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Abstract

This research provides a model of growth of the human development index (HDI) by examining past changes and levels of HDI and creates four "cohorts" of countries. Using a hypothetical cohort approach reveals a model of HDI growth. Generalized Estimating Equations are used to determine the impact that country characteristics have on HDI. The analysis shows that conflict has a significant impact on HDI. Further, while in 1970, the countries whose HDI was most impacted by conflict were developing nations, currently, conflict is most detrimental to the least developed countries. The research also shows that the 1990s presented particular challenges to the least developed countries, perhaps attributable to ramifications of the AIDS crisis. The research then uses the model to predict HDI in the future and compares results from the prediction with projections that result when –recalculating HDI using components that various agencies have separately projected.

Keywords: human development index, conflict, hypothetical cohorts.

JEL classification: C53, F01, O10

I. Introduction

Since 1990, the United Nations Development Programme (UNDP) has calculated a Human Development Index (HDI) for as many countries as the availability of reasonable quality data allow. The HDI aims to operationalize the "capabilities" of a country's population (see ul Haq 2003, Sen 1999, UNDP 2010). The index, a compilation of data intended to reflect the health, education, and income of a country's population, uses the most recent data available. Over time, countries may experience HDI change, depending on movement of any of the elements of the index.

While the index does not encompass the entire construct of human development (Ranis *et al* 2005). the demographic and development literature has long deliberated the interaction between mortality, income, and education, exploring the confluence of changes in these aspects of human development (e.g., Aka and Dumont 2008; Cutler *et al* 2006; Deaton 2003; Elo and Preston 1996; Kitagawa 1980; Lucas 1988; Morand 2004; Preston 1975; Preston 1980). By considering these three aspects of development holistically, one can consider the overall well-being of a population and circumvent the debate regarding causation in the development of these three aspects of human development.[1]

This paper develops a model of HDI growth which can be used to project HDI at the country level. The model was developed by creating "cohorts" of countries and then by applying demography's hypothetical cohort approach to observed 1970-2005 country-level changes in HDI. The model is verified by comparing historic HDIs for a subset of countries

[1] While debate continues about the proper weights for each of the components of the HDI (Arcelus et al 1999; Chakravarty and Majunder 2000) and how to properly measure each of the components (Arcelus et al 1999; Harkness 2004), the equal weighting of health, income, and education and the wide availability of indicators used have created an index that is transparent, even if imperfect.

with the model-inferred past HDIs and by comparing implications of independent projections of components of HDI with model-inferred HDI projections.

The projections suggest a possible future for the progression of HDIs, but are not designed to be predictive as changes in conditions and policies will impact a particular country's HDI. Further, unanticipated "shocks," such as war, economic sanctions, epidemics, and environmental calamities may negatively impact the HDI, while other shocks such as cures for prevalent diseases such as malaria and HIV/AIDS, end of conflict, sudden dramatic investments in and take-up of education, can positively impact a country's HDI. Thus, the projections should be interpreted as what might occur based on a past global experience with HDI growth, not a normative suggestion as to what will occur.

The remainder of this paper is structured as followed: First, data sources and relevant literature are discussed. Then, we explore the mathematical nature of HDI change, drawing on observations of the past. Third, we create development cohorts, and then apply a hypothetical cohort approach to the data at hand to derive a model of HDI growth. We consider how historical data on some of the world's most developed countries concurs with the model that we develop. We use Generalized Estimating Equations to estimate the impact of region and negative shocks on the growth of HDI. Then, we present "user" projected HDIs, showing how those projections concur with the Cohort model developed.

Our findings suggest that a trajectory of development exists. When developing, at first, HDI fluctuates. In this first stage, countries frequently enter into and exit from conflict and it appears that they are in the first stage of the epidemiological transition. Then, the HDI gradually develops. HDI growth shows considerable acceleration before reaching a plateau at a high level. Country characteristics and experiences, namely region, latitude, experience with malaria, and experience with natural disasters (floods, droughts, and earthquakes) do not consistently and significantly impact HDI once the cohort to which a country belongs and years since launch are considered. Conflict is the only characteristic that significantly impacts the development trajectory. Conflict prevents countries from development and takes countries that have been developing off of their development path.

II. Literature Review

There exists a tremendous volume of literature that examines income growth (e.g., Barro and Sala-i-Martin 2003, Lucas 1998, Pritchett 1997), mortality changes (e.g., Preston 1975, Deaton 2003) and investments in human capital, but researchers have not yet considered how the HDI will change in the future. Much of the literature that exists relies on regression analysis, using one component of the HDI (often income) as a dependent variable in an analysis with the other two components, along with other variables, considered independent variables. But as societies develop all three components usually advance--decreases in mortality make investing in human capital rational, education decreases mortality, income decreases mortality and is both a cause and consequence of education, etc. Morand notes “the relationship between economic growth and longevity runs both ways.” (Morand 2004, p. 170). By considering HDI and considering development as a holistic process, we sidestep debate about the endogenous causes of changes in health, education, and income.

Others have considered development as a progression, where some countries have started a path before other countries. Rostow discusses stages of economic growth, where a traditional society has a period where it establishes “preconditions for takeoff.” (Rostow, 1990, p. 479). A country’s “political institutions and social structure, as well as education system, require transformation before the technological backlog can be absorbed efficiently and regularly….Depending on a good many circumstances, including the character of the traditional society’s culture, the period of preconditions for takeoff could be long or short…

Once takeoff begins… the absorption of technologies does not proceed painlessly or, necessarily, swiftly.” (Rostow 1990, p. 479).

Rostow regarded takeoff as first affecting relatively few sectors and regions and then diffusing to others. The diffusion may require “further political and social conflict and institutional change. At the end of the process---the drive to technological maturity--- a national society will have absorbed all the major technologies from the global backlog.” (*Ibid.,* p. 480)

Regarding the length of time it takes to move through this process, Rostow thought that “for the countries whose takeoffs occurred before 1914, it required something like 40 years from the end of takeoff to the end of the drive to technological maturity. A few of the most precocious performers for the fourth graduating class into takeoff-- notably, Taiwan and South Korea-- have moved more briskly.” (p. 480).

Others have also seen aspects of development as following a path. For example, while examining school enrollments, Clemens (2004) suggested a common pathway that countries follow, once they launch on the path. Despite “an extraordinary diversity of approaches to education policy and of rates of change in educational attainment” there has been “a remarkably narrow range of experience in the transition from low to high enrollments….The surprisingly rigid constraints on this transition have applied not only to today’s developing countries but also to today’s rich countries in the course of their long-term development” (Clemens 2004, p.8). Clemens sees the transition to high enrollment as relatively uniform, once countries takeoff into the transition to high enrollment. “While country characteristics strongly affect the timing of the beginning of an ascent to high schooling rates, these characteristics have only a limited effect on the rate at which that ascent proceeds over the long term." That is, the path to higher rates is relatively uniform. What is not uniform is the date that countries enter this path.

III. Data

Data on the HDI[2], calculated as they were in the 2009 *Human Development Report,* derive from the Gray Molina-Purser dataset (version 1.0, November 2009). That dataset includes the HDI 1970-2005 in 5-year intervals for 111 countries. Since the *Human Development Report* only calculated the HDI for 82 countries throughout 1980-2005 and modified the formula for calculating HDI during that period, Molina and Purser created a dataset where the calculation of HDI was applied consistently throughout the 1970-2005 period. Further, to create a consistent trend for the maximum number of countries possible, Molina and Purser relied on extrapolation and interpolation for some countries (see Molina and Purser 2010). But, while in *2009 Human Development Report* presented the HDI for 182 countries and 12 other member states, the Gray and Purser dataset includes only 111 countries. Thus, one's understanding of the past depends on the external validity of the trends observed of the included countries to the countries excluded from the data set.

Other country characteristics and experiences were drawn from a variety of sources. Most variables were time-varying, meaning that when a time series of events or country characteristics were available, for those events or characteristics that could change over time, a variable(s) was/were created to reflect the time of the occurrence. For example, data on natural disasters and epidemics came from the WHO Collaborating Centre for Research on the Epidemiology of Disasters (CRED): Emergency Events Database EM-DAT (WHO

[2] The HDI equally weights three components of well-being-- health, education, and income—intended to reflect the "capabilities" (Sen 1999) of a country's population. Life expectancy at birth measures the capability of health, gross enrollment and adult literacy reflect the capability of education, and GDP (PPP) reflects the capability of income (UNDP 2009, p. 170) .

2010). From that source, we obtained the date when a natural disaster (flood, earthquake, and drought) occurred and the country of occurrence. Thus, natural disasters are time-varying covariates. The same source also included the date when a country experienced an epidemic, also a time-varying variable.

The World Health Organization provides to the United Nations data on deaths due to malaria amongst children younger than five years of age. These data were used to create a bivariate variable indicating the presence of malaria in a country (UN Statistical Division 2010). The average longitude and latitude of the country was used (Mobilgixstix 2010) as was the region to which the country belonged.

The prevalence of HIV/AIDS in a country, as reflected in the proportion of adults infected, was obtained from UN AIDS/WHO (2008). Countries were classified as democratic if they have an elected legislature, as measured by the Democracy versus Dictatorship project at the University of Illinois (Cheibub *et al* 2009, 2010). This variable is time-varying.

Finally, time-varying variables reflecting the existence and intensity of conflict were created. A bivariate time-varying indicator variable was developed to reflect whether the country experienced fighting within its borders. Thus, conflicts that the country may have supported, either by sending troops or other resources, to a destination outside of the country's borders, are not reflected in the bivariate variable. The intensity and/or breadth of conflict are measured using a time-varying variable that reflects the proportion of a country's population living as refugees in another country two years prior to and during the reference year. The numerator of this variable is based on data from the Office of the United Nations High Commissioner for Refugees and the denominator is country-level population figures as estimated by the United Nations Population Division for the respective year (UNDP, Human

Development Report Office, Statistics Team 2010; United Nations Population Division 2008).

IV. Cohort Approach

A. Key Concepts

It is useful to review the fundamental demographic concepts that will be used. Demographers think of time and growth in terms of age, period, and cohorts (see Ryder 1965; Preston and Van de Walle 1978; Wu 2003; Cook and Daponte 2008). "A cohort may be defined as the aggregate of individuals (within some population definition) who experienced the same event within the same time interval." (Ryder 1965, p. 845.) Birth cohorts--people who were born within a given period--are commonly referred to, however one can also think of cohorts created by other life events such as graduation cohorts or groups who enter school at the same time. Age refers to the amount of time since the event of birth. Period effects are the impact from having experienced an event that occurred during a certain point in time--usually as indicated by a year or a time span. One only needs to know two dimensions of time to determine the third. If one knows the birth cohort and age, one can determine the period effects that a cohort experienced.

The age at which one experiences certain period effects can create a cohort effect. Preston and Van de Walle (1978) showed that the age at which birth cohorts experience a period effect can create differences between them. Specifically, they examined the impact that gaining access to clean water and a sewage system at a particular age had on the physical well-being of cohorts. It was possible to disentangle cohort effects since cohorts were of various ages when introduced to improvements in the sewage system.

Cook and Daponte (2008) used the age-period-cohort approach to tease out the impact of these three dimensions of time on the increasing obesity trend in the United States. They showed that while there is an age pattern of change in weight over the life course, different birth cohorts entered adulthood with different rates of obesity. Period effects seem to have had the greatest impact in childhood.

U.S. baby boomers represent a cohort which experienced the period effect of the Vietnam War at a certain age (teenaged/young adult). Period effects can have different impacts depending on age. Certainly, the Vietnam War has a different resonance to U.S. baby boomers than to those born after 1965 or before 1940. Although many cohorts were exposed to that period effect, they experienced it in different ways.

Elder's research on the impact of the Great Depression on children (1999) showed that the responsibility that was imposed on children during the Great Depression created a cohort effect-- e.g., a desire to marry and have a stable home environment. World War II had a different resonance on different birth cohorts because of the interaction of war with age.

The rise in housing prices in the U.S. has had different implications on people, depending on their age (which is correlated with their propensity to have held real estate before prices escalated). It is believed that the economic crisis and rising unemployment of 2007-08 will produce a cohort effect, depressing the lifelong wages of the cohort of people who in 2007 were entering the labor force (e.g., those born in the 1980s).

Recently, countries themselves have argued that they belong to different cohorts. Essentially, China and India argue that they are in the same development cohorts, which differ from the world's most developed nations when they say that anti-global warming initiatives may impact their economies differently because they are at a different "stage" of development (BBC News 2009).

Our research applies a demographic approach to analyzing past trends and projecting the countries' future HDI. This approach allows one to consider whether period effects have different effects on different development cohorts. For example, given the rise of international foundations, governmental aid programs, and the Millennium Development Goals (MDGs), do countries developing now have better prospects for improving child mortality than countries that developed earlier (a period-cohort interaction effect)? Another possible period effect is the emergence of HIV/AIDS in the late 1980s-early 1990s—countries had difference capacities to deal with it proactively depending on their respective stage of development. Thus, period and cohort would interact.

If cohorts exist, can data be used to define them? How robust are these cohorts? The next section explains the assignment of countries to development cohorts.

B. Creating Development Cohorts

We use the 1970-2005 HDI data to create development cohorts. To develop meaningful cohorts of countries requires that cohorts be determined based on factors related to development. The most obvious data to use for determining cohorts is the HDI itself. We considered a few different ways of creating the cohorts, which ultimately provided similar results.

One alternative was to use the Human Development Report's level of development (very high, high, medium, and low) assigned to countries as the cohorts. This approach was rejected because those designations consider HDI only during the most recent year and the thresholds set between them are somewhat arbitrary. Single-year observations of HDI can fluctuate due to sudden events (e.g., epidemics, armed conflict, calamities) thus a country may be mis-assigned to a cohort. For example, the HDI for Rwanda drops significantly during the time period of the genocide. The most recent HDI could cause one to mis-assign countries to cohorts if the most recent reflects relatively recent booms in the economy. In some cases using a single year might cause some countries to shift cohorts, depending on the year chosen and their proximity to an HDI-group threshold.

Thus, a more robust approach considers the time series of HDIs to assign countries to cohorts. But, there exist other factors not measured in the HDI that affect the path of development for particular sets of countries; some of those factors have been measured across countries and can be used for determining cohort placement. One such factor is the presence or absence of malaria in the country. Although malaria itself has a strong affect on development, it also serves as a "proxy" for a host of other diseases specific to more tropical regions of the globe. Further, geographic location of countries might be an important factor for developing cohorts. Phenomena such as industrial developments are transferred more quickly from country to country if the countries in question are closer both culturally and also geographically (Spolaore and Wacziarg 2009). Finally, there are several UN-developed designations for countries, such as Small Island Developing State, Landlocked Developing Country, and Least Developed Country.

For the reasons listed above, the following variables were used to determine the cohorts:

- HDI values 1970-2005;
- the geographic region and sub-region of each country according to United Nations guidelines;[3]
- least developed country status; and
- presence of malaria within the country as determined by the World Health Organization.[4]

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[3] See http://unstats.un.org/unsd/methods/m49/m49regin.htm#least (accessed December 25 2009).

[4] See http://data.un.org/Data.aspx?q=malaria&d=WHO&f=inID%3aMBD32 (accessed December 25 2009).

A decision tree was created using the above information. All countries were ordered from high to low HDI. First, the "historic launching" cohort (Cohort 4) was created. This cohort includes countries that have enjoyed long-term, high levels of HDI. For inclusion in this cohort, a country's HDI_{1970} had to be at least 0.80 and its HDI_{2005} must have exceeded 0.93. Twenty countries meet those criteria. Japan is the only Asian country that fell into the most developed cohort, affirming Rostow's description of Japan's progress as "precocious" (Rostow, p. 479). Australia, New Zealand, USA, Canada also fit into the cohort, as do most countries in western and southern Europe (with the exceptions of Portugal and Greece).

At the other end, the "recent launching" cohort (Cohort 1) was created by including all countries that in 2005 had an HDI below 0.60. Thirty-two countries located either in Africa or Southeast Asia fell into this category.

Assigning the remaining countries to the middle two cohorts involved examining a combination of variables (geographic sub-region, malaria status, LDC status, and the clustering of the 2005 HDIs for similar countries in the sub-region). Determining whether the remaining countries belonged to Cohort 2 versus 3 was at first based on the clustering of geographic sub-region above or below the 0.86 threshold. Generally, if HDI_{2005} was at or above the 0.86 threshold, the sub-region was considered for assignment to Cohort 3 and if below, to Cohort 2. But, in many cases the HDI profile of individual countries within a sub-region appeared too diverse to place all of the countries in the sub-region into the same cohort. For example, Libya seemed exceptional for its sub-region, as did Greece and Portugal among Western European nations and Iran among Southern Asian nations. Thus, the additional clustering variables of least developed country and presence of malaria were used to subdivide sub-regions. In general, LDC status, and high malaria propensity resulted in being assigned to Cohort 2 rather than Cohort 3.

A cluster of countries—Panama, Costa Rica, and Mexico—was classified into Cohort 3 rather than Cohort 2 though the decision rules suggested its placement into Cohort 2. On closer examination, though, the anomalous nature of the countries' HDI growth as well as their ties with the USA suggested that moving them to a higher cohort created a better fit. While other borderline countries' history and demographic factors were individually considered in their cohort assignment, ultimately the decision rules were relied upon for their placement (these countries included Jamaica, Libya, and Brazil).

Table 1 displays countries by cohort. One-hundred and eleven countries were grouped into cohorts. Cohort 3 consists of countries that displayed the highest growth during the 1970 and 2005 period-- a number of wealthy middle-eastern countries, plus some from Central and South America. Cohort 2 includes other South American countries and countries on the cusp of substantial and rapid HDI growth.

We conducted a cluster analysis, using all of the panel data available. HDI time series were clustered using both Euclidian and Manhattan distance functions (i.e., sum of square differences and sum of absolute differences), and both median and centroid cluster methods. In the interest of parsimony, we decided to maintain four clusters. Results across those treatments were consistent with the cohorts to which countries had been assigned.[5]

We also conferred the reasonableness of the assignments with historical data. With few exceptions, the assignment of countries that are not of Cohort 1 or 4 into Cohort 3 was consistent with countries which in 1960 (UN Population Division) had a life expectancy at birth of at least 57 years.

The assignment of countries to cohorts almost perfectly concurs with the ranking of countries by HDI in 1970. There are exceptions, though. Considering the twenty countries with the highest HDI in 1970, all were assigned to Cohort 4 with the exception of Barbados,

[5] These results are available from the authors.

which was assigned to Cohort 3. All of the next 25 countries were assigned to Cohort 3. All of the next 38 countries were assigned to Cohort 2 with a few exceptions-- Libya and the UAE were bumped up to Cohort 3, while Congo, Zambia, Swaziland, and Kenya were moved to Cohort 1. Thus, generally the cohort to which a country is assigned reflects its potential for development in 1970. Some countries, such as Libya and the UAE, had unrealized that potential in 1970, a potential that may have been revealed with the rising demand for oil in the 1970s.

C. HDI Trends by Development Cohort

Figure 1 displays the HDI trends of the four cohorts, based on the 1970-2005 HDI data. While all cohorts show an increase in the HDI over time, the steepness of the rise in the HDI decreases as one goes from Cohort 1 to Cohort 4. The change in HDI during the 1970-2005 period was least for the most developed cohort (Cohort 4). Further, the figure shows that in Cohort 1, HDI fluctuates moreso than for other cohorts, obviously impacted by conflict.

Table 2 displays the variance and standard deviation of the cohorts, with each country weighted equally. While the variance of the HDI stayed stable or decreased over the 1970-2005 period for cohorts 2, 3, and 4, for cohort 1 the variance of the HDI increased. Cohort 1's pattern suggests that until the HDI takes off, there can be substantial volatility, some due to conflict and other shocks. Alternatively, the shocks may be preventing development from progressing. In Cohort 1, one observes a number of countries that seem to have been steadily developing, only to experience setbacks. For example, in Cohort 1, six (19%) countries experienced a decrease in their HDI by at least 5 percent between subsequent measures, and 17 (53%) countries experienced a decrease in HDI for at least one inter-observation period. In comparison, among Cohorts 2, 3, and 4, no country experienced a decrease as high as 5 percent between subsequent measures, and only 16, 36, and 0 percent, respectively, experienced a decline in their HDI within at least one inter-observation period. Thus, rather than follow a relatively stable path of increasing HDI, countries in Cohort 1 show a substantial amount of chaos. In 1990, HDI for countries in Cohort 1 ranged from approximately 0.23 to 0.62.

With respect to change in level of HDI by cohort, Table 3 presents the median HDI for each cohort by year. The median HDI of Cohort 1 grew by 0.16, of Cohort 3 by 0.14, and of Cohort 4 by 0.11. In contrast, Cohort 2 experienced relatively exceptional growth during this period with growth of the median by 0.19.

Looking at growth during 5-year intervals during 1970-2005, one observes that Cohorts 2, 3, and 4 seem to have experienced at times similar patterns of HDI growth, albeit during different time periods. While Cohort 1's level of HDI does not match with that of any other cohort, Cohort 2's median HDI grew from .72 to .75 between 2000 and 2005, similar to the growth in Cohort 3's HDI between 1970 and 1975. Further, Cohort 3's growth in HDI from 2000 to 2005 resembles cohort 4's change in HDI from 1970 to 1980. One might infer that Cohort 4 launched into a development path 25 years earlier than did Cohort 3. Similarly, one might infer that Cohort 3's launch preceded Cohort 2's by 30 years.

Roughly applying the epidemiological framework to the cohorts (Omran 1971; Olshansky and Ault 1986), it may seem that Cohort 1 is still is the "Age of Pestilence and Famine, when mortality is high and fluctuating." (However, the life expectancy at birth range that Omran posited for this stage, 20-40 years is well below the life expectancies in the high-40s of countries in Cohort 4.) Cohort 2 seems analogous to societies in the second stage of the epidemiological transition-- "The Age of Receding Pandemics, when mortality declines progressively and the rate of decline accelerates as epidemics peaks become less frequent or disappear" (Omran 1971, p. 546). Cohort 3 seems to be in "The Age of Degenerative and Man-Made Diseases, when mortality continues to decline and eventually approaches stability at a relatively low level." (*Ibid,* p. 517). Cohort 4 is analogous to countries in the last stage of the epidemiological transition posited by Olshansky and Ault, the "Age of Delayed Degenerative Diseases."

D. Hypothetical Cohorts

Given the determination of cohorts and their patterns of HDI growth in the 1970-2005 period, one can apply the hypothetical cohort approach used in the field of demography to enlighten the development trajectories of the cohorts.

Demographers apply the concept of the hypothetical cohort most famously in computing "life expectancy" and total fertility rates. Life expectancy at birth and total fertility rates are summary measures that take a period's age-specific rates of mortality and fertility, respectively, and age (or progress) a hypothetical cohort through life exposed to those rates. The essence of a life expectancy measure is a period's (year's) age-specific mortality rates. Life expectancy answers the question "how long might a hypothetical cohort expect to live, if everybody in it went through life exposed to a period's age-specific mortality rates?" The total fertility rate answers the question of "how many live births on average would a woman have if exposed to the age-specific rates observed in a particular period (year)?" These measures reflect an actual cohort's experience if the age-specific rates do not change throughout that cohort's lifetime. But, since age-specific rates are likely to change (e.g., a society's fertility and/or mortality may be decreasing), the cohort's actual experience probably will not match the hypothetical cohort's experience.

One can borrow this framework from demography and apply it to the HDI experiences observed in the 1970-2005 period by the four development cohorts to answer two questions:

> "How would HDI change if a country that launched its development path (with an HDI of approximately 0.33) were to develop having the same experience as the world has seen during the 1970-2005 period?" and
>
> "Does a relatively consistent development path exist?"

The curves of HDI growth presented in Figure 1 leads one to explore the application of the hypothetical cohort approach to the observed changes in HDI for the respective cohorts during the 1970-2005 period. Thus, development cohorts are "aged" through the 1970-2005 rates observed by cohorts with earlier launch dates. That is, one can explore what the development trajectory of Cohort 1 might resemble if the next stage of development for Cohort 1 were Cohort 2's experience, then Cohort 3's, then Cohort 4's.

E. Length of Time to Develop

If the HDI_{1970} of Cohort 1 defines the "launch," then one can determine the length of time it would take for the entire development trajectory to occur—going from the Cohort 1 1970 level to the Cohort 4 2005 level of HDI.

Examining how the medians of the cohorts align, we arrive at the following critical assumptions:

- there is approximately a 10-year gap between the end of Cohort 1's measurements and the commencement of Cohort 2's measurements;
- Cohorts 2 and 3 have a 10 year overlap; and
- Cohorts 3 and 4 have a 10 year overlap.

Figure 2 and Table 4 present the HDI of the cohorts, aligned with time, based on the above assumptions. Figure 2's development trajectory implies that Cohort 2 launched into HDI growth 45 years before Cohort 1; Cohort 3 launched 30 years before Cohort 2; and Cohort 4 launched 25 years before Cohort 3. Based on these assumptions, we estimate the year of HDI launch by cohort, where launch is defined as a cohort having a similar median HDI as Cohort's 1 in 1970.

Cohort	**Approximate Year of "Launch"**
4	1865
3	1895
2	1925
1	1970

Roughly, Cohort 4 launched in 1865, Cohort 3 in 1895, Cohort 2 in 1925, and Cohort 1 in 1970. Thus, if countries developed at the 1970-2005 rate of development, the model suggests it would take approximately 140 years for the Cohort 1 countries at their 1970 HDI to attain the Cohort 4's median 2005 HDI. The appropriateness of this approach rests on the assumptions that the future will resemble the 1970-2005 period and that we have correctly identified the gap and overlap assumed between cohorts.

Some may argue that the 1970-2005 period presented unique circumstances, while other may argue that "history repeats itself." Certainly, the 1970-2005 circumstances, with defined business cycles, the advent of the HIV/AIDS epidemic, regional and local wars, and transfer of technology to developing countries might seem unique to those who lived through it. But, other periods in history have experienced deadly epidemics (e.g., polio, influenza), conflict and war, and business cycles have always existed. The transfer of technology has existed for eras (e.g., Marco Polo learning how to cook pasta from the Chinese).

To explore the robustness of the hypothetical cohort approach, we superimposed historical HDI data onto the hypothetical cohort data. Others who have estimated the 1870 HDI of Cohort 4 countries have generally found that the HDI in 1870 ranged from 0.22 to 0.47 (see Conte *et al* 2007; Felice 2005; Crafts 1997). Crafts' carefully constructed HDI* measure, which put historical income in reference to the US's 1992 income level, arrives at an 1870 HDI* measure for a subset of countries in Cohort 4 that has a median of 0.328, remarkably similar to what was found for Cohort 1 in 1970. Other measures of 1870 HDI of such countries report a median HDI of 0.41 to 0.47.

Figure 3 superimposes Conte *et al's* historic HDI estimates of "Advanced Capitalist Countries" for the 1870-1990 period (Conte *et al* 2007, p. 10) on the hypothetical cohort data. One observes striking consistency between the actual historic data and the hypothetical cohort data. The historic HDI's fit in with the cohorts being proposed reasonably well. Spain, though, appears as a bit of an outlier, its HDI drawn down by the Spanish Civil War of 1936. Although the country continued increasing its HDI, after Franco died in 1975 the increase in HDI accelerated and Spain "caught up" with the rest of western Europe.

Figure 3 demonstrates that at earlier dates, Cohort 4 showed more diversity in its HDIs than it does today, resembling Cohort 1's recent spread. Not only did Cohort 4's median resemble Cohort 1's at the analogous point in development, so did its variance. **Table 5** shows the HDIs of the cohorts, combined with the historic data for the subset of Cohort 4 countries. The triangulation of the hypothetical cohort approach with historical data assures that the hypothetical cohort approach applied to this situation is reasonable.

With respect to the assumptions regarding the timing of the gaps and overlap between cohorts, if these assumptions are incorrect, then the length of time of the trajectory would be affected. The connection between Cohorts 2, 3, and 4 is evident in the level and growth of their median HDIs. However, we assume that there is a 10-year gap between Cohort 1 and Cohort 2. It may take longer than 10 years for countries in Cohort 1 to "jump" to Cohort 2's experience, or, pessimists may fear that Cohort 1 countries will never proceed to Cohort 2's experience.

F. The 1865-1870 period

The year 1865 is defined as the "launch" date for Cohort 4 countries. It is intriguing that this year resulted from the hypothetical cohort approach. In 1865, many of the Cohort 4 countries experienced an expansion of capabilities (Sen 1990). For example, in 1965 the U.S. Civil War ended and U.S. President Abraham Lincoln was assassinated in 1865. Substantial improvements were made to the London sewage system, affecting health. On the empowerment front, Lewis Carroll's *Alice's Adventures in Wonderland* was published, and with respect to health, Louis Pasteur hypothesized that air is full of bacteria. His hypothesis is the fundamental of the germ theory of disease, which, once widely accepted in the 1880s and 1890s, "led to a wave of new public health initiatives and the conveyance of safe health practices to individuals." (Cutler *et al* 2006, p. 102).

The 1865-1870 time period was one of substantial change for Japan, the only Asian Cohort 4 country. In 1868, Tokyo was declared the capital of Japan after the overthrow of the shoguns who had controlled Japan for 250 years. Worldwide, the 1865-1870 period was a year of substantial change in the areas of democracy, public health, and empowerment. It is important to note that the launch dates of development of the cohorts derived from the hypothetical cohort approach coincide with dates that others have noted being as significant. Cutler *et al* (2006) refer to 1870 as the approximate start date of the first phase of mortality decline in developed nations.

Pritchett also noted the 1865-1870 period as the beginning of the "modern economic period," writing "An argument can be made that 1870 marks a plausible date for a modern economic period … as it is near an important transition in several countries: for example, the end of the U.S. Civil War in 1865; the Franco- Prussian War in 1870-71, immediately followed by the unification of Germany; and Japan's Meiji Restoration in 1868. Perhaps not coincidentally, Rostow (1990) dates the beginning of the 'drive to technological maturity' of the United States, France and Germany to around that date, although he argues that this stage began earlier in Great Britain" (Pritchett 1997, p. 4).

V. Mathematical Model of HDI Growth

Taking the countries by cohort and plotting them against reference year, or years since launch, allows us to fit a curve to the HDI's of countries presented in Figure 2 and thereby quantify an overall trend for HDI. Because of the curved nature of growth of the HDI in the hypothetical cohort, issues of heteroscedasticity, and non-homogeneous error (error that is negatively correlated with "age" since launch), a logit transformation was taken of the HDI, allowing the logit transformation to be used as a dependent variable in a linear model:

$$\log\left(\frac{\mathrm{HDI}_{i\tau}}{1-\mathrm{HDI}_{i\tau}}\right) = \alpha + \beta\tau + \varepsilon_{i\tau}$$

for country i in year τ, with the error terms assumed to follow a Gaussian distribution. Of all the transformations attempted, this model best fits the data in terms of allowing a linear relationship between the dependent and independent variable.[6] However, the assumed error structure in the data required of a linear model is inappropriate for these data for another reason: we expect both correlation between measures of HDI for a country, and also correlation of measures that are of a particular year since launch. We therefore turn to Generalized Estimating Equations, a class of generalized linear regression models that allows for correlation between observations introduced in Liang and Zeger (1986) in the context of longitudinal surveys.

Within the GEE framework, the observations across countries are assumed to be independent, but observations for a single country are considered to be subject to some correlation structure. Several potential structures for the variance-covariance matrix of error

[6] We also considered transformations of log(HDI), log (log(HDI)), and exponential.

terms can be considered within the GEE framework, including independence (observations are independent both across time and across country), exchangeability (the correlation between observations is not zero, but not related to the time sequence of those observations) and unstructured (the correlation pattern across time is unknown). Within this context, we believe that not only is there correlation, but also the correlation is specific to the distance in time between two observations for country *i*. For that reason, we choose an autoregressive structure of order 1 for the variance-covariance matrix assumed for the model:

$$R = \begin{bmatrix} 1 & \rho & \cdots & \rho^7 & \rho^8 \\ \rho & 1 & \cdots & \rho^6 & \rho^7 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \rho^7 & \rho^6 & \cdots & 1 & \rho \\ \rho^8 & \rho^7 & \cdots & \rho & 1 \end{bmatrix}$$

To implement the model, we use the software package Geepack on the software platform R, as described in Halekoh *et al* (2006).

In this simple model, the effects associated with being county "*i*" are not explained in the dependent variables; that is, we assume exchangeability across countries at a given time τ. However, the value that τ takes is determined by the cohort of country *i* and reflects the time since "launch." Figure 4 shows the curve of the HDI, taking into account the correlated error structure of the time series of countries' data.

VI. Generalized Estimating Equations: Results

In order to model the possible effects of within-country conditions on the HDI, two sets of equations were estimated, both using a stepwise approach. Both sets of equations include variables for geography, health, democracy, natural calamities, and conflict. Descriptive statistics for those variables are given in Table 6. Geography is considered using latitude (a continuous variable) and region (four dummy variables, with western Europe the omitted category). The presence of malaria in the population was used to create a dummy variable, with 0.001 percent of population being infected the threshold level.[7]

Democracy was included as a time-varying dummy variable that pertains to the reference year, with 1 reflecting that the legislature in the country was elected (Cheibub *et al*). Natural disasters were considered using three dummy variables-- one reflected whether the country had experienced drought the year prior to the reference year, another reflected whether the country had experienced floods the year prior to the reference year, and a third whether the country had experienced an earthquake the year prior to the reference year. It was believed that if these events had an effect, it would be reflected in the data a year after the event(s). The lag is due, in part, to issues regarding the length of time it might take data collection agencies to record the impact.

In the first set of equations, presented in Table 7, cohort is reflected as "years since launch." This can take on four values in any given year, depending on the cohort to which a country was assigned. Naturally, the "years since launch" changes as the time period changes.

In the second set of equations, presented in Table 8, we are interested the "period" effect, reflected as the year to which the data refers. Thus, the cohort to which a country belongs is a dummy variable, with Cohort 4 the omitted category. Period effects-- 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005-- are reflected as dummies, with the year 2005 the omitted category. Multiplicative interaction variables were created to reflect period and cohort, allowing one to determine whether certain periods impacted some cohorts differently than others.

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[7] We also considered including the proportion of the adult population infected with HIV/AIDS. However, results suggested that this variable may have been picking up other dimensions of health and development, thus it was ultimately dropped from the analysis.

Table 7 and Table 8 also present several model quality measures. Because GEEs assume a complicated error structure and use a semi-parametric method to estimate that structure, standard goodness-of-fit statistics are not applicable. Pan (2001) proposes a Quasi-likelihood Information Criterion (QIC) as an alternate form of Akaike's Information Criterion (AIC) more appropriate for GEEs. Values of the QIC that are closer to zero are preferable, and like the AIC it balances the parsimony of the model against its precision. As an alternative measure, we also include the R^2 for each model; however, one should note that this measure is not as easily interpretable here as for linear regression models. Finally, we include the estimate of the correlation parameter for each model.

A. **Years Since Launch Models**

The first model (Column "A" of Table 7), which includes only latitude, provides a positive, significant intercept, significant coefficient, and a Correlation parameter alpha (CPA) of 0.946. A CPA at that level assures that there in fact exists correlation between subsequent HDIs of countries.

The equation that includes only years since launch, which takes on four different values for a given period, yields a CPA of 0.878 and the coefficient on years since launch, 0.026, is highly statistically significant. The predicted HDIs by cohort for 1970 and 2005 are shown to the right.

Predicted HDI Considering Only Time Since Launch				
Year	**Cohort**			
	I	II	III	IV
1970	0.28	0.56	0.73	0.86
2005	0.49	0.76	0.87	0.95

However, once "years since launch" is included, all variables reflecting geography are insignificant. This may reflect that to some extent geography was considered when forming the cohorts. However, the independent verification of the cohorts with the 1970 HDI and cluster analysis contradicts the redundancy argument. Nonetheless, geography seems to have no bearing on HDI once a measure of cohort is included in the model. Similarly, the presence of malaria has no significant impact once cohort is taken into account.

The measure of democracy, a time-varying variable reflecting whether the country has a democratically elected legislature in a given year, shows significance at the .05 level until variables reflecting the presence and severity of conflict are included. The coefficient of the variable is positive.

Natural disasters have no significant impact on HDI. This may be because many natural disasters do not have the breadth to reach a large portion of the population or the impact of the disasters may be ephemeral and lack the depth to significantly impact HDI as measured at the country level. Alternatively, disasters may impact the ability of the country to measure changes in the indicators used for constructing the HDI, thus data used for the HDI may not reflect the true nature of the country's circumstances.

Of particular interest is the impact of conflict on HDI. When conflict is considered as a dummy variable (Column I), showing whether the country had conflict within its borders the year prior to the reference year, then the coefficient is -.036, with the coefficient on years since launch unchanged. The next model, which includes variables reflecting the intensity of the conflict (the proportion of the country's population living in another country(ies) as refugees during and two years prior to the reference year), shows that the intensity of the conflict has a strong, negative, and significant impact on HDI.

% reduction in HDI with conflict…	**Cohort 1**		**Cohort 2**		**Cohort 3**		**Cohort 4**	
	1970	**2005**	**1970**	**2005**	**1970**	**2005**	**1970**	**2005**
1% refugee movement	1.9	1.8	1.2	.8	.7	.4	.4	.2
5% refugee movement	5.5	4.3	3.4	2.0	1.0	2.0	1.1	.5

While conflict decreases the predicted HDI of all countries, it has the greatest proportional impact on Cohort 1 countries. In 2005, a conflict that involved a refugee movement of 1% of the country's population, both 2 years prior to and during the reference period, would have reduced the HDI of a Cohort 1 and Cohort 4 country by 1.8% and .2%, respectively. In 1970, comparable figures for Cohorts 1 and 4 were a reduction of HDI by 1.9% and .4%, respectively. However, the absolute impact of conflict on HDI in 2005 exceeds that in 1970 for Cohort 1. All other cohorts have experienced a decrease in the absolute impact of conflict on HDI. Conflict's impact depends on the country's level of development at the time of conflict. When a country is at a steep development trajectory (e.g., Cohort 2 countries in 1970, Cohort 1 countries in 2005), conflict has the potential to have a particularly devastating impact.

B. Cohorts Considered as Dummy Variables

Another way of considering cohorts is to include them as dummy variables then include dummy variables that reflect the period. This approach allows one to consider cohort-period interactions. The omitted categories are Cohort 4 and 2005. Table 8 shows that when cohorts are considered as dummies, the coefficients are negative and significant (Model A). The coefficients follow the expected pattern, with Cohort 1 having a coefficient of -2.7, Cohort 2 of -1.7, and Cohort 3 of -.8.

Without the Cohort dummies included, the years are significant and the coefficients show HDI increasing throughout the period (Model B). Model C includes both the year and cohort dummies, and the coefficients barely shift from those obtain in Models A and B. The QIC statistic decreases, indicating that the additive model has greater explanatory power.

Model D adds Cohort*Period interactions. Analyzing the data this way allows one to determine whether some periods were better (or worse) for different cohorts. Nearly all of the interaction terms proved highly statistically significant.

The following results about cohort's HDI performance emerge:

- Cohort 1 countries enjoyed exceptional but declining growth in HDI during the 1970-1990 period. Since 1995, these countries have had slower growth than expected.
- Cohort 2 countries experienced better HDI growth than predicted until 2005.
- Cohort 3 countries were worse than expected in the 1970s, had a boom period in the 1980s, and from 1990-2000 experienced lower HDIs than expected. But, 2005 was a good year for these countries.
- Cohort 4 experienced somewhat lower HDI than expected, but perhaps this went unnoticed because they enjoyed much higher HDI than the other cohorts. The year 2000 was a turnaround for this cohort, with HDI being higher than expected.

Considering the period results by year, one sees the following:

- The 1970s were a good time for Cohort 1 and 2 countries, but a bad time for Cohort 3 and 4 countries.
- In the 1980s, all Cohorts except Cohort 4 had HDIs higher than expected.
- 1990 was bad for Cohorts 3 and 4 but good for Cohorts 1 and 2.
- 1995 was good only for Cohort 2.
- 2000 was good for Cohorts 2 and 4 but bad for Cohorts 1 and 3.
- 2005 resembled 1990 in its differential impact on Cohorts.

The analysis shows that while there are period effects, the effects are not equally distributed across cohorts. Where a country is in terms of its development impacts its vulnerability to shocks and world events and trends.

VII. Projecting HDI: Two Approaches

The base model, with years since launch, can be used to approximate the time it would take for a country to move from one level of HDI to another. Period effects are not included in this model, because they can only be estimate after the fact. Further, no other variables are included because of their insignificance. While the set of conflict variables were significant and had a substantial impact on HDI, the impact of a particular severity of a conflict is more complex than this simple illustration allows. Table 9 shows the number of years it may take for a country at an initial level of HDI at one time to reach a desired HDI at a future point in time. There is substantial error in these estimates.

However, the table suggests that if countries changed at the rates observed in the 1970-2005 period, it would take about 25 years (roughly, a generation), give or take a few years, for the following to happen:

- A country to go from an HDI of .43 to .60;
- A country to go from an HDI of .49 to .65;
- A country to go from an HDI of .61 to .75
- A country to go from an HDI of .75 to .85;
- A country to go from an HDI of .9 to .95.

For a country to move from, say, Philippines' HDI2007 of .75 to Spain's of .95 would take, according to this model, in the proximity of 71 years.

One can compare results from the base model with independent projections of HDI (Table 11). These projections, provided by the Human Development Report Office[8], were done by recalculating the HDI, using, for components of the HDI, projections of the components conducted by agencies that provide the UNDP with data for the HDI. Using this approach ("user approach") HDI was projected/re-calculated for 82 countries for which there was a complete data series for the 2010-2030 period. The approach relies upon projected information from UNESCO, the Economist Intelligence Unit, and the United Nations Population Division. In the User Approach, Japan will lead amongst countries in the data set, with an HDI of .998 in 2010.

Comparing the results of projecting the HDI using different approaches, one sees remarkable similarities. The datasets for the user and cohort projections overlap for only 59 countries. However, dividing those countries into their respective cohorts, one sees that the results for 2030 differ only slightly. Generally, by 2030, one needs to go to the thousandth digit to detect results that differ by cohort. For the 2030 projections, in Cohort 1, the median of the user approach was .675 whereas the Cohort approach projected a median of .649. For Cohort 2, the user and cohort approaches yielded 2030 HDIs of .849 and .856, respectively. For Cohort 3, the difference was even narrower, with .931 for the user approach and .928 for the Cohort approach, and for Cohort 4, the difference in the projected HDIs is .960 versus .966.

VIII. Discussion

The research presents a model for making sense of changes in the HDI, where time since "launch" is the most important variable. A hypothetical cohort approach allowed for the model of change in HDI to be created. Amongst the variables considered, the only one

[8] Daponte, B. Osborne and Hu, Difei. "Technical Note on Re-Calculating the HDI Using Projections of Components of the HDI." April 2010. UNDP/Human Development Report Office.

that consistently and substantially modifies a country's development pathway is conflict. Conflict has a deleterious effect on HDI, not only during a conflict, but may draw a country down perhaps indefinitely. However, it may be that many countries can "catch up" to their development path eventually, as was the case of Spain.

The findings are consistent with many strands of literature. Demographers have written about the "epidemiological transition" where some countries (our Cohort 1 minus Japan) started early through an epidemiologic path that begins with countries in the "age of pestilence and famine" progresses to the "age of receding pandemics," moves an "age of degenerative and man-made diseases" and finally ends with the "age of delayed degenerative diseases." (Omran 1971; Olshansky and Ault 1986). Omran asserted that the transition started early amongst some countries and lasted approximately 100 years. Further, some have explicitly pointed to some countries as have a "delayed epidemiological transition (most countries in Africa, Latin America, and Asia)." (Morand 2004, p. 172).

Whether cohort differences persist as countries "catch up" to the "advanced capitalist countries" is yet to be determined. Ryder noted that with people, "in later years, the cohort identity is blurred. Age becomes progressively less precise as an index of a person's social characteristics. Individuals… possess different 'ages' in the various institutional spheres….The intrinsic aging process may be variously accelerated or retarded by many different institutional arrangements." (Ryder, p. 858).

Certainly, cultural homogenization occurs as borders open and information is transmitted quickly. The long-term impact of cohorts may be simply that it aids in determining a development trajectory, but that eventually the impact of years since launch will dissipate as countries reach a development plateau. The model, though, helps one to identify leaders and laggards in the development process. The model can be used to assess a reasonable counterfactual to a country's progress.

Table 1: Countries by Cohort

Cohort 1 [N]=32	Cohort 2 [N]=31	Cohort 3 [N]=28	Cohort 4 [N]=20
Bangladesh Benin Burkina Faso Burundi Cambodia Cameroon Central African Republic Congo Cote d'Ivoire Democratic Republic of the Congo Ethiopia Ghana India Kenya Lao People's Democratic Republic Lesotho Liberia Madagascar Malawi Mali Mozambique Nepal Niger Nigeria Rwanda Senegal Sudan Swaziland Tanzania (United Republic of) Togo Uganda Zambia	Algeria Belize Bolivia Botswana Brazil China Colombia Dominican Republic Egypt El Salvador Fiji Guatemala Guyana Honduras Indonesia Iran Jordan Malaysia Mauritius Mongolia Morocco Nicaragua Paraguay Peru Philippines Samoa South Africa Thailand Turkey Tunisia Viet Nam	Argentina Bulgaria Bahrain Barbados Brunei Darussalam Chile Costa Rica Cyprus Greece Hong Kong Hungary Israel Jamaica Korea (Republic of) Kuwait Lebanon Libyan Arab Jamahiriya México Panama Poland Portugal Qatar Romania Soviet Union (former) Tonga Trinidad and Tobago United Arab Emirates Uruguay	Australia Austria Belgium Canada Denmark Finland France Iceland Ireland Italy Japan Luxembourg Netherlands New Zealand Norway Spain Sweden Switzerland United Kingdom United States of America

Table 2: HDI Variance and Standard Deviation by Cohort and Year

Year	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Overall
VARIANCE					
1970	0.0049	0.0056	0.0030	0.0003	0.040
1975	0.0063	0.0047	0.0020	0.0003	0.039
1980	0.0072	0.0042	0.0019	0.0003	0.038
1985	0.0083	0.0031	0.0015	0.0003	0.038
1990	0.0087	0.0025	0.0018	0.0002	0.037
1995	0.0085	0.0021	0.0021	0.0002	0.038
2000	0.0066	0.0020	0.0025	0.0002	0.037
2005	0.0055	0.0018	0.0027	0.0001	0.035
STANDARD DEVIATION					
1970	0.070	0.075	0.055	0.017	0.200
1975	0.079	0.069	0.045	0.017	0.197
1980	0.085	0.065	0.044	0.017	0.195
1985	0.091	0.056	0.039	0.017	0.195
1990	0.093	0.050	0.042	0.014	0.192
1995	0.092	0.046	0.046	0.014	0.195
2000	0.081	0.045	0.050	0.014	0.192
2005	0.074	0.042	0.052	0.010	0.187

Table 3: Median HDI by Cohort and Year, 1970-2005

Year	**Cohort 1**	**Cohort 2**	**Cohort 3**	**Cohort 4**
1970	0.33	0.56	0.73	0.84
1975	0.36	0.60	0.75	0.85
1980	0.37	0.63	0.78	0.87
1985	0.38	0.65	0.79	0.88
1990	0.41	0.67	0.80	0.90
1995	0.44	0.70	0.82	0.92
2000	0.47	0.72	0.84	0.94
2005	0.49	0.75	0.87	0.95
Overall Change	**0.16**	**0.19**	**0.14**	**0.11**

Table 4: Median and Fitted HDI by Cohort, Year, and Years since Launch

Years since Launch	Cohort 1			Cohort 2			Cohort 3			Cohort 4		
	Year	**Med. HDI**	**Fitted HDI**	**Year**	**Med. HDI**	**Fitted HDI**	**Year**	**Med. HDI**	**Fitted HDI**	**Year**	**Med. HDI**	**Fitted HDI**
0	1970	0.33	0.28	1925			1895			1865		
5	1975	0.36	0.31	1930			1900			1870		
10	1980	0.37	0.34	1935			1905			1875		
15	1985	0.38	0.37	1940			1910			1880		
20	1990	0.41	0.40	1945			1915			1885		
25	1995	0.44	0.43	1950			1920			1890		
30	2000	0.47	0.46	1955			1925			1895		
35	2005	0.49	0.49	1960			1930			1900		
40				1965			1935			1905		
45				1970	0.56	0.56	1940			1910		
50				1975	0.60	0.59	1945			1915		
55				1980	0.63	0.62	1950			1920		
60				1985	0.65	0.65	1955			1925		
65				1990	0.67	0.68	1960			1930		
70				1995	0.70	0.71	1965			1935		
75				2000	0.72	0.73	1970	0.73	0.73	1940		
80				2005	0.75	0.76	1975	0.75	0.76	1945		
85							1980	0.78	0.78	1950		
90							1985	0.79	0.80	1955		
95							1990	0.80	0.82	1960		
100							1995	0.82	0.84	1965		
105							2000	0.84	0.86	1970	0.84	0.86
110							2005	0.87	0.87	1975	0.85	0.87
115										1980	0.87	0.89
120										1985	0.88	0.90
125										1990	0.90	0.91
130										1995	0.92	0.92
135										2000	0.94	0.93
140										2005	0.95	0.94

Table 5: Comparison of Median HDI by Cohort and Year to Historic HDI Medians

Reference Year	Cohort 1	Cohort 2	Cohort 3	Historic Year (Reference Year)	Cohort 4	Variance Cohort 4
5	0.33			1870 (5)	0.48	0.0138
10	0.36					
15	0.37					
20	0.38					
25	0.41			1890 (25)	0.53	0.0116
30	0.44					
35	0.47					
40						
45		0.56		1910 (45)	0.61	0.00787
50		0.60		1913 (48)	0.62	0.00754
55		0.63				
60		0.65				
65		0.67		1929 (64)	0.68	0.00428
70		0.70				
75		0.72	0.73	1938 (73)	0.70	0.00411
80		0.75	0.75			
85			0.78	1950 (85)	0.76	0.00322
90			0.79			
95			0.80	1960 (95)	0.79	0.00117

Table 6: Descriptive Statistics for Variables Used for Modeling

Variable Name	Values Taken	Mean	Variance	1st Quartile			Median			3rd Quartile		
Reference Year	{0, 5, 10, …, 135, 140}	67.9	1,563	30			75			100		
Latitude	[-41, 65]	16.6	654	1.0			15.5			36.0		
				Frequencies								
				0	**0.01 to 0.02**	**0.03 to 0.04**	**0.05 to 0.06**	**0.07 to 0.08**	**0.09 to 0.10**	**0.11 to 0.15**	**0.33 to 0.35**	**0.36 to 0.38**
% Refugees 2 years prior to reference year	[0.00, 0.36]	0.003	0.0003	827	34	12	5	6	0	3	0	1
% Refugees reference year	[0.00, 0.38]	0.003	0.0005	822	40	13	5	2	3	0	2	1
				Frequencies								
				0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**
Flood year prior to reference year	{0, 1, …, 8, 9}	0.446	0.962	651	158	40	19	9	4	6	0	1
Conflict w/in borders, year prior to reference year	{0, 1, 2, 3, 4, 5, 6, 7}	0.259	0.542	744	89	43	4	3	1	2	2	
Earthquake year prior to reference year	{0, 1, 2, 3, 4, 5, 6}	0.155	0.391	808	52	13	9		3	3		
Drought year prior to reference year	{0, 1, 2}	0.077	0.073	821	66	1						
Cohort 1 Effect	{0,1}	0.288	0.205	632	256							
Cohort 2 Effect	{0,1}	0.279	0.202	640	248							
Cohort 3 Effect	{0,1}	0.252	0.189	664	224							
Region 1 (Latin America)	{0,1}	0.153	0.130	752	136							
Region 2 (Eastern Europe)	{0,1}	0.045	0.043	848	40							
Region 3 (Sub-saharan Africa)	{0,1}	0.261	0.193	656	232							
Region 4 (South-eastern Asia)	{0,1}	0.072	0.067	824	64							
Malaria Indicator	{0,1}	0.532	0.249	416	472							
Legislation elected	{0,1}	0.836	0.138	146	742							
Indicator, conflict w/in borders, year prior to reference year	{0,1}	0.162	0.136	744	144							

Table 7: Generalized Estimating Equation Coefficients, Basic Models

	(A) Latitude only	(B)= Base Model Years Since Launch only	(C)=(B) +Latitude	(D)=(B)+ Region	(E)=(B)+ Region & Latitude	(F)=(E) + Health	(G)=(F)+ Governa nce	(H)=(G)+ Natural Disaster	(I)=(H)+ Presence of Conflict	(J)=(H)+ Severity of conflict
Goodness of Fit (QIC)	-1577.57	-193.63	-201.42	-223.52	-233.19	-237.65	-242.86	-251.74	-257.99	-260.74
$1-\frac{SSE(residuals)}{SSE(\frac{\log(HDI)}{\log(1-HDI)})}$	0.198	0.912	0.913	0.914	0.914	0.916	0.916	0.916	0.917	0.918
Correlation parameter (AR1 model)	0.946	0.878	0.877	0.874	0.874	0.873	0.872	0.872	0.873	0.874
Intercept	***0.514	***-0. 936	***-0.935	***-0.954	***-0.930	*** -0.866	***-0.875	***-0.873	***-0.870	***-0.873
Cohort: Years since launch		***0.026	***0.026	***0.026	***0.026	***0.026	***0.026	***0.026	***0.026	***0.026
Region 1 (Latin America)				-0.081	-0.110	-0.096	-0.098	-0.098	-0.098	-0.097
Region 2 (Eastern Europe)				-0.113	-0.097	-0.122	-0.125	^-0.126	^-0.125	^-0.124
Region 3 (Sub-Saharan Africa)				0.032	0.004	0.015	0.011	0.011	0.010	0.020
Region 4 (South-eastern Asia)				0.091	0.073	0.099	0.098	0.098	0.109	0.106
Latitude	***-0.019		-0.0006		-0.0009	0.0008	0.0009	-0.0009	-0.0008	-0.0008
Malaria Indicator						-0.074	-0.076	-0.078	-0.073	-0.070
Legislature elected							*0.020	*0.021	*0.020	^0.013
Drought year prior to reference year								0.002	0.002	0.002
Earthquake year prior to reference year								-0.004	-0.004	-0.004
Flood year prior to reference year								0.003	0.003	0.003
% Refugees 2 years prior to reference year										***-0.539
% Refugees reference year										***-0.649
Conflict w/in borders year prior to reference year									**-0.036	*-0.024

Notes : Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

QIC=quasi-likelihood under independent model criterion; SSE=sum of squared errors.

Malaria= 1, 0 (1 if malaria present; Region: 1=Latin America (= South America, Central America); 2=Eastern Europe & former USSR; 3=sub-Saharan Africa; 4=Southeast Asia; the remaining countries are in the omitted category.

Table 8: Generalized Estimating Equation Coefficients, Period and Cohort Effects

Variable	**(B) Period Effects**	**(A) Cohort Effects**	**(C)= (A)+(B) Effects**	**(D)=(C)+ Interactions**
Goodness of Fit Statistic (QIC)	-1789.33	-342.13	-212.74	-210.45
$1 - \frac{\mathrm{SSE}(residuals)}{\mathrm{SSE}(\frac{\log(HDI)}{\log(1-HDI)})}$	0.080	0.834	0.915	0.922
Correlation parameter (AR1 model)	0.993	0.646	0.875	0.915
Intercept	***1.298	***2.273	***2.777	***3.038
Reference Year (0-140)				
Cohort 1 Effect		***-2.689	***-2.724	***-3.131
Cohort 2 Effect		*** -1.661	***-1.698	***-1.986
Cohort 3 Effect		***-0.844	***-0.871	***-1.121
1970 Effect	***-0.929		***-0.929	***-1.389
1975 Effect	***-0.795		***-0.795	***-1.261
1980 Effect	***-0.657		***-0.657	***-1.124
1985 Effect	***-0.555		***-0.555	***-0.981
1990 Effect	***-0.445		***-0.445	***-0.801
1995 Effect	***-0.324		***-0.324	***-0.595
2000 Effect	***-0.156		***-0.157	***-0.224
1970 Effect * Cohort 1 Effect				***0.734
1970 Effect * Cohort 2 Effect				***0.494
1970 Effect * Cohort 3 Effect				***0.438
1975 Effect * Cohort 1 Effect				***0.725
1975 Effect * Cohort 2 Effect				***0.515
1975 Effect * Cohort 3 Effect				***0.450
1980 Effect * Cohort 1 Effect				***0.702
1980 Effect * Cohort 2 Effect				***0.510
1980 Effect * Cohort 3 Effect				***0.484
1985 Effect * Cohort 1 Effect				***0.641
1985 Effect * Cohort 2 Effect				***0.484
1985 Effect * Cohort 3 Effect				***0.421
1990 Effect * Cohort 1 Effect				***0.529
1990 Effect * Cohort 2 Effect				***0.425
1990 Effect * Cohort 3 Effect				***0.337
1995 Effect * Cohort 1 Effect				***0.372
1995 Effect * Cohort 2 Effect				***0.354
1995 Effect * Cohort 3 Effect				***0.259
2000 Effect * Cohort 1 Effect				*0.105
2000 Effect * Cohort 2 Effect				^0.098
2000 Effect * Cohort 3 Effect				0.039

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. Missing categories are 2005 for period effects and Cohort 4 for cohort effects.

Table 9: Future HDI prediction: Base Model

Current HDI	Future HDI														
	0.35	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**0.99**	**0.995**
0.33	3	12	20	27	35	43	51	60	70	81	94	112	140	203	228
0.35	-	9	17	24	32	40	48	57	67	78	91	109	137	200	225
0.37	-	5	13	20	28	36	44	53	63	74	87	105	133	196	221
0.39	-	2	10	17	25	33	41	50	60	71	84	102	130	193	218
0.41	-	-	7	14	22	30	38	47	57	68	81	98	127	190	215
0.43	-	-	3	10	18	26	34	43	53	64	77	94	123	186	211
0.45	-	-	-	7	15	23	31	40	50	61	74	91	120	183	208
0.47	-	-	-	4	12	20	28	37	47	58	71	88	117	180	205
0.49	-	-	-	1	9	17	25	34	44	55	68	85	114	177	202
0.51	-	-	-	-	6	14	22	31	41	52	65	82	111	174	199
0.53	-	-	-	-	3	11	19	28	38	49	62	79	108	171	196
0.55	-	-	-	-	-	8	16	25	35	46	59	76	105	168	193
0.57	-	-	-	-	-	5	13	22	32	43	56	73	102	165	190
0.59	-	-	-	-	-	2	10	19	29	40	53	70	99	162	187
0.61	-	-	-	-	-	-	6	15	25	36	49	66	95	158	183
0.63	-	-	-	-	-	-	3	12	22	33	46	63	92	155	180
0.65	-	-	-	-	-	-	-	9	19	30	43	60	89	152	177
0.67	-	-	-	-	-	-	-	6	16	27	40	57	86	149	174
0.69	-	-	-	-	-	-	-	2	12	23	36	53	82	145	170
0.71	-	-	-	-	-	-	-	-	8	19	32	49	78	141	166
0.73	-	-	-	-	-	-	-	-	5	16	29	46	75	138	163
0.75	-	-	-	-	-	-	-	-	-	12	25	42	71	134	159
0.77	-	-	-	-	-	-	-	-	-	7	20	37	66	129	154
0.79	-	-	-	-	-	-	-	-	-	3	16	33	62	125	150
0.81	-	-	-	-	-	-	-	-	-	-	11	28	57	120	145
0.83	-	-	-	-	-	-	-	-	-	-	6	23	52	115	140
0.85	-	-	-	-	-	-	-	-	-	-	-	17	46	109	134
0.87	-	-	-	-	-	-	-	-	-	-	-	11	40	103	128
0.89	-	-	-	-	-	-	-	-	-	-	-	-	32	95	120
0.91	-	-	-	-	-	-	-	-	-	-	-	-	24	87	112
0.93	-	-	-	-	-	-	-	-	-	-	-	-	13	76	101
0.95	-	-	-	-	-	-	-	-	-	-	-	-	-	63	88
0.97	-	-	-	-	-	-	-	-	-	-	-	-	-	42	67
0.99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25

Table 10: User Projections

COUNTRY	HDI2010	HDI2015	HDI2020	HDI2025	HDI2030
JAPAN	0.959	0.971	0.980	0.990	0.998
AUSTRALIA	0.975	0.984	0.988	0.991	0.995
FRANCE	0.961	0.971	0.980	0.988	0.993
SPAIN	0.953	0.962	0.971	0.980	0.991
CANADA	0.969	0.977	0.983	0.986	0.989
NORWAY	0.975	0.979	0.982	0.986	0.989
NEW ZEALAND	0.946	0.955	0.968	0.979	0.988
IRELAND	0.968	0.974	0.978	0.981	0.984
ISRAEL	0.940	0.951	0.961	0.973	0.984
ITALY	0.956	0.963	0.970	0.976	0.984
KOREA, REP. OF	0.946	0.959	0.972	0.978	0.981
NETHERLANDS	0.964	0.971	0.975	0.978	0.980
GREECE	0.944	0.955	0.964	0.973	0.980
SWITZERLAND	0.960	0.967	0.972	0.976	0.979
SLOVENIA	0.933	0.950	0.963	0.974	0.977
DENMARK	0.951	0.959	0.969	0.974	0.977
AUSTRIA	0.953	0.962	0.969	0.973	0.976
FINLAND	0.956	0.963	0.971	0.975	0.976
UNITED STATES	0.958	0.962	0.966	0.969	0.973
UNITED KINGDOM	0.946	0.951	0.957	0.964	0.972
GERMANY	0.943	0.951	0.958	0.964	0.966
SINGAPORE	0.943	0.954	0.957	0.960	0.963
CYPRUS	0.905	0.917	0.931	0.945	0.959
CROATIA	0.892	0.911	0.927	0.943	0.956
SLOVAKIA	0.885	0.907	0.927	0.942	0.956
HONG KONG	0.947	0.949	0.951	0.953	0.956
ESTONIA	0.878	0.898	0.920	0.937	0.953
CHILE	0.883	0.902	0.919	0.935	0.948
HUNGARY	0.884	0.904	0.918	0.932	0.946

COUNTRY	HDI2010	HDI2015	HDI2020	HDI2025	HDI2030
POLAND	0.887	0.902	0.916	0.929	0.943
QATAR	0.913	0.920	0.927	0.934	0.941
CUBA	0.887	0.902	0.914	0.926	0.939
LATVIA	0.862	0.885	0.903	0.920	0.936
UNITED ARAB EMIRATES	0.893	0.907	0.920	0.927	0.934
LITHUANIA	0.867	0.887	0.905	0.920	0.934
PORTUGAL	0.905	0.912	0.919	0.927	0.933
MEXICO	0.858	0.880	0.899	0.912	0.923
BAHRAIN	0.891	0.905	0.909	0.913	0.921
COSTA RICA	0.856	0.872	0.889	0.905	0.920
BELGIUM	0.946	0.944	0.939	0.930	0.920
BULGARIA	0.845	0.866	0.883	0.900	0.918
KUWAIT	0.911	0.911	0.912	0.911	0.909
ARGENTINA	0.869	0.880	0.889	0.898	0.908
LIBYA	0.859	0.876	0.886	0.896	0.907
SWEDEN	0.949	0.941	0.934	0.920	0.906
MALAYSIA	0.833	0.853	0.868	0.884	0.899
VENEZUELA (Bolivarian Republic of)	0.847	0.869	0.877	0.885	0.895
SERBIA	0.832	0.850	0.865	0.878	0.893
ROMANIA	0.806	0.836	0.860	0.875	0.891
CZECH REPUBLIC	0.807	0.838	0.858	0.873	0.889
KAZAKHSTAN	0.812	0.832	0.849	0.866	0.885
SAUDI ARABIA	0.847	0.860	0.866	0.874	0.884
THAILAND	0.787	0.812	0.836	0.861	0.881
COLOMBIA	0.812	0.833	0.851	0.868	0.880
CHINA	0.790	0.820	0.840	0.859	0.876
IRAN(Islamic Republic of)	0.789	0.810	0.833	0.855	0.875
AZERBAIJAN	0.816	0.842	0.854	0.862	0.873
TURKEY	0.805	0.821	0.837	0.854	0.871

COUNTRY	HDI2010	HDI2015	HDI2020	HDI2025	HDI2030
BRAZIL	0.819	0.835	0.847	0.858	0.871
UKRAINE	0.790	0.811	0.831	0.849	0.865
ALGERIA	0.765	0.790	0.813	0.839	0.864
PERU	0.813	0.829	0.840	0.850	0.862
DOMINICAN REPUBLIC	0.804	0.819	0.831	0.845	0.859
TUNISIA	0.779	0.800	0.817	0.838	0.858
JORDAN	0.778	0.796	0.821	0.838	0.853
INDONESIA	0.748	0.778	0.809	0.831	0.852
EL SALVADOR	0.746	0.767	0.795	0.822	0.840
ECUADOR	0.807	0.814	0.819	0.824	0.833
SRI LANKA	0.767	0.788	0.806	0.816	0.829
PHILIPPINES	0.751	0.768	0.786	0.805	0.822
VIETNAM	0.736	0.760	0.782	0.796	0.811
RUSSIAN FEDERATION	0.726	0.742	0.755	0.768	0.780
EGYPT	0.705	0.723	0.740	0.757	0.775
MOROCCO	0.672	0.705	0.725	0.750	0.775
SOUTH AFRICA	0.687	0.710	0.724	0.743	0.764
INDIA	0.634	0.674	0.703	0.732	0.762
ANGOLA	0.576	0.605	0.634	0.662	0.689
KENYA	0.557	0.588	0.617	0.647	0.678
PAKISTAN	0.576	0.597	0.622	0.648	0.673
BANGLADESH	0.559	0.587	0.604	0.624	0.644
NIGERIA	0.529	0.561	0.575	0.594	0.619

Table 11: Contrasting Projections from User and Cohort Models

Cohort 1	User	0.574	0.607	0.627	0.650	0.675
	Cohort	0.524	0.556	0.588	0.619	0.649
Cohort 2	User	0.774	0.795	0.814	0.832	0.849
	Cohort	0.779	0.801	0.821	0.839	0.856
Cohort 3	User	0.887	0.900	0.912	0.922	0.931
	Cohort	0.885	0.897	0.909	0.919	0.928
Cohort 4	User	0.937	0.944	0.951	0.956	0.960
	Cohort	0.944	0.950	0.956	0.961	0.966

Note: User results reflect the mean of the projected HDI for countries in both data sets. Cohort results reflect the predicted HDI for the respective cohort.

Figure 1: HDI by Cohort and Year, 1970-2005

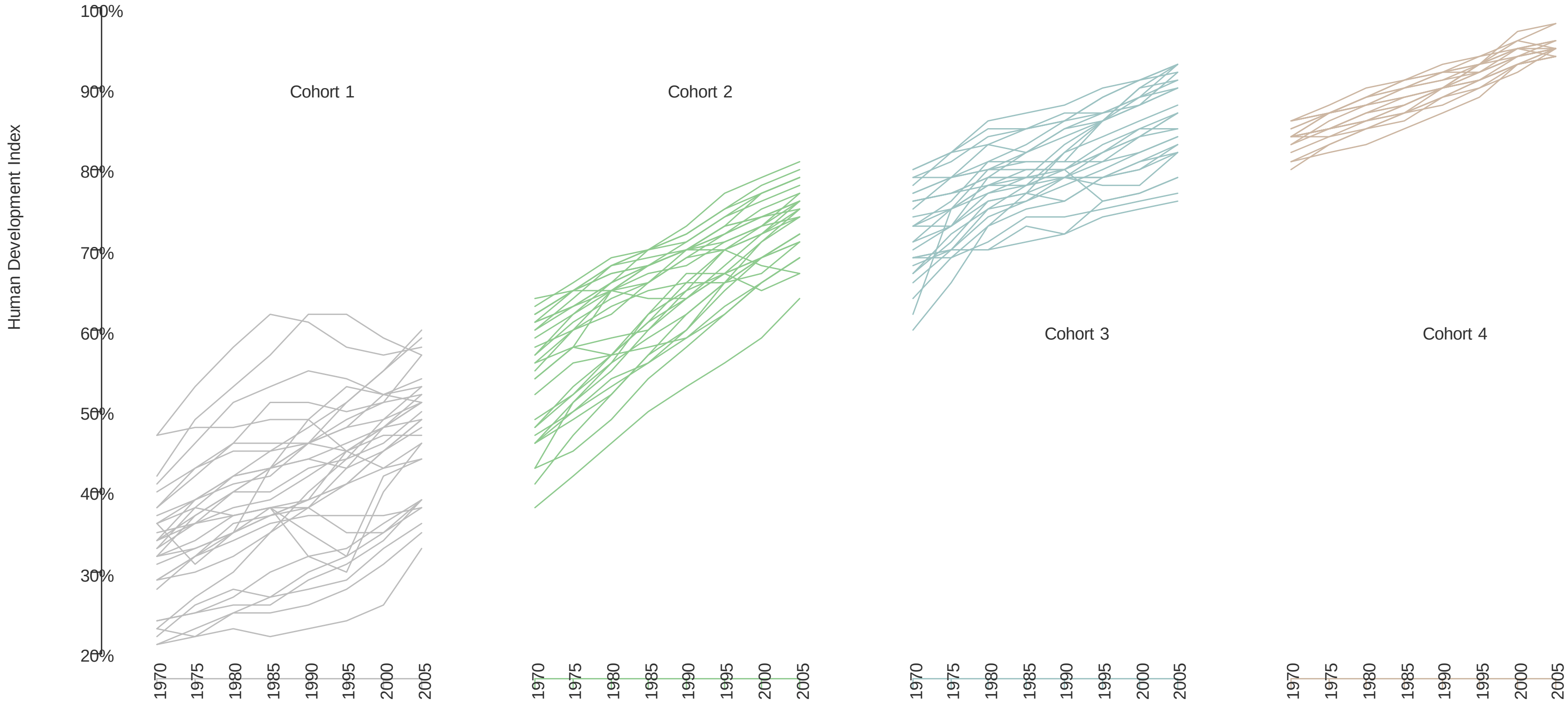


Figure 2: Alignment of HDI Cohorts

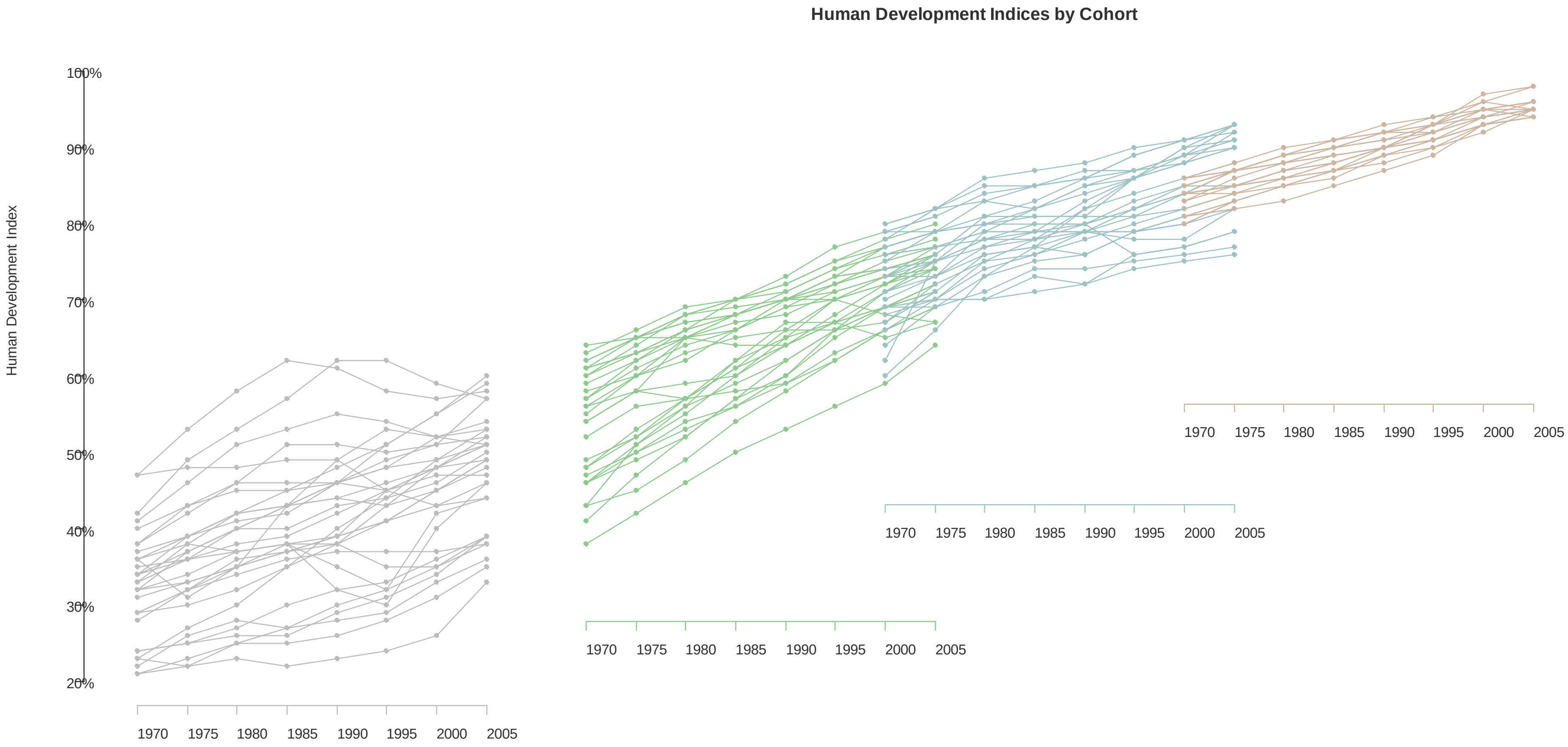


Figure 3: Historic HDI Overlapped on Period Data, by Cohort

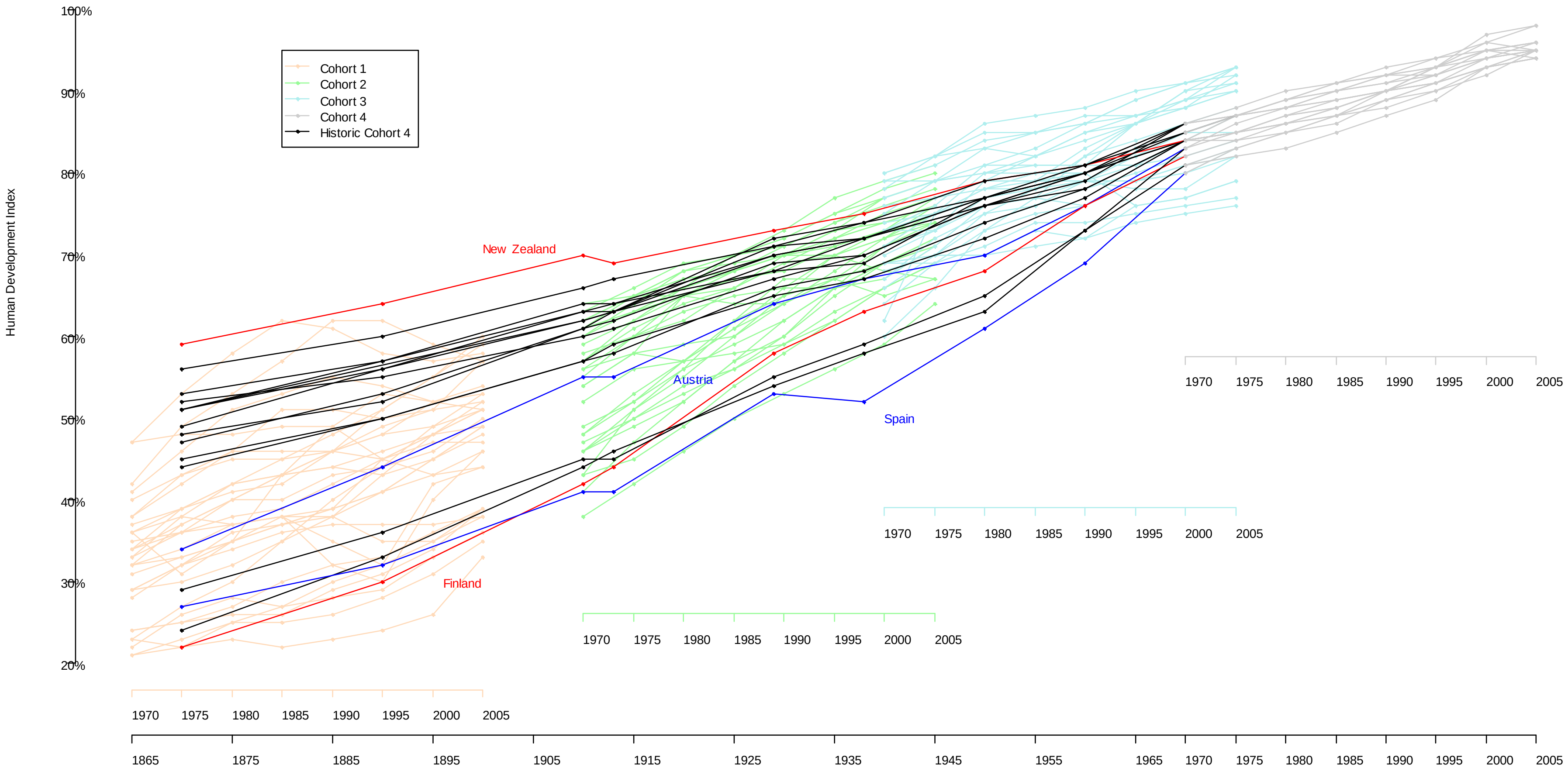
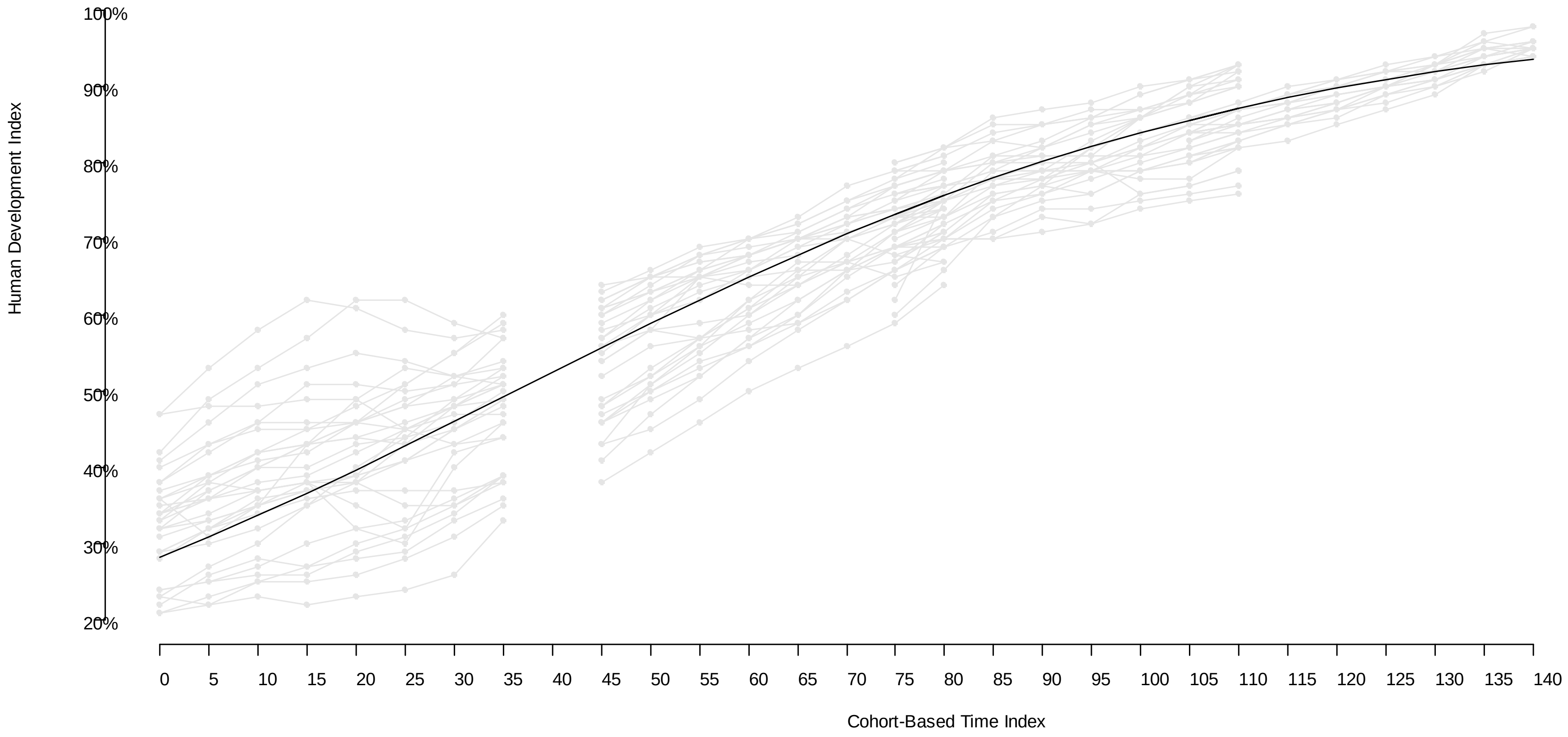


Figure 4: Fitted Model, HDI by Year and Cohort with Correlated Error Structure



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