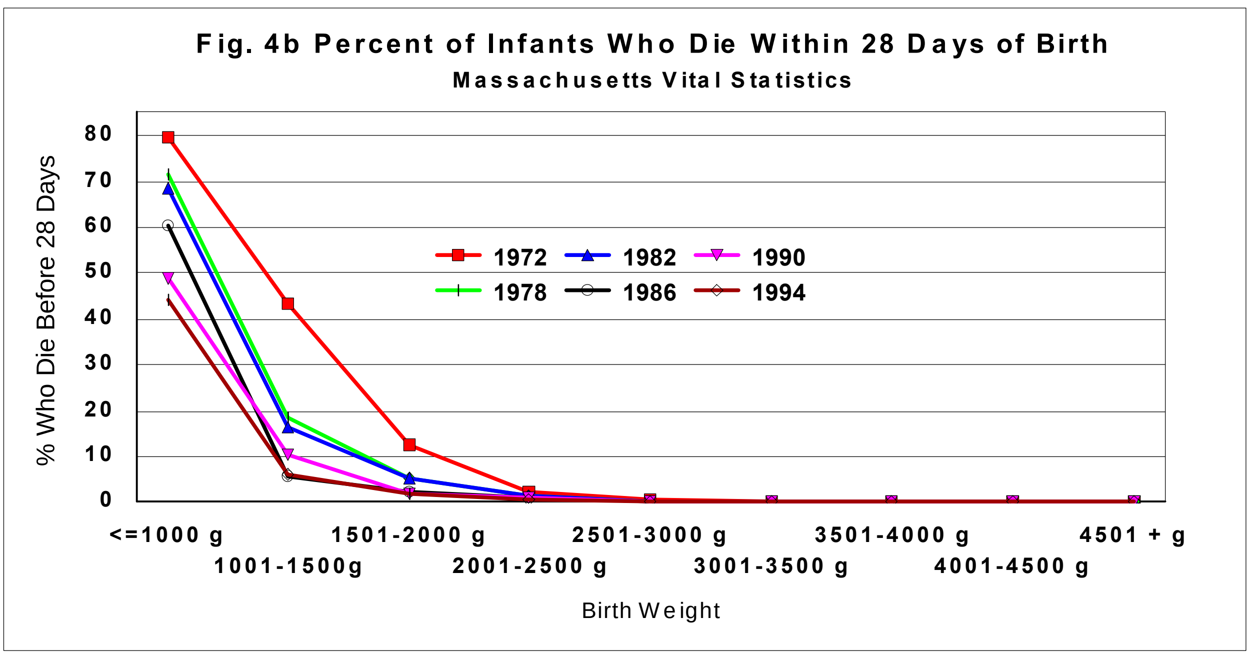
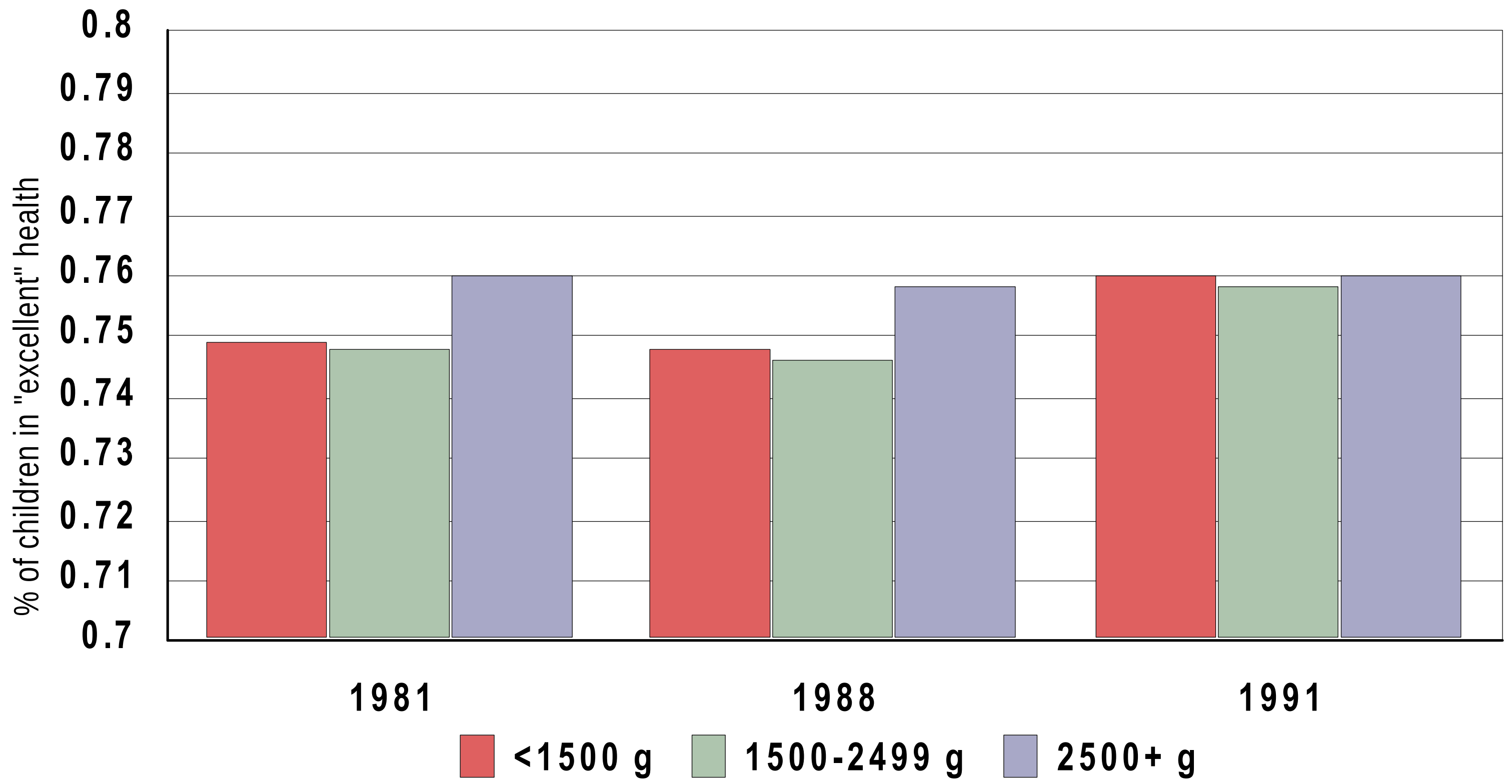


Fig. 4b Percent of Infants Who Die Within 28 Days of Birth
Massachusetts Vital Statistics
% Who Die Before 28 Days
80
70
60
50
40
30
20
10
0
1972
1982
1990
1978
1986
1994
<=1000 g
1001-1500g
1501-2000 g
2001-2500 g
2501-3000 g
3001-3500 g
3501-4000 g
4001-4500 g
4501 + g
Birth Weight

Fig. 5: Change in General Health Status by Birth Weight, 1981-91



Source: '81 and '88 data from the National Health Interview Survey Child Health Supplements
91 data from the National Maternal & Infant Health Survey Follow-up. Data are weighted to reflect population & age-adjusted by age in months to correct for differences in age distribution across samples.

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