Infant mortality during the 1920s-1940s in Puerto Rico and the health of older Puerto Rican adults

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Abstract

Neonatal endogenous mortality reflects conditions originating in utero whereas exogenous mortality reflects conditions experienced during the first year of life. We obtained data for infant mortality rates (IMR) at the county (*municipio*) level during the late 1920s-early 1940s in Puerto Rico using historical records and linked IMR with individual birth year and place using the PREHCO (Puerto Rican Elderly: Health Conditions) study. We classified PREHCO respondents into two groups using the Bourgeois-Pichat method according to if they were born in years when the fraction of neonatal endogenous mortality was either low or high. We then estimated the (1) effects of IMR (using continuous, logit, quartile, Box-Cox transformations) on adult heart disease and diabetes and (2) effects of season of birth and childhood health in each of the two PREHCO groups on adult heart disease and diabetes, controlling for age, gender, obesity, respondent's educational level, adult behavior (smoking, exercise, drinking and) other early life exposures (knee height, childhood SES, and mother's risk of exposure to malaria). Findings: (1) no significant associations between IMR and season of birth, heart disease or diabetes but significant associations between high IMR and low knee height, low education, older age and no rigorous exercise as an adult; (2) stronger effects of season of birth and smoking on adult heart disease and diabetes among respondents born in years with higher fraction of endogenous mortality; (3) stronger effects of poor childhood health and rigorous exercise among respondents born in years with lower fraction of endogenous mortality. Conclusions: (1) the pathways from poor environmental conditions during the first year of life to adult heart disease and diabetes appear to be complex and indirect whereas the pathways to adult disease from in utero exposures appears to be more direct; (2) season of birth appears to reflect in utero exposures more than environmental conditions after birth whereas just the opposite is true for knee height and

childhood health; (3) adult smoking and exercise may differ in their effectiveness to cause or reduce adult disease according to one's early life circumstances.

Introduction

Disentangling the effects of early life conditions to better understand the conditions that precipitate the onset of adult disease continues to be of particular relevance. Infant mortality rates (IMR) and their components (neonatal and post neonatal mortality) may help provide insight.

We know that neonatal mortality rates (deaths during the first month of life) are strongly associated with non-environmental or endogenous causes[1]. Barker and Osmond's (1986) classic geographical analysis in England and Wales showed strong positive associations between neonatal mortality and adult mortality due to coronary heart disease in the 1960s. Nearly 80% of overall neonatal mortality was due to congenital causes. Endogenous mortality thus became an important clue as to the source of early life conditions which led to adult mortality. Barker later concluded that, "coronary heart disease is associated with past infant mortality because it originates in conditions in utero, rather than poor conditions in childhood, though these contribute" (Barker 2002). In Barker's view, living conditions may thus alter the risk of disease or conversely slow early growth may increase vulnerability to the effects of poor living conditions but poor living conditions are not an important confounding factor (Barker et al. 2001) but rather can add to the effects of early life conditions (Barker 1995).

The Barker hypothesis has been controversial, precisely because there are others who believe that circumstances such as poor living conditions are indeed confounding factors in explaining adult health. Important background conditions that influence early growth and development could also have independent effects on later health and mortality (Huxley, Neil, & Collins 2002;

[1] Endogenous infant mortality is defined as "cases in which the child bears within itself, from birth, the cause resulting in its death, whether that cause was inherited from its parents at conception or acquired from its mother during gestation or delivery (Bourgeois-Pichat 1952). Exogenous infant mortality is defined as "cases in which the infant picks up the factor which causes its death in the environment in which it lives" (Bourgeois-Pichat 1952).

Joseph & Kramer 1996). Factors such as poor childhood socioeconomic conditions and poor childhood health can have substantial impacts on adult health (Davey Smith & Lynch 2004; Elo & Preston 1992; Gunnell et al. 1998; Hertzman 1994; Lundberg 1991; Wadsworth & Kuh 1997). Failing to control properly for these conditions will inflate the association between any chosen valid indicator of early growth in utero and adult health and mortality.

A few studies have attempted to disentangle the effects of in utero and early infancy on adult health by using IMR as an indicator of disease load during the first year of life and local food prices as an indicator of access to food and nutrition during pregnancy. Bengtsson & Lindstrom's study of four rural Swedish parishes from 1700-1800s showed a strong positive association between infant mortality and adult mortality but no association between food prices and adult mortality (Bengtsson & Lindstrom 2000). In the case of Sweden during the 1700-1800s, IMR were on average high (200 per 1000 live births) and airborne diseases such as small pox and whooping cough were predominant and crossed all socioeconomic levels, thus leading them to conclude that "economic factors are of rather small importance" in terms of the causes of IMR in Sweden during this period (Bengtsson & Lindstrom 2000). Other studies from the Netherlands and Belgium which have used IMR and local food prices on populations in the 19th century also found weak evidence in support of the effects of in utero conditions on adult health (Svensson, Broström, & Oris 2004; Van den Berg, Lindeboom, & Portrait 2006). In these studies, IMR was also similarly high[2] and in both studies there was little evidence to suggest that in utero nutrition affected adult mortality. Rather it was either the economic conditions into which one is born (Van den Berg et al. 2006) or infectious diseases during the first year of life (Svensson, Broström, & Oris 2004) which were important to adult mortality. In a different type

[2] In fact, the Netherlands experienced a very high level of IMR in the early 1800s—higher than other European countries and mostly due to economic conditions (Van den Berg, Lindeboom, & Portrait 2006; Bideau 1997).

of study, Doblhammer (2004) also found a positive association between IMR in the early 20th century and adult mortality in Denmark.

In previous work we used season of birth as an indicator of poor nutrition and infectious disease in utero to disentangle the effects of early life conditions on heart disease and diabetes among older adult Puerto Ricans (McEniry et al. 2008). We found that the odds of self-reporting heart disease and diabetes increased for those who were born at the end of the lean season (i.e. born during a period where the risk of being more fully exposed to poor nutrition and infectious disease during late gestation was highest in comparison with those born at the end of the harvest season). Furthermore, we found that these effects were independent of the effects of an indicator of self-reported childhood health. Poor childhood health was associated with childhood illnesses such as malaria, asthma, bronchitis, dengue fever, pneumonia, rheumatic fever, and smallpox and with periods of deprivations due to health but not with season of birth. The conclusions of the study found evidence in support of the Barker hypothesis and that the indicator for childhood health appeared to reflect a dimension of childhood health that is not directly linked with conditions in utero but that is more directly linked with conditions during childhood.

The results were convincing but nevertheless it could be argued that season of birth represents environmental factors during the first year of life and not in utero conditions. Birth month is not well defined and could also be capturing infectious diseases in the first year of life. In addition, the relative importance of the timing of the nutritional or infectious disease insult has been less clearly illustrated in the literature regarding in utero and early infancy effects on adult health. Thus, the issue of timing and distinguishing the timing of nutritional insults in late pregnancy or early infancy has not been clearly shown.

One way to address these concerns is to examine the effects of an indicator such as IMR which overall reflect environmental conditions especially at higher levels of IMR but whose components can be broken into endogenous and exogenous mortality. Endogenous mortality reflects, for the most part, conditions originating in utero and exogenous mortality reflects more environmental conditions such as disease load during the first year of life. If the Barker hypothesis has merit, significant associations between endogenous mortality and adult morbidity (heart disease and diabetes) should be apparent whereas if environmental conditions during the first month of life are important, associations between exogenous mortality and adult morbidity should appear. Even if there are scant data on the components of IMR at a particular granular level such as a county[3], it may still be possible to use general knowledge regarding what happens to the fraction of endogenous mortality as mortality begins to decline to identify levels of IMR which reflect a higher fraction (predominance) of endogenous mortality or vice versa. This is because at higher IMR there are poorer environmental conditions and endogenous mortality accounts for a lower fraction of IMR. At lower IMR there are better environmental conditions and endogenous mortality accounts for a higher fraction of IMR. When IMR begins to decline, it is usually due to improvement in environmental conditions and thus as it continues to decline the fraction of exogenous mortality becomes smaller while the fraction of endogenous mortality becomes larger. Thus armed with this knowledge, it may be possible to broadly identify levels of IMR at which endogenous or exogenous mortality is more predominant and use this information to further test the Barker hypothesis[4].

In this paper, we thus continue to examine early life exposures and older adult health using a sample of older Puerto Ricans born in the late 1920s-early 1940s, adding infant mortality as

[3] Such as at the county level as in the study by Barker & Osmond (1986).
[4] See also Johansson & Beise (2008).

another important indicator that could help disentangle the effects of early life and examining an important component of IMR—endogenous mortality. We expect to find two major regularities regarding the association between IMR (or their components) and adult health and the association between exposure in utero (season of birth) and early childhood health on adult health: **First**, (1) if early life environment (during the first year of life) is important to older adult health, then we expect to observe a significant association between IMR and adult heart disease and diabetes; (2) if season of birth is a more accurate indicator of early life environment during the first year of life than it is of in utero exposures, then we expect to observe that the effects of birth month are attenuated when IMR are added to model estimation. **Second**, because we know that neonatal mortality (endogenous mortality) is associated with in utero conditions and that as infant mortality declines neonatal mortality increases as a fraction of IMR, then one way to test the merit of the Barker hypothesis is identify levels of IMR which reflect the predominance of endogenous mortality (i.e. lower IMR and better environmental conditions) in contrast with exogenous mortality (i.e. higher IMR and poorer environmental conditions) at time of birth. If we can reasonably divide the sample of Puerto Rican respondents into two groups accordingly, if there is a sufficient sample size and if the Barker hypothesis has merit, we should expect to observe that (1) the effects of exposure to poor nutrition and infectious disease in utero (season of birth) are stronger among those respondents born when IMR were lower and environmental conditions were better (i.e. endogenous mortality was high as a fraction of IMR). In addition, due to our previous work with childhood health and season of birth (McEniry et al. 2008) we expect to find that the effects of early childhood health are stronger among those born when IMR are high (i.e. poorer environmental conditions when exogenous mortality is high as a fraction of IMR).

Before examining the veracity of these expectations, we first provide a brief background description on infant mortality during the 1920s-1940s in Puerto Rico and identify a critical assumption to modeling IMR.

Infant Mortality in Puerto Rico during the 1920s-1940s

In the early 20th century, Puerto Rico's population was predominantly rural[5] and overall it had a high population density (Bureau of Vital Statistics 1926). Times were difficult during the late 1920s through early 1940s for many Puerto Ricans, especially those who lived in the rural countryside where wages were the main source of income, underemployment and/or unemployment were highly cyclical due to the predominant sugar cane industry and living conditions were particularly precarious (Clark 1930; Morales et al. 1937; Morales et al. 1939; Morales & Pérez 1939; Pérez 1941). Only 45% of the population was literate (Clark 1930) and increased exposure to infectious diseases during the hurricane season brought augmented exposure to infectious disease such as dysentery, diarrhea and malaria (Rigau Pérez 2000). Thus, in spite of improving health conditions during the 1930s in some areas of the island, the leading cause of death in Puerto Rico at the end of the 1930s was still diarrhea in children under the age of two (Garrido Morales 1939/40).

Infant mortality was high during this period[6] and during the late 1920s about 26-27% of all deaths were children under the age of one (Fernós Isern 1930/31; Ortiz 1929/30). Conditions during the late 1920s-early 1940s in Puerto Rico were such that while IMR began to improve during this period as environmental conditions improved partially due to the efforts of public

[5] About 78% in 1920 and about 72% according to the 1930 census (US Bureau of the Census 1920, 1930).
[6] Throughout the late 1920s-early 1940s overall IMR in Puerto Rico was 129 (1927), 150 (1928), 146 (1929), 126 (1930), 122 (1931), 132 (1932), 139 (1933), 113 (1934), 115 (1935), 127 (1936), 138 (1937), 121 (1938), 112 (1939), 113 (1940), 116 (1941), 103 (1942), 95 (1943). Sources are the annual reports of the commissioner of health in Puerto Rico.

health interventions[7] and laws were passed to provide stricter regulation over midwifes (Belaval 1945) (see Figure 1) the overall IMR were still relatively high compared with the US mainland and with other countries such as England and Wales[8] and environmental factors were thus clearly more predominant in Puerto Rico than in the US, England and Wales in explaining IMR.

[insert Figure 1]

An examination of the trend in overall IMR from the 1930s-1980s in Puerto Rico shows the decrease in the fraction of post neonatal mortality over time as conditions improved and an increase in the fraction of neonatal mortality (Table 1). In addition, stillbirths were relatively high in the 1930s (66 per 1000 total births) and a large percentage of perinatal mortality (80-82%) was due to stillbirths indicating that conditions were difficult and many did not survive until birth[9]. Using the Bourgeois-Pichat (1952) biometric method to estimate endogenous mortality, it is not surprising to observe that endogenous mortality is more prevalent at lower levels of IMR[10].

[insert Table 1]

[7] See Annual Reports of the Health Commissioner in reference section.
[8] In 1924-25 IMR, neonatal and post neonatal mortality in Puerto Rico were 148.6, 43.3 (29%), and 105.4 (71%) respectively (Fernós Isern 1928). In 1924, for the state of New York excluding New York City: 69, 40.74 (59%), 28.29 (41%) (Fernós Isern 1928); in 1921-1925 in England and Wales: 76, 33.4 (44%), 42.6 (56%) (Barker & Osmond 1986); and in 1928-1938 in England & Wales: 61.7, 30.9 (50%), 30.8 (50%) (Woolf 1947).
[9] As a way of comparison, Corsica in France in the 1950s had an endogenous mortality of 26.4 per 1000 and a stillbirth mortality of 19.9 for a total perinatal mortality rate of 46.3 per 1000, 43% of which was stillbirths (Pressat 1961).
[10] The Bourgeois-Pichat method makes the following assumptions: (1) exogenous mortality conserves a stable age structure, (2) there is little endogeneity after the first month of life. Therefore, the role of medicine is minimized in this method although it probably was not an issue in the 1920s-1940s in Puerto Rico.

Cause of death

Puerto Rico is situated in the tropics and experienced different climate and disease environments than that of England or Wales during the 1920s. High temperatures year round nurtured infection and thus resulted in generally higher IMR than experienced in northern climates. Malaria and hookworm were common infectious diseases during the late 1920s-early 1940s and add to the complexity of understanding IMR in Puerto Rico.

There were four major reported causes of IMR during the late 1920s-1940s. Table 2 describes the situation in a typical year, 1934: (1) diseases of the digestive system (about 35% of cases), of which diarrhea and gastro-enteritis were predominant; (2) diseases of early infancy (about 24% of cases), of which congenital disability predominated; (3) diseases of the respiratory system (about 18% of cases), of which acute bronchitis predominated; and (4) infectious diseases (about 16% of cases). Factors impacting IMR differed with the age of the infant as can also be seen in Table 2. Most early infancy causes of death including congenital disability occurred during the first month of life whereas diarrhea, acute bronchitis and other infectious diseases were predominant causes of death during post neonatal (1^{st}-11^{th} month of life).

As for the first major cause of death, there was a strongly held belief by public health officials of the day that even though there were difficulties in the reliability of cause of death data, feeding habits were an important cause of diarrhea (Fernós Isern 1928). It was noted by officials that breastfeeding, which is natural and important in the first six months of life, was often impeded due to mothers (especially poor mothers) having to return to working 10-12 hours per day (Fernós Isern & Rodriguez Pastor 1930). This led to irregular hours of breastfeeding--about 63% of rural children were breastfed (Wegman et al. 1942), no breastfeeding or premature feeding of solid foods. Although cow's milk was scarce in Puerto Rico, mixed or artificial

feeding (canned milk, mixtures of herb teas in dirty bottles) during the first month of feeding occurred (Fernós Isern & Rodriguez Pastor 1930)[11]. Unclean breasts may also have been a contributing factor in some cases. It is also important to note that mortality from diarrhea under the age of two was not associated with climate change, rainfall, variations with the seasons of the year whereas for children over the age of two, mortality was associated with rainfall and season (Fernós Isern & Rodriguez Pastor 1930; Phelps 1928), thus leading to a stronger argument that feeding habits during the first year of life may truly have been an important cause of death whereas environmental factors became important at older ages.

[Table 3 about here]

Infections such as malaria and hookworm may be an important explanatory factor for the second leading cause of death, congenital weakness, in Puerto Rico during the 1920s-1940s. Both malaria and hookworm infection reflect the burden of disease in pregnant women which may have manifested themselves partially by congenital problems at birth. Prevalence of malaria occurred mostly in the very hot coastal regions where sugar cane was planted. An association between congenital mortality and malaria was noted by many Puerto Rican public health officials of the time[12] (Fernós Isern & Rodriguez Pastor 1930) and was thought to have more to do with the mother having the disease since the mother's weakened condition can lead to

[11] Wegman et al. (1942) also found that in the rural municipio of Ciales (page 237) a very high percentage of mothers who used the public health unit breastfed up to 6 months (not a representative sample). Low IMR are associated with breastfeeding and in the rural areas many mothers would be breastfeeding and :"rural mothers tend to nurse their babies longer" (Wegman et al. 1942) . Wegman et al. also noted two unusual facts about IMR—1. rapid decline in neonatal mortality rate but not 1-11 rate; 2. geographical distribution of IMR—higher IMR in western part, coastal regions and lower IMR in central and eastern regions of Puerto Rico (page 244).

[12] Example: The municipio, Santa Isabel (located in the southern coast) experienced high IMR but then a dramatic decline in IMR after a successful malaria campaign in the late 1920s. Mortality from congenital disability was also decreasing by the late 1920s (Fernós Isern & Rodriguez Pastor 1930).

congenital weakness in the infant depending on the seriousness of the infection. The highest IMR during the late 1920s and early 1940s tended to be in the coastal southern and western regions of Puerto Rico where the prevalence of malaria was high[13]. Prevalence of hookworm was high in rural areas and suggests that many lived with chronic infection throughout the year[14]. High loads of hookworm are associated with intrauterine growth retardation, prematurity and low birth weight among newborns born to infected mothers and can lead to anemia especially if poor nutrition (protein and iron) is involved[15]. Because it can cause protein malnutrition, anemia is a potential confounding factor for the Barker theory. A high percentage of adults did not wear shoes in rural areas and thus there was a high prevalence of hookworm disease[16]. While hookworm tends to be associated with men and certain occupations (coffee in the case of Puerto Rico and mining in the case of England and Wales)[17], in certain cases adult women in Puerto Rico may also have been more severely affected than men in the coffee regions because of soil conditions close to housing (Hill 1926)[18].

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[13] Is this partially explained by mothers who had malaria and thus resulted in congenital difficulties?

[14] Malaria and hookworm infections were chronic conditions in the rural areas of Puerto Rico but were not seasonal. Note: a high prevalence of hookworm infection does not mean high severity. Historical records do describe the severity (worm burden) of hookworm in certain regions and munlicipios of Puerto Rico (Hill 1926), but it is not clear the severity of the infection in other regions. In the mountainous interior of the island infestation averages were estimated at 500 parasites per person whereas in the coastal areas 200 per person (Hill 1926). In our case, we are interested in maternal infection which may have caused nutritional problems for the developing child. There is some evidence to suggest that hookworm infection by itself may not be the problem but other nutritional factors which affect disease (Gilles & Ball 1991). Nevertheless, even Gilles & Ball (1991) noted the high average infestation averages for Puerto Rico (450) suggesting that the infection was a serious health issue in Puerto Rico during the late 1920s-1930s.

[15] According to the World Health Organization, "In pregnant women, anaemia resulting from hookworm disease results in several adverse outcomes for both the mother and her infant, including low birth weight, impaired milk production, and increased risk of death for both the mother and the child." See the following website: http://www.who.int/vaccine_research/diseases/soa_parasitic/en/index2.html

[16] In a typical sugar plantation, about 60-69% of those above 15 years old did not wear shoes. And many do not wear shoes (Morales Otero et al. 1937, p. 460)

[17] Highest rates in coffee cultivation; average infestation rate of 90% with an extremely high prevalence of hookworm disease—a disease prevalent in Puerto Rico since 1530 (Howard 1928; Daengsvang 1932; Hill 1926).

[18] It is more difficult to identify the severity of hookworm disease since the number of worms is important in terms of morbidity risks for the mother—the mother could be pregnant and be infected but not have that many worms although low worm burdens may also lead to anemia.

In terms of the third leading cause of death--respiratory infections--public health officials in Puerto Rico at the time generally thought that the "most important factor…is direct contagion from older persons suffering from bronchitis and influenza…" (Fernós Isern & Rodriguez Pastor 1930). Already undernourished children exposed to adults with the disease were more susceptible to the disease. Thus, educating older persons to protect children from disease in combination with socioeconomic conditions were important underlying factors explaining the prevalence of these infections.

The 4th leading cause of death was from epidemic, endemic and other infectious diseases affecting newborn infants such as malaria and tetanus. Other diseases such as tuberculosis and measles could escape detection as causes of death and be hidden in diagnoses of either gastro or respiratory causes of death (Fernós Isern & Rodriguez Pastor 1930).

Variation among municipios

Conditions during the late 1920s-early 1940s in Puerto Rico were such that while IMR began to improve during this period, there was a still large amount of variation within and among municipalities (*municipios*) across time. Figure 3 shows IMR per year for each *municipio* but sorting *municipios* from lowest to highest IMR in 1929. The bold line in the figure shows IMR in 1929 and the bold dashed line shows IMR in 1943. Higher IMR in the late 1920s tended to be found in coastal areas where sugar cane was planted and especially in western Puerto Rico where sugar cane and coffee were planted, where there was a high prevalence of malaria and where temperatures were consistently high throughout the year[19]. Higher IMR also existed in more

[19] It is noteworthy to observe that all *municipios* in 1929 which had an IMR >=200 came from the southern or western coastal regions of Puerto Rico which were predominantly sugar cane regions although some parts of the coffee region in the western region also experienced higher IMR. Municipios showing IMR >=200 in 1929 included: Aguada, Anasco, Arroyo, Camuy, Guanica, Guayama, Hormigueros, Juan Diaz, Lajas, Las Marías, Maricao, Mayaguez, Moca, Patillas, Ponce, Rincón, Sabana Grande, Salinas, Santa Isabel, Yabucoa. Although there was improvement with time in IMR, many of these same *municipios* still ranked having the highest IMR in 1943.

urban centers because the population density was greater than in more rural areas due to overcrowding of families in urban areas. Lower IMR in the late 1920s were found in the highlands where tobacco was grown and the lowest IMR in the island at the time were found curiously enough in the center of the island between the coffee and tobacco regions but close to the sugar cane region[20]. Within each county across the time period of the late 1920s-early 1940s, IMR were high during the late 1920s and then improved again during the 1930s as more public health units[21] were constructed and made available in *municipios* throughout the region.

[insert Figure 2 about here]

Methods

Data

The data for this paper come from two major sources: (1) yearly data from 1927-1943 on IMR by *municipio*, acreage planted and amount harvested for major crops (sugar cane, tobacco, and coffee) in 1929 found in either US Census reports (1929), Puerto Rican public health journals or annual reports on the health of the island produced by the Puerto Rican Health Commissioner during the 1920s-1930s; and (2) comprehensive data from the Puerto Rican Elderly: Health Conditions (PREHCO) project[22], a project designed to gather quality baseline

[20] All *municipios* in 1929 which had an IMR <100 came from the central regions of Puerto Rico where tobacco was mostly grown. These included: Aguas Buenas, Aibonito, Barranquitas, Ciales, Cidra, Coamo, Jayuya, Naranjito, Orocovis, Vega Alta, Villalba. Some public health officials attributed lower IMR in the central region to the milder climate in the mountain ranges (Fernós Isern & Rodriguez Pastor 1930). Although population density was associated with higher IMR in Puerto Rico (Fernós Isern & Rodriguez Pastor 1930), when we did an analysis of the five highest IMR and lowest IMR *municipios* according to population density, there were equally higher and lower density areas in both groups.

[21] The first public health unit was created in 1926 and was funded by the Rockefeller Foundation and the US Public Health Service. By 1938, each municipality had its own public health unit.

[22] See http://www.ssc.wisc.edu/cdha/projects/projects.html.

data on issues related to the health of the non-institutionalized population age 60 and over and their surviving spouses.

Today Puerto Rico is divided into 78 *municipios* governed by an elected mayor and legislative assembly. The current location of *municipios*, for the most part, conforms to how Puerto Rico was divided in the late 1920s-early 1940s. According to the 1920 and 1930 census, most of the population of Puerto Rico was classified as rural and only a few *municipios* were predominantly urban[23]. The collection of vital statistics in Puerto Rico in the early 20th century was the responsibility of *municipio* clerks under direct supervision from the mayor of each municipality. While law required that "daily statistics shall be kept in all the registers which must contain such information as may be determined by the Director of Health" (Pérez1926), the Department of Health did not have direct oversight into the local registers and how data were collected until the 1930s. In fact, it is rather dubious if municipal authorities inspected the civil registers in the early 1920s (March 1926). However, Puerto Rican laws established during this period clearly outlined fines for not reporting deaths and required that a physician sign the death certificate and thus the Department of Health viewed the numbers of deaths collected by each *municipio* as fairly accurate and believed that almost all deaths were reported. According to the Department of Health, over 90% of births were reported (Porto Rico Health Review, October 1926, page 15) and thus the reporting of numbers of births and deaths was viewed as being fairly accurate[24].

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[23] US census defined rural as communities with less than 2500 inhabitants (U.S. Bureau of the Census, 1932). Only San Juan, Bayamon and Ponce had predominantly urban populations in 1920. By 1930, Catano and Mayaguez became predominantly urban.

[24] The 90% estimate agrees with official estimates of underreporting in later annual reports to the governor. Furthermore, the problem with underreporting births appears to be related with missing birth reports for infant deaths under one year. In the Fiscal Year (FY) 1930 report, an examination of December 1929 deaths under one year with matching birth reports found that about 45% of births associated were not reported (FY 1930 Annual Report to Governor, page 8): "According to law death reports are 100 per cent complete as no burial permits are issued without a certificate of death from the physician, but on the other hand, birth reports, taking the month of

The important weakness of the system was the classification of births and deaths by race, domicile, age and occupation and the reporting of the cause of death and morbidity. There were no uniform standards across *municipios* for classification into groups. In the 1920s, the Department of Health actively classified deaths according to international standards of disease classification, but many Puerto Rican physicians did not conform to the international standards of disease classification or did not report communicable (transmissible) diseases as required by law. In addition, because of the scarcity of physicians[25], especially in the rural areas, the physician who signed the death certificate often did not actually see the deceased but gave a diagnosis based more on guessing than scientific reasons.

In terms of the survey data used in this paper, the PREHCO sample is a multistage, stratified sample of older adults residing in Puerto Rico with oversamples of regions heavily populated by people of African descent and of individuals aged over 80. The data were gathered through face-to-face interviews with targets and with their surviving spouses, regardless of age. The data collected offer a substantial amount of information within the limits permitted by face-to-face interviews in a cross-section. The questionnaire included extensive modules on a variety of topics including demographic characteristics, health status and conditions, cognitive and functional performance, anthropometric measurements and physical performance. A total of 4,291 interviews with primary respondents were conducted between May 2002 and May 2003 and second wave data were collected during 2006-2007 both with very high response rates.

Measures

December, 1929, as a basis are only about 55 per cent complete…The infant mortality rate….would be 125 per 1,000 live births and after proper checking 118 per 1,000 live births." Thus, in this example, there was about a 6% difference between the higher calculated and lower corrected infant mortality rate for December 1929. It is not clear from the annual reports to the governor the degree to which underreporting of births may have occurred in instances which did not also involve the death of the infant under one year of age.

[25] In some areas there was one physician per 15,000 persons (Report of the Bureau of Vital Statistics 1925-1926; Porto Rico Health Review 2 (September 1925-June 1927):15).

Infant Mortality.—Data for infant mortality for 1927-1943 were obtained by *municipio* and for Puerto Rico as a whole based on official reports compiled by the Department of Health in Puerto Rico[26]. For the years 1927-1931 data were obtained using the Porto Rico Review of Public Health and Tropical Medicine which reported monthly births and deaths for each *municipio*. Yearly infant mortality rates by *municipio* were then calculated using these numbers[27]. For 1932-1943, infant mortality rates were obtained using the Puerto Rican Commissioner of Health annual report to the governor of Puerto Rico which contained already calculated yearly infant mortality rates for each *municipio*.

Infant mortality rate for each *municipio* was modeled in several ways: (1) as a continuous variable with no transformation; (2) as a continuous variable using a suitable transformation; we tried a logit transformation and also chose a square root and cubed root based on Box-Cox power transformation; (3) as a discrete variable using deciles, quartiles and quintiles of IMR; (4) as a discrete variable identifying extreme values of IMR for each *municipio* (values greater than 1 standard deviation from *municipio*-specific trend) using the Hodrick-Prescott (1997) method for decomposing trend from cycle using a filter value of 100[28].

In addition, our first idea was to decompose IMR into neonatal and post neonatal mortality and then endogenous and exogenous mortality by using the Bourguois-Pichat (1952) method at the *municipio* level. However, information on neonatal and post neonatal mortality was only available at the level of Puerto Rico as a whole. Thus, we modified this approach by splitting respondents into two groups: those born in years of lower IMR and those born in years of higher IMR.

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[26] See the citations for Fernós Stern, A. 1930/31, 1942/43, 1944/45; Garrido Morales, E. 1934/35, 1935/36, 1937/38, 1939/40; and Ortiz, P. N. 1925/26, 1926/27, 1929/30 in the references.
[27] For 1927 only January-July were published and for 1931 only January-September were published.
[28] We followed the suggestion of Bengtsson & Lindstrom (2000).

The rationale for this approach is as follows. An examination of when mortality began to decline in Puerto Rico and the fraction of neonatal deaths through time should be an indicator of the degree to which neonatal or endogenous mortality are better indicators of environment versus in utero conditions. If we can reasonably divide the PREHCO respondents into two groups according to higher or lower IMR at respondent's birth, then we can estimate separate models for these different IMR—the one reflecting poorer environmental conditions and the other better environmental conditions.

To divide the PREHCO sample into those cases where respondents were born when endogenous mortality was more predominant than exogenous mortality, we relied on the only known data on IMR and neonatal mortality in Puerto Rico from early periods (1932-1984) (Vázquez Calzada 1988). We then used the Bourgeois-Pichat method to estimate exogenous mortality[29] and then estimated endogenous mortality accordingly. We noted at this point that it is only at very low levels of IMR when endogenous mortality is more predominant, but in the PREHCO sample of respondents IMR were still relatively high in 1927-1943 and thus there were fewer cases at very low levels of IMR. We thus searched for a more reasonable cutoff point by which to divide the sample. We made an important assumption. We assumed that the relationship observed between IMR and neonatal mortality in 1932-1984 was similar to the relationship observed in earlier years (1927-1943) so that we could use the same relationship to say something about IMR during 1927-1943. We decided on three different cutoff points for endogenous mortality: (1) IMR less than or equal to 100 (completely arbitrary but close to IMR of the Barker & Osmond study in 1986); (2) lowest quartile of IMR (cutoff IMR 96.7); (3)

[29] According to Bourgeois-Pichat (1952), about 25% of exogenous mortality was found in neonatal deaths and thus to obtain an estimate for exogenous mortality one need multiply post neonatal mortality by 1.25.

lowest tercile of IMR (cutoff IMR 105)[30]. We created suitable dichotomous variables for each of these cases and then used the variables to estimate separate multivariate models for endogenous and exogenous mortality.

Prenatal exposure to poor nutrition.—We defined seasonal exposure to poor nutrition and infectious diseases based on birth quarter and the months of the slack or lean season (July–December) in the Puerto Rican sugar cane industry (Clark 1930; Gayer, Homan, & James 1938). Mid to late gestation and early infancy may all be periods sensitive to poor nutrition. However, we began with the supposition that late gestation is most relevant (Barker 1998; Gardiner 2007). We thus used a more detailed definition of exposure and identified different levels of exposure according to the degree of overlap between the third trimester of gestation (calculated from month of birth) and the months of the slack season defined above. We defined this indicator of exposure to poor nutrition and infectious diseases, *level of exposure*, as follows: *Full exposure* (fourth quarter of birth) means that the third trimester fell completely within the slack period, *partial exposure* means that the third trimester of gestation fell partially within the window defined by the slack months either early (third quarter) or late (first quarter), and *no exposure* during the third trimester was reserved for those whose third trimester of gestation fell completely outside the window of slack months. We created binary variables to represent levels of exposure, with the reference group being the no exposure group. We also used a broader definition of exposure to poor nutrition and infectious diseases in model estimation called *exposure period*, which identified whether the respondent had been born during the lean season after the sugar cane harvest (July–December).

[30] Using Table 2, linear extrapolation and the Bourgeois-Pichat method we estimate that at the cutoff point of 100, the percent of neonatal mortality is 32% (endogenous mortality 15%). Similarly for the other cutoff point of 96.7 the percent of neonatal mortality is about 33% (endogenous mortality 16%) and for the cutoff point of 105 the percent of neonatal mortality is 31% (endogenous mortality 14%).

Adult Health.— Elderly adult health was defined by dichotomous variables using self-reported heart disease and self-reported diabetes from the PREHCO study. These variables ask the respondent if a doctor has ever diagnosed them with heart disease or diabetes.

Childhood conditions.—Early life conditions in addition to in utero exposures (season of birth) included lowest quartile of knee height, an indicator of nutrition during early childhood (Eveleth & Tanner 1990) and possibly earlier; a retrospective question asked of respondents regarding socioeconomic conditions during childhood and mother's exposure to malaria. This indicator was obtained by identifying *municipios* where malaria infection was highest either through published accounts[31] or through an analysis of acreages of sugar cane planted obtained through the US census (1932).

Adult conditions.—These conditions included the number of years of education, obesity (a dichotomous variable indicating if BMI>=30) and adult behavior (smoking, drinking and exercising). The smoking variable was defined according to non-smokers (never smoked), former smokers and current smokers. In terms of drinking, respondents were asked how often per week they drank alcoholic beverages during the last three months. We created a dichotomized variable to mean 1 drank at least one day per week and 0 to mean did not drink alcoholic beverages during the last three months. In terms of exercising, respondents were asked if during the last year they had played sports, jogged, walked, danced or did heavy work three or more times per week. Responses to this question were dichotomized with 1 reflecting an affirmative response to the question and 0 reflecting a negative response to the question[32].

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[31] These *municipios* were identified in several articles that appeared in the *Porto Rico Review of Public Health and Tropical Medicine* on malaria. *Municipios* with high malaria rates were Barceloneta, Fajardo, and Ponce (Earle 1925). In addition, hookworm was more prevalent in the coffee growing areas and so we also identified predominant coffee growing regions.

[32] Weighting imputed results for 60-74 year olds who lived in the countryside as children: about 21% responded saying that they drank alcoholic beverages on a weekly basis during the last three months; about 44% responded

Analysis

Imputation.—We used multiple imputation procedures (Raghunathan, Reiter, & Rubin 2003; Rubin 1987; Van Buren, Boshuizen, & Knook 1999) using IVEware (Raghunathan, Solenberger, & Van Hoewyk 2007) to ensure that all cases were included. The results obtained with multiple imputation are statistically efficient and avoid systematic biases likely to arise when one deletes cases with missing observations. The validity of our results relies on a weak assumption about missingness (Rubin 1987). The number of missing responses among the subsample of those born in Puerto Rico who lived in the countryside as a child was small (less than 1 percent) in most study variables; knee height and obesity had about 3% missing. However, we were primarily interested in imputing items about living in the countryside as a child, for which about 14% of the cases were missing primarily because proxies were not asked this question.

Subsample for estimation.—We selected a subsample of older adults born in Puerto Rico who responded affirmatively to a survey question that asked them if they had lived for a prolonged period of time in the countryside prior to the age of 18. The imputation created five imputed data sets each of which varied slightly in sample size (from 1447-1464). We only considered respondents aged 60 to 74 to generate estimates for the subpopulation that was most at risk of having been affected by harsh early childhood experiences and, simultaneously, had larger probabilities of surviving due to their exposure to the massive deployment of medical technologies and public health measures during the period after 1930. Thus, this cohort may be able to provide some insights into whether early childhood experiences are indeed important in later life because it was less affected by mortality-driven selection than the group of cohorts who preceded it (those aged 75 and older).

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saying that they exercised at least three times a week during the last year and about 65% responded saying that they had never smoked; 25% were former smokers and 10% current smokers.

Preparation for model estimation.— Municipality-level IMR data were linked with the *municipio* of birth of PREHCO respondents who were born between 1927 and 1943 (excluding those respondents not born in Puerto Rico). We transformed IMR using either a logit, square root or cubed root transformation.

Estimation.—We first estimated the effects of IMR (using the different transformations) on adult heart disease and diabetes using logistic regression. Models for heart disease controlled for age, gender, education, obesity, poor childhood health, rheumatic heart fever, poor childhood socioeconomic status (SES), low knee height, and exposure to poor nutrition and infectious disease (defined broadly as the period between July and December and also defined as quarter of birth). Models for diabetes also included a variable indicating whether the respondent had a family member with diabetes. We then estimated separate models for low IMR (better environmental conditions and a higher fraction of endogenous mortality) and high IMR (poorer environmental conditions and a higher fraction of exogenous mortality), controlling for the same variables for each health outcome. Difficulty in model convergence due to the small number of cases for rheumatic fever led us to drop rheumatic fever from the separate models per endogenous/exogenous group for heart disease. We also used the broad indicator of exposure period (i.e. lean season July-December) in models for heart disease and dropped the indicator for mother's risk of malaria for the same reason of difficulty in model convergence.

Results

The distribution of IMR at respondent's birth when linked with PREHCO respondents (n=1447, first imputed data set) shows that most respondents were born in years with relatively high IMR; only about 1% were born in years with IMR less than or equal to 60; and about 28% born in years with IMR less than or equal to 100 (Figure 5). An examination of several

childhood and adult characteristics with IMR at respondent's birth showed (Table 3) that there were significant differences between IMR and age—a result to be expected since infant mortality improved between 1927 and 1943 (F=50.55, df 2, p=0.0000). There were also significant associations between higher IMR at respondent's birth and lower adult education (F=2.99, df 3, p=0.0298); low knee height (F=18.52, df 1, p=0.0000); and no exercise as an adult (F=8.94, df 1, p=0.0028). There were no significant differences between IMR at respondent's birth and other childhood and adult variables including adult heart disease and diabetes. The results remained the same with each of several different transformations of IMR (continuous, logit, square root, cubed root, deciles, quartiles, quintiles and extreme values), using multivariate models that also included a basic model with only IMR as predictors and estimating separate models for each exposure period (results not shown). An examination of the association with education, knee height, and exercise and other childhood and adult characteristics suggested several possible complex pathways through which IMR could possibly negatively impact health leading to adult heart disease and diabetes (Figure 6). In particular, the importance of educational attainment and exercise as an adult stand out as possibly playing an important mediating role.

[insert Figures 5 & 6 and Table 3]

The strong association between IMR at respondent's birth and low knee height is further examined in Table 4 because previous studies have shown low knee height to be associated with higher odds of adult diabetes (Palloni et al. 2005) and thus it may be that knee height mediates the effects of IMR on adult health. In Table 4 there is no association with season of birth and knee height (Model 1) but when IMR at respondent's birth is added to model estimation we find

that there are highly significant associations between IMR at respondent's birth and low knee height (Models 2 and 3). However, models with diabetes suggest that while the effects of knee height on diabetes are strong in some models (Models 4 and 5) they appear to fade in importance when the indicator "family member with diabetes" is added to the model (results not shown) and when IMR at respondent's birth is added to model estimation (Model 6). This is partially due to the strong association between knee height and having a family member with diabetes ($\chi(1)=5.00$, $p=0.0250$) in that about 26.93% of respondents with family members with diabetes can be classified with low knee height compared with about 21.77% of respondents with no family members with diabetes who can be classified with low knee height. It is also noteworthy to say that there is no association between family members with diabetes and IMR at respondent's birth. This would indicate that the family member with diabetes truly reflects a more genetic component than an environmental component. In addition, knee height appears to reflect environmental conditions during early childhood rather than to be directly linked with in utero exposures although it also has an important genetic component given its association with "family member with diabetes." When knee height is eliminated from the diabetes models with IMR at respondent's birth there is no significant association between IMR and diabetes (results not shown).

[Insert Table 4 about here]

Table 5 shows the prevalence of heart disease and diabetes using different cutoff points to separate PREHCO respondents into those born when endogenous mortality was a lower or higher fraction of IMR. While the prevalence of heart disease and diabetes tended to be larger at

small levels of IMR the sample sizes at smaller levels of IMR were very small and there were no significant associations between IMR and these diseases.

[Insert Table 5 about here]

In the full model for heart disease (Table 6, Model 1), we observe that the odds of reporting heart disease are about 40% higher for those born in the lean season than those born in the harvest season (OR 1.41, SE .20, p=0.012), a result similar to models without adult risk behavior (McEniry et al. 2008). When the sample is split into two groups---**Low IMR** reflecting lower IMR and better environmental conditions at birth (fraction of endogenous mortality is higher) and **High IMR** reflecting higher IMR and poorer environmental conditions at birth (fraction of endogenous mortality is lower)---we make several interesting observations: (1) the effects of exposure period (season of birth) are larger for the **Low IMR** group (OR 2.33, SE .66, p=0.003; OR 2.05, SE 0.55, p=0.007; OR 2.15, SE .52, p=0.001) and becomes insignificant for the **High IMR** group (Models 2-4) (OR 1.19, SE .19, p=0.276; OR 1.22, SE .20, p=0.226; OR 1.12, SE .20, p=0.511). This result provides evidence in support of the Barker hypothesis; (2) on the other hand we find that the effects of poor childhood health are significant and stronger only in the **High IMR** group which reflects poorer environmental conditions at birth (Models 2-4) (OR 1.61, SE .29, p=0.008; OR 1.63, SE .30, p=0.008; 1.50, SE .29, p=0.041). This result suggests that the indicator of childhood health (self-reported rating) reflects environmental conditions during childhood more than it does in utero exposures; (3) the effects of smoking are significant and positive in the overall Model 1 (OR 1.47, SE .26, p=0.028) but then only significant and positive in the **Low IMR** group (OR 3.39, SE 1.12, p=0.000; OR 3.00, SE .96, p=0.001; OR

2.20, SE .62, p=0.005) but not in the **High IMR** group (Models 2-4); (4) exercise and drinking have a protective effect on heart disease in the overall model (Model 1) (Exercise: OR .72, SE .11, p=0.023; Drink: OR .62, SE .13, p=0.020) but then only in the **High IMR** group (Models 2-4) (Exercise: OR .68, SE .12, p=0.023; OR .67, SE .12, p=0.022; OR .61, SE .12, p=0.009; Drink: OR 0.49, SE .13, p=0.006; OR 0.48, SE .13, p=0.005; OR .52 SE .14, p=0.012) and not in the **Low IMR** group. This result is similar to previous results in models without adult risk behavior (McEniry et al. 2008).

[Insert Table 6 about here]

In the full model for diabetes (Table 7, Model 1) there are strong effects on diabetes of having a family member with diabetes (OR 4.09, SE .83, p=0.000), being born in the exposure (lean) period (OR 1.87, SE .43, p=0.006), having a family member with diabetes and being born in the exposure period (OR 0.54, SE .15, p=0.023), being obese (OR 1.42, SE .21, p=0.018) and exercising (OR .67, SE .09, p=0.002). Exercising lessens the odds of diabetes by about 33%. Here we note that when models are estimated separately by groups there are, at times, problems with model convergence in the Low IMR group due to sample size and thus we urge the reader to take the following results for the Low IMR group with caution. When models are estimated separately for the **Low IMR** group (lower IMR and better environmental conditions at birth, higher fraction of endogenous mortality) and the **High IMR** group (higher IMR and poorer environmental conditions at birth; lower fraction of endogenous mortality), we find: (1) the effects of the exposure (lean) period on diabetes are stronger in the **Low IMR** group (OR 2.66, SE 1.21, p=0.031; OR 2.45, SE 1.04, p=0.034; OR 2.12, SE .72, p=0.026) than the overall Model

1 and that in most models the effects are insignificant in the **High IMR** group; (2) while a family member with diabetes is highly significant across all models, the effects are stronger in the **Low IMR** group (OR 6.55, SE 2.79, p=0.000; OR 6.16, SE 2.47, p=0.000; OR 3.99, SE 1.27, p=0.026); (3) interaction effects between family member with diabetes and exposure period are weaker with no significant effects appearing across individual Models 2-4 in both the **Low IMR** and **High IMR** groups; (4) the effects of obesity are significant only in the overall model and the **High IMR** group (OR 1.47, SE .26, p=0.027; OR 1.51, SE .27, p=0.021; OR 1.67, SE .32, p=0.007); (5) exercising has a protective effect on diabetes in the overall Model 1 and then only in the **High IMR** group, Models 2b, 3b and 4b (OR .63, SE .10, p=0.002; OR .64, SE .10, p=0.021; OR .66, SE .11, p=0.007).

[Insert Table 7 about here]

Discussion

In this paper we collected historical data on IMR per *municipio* in Puerto Rico from 1927-1943 and linked them with respondent's place and year of birth using a comprehensive survey of Puerto Ricans aged 60 and older (PREHCO) in order to help disentangle the effects of early exposures in utero and early infancy. By the late 1920s and early 1940s, IMR was declining in Puerto Rico although it was still relatively high in comparison with the US and the UK, reflecting poorer environmental conditions. During this period of time, the major causes of infant mortality were diarrhea, congenital disabilities, chronic bronchitis and other infectious diseases. The **first** set of results concerns associations between IMR and adult health and the degree to which the effects of exposure to poor nutrition and infectious diseases in utero (as

measured by season of birth) were attenuated when IMR is included in model estimation. We found no significant association between IMR and exposure period (birth season). We also found no direct associations between IMR and adult heart disease and diabetes, but higher age, low knee height, lower education and not exercising as an adult were associated with higher IMR and these variables are associated either directly or indirectly with adult heart disease and diabetes. The odds of reporting heart disease and diabetes were higher among those born in the lean period as noted in previous work (McEniry et al. 2008) when IMR at respondent's birth were added and even when adult risk behavior (smoking, drinking and exercising) was added to model estimation. ***Overall, the pathways from IMR at respondent's birth to adult disease appear to be complex and indirect whereas the pathway to adult disease from in utero exposures appears to be more direct***. In other words: (1) IMR, largely reflecting environmental and poor economic conditions since IMR on average were relatively high in Puerto Rico during the 1920s-1940s, have a number of complex pathways by which to affect adult health; (2) exposures in utero have a more direct pathway to heart disease and diabetes; (3) knee height mediates the effects of IMR[33] and due to its association with IMR it appears to reflect environmental more than in utero conditions.

The **second** set of findings is centered on examining the fraction of neonatal (endogenous) mortality as proxied by low and high IMR. Even though neonatal mortality is higher at higher IMR, as mortality declines, the fraction of endogenous mortality increases and thus it may be possible to test the degree to which neonatal or endogenous mortality is a good proxy for conditions that precipitate the onset of adult disease. The results appear to suggest that this approach has merit. Even though there are issues with having a small sample size in some cases,

[33] Educational attainment and adult exercise are also important but we examined knee height in this paper due to previous work with diabetes (Palloni et al.2005).

we found what was expected if the Barker hypothesis has merit: stronger effects of season of birth and weaker effects of poor childhood health among PREHCO respondents who were born in years when the fraction of endogenous mortality was higher (i.e. lower IMR and better environmental conditions) as compared with PREHCO respondents who were born in years when the fraction of endogenous mortality was lower (i.e. higher IMR and poorer environmental conditions). Curiously, we also found that the effects of adult risk behavior were different between groups—strong positive effects of being a former smoker on heart disease and being obese among those born with lower IMR and better environmental conditions. In contrast, we found a protective effect of exercising on heart disease and diabetes and drinking on diabetes and higher odds of reporting diabetes for obese respondents among those born with higher IMR and poorer environmental conditions.

In terms of the **first** set of findings, it is important to point out that there was no significant association between exposure period (season of birth) and IMR which leads us to believe that there was no selective survival during the first year of life according to the timing of birth, a finding that others have also discovered (Doblhammer 2004). Thus, the argument that IMR was higher for those born after the harvest and that the strongest have survived, thus explaining the lower prevalence of heart disease and diabetes, does not appear to be true. In addition, the results suggest that season of birth is capturing in utero exposures more than environmental exposures during the first year of life.

Furthermore, the results contradict those of other studies which found a strong positive association between IMR at respondent's birth and adult mortality (Bengtsson & Lindstrom 2000; Bengtsson & Lindstrom 2003) while at the same time confirm the results of other studies which have not found such associations (Van den Berg, Lindeboom, & Portrait 2006). The

main reason for these differences appears to be due to the different reasons for the causes of death for infants in Sweden during the 18th and 19th century and Puerto Rico during the early 20th century. Small pox and whooping cough dominated IMR in Sweden at the time and these diseases affected everyone across social classes. Thus, economic factors were not a reason for IMR (Bengtsson & Lindstrom 2000). In these studies it has also been possible to obtain more detailed data regarding childhood airborne diseases such as small pox and whooping cough and adult mortality due to airborne diseases. This contrasts with other studies where infant deaths were mainly due to economic conditions (Van den Berg, Lindeboom, & Portrait 2006). Here economic conditions are more "loosely" defined and thus it is more difficult to establish one clear pathway to adult health. IMR are also too crude an indicator of environment to be able to discern particular pathways to adult health.

These observations may also explain the different pathways discovered in Puerto Rico operating through knee height and educational attainment. In the case of Puerto Rico, the two main causes of death—diarrhea and chronic bronchitis—reflected the lower educational level of Puerto Ricans in the rural countryside and pointed to feeding habits and knowing not to get close to a child when one is ill. The highest year of IMR in Puerto during 1927-1943 was in 1929, most probably caused by economic disturbances when the sugar cane industry experienced major down turns. Thus, even though there are studies which attribute poor childhood economic conditions to adult health (Hertzman 1994; Lundberg 1991; Wadsworth & Kuh 1997; Wickrama, Conger, & Abraha, 2005), the exact mechanism by which general poor economic conditions could lead to adult heart disease and diabetes is not clear.

Other reasons that explain differences in non-significance of results for IMR are: (1) the health outcome is morbidity whereas other studies have examined adult mortality; there may be

more ambiguity in measuring morbidity. However, even though there may be an underestimation of disease from the question being asked regarding if a doctor ever diagnosed the respondent with heart disease or diabetes, other studies have shown that the underestimation provides more conservative estimates but not extremely so (Banks et al. 2006; Goldman et al. 2003; Riosmena & Wong 2008). In any regards, the results obtained in this paper could be considered conservative; (2) the cross sectional nature of the PREHCO study means that we cannot observe those who have already died before the study began.

The observation that there is an association between childhood health, poor childhood SES, low knee height and education but not between IMR at respondent's birth and childhood health or poor childhood SES suggests that childhood health and childhood SES represent environmental conditions at different periods in childhood. Why is there no association between IMR at respondent's birth and childhood health or childhood SES? Again, it may be that each is tapping into a different dimension of the environment.

The significant association between IMR at respondent's birth and age is not surprising given that mortality in Puerto Rico had begun to decline during this period, primarily due to a decline in IMR. However, the associations between higher IMR and low educational attainment, not exercising and low knee height as an adult raise interesting issues. **First**, the negative association between IMR at respondent's birth and ***adult educational level*** suggests that poor environmental conditions during the first year of life impacts adult educational attainment, a finding that other studies have demonstrated (Palloni 2006). Even though there were no direct educational effects on adult heart disease or diabetes, the association between IMR at respondent's birth and education merits further investigation (beyond the scope of this paper) to better understand the different pathways to adult diabetes and heart disease through education

and adult exercise. It may be that the curious direct association between IMR at respondent's birth and adult exercise can be explained by the association between IMR and education. It is reasonable to believe that there is a more complex pathway from IMR to adult heart disease or diabetes and that this pathway is through education--lower IMR at respondent's birth is associated with higher educational levels and higher educational levels are associated with more exercise as an adult and exercise is associated with lower prevalence of adult diabetes and heart disease. **Second**, the significant association between IMR at respondent's birth and low knee height suggests that poor environmental conditions during the first year of life are associated with stunting in childhood and thus knee height may reflect this critical period versus in utero exposures. IMR at respondent's birth in the case of knee height is important because of the known association between knee height and diabetes in Puerto Rico (Palloni et al. 2005) but (disappointingly) not so in other Latin American or Caribbean countries. The results of the present paper provide one possible explanation for these previous results. The largely negative previous results with knee height may merely reflect that knee height is a more suitable indicator of early childhood but not necessarily in utero conditions. The initial association between knee height and diabetes, disappearing after "family member with diabetes" is entered into model estimation further suggests that it is mixture of environmental and genetic components at work and not in utero components affecting knee height. Thus, it may be that the effects of IMR at respondent's birth are mediated through knee height but that they may not be strong enough to appear alone in models of diabetes without knee height.

In terms of the **second** set of findings related to splitting up the sample into two groups according to years when the fraction of endogenous mortality was low or high, the results suggest that there may be important regional differences in health due to different early life

conditions—the lower coastal regions where IMR were higher and the interior, mountainous region where IMR were lower. A few other tantalizing results appeared. The effects of season of birth (exposure period) were stronger among respondents born in years when the fraction of neonatal mortality was higher thus suggesting that season of birth is a good proxy for in utero conditions. On the other hand the effects of poor childhood health were significant only among respondents born in years when the fraction of neonatal mortality was lower, suggesting there is need to build on previous studies (Haas 2006) in a more careful examination of the meaning of the indicator of childhood health.

In spite of these results there were necessarily small sample sizes in the group reflecting high endogenous mortality due to the relatively high IMR in Puerto Rico during the 1920s-1940s and thus model convergence was a problem in the case of diabetes. The cutoff points by which we split the sample are arbitrary (cutoff points were at approximately 30% neonatal and 15% endogenous mortality) and we are left with the question whether it is the level of mortality or the fraction of endogenous mortality which is important in the Barker hypothesis. The ideal would have been to have the cutoff point at an IMR of nearly 60 but there were an insufficient number of cases with respondents born in lower IMR (20 under IMR of 60) and thus there is insufficient data to fully test this approach. In that sense, we may indeed be observing what some have described as the "tip of the iceberg" (Palloni et al. 2005). The PREHCO study surveyed only those born up until 1943 and thus the larger question may well be what might be observed for those born in the late 1940s and 1950s. We were left with examining a higher cutoff point.

The results obtained showing different effects of adult behavior (smoking, exercising and drinking) according to lower or high fractions of endogenous mortality are intriguing. The Barker hypothesis suggests that in utero exposure to poor nutrition may lead to increased

vulnerability or susceptibility to environmental conditions after birth (Barker 1995; Barker et al. 2001). It may be that smoking represents such an environmental condition and thus we observe stronger effects of smoking among those born in lower IMR environments. Smoking is also an important inflammatory stimulus and so it may be that it is associated with inflammatory processes that begin in utero (Crimmins & Finch 2006). In terms of those born in higher IMR conditions, it may be true that adult health influenced by poor earlier environmental conditions is more amenable to change and improvement using interventions such as exercise that aim at changing one's environment. The explanation for the protective effects of drinking may be partially true because those who drink are in better overall health than those who do not drink (because those who do not drink may be on medication for heart disease or diabetes). It may also be that those who drink and who are born into poorer environmental conditions are healthier overall than those who drink and who are born into better environmental conditions. If these results have merit then the implication is that effective interventions to improve adult health require accounting for the circumstances of early childhood[34].

In addition to the limitations already cited we present a few more caveats to the analysis appearing in this paper. **First**, earlier models included a variable identifying the mother's risk of malaria according to region of birth, this variable was later discarded when it proved to show no important effects and model convergence was an issue. Future work may return to examine malaria and areas with high infestations of hookworm. Because the causes of IMR may have varied significantly from region to region within Puerto Rico, it may also be profitable to examine more closely respondents who were born in regions with very high IMR at the time of their births (e.g. sugar cane-producing hot lowlands) with respondents who were born in regions

[34] Adult interventions: target adults who were born with lower IMR and better environmental conditions to avoid smoking; target adults who were born with higher IMR and poorer environmental conditions to exercise more.

with very low IMR at the time of their births (e.g. interior mountainous region) to better understand the complex pathway leading to disease[35]. Although this may be a difficult if not impossible task, it may be insightful to more fully examine the hypothesis regarding the effects of inflammation (Crimmins & Finch 2006) in relation to PREHCO respondents who were born in higher IMR regions. **Second**, the analysis may be enriched by having more specific information regarding whether the respondent's mother worked and, if so, if she worked in the fields. A high percentage of respondents say that their mothers were housewives (68-78%) but we cannot obtain information from PREHCO regarding part-time employment and unfortunately there is not enough granularity in the occupation question to identify mothers who worked in sugar cane fields (for example). Mothers may have worked in offices instead of fields, but the question does not reveal this difference. **Third**, approximately 10% of infant births were not reported during the time period 1927-1943 which would tend to overestimate IMR at respondent's birth. However, we do not have data to show if this was the case across all *municipios* or across only a few. **Fourth**, we are not able to calculate IMR by rural versus urban areas and thus the IMR we use in the models are at the entire *municipio* level. About 50% of the *municipios* were identified as completely rural by the US census of 1930 (US census 1932) and about 10% were completely urban with the remaining showing a high percentage of rural residents. We know that IMR was higher in the urban areas but do not know the error we make when we use IMR at the *municipio* level. **Fifth**, the reliability of the cause of infant death is of concern as noted by public health officials in Puerto Rico during the period (Fernós Isern 1928). Diarrhea can hide the real cause of death and there are other diseases which can take on gastro-intestinal forms such as measles, whooping cough, congenital syphilis or TB. However, in

[35] Those born in higher IMR environments should show a strong association with IMR and knee height, educational attainment and those born in lower IMR should show a strong association with season of birth and heart disease.

general, public health officials during the 1930s believed in the overall reliability of these data to provide a big picture view of causes of death. Since we use this information to make an argument for the importance of economic conditions and not part of model estimation, this difficulty is less important in this particular paper. **Sixth**, even public officials of the day warn against interpreting rates by municipality (Morales Otero et al. 1937) because in some cases the rates are based on small numbers and there are different factors that may influence the rates from *municipio* to *municipio*. Future analysis may attempt to smooth these rates by computing, for example, rates by 5 year averages. **Seventh**, there is an unknown impact of how illegitimacy, which was prevalent in certain areas of Puerto Rico, affects IMR at respondent's birth. This might explain the variation between some *municipios*. In addition, still births (if the data are reliable) may also help better understand the variation between *municipios*. **Eighth**, we use cross sectional data which is representative of the population of Puerto Ricans aged 60 and older but which is not representative of the *municipios*. **Ninth**, it is still not clear whether it is the level of endogenous mortality or the fraction of endogenous mortality that is important in testing the Barker hypothesis. As far as we know there have been no other studies which have examined IMR in this way. **Tenth**, a question arises in terms of the degree to which families could plan for the hard times of the lean season in terms of consumption. We do not have consumption data for this period in Puerto Rico, nor do we have accounts of informal methods that families may have used to survive hard lean times. We only know that times were hard in the 1920s-early 1940s and many rural families were living at a subsistence level where expenditures exceeded earnings in many cases (Morales Otero et al. 1937). The annual reports of the health commissioner in Puerto Rico during this time mention the difficult times. However, it would be even more

helpful to obtain a better understanding of what happened with families that were laid off due to the zafra (lean season) and how they were able to survive.

In conclusion, by adding IMR at respondent's birth and examining its components we have added immensely to understanding the importance of in utero exposures versus environmental conditions during the first year of life and how these conditions affect older adult health. In that regard, there is merit to continue to dig even further in order to fully illuminate this most interesting and revealing story regarding early life conditions and adult health in Puerto Rico.

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Table 1: Infant mortality, neonatal and post-mortality rates and endogenous and exogenous mortality based on Bourgeois-Pichat method using 5 year averages for IMR

Year	IMR	Neonatal	Post-neonatal	% neonatal	Endo	Exo	% Endo	Stillbirth A	Perinatal B	% A
1935-39	122.6	36.1	86.5	29.5	14.5	108.1	12	66.3	80.8	82
1940-44	105.3	32.9	72.4	31.2	14.8	90.5	14	58.4	73.2	80
1945-49	78.9	28.8	50.1	36.5	16.3	62.6	21	51.8	68.1	76
1950-54	64.7	26.6	38.1	41.2	17.1	47.6	26	46.8	63.9	73
1955-59	**52.6**	**25.9**	**26.7**	**49.2**	**19.2**	**33.4**	**37**			
1960-64	**44.6**	**25.1**	**19.5**	**56.3**	**20.2**	**24.4**	**45**			
1965-69	**34.8**	**23**	**11.8**	**66.1**	**20.1**	**14.8**	**58**			
1970-74	26.1	20.2	5.9	77.3	18.7	7.4	72			
1975-79	19.9	15.7	4.2	78.7	14.7	5.3	74			
1980-84	17.5	14	3.5	80.0	13.1	4.4	75			
1985	14.9	12.1	2.8	81.1	11.4	3.5	77			

Source: First five columns are from Vázquez Calzada (1988) who cited the following sources:
José L. Vázquez Calzada y Nidia R. de Morales, *Patrones de Mortalidad Infantil en Puerto Rico [Patterns of Infant Mortality in Puerto Rico]* (1965), Monografias Estadísticas, Núm. 3, Biostatistics Section, Department of Preventive Medicine and Public Health, School of Medicine, Universidad de Puerto Rico; Department of Health, *Informe Anual de Estadísticas Vitales [Annual Vital Statistics Reports]*, años de 1963 a 1984 [years 1963-1984].

Endogenous and exogenous infant mortality were calculated by the author using the Bourgeois-Pichat (1952) assumptions and biometric method. Stillbirth rates were obtained from several years of annual reports to the Governor of Puerto Rico by the Commissioner of Health (see reference section for Garrido Morales, Ortiz and Fernós Isern). Perinatal rates and percentages of stillbirths calculated by the author using endogenous mortality plus stillbirth rate. Bolded are the years when the percent endogenous begins to be more predominant, similar to the period when Barker and Osmond (1986) used 1920-1925 data to illustrate the association between IMR and adult mortality due to coronary health disease. Blanks in the table reflect the changing of how still births were defined and/or unavailability of data for stillbirths after the 1950s.

Table 2: Major causes of infant mortality in Puerto Rico in 1934

Category	Predominant Diseases	All ages	Under one month	1st-11th month
Digestive system	Diarrhea & gastro-enteritis	35%	12%	48%
Early infancy	Congenital disability	24%	59%	5%
Respiratory system	Acute bronchitis	18%	9%	22%
Infectious diseases	Malaria, tetanus, TB, measles	16%	13%	17%
Total deaths		7442	2615	4827

Source: Report of the Commissioner of Health of Puerto Rico to the Governor of Puerto Rico for the fiscal year ending June 30, 1935, page 81. Note: Numbers for 1935, 1937, 1939 show similar percentages. Percentages in table do not add to 100. Not shown is other category (7-8%) comprised of unknown causes, nephritis and infantile convulsions.

Digestive system: diarrhea and gastro-enteritis, dysentery
Early infancy: congenital disability, other diseases of earl infancy, congenital malformations
Respiratory system: acute bronchitis, pneumonia, whooping cough
Infectious diseases: malaria, tetanus, TB, measles, syphilis, meningitis, diphtheria

A very high percentage of congenital disability falls within one month of life (82%) as does syphilis (64% of all cases of syphilis), infantile tetanus (99%), other diseases of early infancy (97%), and infantile convulsions (55%). All other mentioned diseases fall predominantly in 1-11 months of life.

Table 3: IMR at respondent's birth by childhood and adult characteristics for PREHCO wave one respondents who lived in countryside as children (n=1447)

Variable	Avg	St dev	N	Percent	Variable	Avg	St dev	N	Percent
Gender					**Family w diabetes**				
Female	119	36.7	833	58%	Yes	120	35.5	861	60%
Male	120	34.6	614	42%	No	118	36.0	586	40%
Age group [1]					**Smokes?**				
60-64	107	26.2	537	37%	Never	118	35.5	945	65%
65-69	121	32.5	511	35%	Previous	121	36.9	364	25%
70-74	136	45.4	399	28%	Current	122	34.1	138	10%
Education [1]					**Exposure**				
None	124	37.5	95	7%	None	119	32.6	390	27%
Primary	120	35.5	632	44%	Partial early	119	36.3	349	24%
Secondary	119	36.7	548	38%	Partial late	119	35.1	339	23%
Higher	116	32.1	168	12%	Full	120	38.9	369	26%
Obesity					**Broad exposure**				
Obese	120	37.3	426	29%	Harvest	119	33.6	725	51%
Not obese	119	35.1	1021	71%	Lean	120	37.5	708	49%
Poor childhood health					**Drinks?**				
Yes	121	34.2	357	25%	Yes	119	32.2	283	20%
No	119	36.2	1090	75%	No	119	36.6	1164	80%
Poor childhood SES					**Exercises?** [1]				
Yes	120	36.6	524	36%	Yes	117	34.8	622	43%
No	119	35.2	923	64%	No	121	36.4	825	57%
Low knee height [1]					**Heart Disease**				
Yes	128	42.0	362	25%	Yes	122	38.3	280	19%
No	116	33.09	1085	75%	No	119	35.1	1167	81%
Rheumatic fever					**Diabetes**				
Yes	129	31.6	34	2%	Yes	119	35.5	466	32%
No	119	35.8	1413	98%	No	119	36.2	981	68%

Source: PREHCO, first wave, imputed data set, weighted; only those living in countryside and between 60-74 years of age (n=1447 using first imputed data set and weighted results. The overall average for IMR at respondent's birth was 119 (35.7), n=1447.

[1]Cases where there was a significant association with IMR at respondent's birth using ANOVA: Age group (F=50.55, df 2, p=0.0000); Education categories (F=2.99, df 3, p=0.0298); Low knee height (F=18.52, df 1, p=0.0000) and exercises (F=8.94, df 1, p=0.0028).

Table 4: Effects of IMR at respondent's birth on low knee height and diabetes

	Knee Height Model 1 OR (SE)	Knee Height Model 2 OR (SE)	Knee Height Model 3 OR (SE)	Diabetes Model 4 OR (SE)	Diabetes Model 5 OR (SE)	Diabetes Model 6 OR (SE)
Female	1.04 (.13)	1.05 (.13)	1.06 (.14)	1.14 (.14)	1.08 (.13)	1.07 (.13)
Age 60-64 (ref)						
Age 65-69	1.06 (.16)	0.97 (.15)	0.97 (.15)	1.09 (.15)	1.12 (.15)	1.20 (.17)
Age 70-74	1.17 (.19)	1.00 (.18)	1.01 (.18)	1.12 (.16)	1.15 (.17)	1.26 (.20)
Education (yrs)	0.94 (.01)***	0.94 (.01)***	0.94 (.01)***	0.99 (.01)	0.99 (.01)	0.99 (.01)
Obesity					1.46 (.20)**	1.45 (.21)**
Poor child health					1.28 (.18)	1.22 (.17)
Poor child SES					1.02 (.13)	1.01 (.14)
Lean period	0.89 (.12)	0.89 (.12)	0.89 (.12)		1.18 (.14)	1.78 (.40)**
IMR at respondent's birth (continuous)		1.01 (.002)***	2.04 (.42)***			1.00 (.002)
IMR at respondent's birth (logit)						
Low knee height				1.37 (.19)*	1.41 (.19)*	1.29 (.18)
Family member with diabetes						3.87 (.78)***
Interaction family with diabetes X lean season						0.58 (.16)*
Range of n[1]	1421-1436	1421-1436	1421-1436	1421-1436	1421-1436	1421-1436
Range of LL[1]	-798, -787	-791, -779	-791, -778	-905, -885	-898, -876	-862, -834

Source: Puerto Rican Elderly: Health Conditions project (PREHCO 2007), imputed; all 60- to 74-year olds who lived in the countryside as children. Results shown are based on combining multiple imputation results. *p<0.05, ** p<0.01, ***p<0.001

[1]The multiple imputation procedure required us to work with five alternative completed data sets. In this case it was not clear how to calculate conventional statistics, such as chi square, BIC, or Akaike's information criterion, all of which are functions of data-specific log-likelihood functions. As a partial resolution to the conundrum, we present in this table the range of values for the chosen statistics obtained after estimating models for each of the imputed data sets.

Table 5: Prevalence of adult heart disease and diabetes according to different IMR at respondent's birth

IMR at respondent's birth	Heart Disease	Diabetes	n
<= 60	40%	36%	20
<= 70	24%	29%	59
<= 80	18%	31%	156
<= 90	18%	32%	270
<= 100	18%	30%	404
> 100	18%	32%	1043
Entire sample	19%	32%	1447

Source: PREHCO, first wave, imputed and weighted, 60-74 years old who lived in countryside as a child.

Note: Cutoff points for splitting PREHCO sample into those born in years of lower vs higher IMR were:
(1) less than or equal to 100 IMR;
(2) lowest quartile of IMR (96.7);
(3) lowest tercile of IMR (105).

Table 6: Effects of early life conditions on heart disease according to low IMR and high IMR groups

IMR at respondent's birth	Model 1	Model 2a Low IMR[1]	Model 2b High IMR[1]	Model 3a Low IMR[1]	Model 3b High IMR[1]	Model 4a Low IMR[1]	Model 4b High IMR[1]
	OR (SE)	OR (SE)	OR (SE)	OR (SE)	OR (SE)	OR (SE)	OR (SE)
Female	1.02 (.16)	1.75 (.59)	0.84 (.16)	1.98 (.65)*	0.79 (.15)	1.30 (.35)	0.87 (.18)
Age 60-64 (ref)							
Age 65-69	1.39 (.23)*	1.86 (.61)	1.24 (.25)	1.68 (.53)	1.29 (.27)	1.48 (.40)	1.36 (.31)
Age 70-74	1.59 (.29)**	2.11 (.75)*	1.46 (.31)	1.84 (.62)	1.52 (.33)	1.55 (.48)	1.61 (.38)*
Education (yrs)	1.00 (.02)	0.99 (.03)	1.00 (.02)	0.98 (.03)	1.00 (.02)	0.97 (.03)	1.01 (.02)
Obesity	1.87 (.27)***	2.38 (.69)**	1.75 (.30)***	2.38 (.65)**	1.73 (.31)**	2.37 (.57)***	1.71 (.32)**
Poor child health	1.49 (.24)*	1.23 (.41)	1.61 (.29)**	1.24 (.40)	1.63 (.30)**	1.43 (.39)	1.50 (.29)*
Low knee height	1.03 (.18)	1.14 (.42)	1.01 (.19)	1.06 (.37)	1.03 (.20)	1.12 (.35)	0.96 (.19)
Poor child SES	1.08 (.16)	0.87 (.27)	1.11 (.19)	0.91 (.27)	1.10 (.19)	0.97 (.24)	1.10 (.20)
Exposure period	1.41 (.20)*	2.33 (.66)**	1.19 (.19)	2.05 (0.55)**	1.22 (.20)	2.15 (.52)***	1.12 (.20)
Never smoked (ref)							
Previous smoker	1.47 (.26)*	3.39 (1.12)***	1.10 (.23)	3.00 (.96)***	1.13 (.24)	2.20 (.62)**	1.17 (.26)
Current smoker	0.85 (.25)	0.81 (.55)	0.83 (.27)	0.71 (.47)	0.86 (.28)	0.44 (.28)	1.01 (.33)
Exercises	0.72 (.11)*	0.95 (.36)	0.68 (.12)*	0.94 (.26)	0.67 (.12)*	0.95 (.23)	0.61 (.12)**
Drinks	0.62 (.13)*	0.94 (.28)	0.49 (.13)**	0.98 (.36)	0.48 (.13)**	0.82 (.28)	0.52 (.14)*
Range of n[2]	1429-1444	398-403	1023-1033	433-439	994-997	475-481	852-861
Range of LL[2]	-686, -670	-174, -171	-501, -486	-186, -192	-485, -472	-246, -251	-417, -427

Source: Puerto Rican Elderly: Health Conditions project (PREHCO 2007), imputed; all 60- to 74-year olds who lived in the countryside as children. Results shown are based on combining multiple imputation results. *p<0.05, ** p<0.01, ***p<0.001

[1]**Low IMR** are respondents born in years of lower IMR and better environmental conditions and **High IMR** includes respondents born in years of higher IMR and poorer environmental conditions. Model 1: Full model: Model 2: Cutoff point is IMR 100 at respondent's birth. Model 3: Cutoff is lowest quartile of IMR at respondent's birth (96.7). Model 4: Cutoff point is lowest tercile of IMR at respondent's birth (105).

[2]The multiple imputation procedure required us to work with five alternative completed data sets. In this case it was not clear how to calculate conventional statistics, such as chi square, BIC, or Akaike's information criterion, all of which are functions of data-specific log-likelihood functions. As a partial resolution to the conundrum, we present in this table the range of values for the chosen statistics obtained after estimating models for each of the imputed data sets.

Table 7: Effects of early life conditions on diabetes according to low IMR and high IMR groups

IMR at respondent's birth	Model 1	Model 2a Low IMR[1]	Model 2b High IMR[1]	Model 3a Low IMR[1]	Model 3b High IMR[1]	Model 4a Low IMR[1]	Model 4b High IMR[1]
	OR (SE)	OR (SE)	OR (SE)	OR (SE)	OR (SE)	OR (SE)	OR (SE)
Female	0.89 (.13)	0.90 (.25)	0.85 (.14)	0.91 (.24)	0.85 (.14)	1.06 (.23)	0.75 (.14)
Age 60-64 (ref)							
Age 65-69	1.17 (.17)	1.70 (.47)	1.01 (.17)	1.72 (.46)*	0.99 (.17)	1.41 (.31)	1.04 (.20)
Age 70-74	1.25 (.19)	2.02 (.63)*	1.04 (.19)	2.12 (.62)**	0.99 (.19)	1.73 (.43)*	1.01 (.21)
Education (yrs)	0.99 (.01)	1.00 (.03)	0.99 (.02)	1.01 (.03)	0.99 (.02)	1.00 (.02)	0.99 (.02)
Obesity	1.42 (.21)*	1.27 (.32)	1.47 (.26)*	1.20 (.30)	1.51 (.27)*	1.13 (.24)	1.67 (.32)**
Poor child health	1.22 (.17)	0.99 (.29)	1.33 (.21)[φ]	1.19 (.33)	1.24 (.21)	1.31 (.30)	1.24 (.22)
Low knee height	1.29 (.18)	1.18 (.36)	1.33 (.21)	1.11 (.34)	1.35 (.22)	1.26 (.31)	1.31 (.23)
Poor child SES	1.02 (.14)	1.65 (.402)*	0.85 (.14)	1.72 (.43)*	0.81 (.14)	1.41 (.29)	0.79 (.16)
Family member with diabetes	4.09 (.83)***	**6.55 (2.79)*** **	3.37 (.77)***	**6.16 (2.47)*** **	3.36 (.79)***	**3.99 (1.27)*** **	4.00 (1.04)***
Exposure period	1.87 (.43)**	2.66 (1.21)*	1.71 (.46)[*]	2.45 (1.04)[*]	1.70 (.46)	2.12 (.72)*	1.57 (.51)
Family member X exposure period interaction	0.54 (.15)*	0.38 (.20)[φ]	0.61 (.20)		0.62 (.21)	0.45 (.18)	0.70 (.27)
Never smoked (ref)							
Previous smoker	0.79 (.12)	0.86 (.25)	0.72 (.14)	0.86 (.24)	0.72 (.14)	0.98 (.24)	0.64 (.13)*
Current smoker	0.84 (.19)	0.46 (.26)	0.89 (.22)	0.41 (.22)	0.92 (.23)	0.50 (.22)	0.97 (.26)
Exercises	0.67 (.09)**	0.77 (.19)	0.63 (.10)**	0.70 (.17)	0.64 (.10)**	0.64 (.13)*	0.66 (.11)*
Drinks	0.77 (.13)	0.73 (.24)	0.73 (.14)	0.75 (.24)	0.73 (.15)	0.74 (.21)	0.75 (.16)
Range of n[1]	1427-1444	398-402	1023-1033	433-439	988-997	569-576	852-861
Range of LL[1]	-858, -831	-227, -221	-617, -599	-237, -245	-598, -591	-340, -331	-494, -503

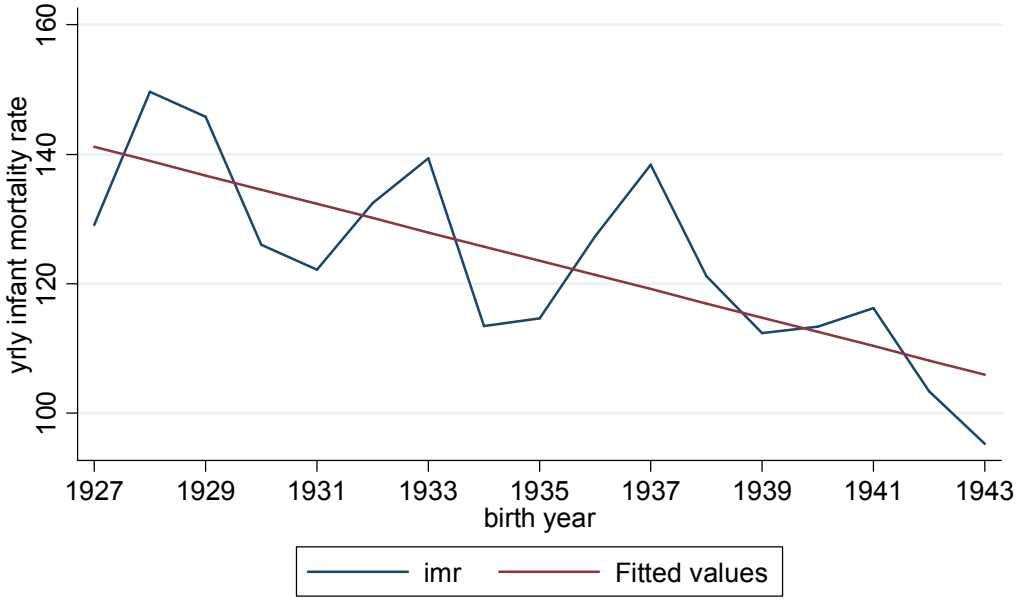
Source: Puerto Rican Elderly: Health Conditions project (PREHCO 2007), imputed; all 60- to 74-year olds who lived in the countryside as children. Results shown are based on combining multiple imputation results. *p<0.05, ** p<0.01, ***p<0.001. **Bolded** coefficients reflect difficulties in model convergence.

[1]**Low IMR** are respondents born in years of lower IMR and better environmental conditions and **High IMR** includes respondents born in years of higher IMR and poorer environmental conditions. Model 1: Full model. Model 2: Cutoff point is IMR 100 at respondent's birth. Model 3: cutoff is lowest quartile of IMR at respondent's birth (96.7). Model 4: Cutoff is lowest tercile of IMR at respondent's birth (105).

[2]The multiple imputation procedure required us to work with five alternative completed data sets. In this case it was not clear how to calculate conventional statistics, such as chi square, BIC, or Akaike's information criterion, all of which are functions of data-specific log-likelihood functions. As a partial resolution to the conundrum, we present in this table the range of values for the chosen statistics obtained after estimating models for each of the imputed data se

Figure 1: Infant mortality per 1000 live births

Puerto Rico 1927-1943



Source: Annual reports of Commissioner of Health; Note: slope is -2.20, p=0.000

Figure 2: Mortality rates in Puerto Rico (1927-1943)

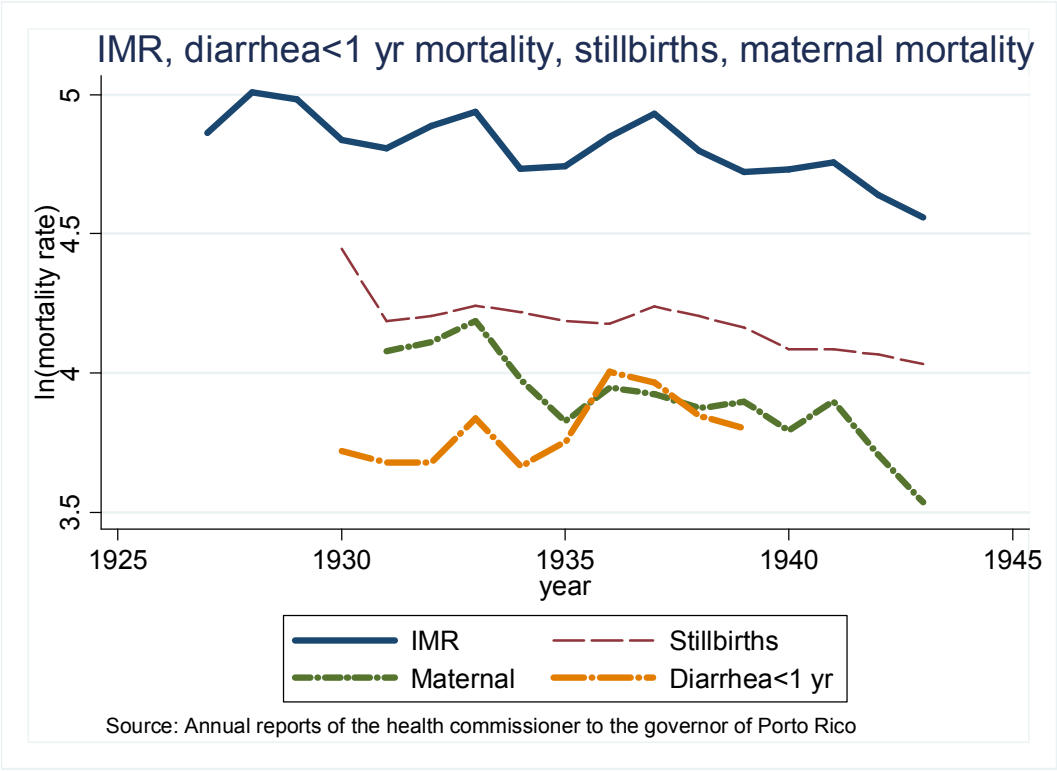


Figure 3:

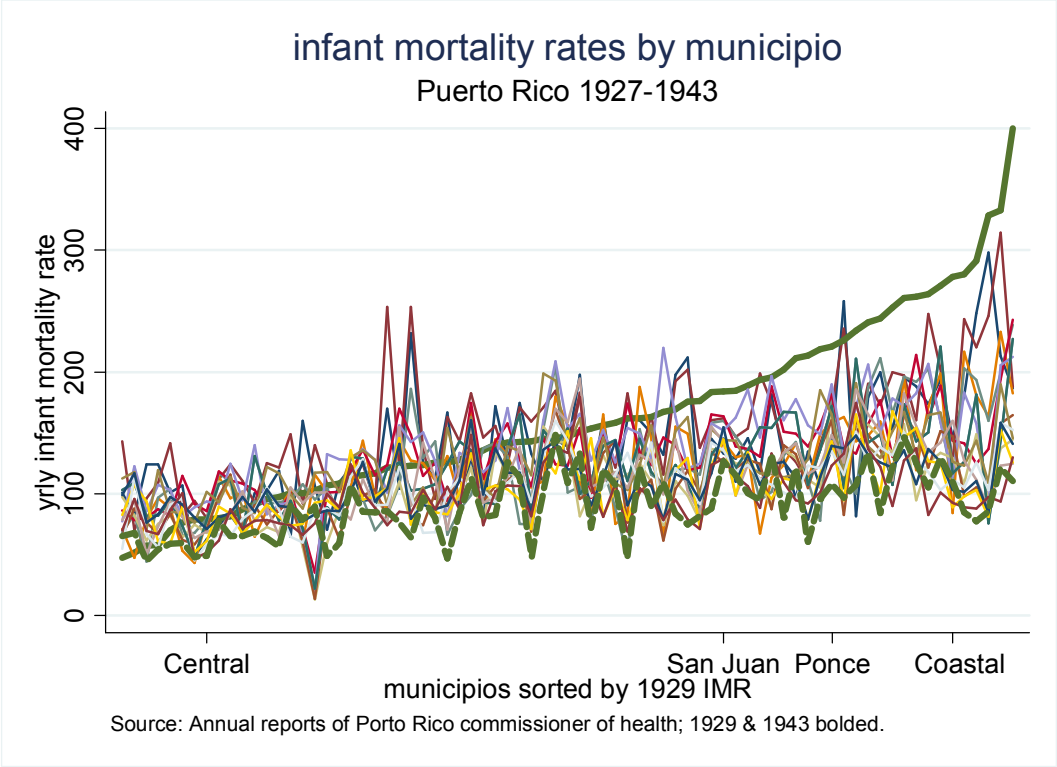

infant mortality rates by municipio
Puerto Rico 1927-1943
yrly infant mortality rate
0
100
200
300
400
Central
San Juan
Ponce
Coastal
municipios sorted by 1929 IMR
Source: Annual reports of Porto Rico commissioner of health; 1929 & 1943 bolded.

Figure 4:

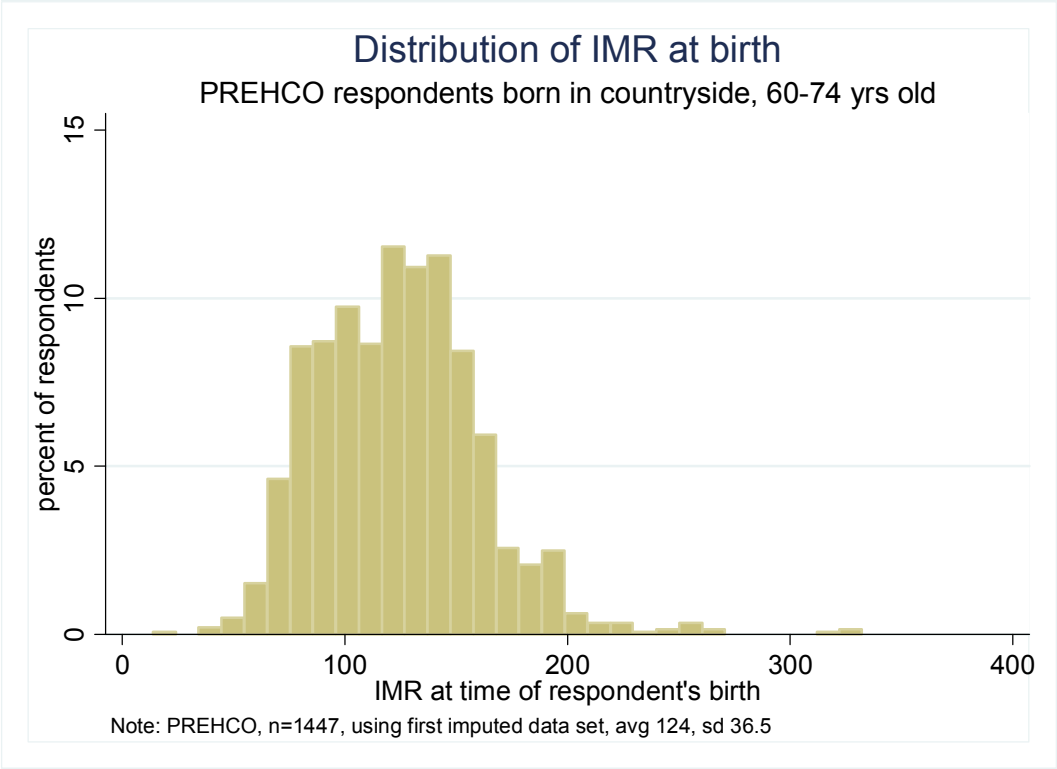
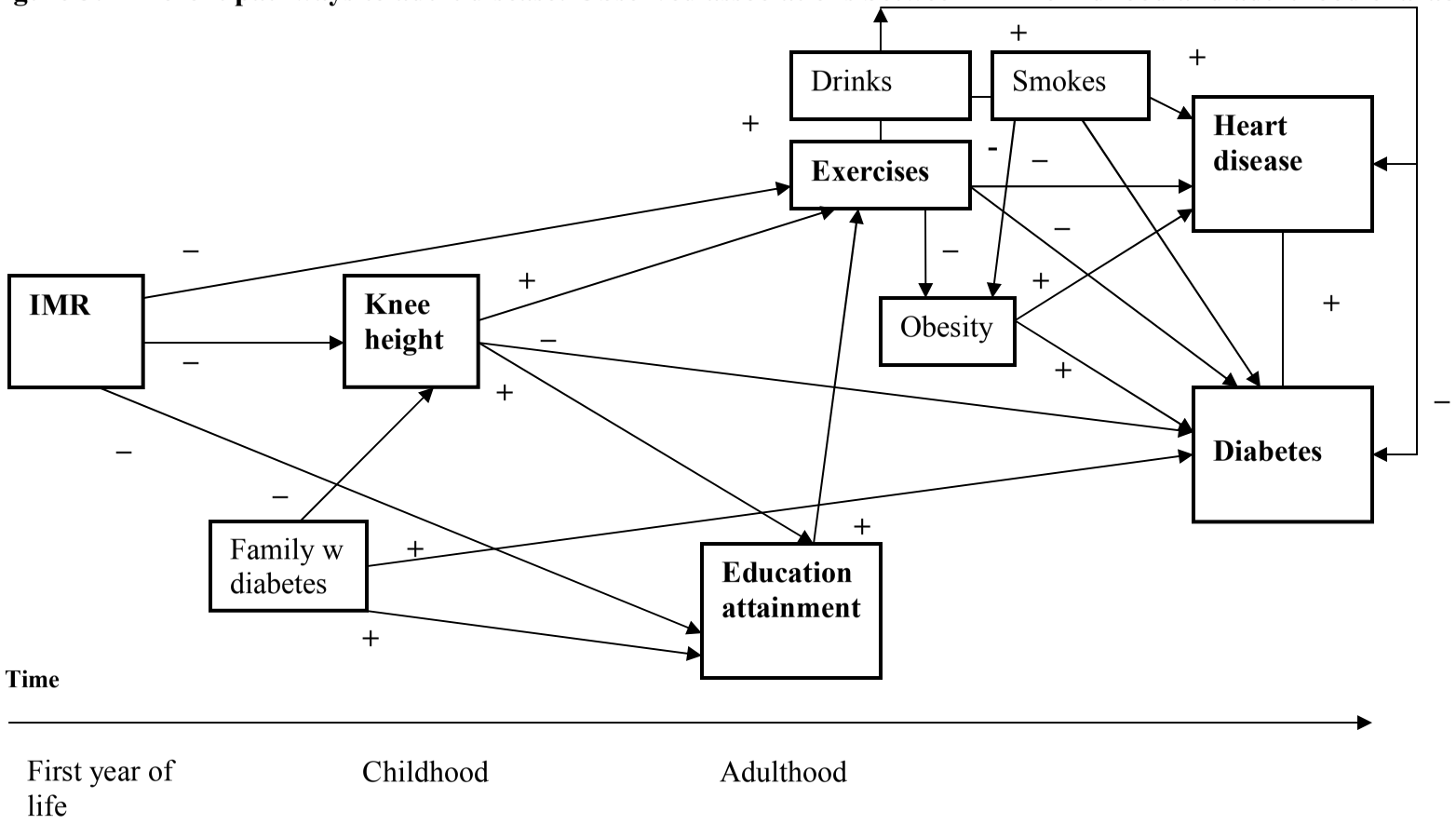

Distribution of IMR at birth
PREHCO respondents born in countryside, 60-74 yrs old
percent of respondents
0
5
10
15
0
100
200
300
400
IMR at time of respondent's birth
Note: PREHCO, n=1447, using first imputed data set, avg 124, sd 36.5

Figure 5: Different pathways to adult disease: Observed associations between IMR childhood and adulthood characteristics



Note: Poor childhood health and poor childhood SES were not associated with IMR but were negatively associated with educational attainment. Season of birth (exposure period) was associated only with heart disease and diabetes. Age not included in above diagram although it was positively associated with IMR (Source: PREHCO, first wave, imputed and weighted 60-74 years old living in countryside as child (n=1447).