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HEALTH AND THE EVOLUTION OF WELFARE ACROSS BRAZILIAN MUNICIPALITIES

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ABSTRACT

This paper describes the pattern of reductions in mortality across Brazilian municipalities between 1970 and 2000, and analyzes its causes and consequences. It shows that, as in the international context, the relationship between income and life expectancy has shifted consistently in the recent past. But reductions in mortality within Brazil have been more homogeneously distributed than across countries. We use a compensating differentials approach to estimate the value of the observed reductions in mortality. The results suggest that gains in life expectancy had a welfare value equivalent to 39% of the growth in income per capita, being therefore responsible for 28% of the overall improvement in welfare. We then use a dynamic panel to conduct a preliminary assessment of the potential determinants of these gains. We show that improvements in education, access to water, and sanitation seem to be important determinants of the dimension of changes in life expectancy not correlated with income.

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1 Introduction

This paper analyzes the causes and consequences of improvements in life expectancy across Brazilian municipalities between 1970 and 2000. We use a compensating differentials approach to give monetary values to life expectancy gains, and compare these gains to the evolution of income. Mortality reductions in the period had a welfare value equivalent to an increase of $1,800 in yearly income (1996 international prices), and therefore were responsible for 28% of the overall improvements in welfare. In an exploratory panel analysis, we show that a large part of the welfare gains from life expectancy seems to be attributed to improved access to treated water and sanitation, and reductions in illiteracy rates. In our estimates, these variables together with income explain 71% of the within municipality variation in life expectancy in Brazil. Nevertheless, in contrast to cross-country evidence (Bourguignon and Morrison, 2004 and Becker et al, 2005), reductions in mortality did not contribute to reduce overall welfare inequality.

Brazil experienced significant improvements in health in recent decades. Between 1960 and 2000, infant mortality rate before age 1 was reduced from 115 to 32 (per 1,000 live births), while life expectancy at birth increased from 55 to 68 years (World Bank, 2005). At the same time, income per capita measured in constant prices increased by roughly 190% (Penn World Tables 6.1). Though income was partially responsible for the improvements in health, amounting evidence suggests that a significant portion of recent changes in life expectancy across the developing world has been orthogonal to changes in income (Preston, 1975 and 1980, Becker et al, 2005, and Deaton, 2005, among others). Therefore, if life expectancy is a relevant dimension of welfare, its explicit incorporation in the evaluation of changes in well-being in Brazil, and the understanding of its determinants, become very important questions. Recent estimates suggest that longevity has indeed been a quantitatively important component of the overall gains in welfare during the twentieth century, both within and across countries.[1]

This paper looks at the extent and variation of life expectancy gains between 1970 and 2000 across Brazilian municipalities. We show that, as in the international context, there has been a consistent shift in the relationship between income and life expectancy at birth. For constant levels of income, gains in life expectancy in this thirty-year interval have been typically above 5 years. Nevertheless, the pattern and evolution of life expectancy inequality across Brazilian municipalities has been quite different from that observed across countries. The income gradient of life expectancy is less steep across Brazilian municipalities than across countries. In addition, gains in life expectancy have been more homogeneously distributed within Brazil than across countries, so that poorer areas did not gain as much in relation to rich areas as poor countries did in relation to rich countries.

In order to estimate the welfare implications of the extent and pattern of changes in life expectancy, we use a hypothetical life-cycle individual set up (Becker et al, 2005). Using the concept of compensating differentials, we estimate the monetary value of the gains in life expectancy observed in the period and evaluate their relative importance in terms of the overall gains in welfare. For our representative individual, reductions in mortality had a value corresponding to an increase of $1,800 in annual income, or 39% of the observed growth in income per capita. Nevertheless, given the profile of changes described before, mortality reductions did not contribute much to change overall welfare inequality, even though inequality in life expectancy itself was reduced. This was possible because the higher value attributed to mortality reductions by wealthier individuals was more than enough to compensate for the smaller gains they experienced. The inequality reducing role of life expectancy noticed in the cross-country context was not as relevant across different regions of Brazil.

Finally, we use a panel of 3,636 municipalities between 1970 and 2000 to conduct an investigative assessment of the role of public health infrastructure and education in determining the changes in life expectancy. We concentrate on the role of public health infrastructure and education because these are dimensions over which significant improvements have been registered. For example, according to our dataset (to be presented in the next section), the fraction of households with access to treated water connected to the public water system increased from 15% in 1970 to 63% in 2000, while illiteracy rates were reduced from 44% to 21%. We use the dynamic panel techniques developed by Arellano and Bond (1991) to evaluate the roles of education, provision of clean water, and sanitation. Changes in these three variables explain 38% of the within municipality variation in life expectancy in the sample (16% attributed to improved access to water, 6% to improved sanitation, and 16% to reductions in illiteracy

[1] See Cutler and Richardson (1997), Nordhaus (2003), and Murphy and Topel (2003) for US studies. Burström et al (2003) look at the case of Sweden and García-Verdú (2005) looks at the case of Mexico. Becker et al (2005) analyze the impact of life expectancy on the evolution of welfare inequality across countries.

rates), or 51% of the overall variation. For our representative individual, this implies that changes in access to water and illiteracy rates between 1970 and 2000 had a lifetime value of $7,500 each, only taking into account their effects on mortality. The equivalent number for improved sanitation was $2,800.

The paper contributes to the literature on health and development in two ways. First, we bring the discussion on the welfare value of health improvements – which has been mostly restricted to developed countries – to a developing country context. We show that the share of welfare gains due to health improvements in Brazil has been larger than that typically observed in developed countries. Nevertheless, in contrast to international trends, health improvements have not contributed to reduce overall welfare disparities within Brazil. Second, we add to the literature on the determinants of mortality reductions in the developing world (Preston, 1975 and 1980, Palloni and Wyrick, 1981, and Becker et al 2005). A large part of the gains in life expectancy in developing countries in the post-war period seems to be unrelated to growth in income or improvements in material living conditions. To a large extent, there is still no consensus on the specific factors responsible for these gains. We find that, in the case of Brazil, improvements in education and public health infrastructure seem potentially important in explaining a large part of the observed changes in life expectancy.

The structure of the remainder of the paper is outlined as follows. Section 2 describes the dataset used and discusses the recent pattern of changes in life expectancy and life expectancy inequality across Brazilian municipalities. Section 3 summarizes the methodology used to assess the economic value of life expectancy changes and applies it to our dataset. Section 4 discusses the determinants of life expectancy changes across Brazilian municipalities and estimates the role played by education, access to water, and sanitation. Finally, section 5 concludes the paper.

2 Data and Recent Trends

All the variables used in the remainder of the paper come from a municipality dataset constructed by the Instituto de Pesquisa Econômica Aplicada (IPEA, from the Brazilian Ministry of Planning), based on census files from 1970 to 2000.[2] Municipalities are the smallest

[2] The Brazilian censuses were conducted in 1970, 1980, 1991, and 2000. For simplicity and for the sake of symmetry, we refer to the 1991 census in the text as if it had taken place in 1990.

administrative units in the Brazilian political system.[3] The dataset contains a series of variables, including average household income per capita and life expectancy at birth, calculated at the municipality level. The detailed definition of the variables used in the paper and the description of the way they were constructed by IPEA is contained in the Appendix. A problem with the use of these data across different periods of time is that a large number of new municipalities was created in Brazil following the 1985 re-democratization and the writing of a new constitution in 1988. So the number of municipalities in the dataset changes from 3,952 in 1970 to 5,507 in 2000. Typically, this was the outcome of a process where regions of an existing municipality would demand emancipation, as a result of potential benefits from tax collection and redistribution of federal resources (for a thorough discussion, see Shikida, 1999).

We concentrate the analysis on municipalities that already existed in 1970 and ignore the newly created ones. Even though there is a large number of new municipalities (1,555), their importance in terms of population is minimal. The existing municipalities in 1970 account for roughly 90% of the Brazilian population in 2000. Given that our following descriptive analysis and discussion trusts on statistics weighted by municipality population, the newly created municipalities should have no impact on the results.[4]

Using this strategy, we generate the data on life expectancy at birth and income per capita presented in Table 1. For comparison purposes, the income data are normalized so that Brazilian income per capita in 1990 corresponds to the value from the Penn World Tables 6.1 (1996 international prices). The numbers presented here can therefore be immediately compared to the international evidence discussed elsewhere. The table contains the mean, standard deviation, minimum and maximum for life expectancy at birth and income per capita in Brazil, for 1970 and 2000.

The changes in the period are substantial. Income per capita increases by 170%, while life expectancy at birth rises by 16 years.[5] The extent of variation at a point in time reflects the

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[3] Each municipality is governed by a mayor and has a chamber of representatives. Brazilian municipalities are analogous to US counties.

[4] For the period between 1970 and 1990, when roughly one-third of the new municipalities had already been created, data are available for "minimal comparable areas," which are geographically defined areas kept constant throughout the period. Results obtained with the strategy described in the text for the period between 1970 and 1990 are virtually identical to those obtained using the "minimal comparable areas".

[5] This dataset generates average income and life expectancy numbers somewhat different from the ones obtained from the aggregated datasets widely used (such as the World Development Indicators and the Penn World Tables). Life expectancy in the municipality data is lower than in the aggregate data in 1970 and higher in 2000. In the case of income, the growth rate in the period is higher in the municipality data. The specific values for income come from

high degree of inequality in Brazilian society. In 2000, the minimum and maximum values of life expectancy and income are close to the extent of variation observed among poor and wealthy nations of the world (with the exception of the extreme poverty in Sub-Saharan Africa).[6] Income per capita in 2000 ranges from $986 in a municipality in the poor state of Alagoas (Northeast) to $25,018 in a municipality in the state of São Paulo (Southeast). Life expectancy at birth ranges from 55 years in a municipality in Maranhão (Northeast) to 78 in another municipality in São Paulo.

Despite the high degree of inequality at a point in time, and the persistence of income inequality at the individual level, the dispersion in income and health across Brazilian municipalities was reduced. Table 2 calculates several inequality measures for income per capita and life expectancy at birth across Brazilian Municipalities, in 1970 and 2000. By any measure, inequality in income and life expectancy decreases considerably. The regression to the mean coefficient implies that a municipality 100% richer in 1970 experienced income gains on average 16% lower in the following 30 years. In the case of health, municipalities with life expectancy 10 years higher in 1970 experienced gains in life expectancy on average 3.7 years lower between 1970 and 2000.

It is important for our later discussion to highlight some patterns that arise from this table. First, inequality in life expectancy is lower across Brazilian municipalities than across countries. According to any of the measures used, the extent of life expectancy inequality in 2000 within Brazil is only 40% of that observed across countries (comparing numbers from Table 2 with the results presented in Becker et al, 2005). On the other hand, the degree of regression to the mean in life expectancy and the relative reduction in inequality within Brazil are lower than those observed across countries between 1960 and 1990 (we use this period for comparison because, after 1990, the effects of AIDS in Sub-Saharan Africa take over the trend of mortality inequality across countries). The different indexes of life expectancy inequality across Brazilian municipalities are reduced between 40% and 46% in the thirty years in question, while the degree of regression to the mean is -0.37. Across countries, between 1960 and 1990, the different

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the fact that we normalize the data so that income per capita in 1990 is equal to the value from the Penn World Tables 6.1 for that same year.

[6] To give a standard of comparison with Table 2, the Gini coefficient for income per capita across countries in 2000 was 0.49, while it was 0.07 for life expectancy (weighted by population); the standard deviation of logs for that same year was 0.96 for income per capita, and 0.15 for life expectancy (Becker et al, 2005). Income inequality across countries remained stable between 1960 and 1990, and then decreased slightly between 1990 and 2000.

indexes of inequality are reduced between 47% and 57%, and the regression to the mean coefficient is -0.61.

This observation is particularly relevant because the difference in the profile and evolution of life expectancy inequality within and across countries may reveal something about the nature of mortality reductions. When compared to international numbers, the evidence from Brazil suggests that reductions in mortality were more homogeneously distributed across the country's municipalities. In principle, improvements that had similar impacts in the different regions of the country may have played an important role in determining the observed gains in life expectancy. We explore this point further by looking at how changes in the relationship between life expectancy and income in Brazil compare to those observed across-countries.

Figure 1 plots the cross-sectional relationship between income per capita and life expectancy at birth for Brazilian municipalities, in 1970 and 2000. Since our focus at this point is on how life expectancy varies within Brazil and how this pattern differs from its variation across countries, rather than on the evolution of life expectancy through time, we renormalize the numbers such that the statistics are strictly comparable to international aggregate data at each point in time (this renormalization applies only to Figures 1 and 2). In other words, income per capita and life expectancy in both years are normalized such that the averages for Brazil in the municipality data correspond to the aggregate numbers from the WDI (for life expectancy) and from the PWT 6.1 (for income per capita adjusted for terms of trade). Therefore, the average levels in the figures correspond to the values observed in the aggregate data, but the relative variation within Brazil corresponds to that observed in the municipality data. Figure 1 shows a shift in the cross-sectional relationship between income and life expectancy that is similar to that observed in cross-country data. In the case of Brazil, for constant levels of income, life expectancy has typically risen by more than 5 years. This means that at least 55% of the improvements in life expectancy in Brazil during these thirty years seem to be unrelated to gains in income per capita. This result is even stronger than that observed across countries between 1970 and 2000, partly because of the effect of AIDS in Sub-Saharan Africa.

But the pattern observed within Brazil is also different in one particularly important respect. In the relevant range, the relationship between income and life expectancy is much steeper in the international data than in Brazil. Figure 2 explores this point by plotting the logarithmic curves summarizing the relationship between these two variables in Brazil and across countries, for the years 1970 and 2000. In both years, the effect of income on life expectancy at birth is much more pronounced across countries than across Brazilian municipalities. The difference in slope is so large that in both years the two curves end up crossing each other at income levels somewhat above the respective Brazilian income per capita (the curves cross each other at $6,000 in 1970 and $10,000 in 2000). This result is consistent with the idea that there is a dimension of variation in the determinants of health across countries that is held constant within a country. Similar evidence is available for Mexico, where the income-life expectancy profile across states in 1970 is remarkably similar to that estimated here for Brazilian municipalities, while the 1995 relationship is even flatter than that observed in Brazil in 2000 (see García-Verdú, 2005).

Later on, we estimate the role of some potential candidates in explaining this pattern of change. But first, in the following section, we evaluate the relative importance of income and mortality in terms of the overall improvements in welfare observed in the period.

3 Welfare Gains from Mortality Reductions

3.1 Methodology

The methodology used in this section is a simplified version of that proposed by Becker et al (2005). Consider the indirect utility function $V(Y,T)$ of an individual with lifetime T and lifetime income Y:

$$V(Y,T) = \max_{\{c(t)\}} \int_0^T e^{-\rho t} u(c(t))dt \quad \text{subject to} \quad Y = \int_0^T e^{-rt} y(t)dt = \int_0^T e^{-rt} c(t)dt, \tag{1}$$

where $y(t)$ is income at age t, $c(t)$ consumption at t, r is the interest rate, and ρ is the subjective discount factor. This budget constraint assumes the existence of perfect capital markets.

Now consider a given individual at two points in time, with lifetime income and life expectancy denoted by Y and T, and Y' and T' respectively. We are interested in the infra-marginal income $W(T,T')$ that would give a person the same utility level observed in the second period, but with the life expectancy observed in the first period:

$$V(Y'+W(T,T'),T) = V(Y',T'). \tag{2}$$

Income per capita can be used to measure material improvements only with a set of assumptions that justify using a single number to portray changes in a country's welfare. Similar simplifying assumptions are needed here to measure the monetary value equivalent to certain gains in life expectancy. More precisely, to use the model with commonly available income per capita and life expectancy statistics for a given municipality and year, we define a *hypothetical life-cycle individual*. This is a representative individual who receives the municipality's income per capita in all years of life and lives to the age corresponding to the municipality's life expectancy at birth. In order to implement this concept in a simple way, we assume that the subjective discount rate is equal to the interest rate ($\rho = r$), so that optimal consumption is constant and equal to the constant flow of income ($c(t) = c = y$). In this case, the indirect utility function can be expressed in terms of yearly income y as:

$$V(y,S) = u(y)A(T) \tag{3}$$

where $A(T) = (1 - e^{-rT})/r$. Define $w(T,T')$ as the yearly – as opposed to lifetime – income that measures the gain in longevity in a manner similar to before. Therefore, w satisfies

$$u(y'+w(T,T'))A(T) = u(y')A(T'). \tag{2'}$$

In this context, the monetary value of the overall gain in welfare observed in the period, when measured in terms of yearly income, can be denoted as $(y' - y) + w$. The equivalent lifetime value is simply the present discounted value of this annual flow of income. And the contribution of health to the overall gain in welfare is the fraction $w/[(y' - y) + w]$.

If we can invert the instantaneous utility function $u(.)$, w can be written as:

$$w = u^{-1}\left[\frac{u(y')A(S')}{A(S)}\right] - y'. \tag{4}$$

The interpretation of w in this context is straightforward. For a given municipality at a point in time, it tells us the value that an individual being born in that moment – earning the average income of the municipality in every period of life and living with certainty to an age equal to the municipality's life expectancy at birth – would attribute to a change in life expectancy from T to T'. By definition, w measures this value as a yearly flow of income.

As stressed by Rosen (1988), two dimensions of the instantaneous utility function affect the willingness to pay for extensions in life expectancy. The first is the substitutability of consumption in different periods of life, i.e. the inter-temporal elasticity of substitution, and the second is the value of being alive relative to being dead. We calibrate the following functional form for the instantaneous utility function to capture these two different dimensions:

$$u(c) = \frac{c^{1-1/\gamma}}{1-1/\gamma} + \alpha. \tag{5}$$

The parameter α determines the level of annual consumption at which the individual would be indifferent between being alive or dead, arising from the normalization of the utility of death to zero. If the inter-temporal elasticity of substitution γ is larger than 1, then α is negative. With expression (4) and this functional form, we obtain a closed form solution for w.

The set of parameters (α, γ, r) needed to compute w can be calibrated from other parameters more commonly estimated in the "value of life" and consumption literatures. More precisely, we have that $\alpha = c^{1-1/\gamma}\left(\frac{1}{\varepsilon} - \frac{1}{1-1/\gamma}\right)$, where $\varepsilon = \frac{u'(c)c}{u(c)}$ is the elasticity of the instantaneous utility function, often discussed and estimated in empirical studies of compensating differentials for occupational mortality risks (see Murphy and Topel, 2003, for example).

We employ the same parameter values suggested by Becker et al (2005), where $\gamma = 1.25$ and $\alpha = -16.2$. As the authors, we also assume the annual interest rate r to be 0.03. In the case of Brazil, these calibrated parameters lead to an implicit value of a statistical life equal to roughly \$310,000. Corbi et al (2006) obtain estimates of the value of a statistical life in Brazil ranging from \$270,000 to \$1,700,000 (expressed in 1996 dollars adjusted for terms of trade). Therefore, our calibrated parameters imply a value of a statistical life that is well in the lower range of available estimates for Brazil.[7] Similarly, our implicit value of a statistical life is also in the lower range of estimates available for other developing countries, such as India, South Korea and Taiwan (see discussion in Viscusi and Aldy, 2004). If anything, our calculations will give conservative estimates of the value of changes in life expectancy.

3.2 Results

The results are presented in Table 3, organized by state averages (weighted by population). Statistics for life expectancy and income are presented for 1970 and for the variation between 1970 and 2000. The last three columns contain the value of life expectancy gains measured in annual income, the present value of these gains, and the share of these gains in the total welfare improvements observed in the period.

[7] As noted by Becker et al (2005), the functional form adopted is extremely flexible, so that the income-elasticity of the willingness to pay for gains in life expectancy changes substantially with income. In this sense, as the evidence discussed above confirms, the calibration does not seem to impose a willingness to pay value that does not belong to less-developed countries.

As noted before, there were substantial improvements in both income and life expectancy in Brazil between 1970 and 2000. The table shows that the welfare gains derived from life expectancy improvements were comparable in magnitude to the gains derived from income growth. The share of health in the total gains in welfare varies from 22% to 35%. As in the cross-country case, initially poorer regions tended to have a larger fraction of the overall welfare gains attributable to health. But, in this case, the dispersion in the magnitude of life expectancy changes is much smaller than that observed across countries. Life expectancy gains in the period varied from 13 to 22 years, with the vast majority of states being in the even narrower range between 13 and 17 years.

As in the international case, the income dimension is an important determinant of the absolute value of life expectancy improvements. The highest values of life expectancy gains – as measured by yearly income – are around $3,000 and are observed in states that were relatively wealthy in 1970 (Distrito Federal, Rio de Janeiro, and São Paulo). These, as well as other Southern Brazilian states (Rio Grande do Sul and Santa Catarina), reach the end of the period with life expectancy numbers above 70 years, close to the levels currently observed in some developed countries. In any case, for all the different regions of the country, gains in life expectancy represented a significant share of the welfare improvements registered between 1970 and 2000. On average, they increase the estimated gains in welfare by roughly 39%, when compared to the growth in income per capita alone.

Nevertheless, the pattern of initial income inequality, and of homogeneous gains in life expectancy, is such that the reduction in life expectancy inequality does not affect substantially the evolution of welfare inequality. Table 4 calculates the same indexes of inequality presented in Table 2 for our measure of "full-income." This measure is defined as the income level that would have been observed in 2000 if all the welfare improvements between 1970 and 2000 had taken the form of income growth. Table 4 shows that the evolution of "full-income" inequality between 1970 and 2000 is remarkably similar to the evolution of income inequality. This is possible because, despite a reduction in life expectancy inequality, the value of changes in life expectancy is higher for relatively wealthier municipalities. Therefore, contrary to the cross-country case, life expectancy changes did not contribute to reduce overall welfare inequality across Brazilian municipalities. A high degree of initial income inequality, coupled with a more or less homogeneous gain in life expectancy, led to a situation where mortality reductions had an important impact on welfare levels, but no significant impact on welfare distribution. Following, we conduct a preliminary investigation of the determinants of these gains in life expectancy.

4 The Determinants of Mortality Reductions

4.1 Previous Evidence and Methodology

Previous papers have analyzed the determinants of mortality variation across regions of Brazil, finding important roles for some dimensions of public health provision. Merrick (1985), Macinko et al (2005), and Alves and Beluzzo (2004), for example, analyze various different aspects of the reductions in mortality in Brazil during the last decades. Among these papers, this section is closest in spirit to the work of Alves and Belluzzo (2004). As these authors, we analyze the period between 1970 and 2000 and make use of municipality level data, but we expand the analysis in other ways by: looking at life expectancy and child mortality; exploring the independent roles of sanitation and access to clean water; dealing with the dynamic panel in a more appropriate way; and accounting for a broader set of controls. Finally, we also use the results from the previous section to estimate the economic value of the observed improvements in sanitation, access to water, and literacy rates.

From the same municipality dataset discussed before, we obtain data on: percentage of households with access to piped water connected to the public water system; percentage of households with access to sanitation connected to the public sewer system; percentage of illiterate people in the population; degree of urbanization (fraction of population residing in urban areas); and child mortality rate before age five (see Appendix for details). Changes in public health infrastructure and education since 1970 have been quite substantial. The proportion of households with access to water connected to the public water system increased from 15% in 1970 to 63% in 2000, while the percentage of households with sanitation connected to the public sewer system raised from 5% to 28%. At the same time, the percentage of illiterate people in the population was reduced from 44% to 21%. For illustrative purposes, Table 5 presents descriptive statistics for all the variables used in our statistical analysis (simple averages restricted to the sample actually used in the regressions).

All municipalities for which these variables are available for 1970, 1980, 1990, and 2000 are included in the analysis. This leaves us with a sample of 3636 municipalities, and a total of 14544 observations. Our goal is to estimate the impact of each of these factors on the changes in life expectancy observed between 1970 and 2000. Therefore, we adopt the following baseline specification:

$$\textit{life expectancy}_{i,t} = \alpha_0 + \alpha_1.\textit{life expectancy}_{i,t\text{-}10} + \beta.X_{i,t} + \varepsilon_{i,t}, \qquad (6)$$

where i refers to municipality and t to time period, and $X_{i,t}$ is a vector of municipality characteristics including the variables of interest (access to water, sanitation and illiteracy rate) and other controls. We include a lagged dependent variable in the baseline specification to account for the sluggish response of health to changes in health inputs, given that health outcomes in a certain period depend on the stock of health human capital accumulated before (as suggested, for example, by Grossman, 1972). We also replicate the preferred specification of our empirical exercise using child mortality as the dependent variable, and run some alternative specifications in order to better understand the driving forces behind the results.

The main limitation of the dataset is that it leaves out early childhood immunization and access to other medical services. We therefore include income per capita and urbanization in $X_{i,t}$ as additional controls, to take into account factors known to be correlated with these variables and also with changes in mortality. These include, among others, nutrition, access to public medical care and, to some extent, immunization coverage. As long as populations in wealthier or more urbanized municipalities have better medical support or easier access to services, we will be partly controlling for these factors.

As in the cross-country context, the main concerns in this type of estimation are unobserved municipality specific characteristics and endogeneity of right hand side variables. In order to address the first of these problems, and to capture nation wide changes, we allow for both municipality and time specific factors in the random term, such that $\varepsilon_{i,t} = \theta_i + \gamma_t + u_{i,t}$. To deal with the inconsistency of the fixed-effects estimator in the presence of lagged dependent variables, and to partially address the issue of endogeneity, we resort to the Arellano-Bond dynamic panel estimator (Arellano and Bond, 1991).

There are two reasons why one should be concerned about endogeneity in this context. First, non-observed municipality-specific shocks may lead to simultaneous changes in all of these variables, even in the absence of any causal relationship. Specifically, development may bring together increases in life expectancy, income, access to water, sanitation, urbanization, and education. As mentioned before, we partly control for this possibility by including income per capita and degree of urbanization as independent variables. Second, it is reasonable to expect that some of these variables may respond directly to life expectancy. This would be the case if governments responded to poor health conditions in certain areas by constructing new water and sewer systems. This type of reverse causality would lead to underestimation of the impact on life expectancy of exogenous changes in access to water and sanitation.

The use of the Arellano and Bond (1991) dynamic panel technique partially deals with these problems to the extent that it does not explore simultaneous correlations between dependent and independent variables. The method estimates the dynamic fixed-effects model by differencing the data, and then using lagged levels of the dependent, predetermined, and endogenous variables to instrument for the differences in the right hand side variables (when there are strictly exogenous variables, their lagged differences are also used as instruments). We treat the variables in $X_{i,t}$ as endogenous and apply the standard procedure for this case (use $t-2$ lagged levels as instruments for the endogenous variables).[8] Nevertheless, we cannot expect this technique to take care of all dimensions of endogeneity in the data in an entirely satisfactory way, even more so in the absence of a strictly exogenous variable. So we see our estimates simply as an initial effort in the direction of trying to understand the causal determinants of reductions in mortality across Brazilian municipalities.

4.2 Results

The results of the estimation are presented in Table 6. For illustrative purposes, columns 1 and 2 present the OLS regression in the pooled data and the fixed-effects estimator. Column 3 presents the standard Arellano-Bond estimator with one lag of the dependent variable included in the right-hand side. The comparison of the coefficients of $Life_{-1}$ in the OLS, fixed effects, and Arellano-Bond estimators gives support to the use of the dynamic model: in such setting, the OLS estimate should be biased upward and the fixed-effects should be biased downward (Bond, 2002). But the standard Arellano-Bond estimator with only one lag of the dependent variable does not satisfy the Sargan test of over-identifying restrictions. Therefore, we include a second lag of the dependent variable ($Life_{-2}$) in the specification, as shown in column 4, and use three-period lagged levels as instruments.[9] Columns 5 to 7 maintain two lags of the dependent variable

[8] Mobarak et al (2004) show that provision of health services in Brazil depends to some extent on political considerations, suggesting that there is a dimension of change exogenous to the health conditions.

[9] Specifically, $X_{i,t}$ is assumed to be correlated with $\varepsilon_{i,t}$ and earlier shocks, but not with $\varepsilon_{i,t+1}$ and subsequent shocks. So, in the case of one lag of the dependent variable included in the right-hand side, the levels of $X_{i,t-2}$ and *life expectancy*$_{i,t-2}$ are valid instruments in the first-differenced version of equation 6. When two lags of the dependent variable are included in the right-hand, $X_{i,t-3}$ and *life expectancy*$_{i,t-3}$ are the instruments. The method also assumes

in the right-hand side of the regression, but change slightly the specification to shed some light on the results: column 5 excludes income per capita as an explanatory variable; column 6 includes interactions of the initial level of income with sanitation and access to water; and column 7 uses child mortality as the dependent variable.

In columns 1 to 4, as additional lags of the dependent variable are included and increasingly higher lags of the independent variables are used as instruments, the coefficients on access to water, sanitation, and illiteracy rates increase in magnitude. This should be the case if the main problem of endogeneity is related to the response of governments to poor health conditions. In this situation, higher lags of the independent variables represent increasingly exogenous variation, and therefore an increase in the coefficient of the variables of interest indicates that there was a downward simultaneity bias.

Quantitatively, the estimated effects are quite large. Based on column 4, a fifty percentage points increase in the fraction of households with access to treated water is associated with a 2.4 year gain in life expectancy at birth in the sort-run, and 3.8 in the long-run. For access to sanitation, these numbers are 1.3 in the short run and 2.1 in the long-run. In the case of illiteracy rates, a reduction of fifty percentage points is associated with an increase of 5.4 years in life expectancy at birth in the short-run, and 8.5 years in the long run.

In terms of the extent of variation actually observed in the sample, the short term impact of income, access to water, sanitation, and illiteracy can explain 72% of the within municipality variation in life expectancy. According to the coefficients in column 4, 38% of the within municipality variation in mortality can be attributed to variations in access to water, sanitation, and illiteracy rates (16%, 6%, and 16%, respectively). The short run impact of these three variables explains 50% of the overall variation in life expectancy (94% if we also account for income per capita). Finally, the estimated dynamics of life expectancy implies that the long-run effects should be 57% higher than the short run effects discussed above. It is therefore likely that the effects of improvements in public health and education between 1970 and 2000 will continue to be felt in years to come.

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that the $u_{i,t}$ are serially uncorrelated (for a detailed discussion, see Bond, 2002). Since we use two lags of the dependent variable in the right-hand side and use additional lags of levels as instruments, we are simply unable to explicitly test for autocorrelation in the residuals. But we do believe that, given the dynamic structure of the estimated model, this should not be the main concern in the final specification.

Our results are remarkably similar to those obtained in a series of cross-country studies (see, for example, Preston, 1980, Palloni and Wyrick, 1981, and Heuveline, 2001). These studies have generally found that, during the post-war period, changes in income and nutrition can explain at most 50% of the variation in mortality across countries. We find here that income per capita explains 42% of the variation in mortality across Brazilian municipalities. In addition, we show that changes in education and public health infrastructure explain almost all the residual variation in life expectancy. Preston (1980) hypothesized that the estimated effect of income in the cross-country context also captured variations in provision of public health infrastructure associated with economic development. Therefore, he excluded these factors from what he called "structural" determinants of life expectancy (those not associated with changes in income per capita). Our results show that, in the within country context, there is a significant dimension of change in public health infrastructure that is orthogonal to changes in income.

Columns 5 to 7 introduce some changes to our main specification, in order to clarify the type of variation that is driving the results. First, in column 5, we exclude income per capita from the regression. Since variations in health infrastructure and education may be correlated to growth, income may be capturing part of the effect that is in reality attributable to our variables of interest. The coefficients estimated for water and sanitation remain surprisingly stable, while the coefficients on illiteracy and urbanization drop substantially in magnitude. So it seems to be the case that changes in education uncorrelated with income are much more important determinants of life expectancy than changes in education correlated with income. In any case, the presence of income per capita in our main specification does not seem to introduce any sizable bias towards zero in the coefficients of interest.

In column 6, we introduce interactions between the public health measures and initial income, to test whether these changes were particularly important for areas that were initially poor. Though the coefficient on access to water ceases to be significant, the estimated average effects (taking into account the interaction term and the average for income per capita in 1970) remain within the same order of magnitude of the coefficients estimated in column 4. In terms of the interaction terms, only the one for sanitation is negative and significant, meaning that poorer areas in 1970 benefited more from expanded access to sanitation than wealthier areas. In the case of access to water, the interaction is positive and not statistically significant.

Finally, in column 7, we use child mortality as the dependent variable. Both reductions in child and adult mortality have been important in the case of Brazil after 1970, but they may have responded differently to the factors analyzed in this section.[10] According to the results, illiteracy is the variable most closely related to child mortality. Alone, its short-run impact can explain 29% of the overall variation in child mortality in the sample, and its long-run impact is estimated to be more than 100% larger than the short-run effect. This result is in line with a vast array of evidence linking child health to education, particularly maternal education, in the context of developing countries (see, for example, review in Hobcraft, 1993).

5 Concluding Remarks

This paper shows that the income-life expectancy profile across Brazilian municipalities has been shifting consistently throughout recent decades. For constant levels of income, life expectancy rose by more than 5 years between 1970 and 2000. Though this evidence reproduces the pattern observed internationally, the income-gradient of life expectancy within Brazil is much less pronounced than that across countries. Similarly, the gains in life expectancy have been more homogeneously distributed across municipalities than across countries.

We calculate that, between 1970 and 2000, reductions in mortality had a welfare value corresponding to 39% of the observed growth in income. Our initial effort in the direction of understanding the determinants of these changes suggests that improvements in education, access to treated water, and sanitation played an important role. Bringing together the results from sections 3 and 4, we can estimate the per capita value of the improvements in health infrastructure for our representative individual. The results imply that improvements in access to water and education had a lifetime value of $7,500 each, while improved sanitation had a value of $2,800. When compared to the income per capita in Brazil, these numbers imply that an individual born in 1970 would be willing to pay the following proportions of one year's income in order to finance the improvements registered between 1970 and 2000: 248% for either access to water or education, and 93% for sanitation (lifetime values). Still, since there are many other dimensions through which these same factors increase welfare, these are likely to be lower

[10] Child mortality before 5 was reduced from 135 to 38 per 1,000 live births, while female mortality between 15 and 60 was reduced from 186 to 136 per 1,000 adult females (World Development Indicators). There was a recent increase in male adult mortality after 1990 due to increased number of violent deaths.

bounds for the true economic value of the observed improvements in public health infrastructure and education.

Finally, given that initial income inequality across Brazilian municipalities was very high and that life expectancy gains were more or less homogeneous, changes in mortality did not contribute to reduce overall welfare inequality. In Brazil, life expectancy had a significant impact on the level of welfare, but it did not play the same role in reducing welfare inequality as it did across countries.

Appendix: Variables

The municipality level variables used in the paper were constructed by the Instituto de Pesquisa Econômica Aplicada (IPEA, from the Brazilian Ministry of Planning), based on census files from 1970 to 2000. Given the change in the number of municipalities in the period, variables are originally calculated for the period between 1970 and 1991, and separately for the period between 1991 and 2000. In order to obtain a single consistent series for the municipalities that already existed in 1970, we apply the percentage change between 1991 and 2000 to the series starting in 1970. The variables are defined in the following way:

access to sanitation: fraction of population living in households with adequate sanitation (sanitation connected to the public system);

access to water: fraction of the population living in households with adequate supply of water (water supply connected to public water system);

child mortality rate: number of deaths between birth and the age of 5, per 1,000 live births; calculated based on information on number of births and number of surviving children, using an adapted version of the Brass technique (Brass et al, 1968), as explained in Horta et al (1998);

illiteracy rate: fraction of the population above 15 years of age who are illiterate (cannot read or write a simple message);

income per capita: average household income per capita;

life expectancy at birth: expected years of life at birth; constructed based on an adapted version of the indirect methodology of the Brass technique (Brass et al, 1968), as explained in Horta et al (1998); the Brass technique for life expectancy at birth uses information on number of births and surviving children for the estimation of child and juvenile mortality rates, and then uses model life tables to obtain other age specific mortality rates; the application of the technique to Brazilian municipalities is discussed in detail in Horta et al (1998); and

urbanization: fraction of the population residing in an urban area.

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Table 1: Descriptive Statistics, Income and Life Expectancy, Brazil, 1970-2000

	Income per Capita		Life Expectancy	
	1970	2000	1970	2000
Mean	3,013	8,160	52.9	69.3
Std Dev	2,280	4,676	4.8	3.7
Min	271	986	36.7	55.2
Max	11,050	25,018	67.8	78.2

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Life expectancy is life expectancy at birth. Statistics weighted by municipality population.

Table 2: Evolution of Cross-Municipality Inequality in Income and Life Expectancy, Brazil, 1970-2000

	Income per Capita		Life Expectancy	
	1970	2000	1970	2000
Relative Mean Dev	0.3035	0.2329	0.0370	0.0201
Coeff of Variation	0.7566	0.5730	0.0903	0.0539
Std Dev of Logs	0.7615	0.6695	0.0927	0.0556
Gini Coeff	0.4130	0.3289	0.0513	0.0290
Regression to the Mean over Previous Date		-0.1623 (p-value=0.00)		-0.3713 (p-value=0.00)

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Life expectancy is life expectancy at birth. Inequality measures weighted by municipality population (abstracting from within inequality). Regression to the mean is the coefficient of a regression of the change in the variable over the period on its initial level (natural logs used in the income regressions; weighted regressions).

Table 3: Income Life Expectancy and Value of Life Expectancy Gains; 1970-2000; Brazilian States

State	Life exp 1970	Income per capita 1970	Gain in life exp, 1970-2000	Gain in income, 1970-2000	Value of life exp gain in yearly inc.	NPV of life exp gains	Health share in welfare gains
Acre	50.8	1,944	15.9	2,586	931	24,365	26%
Alagoas	48.4	1,421	15.5	1,613	626	16,086	28%
Amapa	54.9	2,310	13.0	3,584	1,055	28,379	23%
Amazonas	51.4	2,104	14.6	1,569	714	18,828	31%
Bahia	48.4	1,713	16.1	1,994	1,004	25,602	33%
Ceara	49.6	1,239	17.8	2,310	1,018	26,061	31%
Distrito Federal	57.2	5,238	13.2	10,628	3,266	89,298	24%
Espirito Santo	52.9	2,006	15.5	5,170	1,795	47,395	26%
Goias	53.2	2,144	16.3	4,959	1,704	45,247	26%
Maranhao	46.2	1,303	15.0	1,164	567	14,272	33%
Mato Grosso do Sul	55.4	2,412	14.4	4,266	1,338	35,994	24%
Mato Grosso	52.0	1,975	16.9	4,569	1,720	45,166	27%
Minas Gerais	52.7	2,235	17.6	4,429	1,759	46,611	28%
Para	53.0	1,944	15.8	2,446	920	24,510	27%
Paraiba	46.5	1,104	16.1	2,206	892	22,428	29%
Parana	53.8	2,390	15.8	4,830	1,702	45,420	26%
Pernambuco	48.4	1,771	18.4	2,911	1,404	36,026	33%
Piaui	49.6	959	14.7	2,052	678	17,374	25%
Rio de Janeiro	54.4	5,609	15.3	5,958	2,872	77,159	33%
Rio Grande do Norte	44.9	1,246	21.9	2,639	1,452	35,978	35%
Rio Grande do Sul	58.2	3,277	13.9	5,914	1,711	46,976	22%
Rondonia	49.1	3,225	16.2	4,179	2,208	56,482	35%
Roraima	52.8	2,171	14.3	5,280	1,676	44,379	24%
Santa Catarina	58.2	2,269	15.4	6,216	1,704	46,595	22%
Sao Paulo	56.7	5,382	14.7	6,554	2,564	69,856	28%
Sergipe	47.3	1,452	16.4	2,410	1,157	29,310	32%
Tocantins	48.2	1,320	17.1	2,388	972	24,747	29%
Brazil	52.9	3,013	15.9	4,462	1,752	46,762	28%

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Life expectancy is life expectancy at birth. Statistics weighted by 1970 municipality population.

Table 4: Evolution of Cross-Municipality Inequality in Full-Income, Brazil, 1970-2000

	Income per Capita		Full-Income
	1970	2000	2000
Relative Mean Dev	0.3035	0.2329	0.2341
Coeff of Variation	0.7566	0.5730	0.5718
Std Dev of Logs	0.7615	0.6695	0.6816
Gini Coeff	0.4130	0.3289	0.3291
Regression to the Mean over Previous Date		-0.1623 (p-value=0.00)	-0.1486 (p-value=0.00)

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Full-income is based on the author calculations using life expectancy at birth. Inequality measures weighted by municipality population (abstracting from within inequality). Regression to the mean is the coefficient of a regression of the change in the variable over the period on its initial level (natural logs used in the income regressions; weighted regressions).

Table 5: Summary Statistics, Brazilian Municipalities, 1970-2000

Variable	Mean	Std. Dev.		Min	Max
income per capita	3,369	overall	2345	271	25,018
		btwn	1878		
		within	1404		
life expectancy	60	overall	8	37	78
		btwn	5		
		within	6		
child mortality	75	overall	53	3	304
		btwn	37		
		within	38		
access to water	0.36	overall	0.28	0.00	1.00
		btwn	0.19		
		within	0.20		
access to sanitation	0.15	overall	0.25	0.00	0.98
		btwn	0.20		
		within	0.14		
illiteracy rate	0.33	overall	0	0.01	0.92
		btwn	0		
		within	0		
urbanization rate	0.48	overall	0.25	0.00	1.00
		btwn	0.21		
		within	0.13		

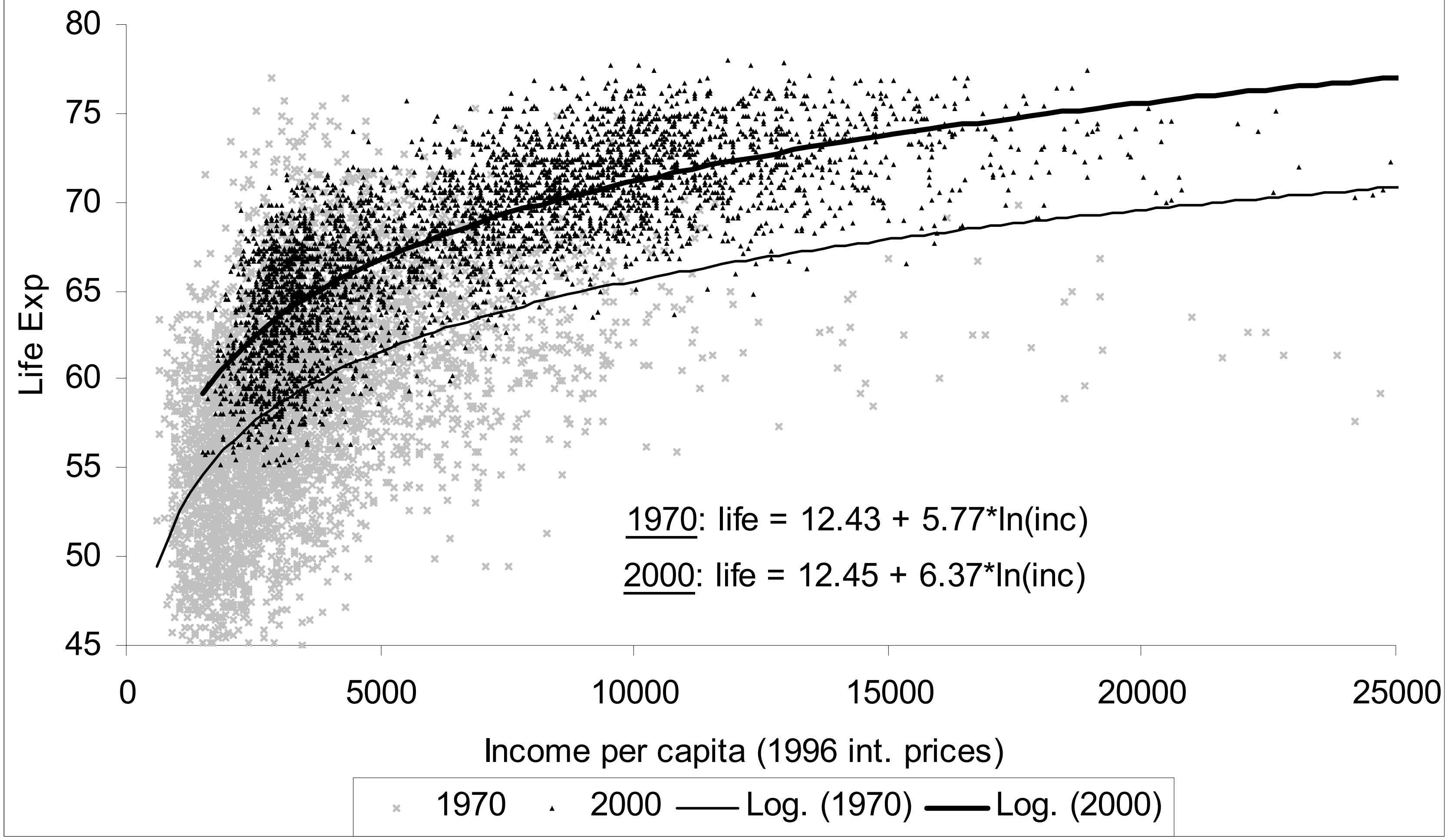
Obs.: Number of observations equals 14544 for all variables (3636 municipalities, 4 observation each). Variables constructed based on census files (1970, 1980, 1991, and 2000). Unweighted averages based on the sample used in the regression analyses. Variable are average per capita household income (normalized to 1996 international prices according to the PWT 6.1), life expectancy at birth, child mortality rate, percentage of households with access to piped water connected to the public water system, percentage of household with access to sanitation connected to public sewer system, percentage of illiterate people in the population, and the degree of urbanization (fraction of population residing in urban areas).

Table 6: Determinants of Life Expectancy and Child Mortality Changes, Brazilian Municipalities, 1970-2000

	Life Expectancy at Birth				Alternative Specifications – AB-2		
	OLS (1)	F.E. (2)	AB-1 (3)	AB-2 (4)	No Income (5)	Interact. Initial Inc. (6)	Child Mortality (7)
$Life_{-1}$	0.617	0.044	0.415	0.323	0.367	0.326	0.498
	(0.006)***	(0.011)***	(0.023)***	(0.036)***	(0.035)***	(0.035)***	(0.022)***
$Life_{-2}$				0.042	0.055	0.045	0.054
				(0.018)**	(0.017)***	(0.017)***	(0.013)***
ln(inc)	1.186	0.937	3.321	4.963		3.582	-11.802
	(0.082)***	(0.126)***	(0.573)***	(1.094)***		(1.417)**	(6.916)*
water	0.801	1.627	3.477	4.884	6.171	2.048	10.012
	(0.182)***	(0.229)***	(0.615)***	(1.173)***	(1.041)***	(6.809)	(6.723)
sanit	0.401	0.743	1.191	2.608	2.196	20.614	-9.919
	(0.110)***	(0.191)***	(0.791)	(1.214)**	(1.152)*	(9.309)**	(7.140)
illit	-5.562	-3.105	-9.282	-10.830	-5.872	-8.864	83.594
	(0.267)***	(0.512)***	(1.088)***	(2.097)***	(1.561)***	(2.871)***	(15.027)***
urb	-1.332	-2.662	-8.494	-7.126	-0.356	-6.620	20.979
	(0.162)***	(0.358)***	(1.204)***	(2.035)***	(1.993)	(2.614)**	(12.660)*
water x ln(inc 1970)						0.2961	
						(0.920)	
sanit x ln(inc 1970)						-2.574	
						(1.357)*	
const	18.469	49.666	1.741	-1.034	-0.155	-0.243	8.228
	(0.708)***	(1.174)***	(0.319)***	(0.554)*	(0.452)	(0.659)	(2.628)***
Sarg. Test (p-val)			0.00	0.19	0.89	0.15	0.64
R Sq	0.89	0.95					
N Obs	10908	10908	7272	3636	3636	3636	3636

Obs.: Standard errors in parentheses; *** indicates significance at 1%, ** indicates significance at 5%, and * indicates significance at 10%. When possible, all regressions control for period specific dummies. Dependent variable is life expectancy at birth or child mortality rate. Independent variables are average per capita household income (ln), percentage of households with access to piped water connected to the public water system, percentage of household with access to sanitation connected to public sewer system, percentage of illiterate people in the population, and the degree of urbanization (fraction of population residing in urban areas). 3636 municipalities included in all regressions. In the case of child mortality, the lagged dependent variable is also child mortality.

Figure 1: The Changing Relantionship between Income and Life Expectancy in Brazil, 1970-2000



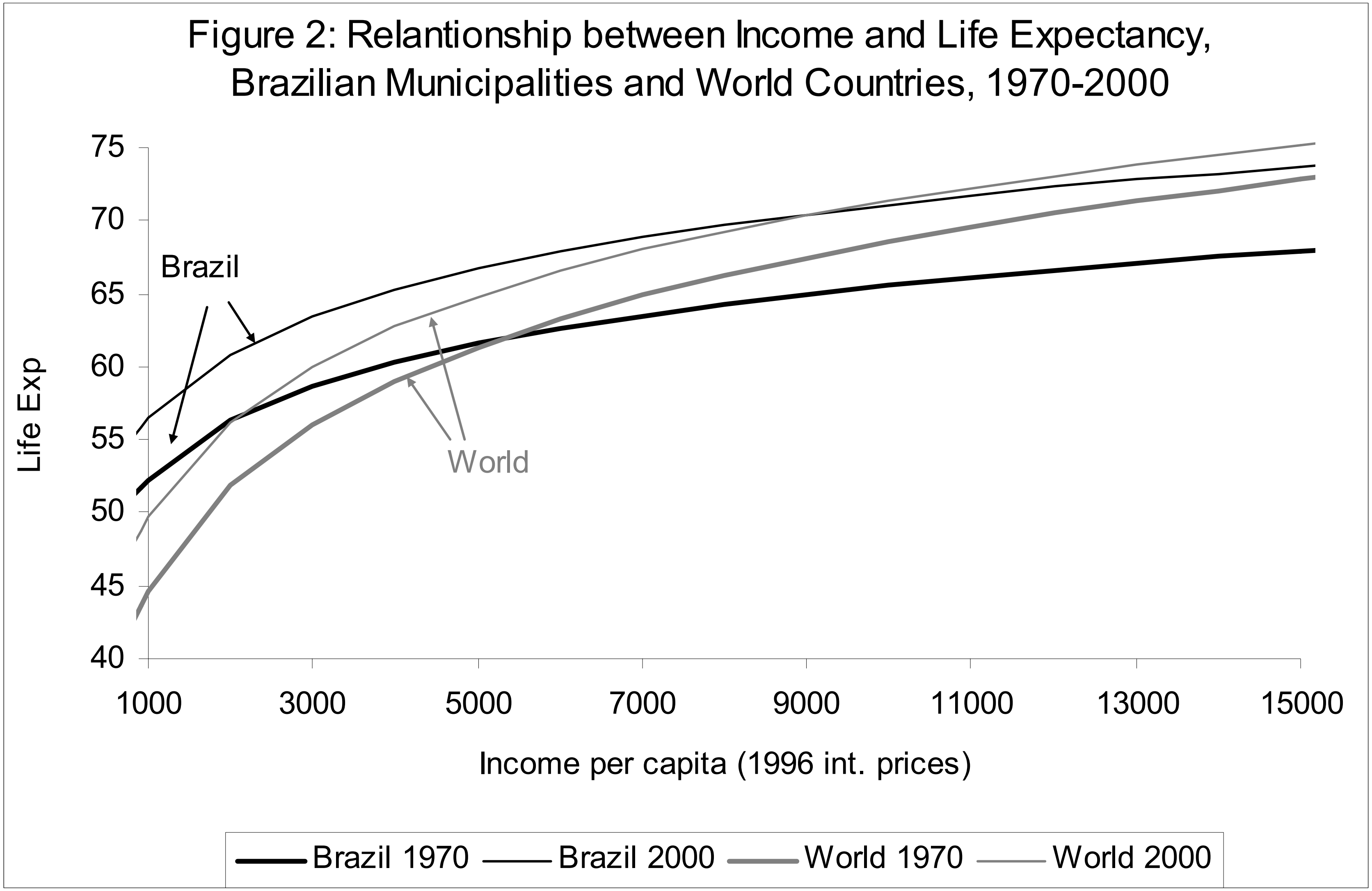


Figure 2: Relantionship between Income and Life Expectancy,
Brazilian Municipalities and World Countries, 1970-2000
75
70
65
60
55
50
45
40
Life Exp
Brazil
World
1000
3000
5000
7000
9000
11000
13000
15000
Income per capita (1996 int. prices)
Brazil 1970
Brazil 2000
World 1970
World 2000