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Pharmaceutical Innovation and Longevity Growth in 30 Developing and High-income Countries, 2000-2009

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ABSTRACT

We examine the impact of pharmaceutical innovation, as measured by the vintage of prescription drugs used, on longevity, using longitudinal, country-level data on 30 developing and high-income countries during the period 2000-2009. We control for fixed country and year effects, real per capita income, the unemployment rate, mean years of schooling, the urbanization rate, real per capita health expenditure (public and private), the DPT immunization rate, HIV prevalence and tuberculosis incidence.

Life expectancy at all ages and survival rates above age 25 increased faster in countries with larger increases in drug vintage. The increase in drug vintage was the only variable that was significantly related to all of these measures of longevity growth. Controlling for all of the other potential determinants of longevity did not reduce the vintage coefficient by more than 20%. Pharmaceutical innovation is estimated to have accounted for almost three-fourths of the 1.74-year increase in life expectancy at birth in the 30 countries in our sample between 2000 and 2009, and for about one third of the 9.1-year difference in life expectancy at birth in 2009 between the top 5 countries (ranked by drug vintage in 2009) and the bottom 5 countries (ranked by the same criterion).

Frank R. Lichtenberg

Columbia University

504 Uris Hall

3022 Broadway

New York, NY 10027

and NBER

frl1@columbia.edu

I. Introduction

Longevity increase is increasingly recognized by economists to be an important part of economic growth and development.² Economists also recognize that, in the long run, the rate of economic “growth...is driven by technological change that arises from intentional [research and development (R&D)] investment decisions made by profit-maximizing agents” (Romer (1990)). According to the National Science Foundation (2012), the medical devices and substances industries are the most research intensive industries in the economy. In 1997, “medical substances and devices firms had by far the highest combined R&D intensity at 11.8 percent,...well above the 4.2-percent average for all 500 top 1997 R&D spenders combined. The information and electronics sector ranked second in intensity at 7.0 percent.” Moreover, new drugs often build on upstream government research (Sampat and Lichtenberg (2011)).

In principle, technological change could be either disembodied or embodied in new goods. Solow (1960) hypothesized that most technological change is embodied: to benefit from technological progress, one must use newer, or later vintage, goods and services. Bresnahan and Gordon (1996) argued that “new goods are at the heart of economic progress,” and Hercowitz (1998, p. 223) also reached the “conclusion...that 'embodiment' is the main transmission mechanism of technological progress to economic growth.”

When technological progress is embodied in new goods, the welfare of consumers (and the productivity of producers) depends on the *vintage* of the goods (or inputs) they purchase. Solow (1960) introduced the concept of vintage into economic analysis.³ Solow’s basic idea was that technical progress is “built into” machines and other goods and that this must be taken into account when making empirical measurements of their roles in production. A number of econometric studies (Bahk and Gort, Hulten, Sakellaris and Wilson) have shown that manufacturing firms using later-vintage equipment have higher productivity.

We hypothesize that the health and longevity of a population depends on how technologically advanced the medical goods (including drugs) and services its members use are.

² See e.g. Nordhaus (2003) and Murphy and Topel (2006). Murphy and Topel estimated that, over the 20th century, cumulative gains in U.S. life expectancy were worth over \$1.2 million per person for both men and women. Between 1970 and 2000, increased U.S. longevity added about \$3.2 trillion per year to national wealth, an uncounted value equal to about half of average annual GDP over the period.

³ This was one of the contributions to the theory of economic growth that the Royal Swedish Academy of Sciences cited when it awarded Solow the 1987 Alfred Nobel Memorial Prize in Economic Sciences.

Furthermore, how technologically advanced a medical good or service is depends on its *vintage*, defined as its year of invention or first use.⁴

This study will examine the impact of pharmaceutical innovation, as measured by the vintage of prescription drugs used, on longevity using longitudinal, country-level data on 30 developing and high-income countries during the period 2000-2009.⁵ The analysis will be based on data drawn from several reliable databases: data on the utilization of over 89,000 pharmaceutical products from the IMS Health MIDAS database; life tables produced by the World Health Organization; and indicators of socioeconomic status, health expenditure, risk factors, and other variables from three World Bank databases and the OECD Health database.

In Section II, we postulate a model of longevity as a function of drug vintage and other variables. We also consider why the increase in drug vintage is likely to vary across countries, describe the other variables we will control for, and briefly review some of the literature about the determinants of longevity. In Section III, we discuss the measurement of longevity and pharmaceutical innovation. Descriptive statistics are presented in Section IV. Empirical results are presented in Section V. Implications of the estimates are discussed in Section VI. The final section provides a summary.

II. A model of longevity

We hypothesize the following model of longevity:

$$\text{LONGEVITY}_{ct} = \beta \text{VINTAGE}_{ct} + \gamma Z_{ct} + \alpha_c + \pi_t + \varepsilon_{ct} \quad (1)$$

where

- LONGEVITY_{ct} = a measure of longevity in country c in year t
- VINTAGE_{ct} = a measure of the vintage of prescription drugs used in country c in year t
- Z_{ct} = a vector of other attributes (e.g. income, education, risk factors, health expenditure) of country c in year t
- α_c = a fixed effect for country c

⁴ According to the Merriam Webster dictionary, one definition of vintage is “a period of origin or manufacture (e.g. a piano of 1845 vintage)”. <http://www.merriam-webster.com/dictionary/vintage>.

⁵ Previous studies have examined the effect of drug vintage on longevity using data from developed countries (cross-sectional patient-level data from Canada and Puerto Rico and longitudinal state-level data from the U.S. and Germany).

π_t = a fixed effect for year t
 ε_{ct} = a disturbance

The country fixed effects control for unobserved determinants of longevity that vary across countries but are constant (or very stable) over time; the year fixed effects control for unobserved determinants of longevity that change over time but are invariant across countries. Eq. (1) is a difference-in-differences model: a positive and significant estimate of β would signify that countries with larger increases in vintage had larger longevity increases, controlling for changes in other included attributes.

As explained below, there are only two years (2000 and 2009) for which data on LONGEVITY and VINTAGE are both available. We can write versions of eq. (1) for each of these two years:

$$\text{LONGEVITY}_{c,2000} = \beta \text{VINTAGE}_{c,2000} + \gamma Z_{c,2000} + \alpha_c + \pi_{2000} + \varepsilon_{c,2000} \quad (2)$$

$$\text{LONGEVITY}_{c,2009} = \beta \text{VINTAGE}_{c,2009} + \gamma Z_{c,2009} + \alpha_c + \pi_{2009} + \varepsilon_{c,2009} \quad (3)$$

When we subtract eq. (2) from eq. (3), the country fixed effects vanish:

$$\Delta \text{LONGEVITY}_c = \beta \Delta \text{VINTAGE}_c + \gamma \Delta Z_c + \Delta \pi + \Delta \varepsilon_c \quad (4)$$

where, for example, $\Delta \text{LONGEVITY}_c = \text{LONGEVITY}_{c,2009} - \text{LONGEVITY}_{c,2000}$ and $\Delta \pi = \pi_{2009} - \pi_{2000}$. Eq. (4) indicates that the 2000-2009 *change* in longevity in country c depends on the change in drug vintage and the changes in other determinants of longevity in country c. We will estimate eq. (4) by weighted least squares, weighting by 2009 country population.

Sources of international variation in drug vintage growth. There are several reasons why the increase in drug vintage ($\Delta \text{VINTAGE}$) is likely to vary across countries. Danzon et al (2005) demonstrated that both the probability and timing of the launch of a new drug in a country depends on the expected price of the drug (which is influenced by the regulatory environment) and the size of the market. They analyzed the effect of price regulation on the timing of launches in 25 major markets, including 14 EU countries, of 85 new chemical entities (NCEs) launched between 1994 and 1998. Their results indicated that countries with lower expected prices or smaller expected market size have fewer launches and longer launch delays, controlling for per

capita income and other country and firm characteristics. Controlling for expected price and volume, country effects for the likely parallel export countries are significantly negative.⁶

The rate of pharmaceutical innovation varies across diseases. Therefore, even if the drugs used to treat a given disease were the same in different countries, heterogeneity of countries with respect to the nature of diseases afflicting the population would cause the increase in drug vintage to vary across countries. Moreover, due to physician practice variation, the drugs used to treat a given disease are likely to be different (and to change at different rates) in different countries.

Other potential determinants of longevity. We will control for a number of other country attributes that some previous studies have indicated may be important determinants of longevity:

- income (real per capita GDP in constant 2000 US\$)
- unemployment rate
- education (mean years of schooling, 15+, total)
- urbanization rate
- real per capita health expenditure (public and private)
- DPT immunization rate (% of children ages 12-23 months)
- risk factors (HIV prevalence (% of population ages 15-49) and tuberculosis incidence)

Although the effects on longevity of at least some of these variables might seem obvious, the effects of some of them are theoretically ambiguous, or there is mixed evidence about their effects. We briefly review some of this evidence below.

Real income. Cutler, Deaton and Lleras-Muney (2006) observed that, “in both the time-series and the cross-section data, there is a strong correlation between income per capita and mortality rates, a correlation that also exists within countries, where richer, better-educated people live longer.” However, based on their review of the literature, they “downplay direct causal mechanisms running from income to health,” and “tentatively identify the application of scientific advance and technical progress (some of which is induced by income and facilitated by education) as the ultimate determinant of health.” Deaton and Paxson (2004)’s examination of patterns of mortality, income, and income inequality in the United States and in Britain since

⁶ Each NCE's expected price and market size in a country are estimated using lagged average price and market size of other drugs in the same (or related) therapeutic class. We estimate a Cox proportional hazard model of launch in each country, relative to first global launch. Only 55% of the potential launches occur. The US leads with 73 launches, followed by Germany (66) and the UK (64). Only 13 NCEs are launched in Japan, 26 in Portugal and 28 in New Zealand. Because a low price in one market may ‘spill-over’ to other markets, through parallel trade and external referencing, manufacturers may rationally prefer longer delay or non-launch to accepting a relatively low price.

1950 did “not suggest any simple relationship between income growth and the decline in mortality, nor between income inequality and mortality rates. In the United States, the period of slowest income growth saw substantial accelerations in the rate mortality decline.” Lichtenberg (2010, 2012) found no correlation and in some cases a negative correlation across states between income growth and longevity growth, both in the U.S. and in Germany.

Unemployment rate: Mean income tends to decline when the unemployment rate rises.

Therefore, if income had a positive effect on longevity, one would expect mortality rates to rise when the unemployment rate rises. But Ruhm (2005) has shown that the death rate rises during periods of low unemployment rates, and it falls when the unemployment rate goes up.

Education. Many studies have found a positive correlation between education and life expectancy. However, cross-sectional correlations between longevity and either income or education may substantially overestimate the effect of socioeconomic status per se on longevity. For example, the positive correlation between income and longevity may reflect the effect of health on income (“reverse causality”) as well as the effect of income on health. Almond and Mazumder (2006) argue that, “although it is well known that there is a strong association between education and health, much less is known about how these factors are connected, and whether the relationship is causal.” Lleras-Muney (2005) provided perhaps the strongest evidence that education has a causal effect on health. Using state compulsory school laws as instruments, Lleras-Muney found large effects of education on mortality. Almond and Mazumder (2006) revisited these results, noting they were not robust to state time trends, even when the sample was vastly expanded and a coding error rectified. They employed a dataset containing a broad array of health outcomes and found that when using the same instruments, the pattern of effects for specific health conditions appeared to depart markedly from prominent theories of how education should affect health. They also found suggestive evidence that vaccination against smallpox for school age children may account for some of the improvement in health and its association with education.

Urbanization: Leon (2008) disputes the largely negative view in the epidemiological and public health literature of the population health impact of cities and urbanization in the contemporary world.

Risk factors. Although a rise in the *incidence* of HIV would be expected to reduce longevity, one would not necessarily expect an inverse correlation between HIV *prevalence* and longevity.⁷ Advances in the treatment of HIV/AIDS are expected to increase survival (longevity) of AIDS patients, hence the number of people living with HIV (prevalence).

The World Bank Health, Nutrition and Population (HNP) database contains some data on other risk factors, such as the number of malaria cases reported, diabetes prevalence, and smoking prevalence. Unfortunately, data on these risk factors is missing so frequently that it is infeasible to include them in the longevity models we estimate, or to investigate their correlation with pharmaceutical innovation. However, more complete data on the following risk factors are available for OECD countries from the OECD Health database:

- BMI_GT25: Overweight or obese population, self-reported, % of total population
- BMI_GT30: Obese population, self-reported, % of total population
- TOBACCO: Tobacco consumption, % of population aged 15+ who are daily smokers
- ALCOHOL: Alcohol consumption, liters per capita (15+)

To determine whether growth in these risk factors was correlated across countries with pharmaceutical innovation (growth in VINTAGE), we estimated models of the following form, using annual data during the period 1999-2009:

$$\ln(\text{RISK}_{ct}) = \gamma \text{POST1990\%}_{ct} + \alpha_c + \pi_t + \varepsilon_{ct} \quad (5)$$

where RISK = BMI_GT25, BMI_GT30, TOBACCO, or ALCOHOL, and POST1990% is the quantity-weighted-mean fraction of pharmaceutical products sold in country c in year t that were launched after 1990.⁸ Eq. (5) was estimated by weighted least squares, weighting by POP_{ct} (the population of country c in year t); disturbances were clustered within countries. The results are shown in the following table:

RISK measure	average annual growth rate	γ	Z	Pr > Z
BMI_GT25	1.1%	0.5779	3.02	0.0025
BMI_GT30	2.8%	0.0321	0.06	0.9546
TOBACCO	-1.7%	-1.2128	-0.76	0.4452
ALCOHOL	1.3%	1.3873	0.58	0.5649

⁷ The World Bank publishes data on HIV prevalence, but not on HIV incidence.

⁸ Measurement of POST1990% will be described in detail below.

The increase in drug vintage was not correlated across OECD countries with the growth in obesity, tobacco use, or alcohol use. It was significantly *positively* correlated with growth in the fraction of the population that was either overweight or obese (whose mean value was 54%), but Flegal et al (2005) concluded that “overweight [is] not associated with excess mortality.”

Therefore, failure to control for these variables in the longevity growth equation (eq. (4)) is unlikely to bias estimates of the effect of pharmaceutical innovation on longevity growth.

Non-pharmaceutical medical innovation. We hypothesize that the health and longevity of a population depends on how technologically advanced the non-pharmaceutical as well as pharmaceutical medical goods and services its members use are. Unfortunately, non-pharmaceutical medical innovation is much more difficult to measure than pharmaceutical innovation. However, data on one important type of non-pharmaceutical medical innovation—advanced imaging equipment—is available for OECD countries during the period 1999-2009 from the OECD Health database. Two indicators contained in that database are the number of Computed Tomography (CT) scanners and the number of Magnetic Resonance Imaging (MRI) units per million population.⁹ To investigate the correlation across countries between the diffusion of pharmaceutical and non-pharmaceutical medical innovations, we estimated models of the following form, using annual data during the period 1999-2009:

$$\ln(\text{IMAGE}_{ct}) = \gamma \text{POST1990}\%_{ct} + \alpha_c + \pi_t + \varepsilon_{ct} \quad (6)$$

where IMAGE = the number of CT scanners, the number of MRI units, or the sum of the number of CT scanners and MRI units, all defined per million population.¹⁰ Eq. (6) was estimated by weighted least squares, weighting by POP_{ct} ; disturbances were clustered within countries. The results are shown in the following table:

⁹ The U.S. Centers for Medicare and Medicaid Services classifies both CT and MRI procedures as “advanced imaging” (as opposed to “standard imaging”) procedures in its Berenson-Eggers Type of Service (BETOS) health care procedure coding system. See <http://www.cms.gov/Medicare/Coding/HCPCSReleaseCodeSets/BETOS.html> Lichtenberg (2010) found that life expectancy increased more rapidly in U.S. states where the fraction of Medicare diagnostic imaging procedures that were advanced procedures increased more rapidly, and Lichtenberg (2012) found that the age-adjusted mortality rate declined more rapidly in German states with larger increases in the per capita number of CT scanners.

¹⁰ On average, there were almost twice as many CT scanners as there were MRI units during the period 1999-2009 (sample mean values are 22 and 14 per million people, respectively), but the number of MRI units increased more rapidly.

IMAGE measure	average annual growth rate	γ	Z	Pr > Z
CT	6.5%	-3.0439	-2.15	0.0313
MRI	18.6%	6.0763	2.66	0.0078
CT + MRI	9.3%	1.1257	0.78	0.4362

The increase in drug vintage is positively correlated across OECD countries with growth in the number of MRI units per million population. However, it is negatively correlated with growth in the number of CT scanners per million population, and it is not significantly correlated with growth in the overall quantity of advanced imaging equipment (CT + MRI) per million population. This suggests that failure to control for non-pharmaceutical medical innovation in the longevity growth equation (eq. (4)) is unlikely to bias estimates of the effect of pharmaceutical innovation on longevity growth.

III. Measurement of longevity and pharmaceutical innovation

Longevity measurement. Beginning with the year 1999, the World Health Organization (WHO) began producing annual life tables for all Member States. These life tables form the basis of all WHO's estimates about mortality patterns and levels worldwide. Life tables have been developed for all Member States for the reference year 1990, 2000 and 2009 starting with a systematic review of all available evidence from surveys, censuses, sample registration systems, population laboratories and vital registration on levels and trends in under-five and adult mortality rates. WHO applies standard methods to the analysis of Member State data to ensure comparability of estimates across countries.

We will analyze two types of measures contained in the WHO life tables: life expectancy at different ages (0, 25, 45, 65), and survival from age a_0 to age a_1 (birth to 25, 25 to 65, 65 to 75, and birth to 75). Life expectancy at a given age reflects mortality (or survival) at all subsequent ages. For example, life expectancy at birth depends on mortality rates among the elderly. We examine age-specific survival rates as well as life expectancy because the effect of pharmaceutical innovation on survival rates may vary across age groups. As shown in Figure 1, which is based on data from Denmark, utilization of prescription drugs rises sharply with age: per capita consumption of medicines by people age 75-79 is over 10 times that of people age 25-

29. The effect of pharmaceutical innovation on survival rate of young people may be much smaller than its effect on the survival rate of older people; it may even be zero.

Pharmaceutical innovation measurement. We construct measures of pharmaceutical innovation from the IMS Health MIDAS database, which provides annual data on the quantity (number of “standard dose units”) of every prescription drug product sold in each country during the period 1999-2010.¹¹ The database also indicates the molecules (active ingredients) contained in each product, and the world launch year of most molecules (world launch years of some (apparently very old) molecules are unknown).

We use a two-step procedure to measure pharmaceutical innovation. The first step is to measure the vintage of each “international product”:¹²

$$\text{PROD_YEAR}_p = \frac{\sum_m \text{INGRED_OF}_{pm} \text{LAUNCH_YEAR}_m}{\sum_m \text{INGRED_OF}_{pm}}$$

where

PROD_YEAR_p = the vintage of product p, i.e. the (mean) launch year of the active ingredient(s) of product p
 INGRED_OF_{pm} = 1 if product p contains molecule m¹³
 = 0 otherwise
 LAUNCH_YEAR_m = the world launch year of molecule m

The second step is to measure the quantity-weighted-mean launch year of products sold in country c in year t:

$$\text{LAUNCH_YEAR}_{ct} = \frac{\sum_p Q_{pct} \text{PROD_YEAR}_p}{\sum_p Q_{pct}}$$

where

LAUNCH_YEAR_{ct} = the quantity-weighted-mean launch year of products sold in country c in year t

¹¹ The number of standard ‘dose’ units sold is determined by taking the number of counting units sold divided by the standard unit factor which is the smallest common dose of a product form as defined by IMS HEALTH. For example, for oral solid forms the standard unit factor is one tablet or capsule whereas for syrup forms the standard unit factor is one teaspoon (5 ml) and injectable forms it is one ampoule or vial. Other measures of quantity, such as the number of patients using the drug, prescriptions for the drug, or defined daily doses of the drug, are not available.

¹² There are over 89,000 international products. $(\sum_m \text{INGRED_OF}_{pm})$ = the number of active ingredients of product p. About 28% of standard units are for combination drugs.

¹³ There are approximately 5600 molecules. IMS provides world launch dates for about 1600 of these molecules.

Q_{pct} = the quantity (number of standard dose units) of product p sold in country c in year t

The world launch year of some molecules is not known. But it is safe to assume that molecules with missing world launch years are generally old molecules, e.g. that they were not launched after 1990.¹⁴ Therefore it is useful to define the following binary variable:

$$\begin{aligned} \text{POST1990}_m &= 1 \text{ if } \text{LAUNCH_YEAR}_m > 1990 \\ &= 0 \text{ if } \text{LAUNCH_YEAR}_m \leq 1990 \text{ or } \text{LAUNCH_YEAR}_m \text{ is unknown} \end{aligned}$$

An alternative measure of the vintage of each “international product” based on this binary measure is:

$$\text{POST1990}\%_p = \frac{\sum_m \text{INGRED_OF}_{pm} \text{POST1990}_m}{\sum_m \text{INGRED_OF}_{pm}}$$

where

$\text{POST1990}\%_p$ = the fraction of product p’s active ingredients that were launched after 1990

An alternative measure of the mean vintage of pharmaceuticals consumed in a country in a given year is:

$$\text{POST1990}\%_{ct} = \frac{\sum_p Q_{pct} \text{POST1990}\%_p}{\sum_p Q_{pct}}$$

where

$\text{POST1990}\%_{ct}$ = the quantity-weighted-mean fraction of products sold in country c in year t that were launched after 1990

$\text{POST1990}\%_{ct}$ can be computed using data on all products, whereas LAUNCH_YEAR_{ct} can be computed only using data on products containing molecules with known launch years. We also calculated measures analogous to $\text{POST1990}\%_{ct}$ using different launch-year cutoff values, e.g.

¹⁴ The quantity-weighted-average fraction of products with molecules with missing launch years declined from 31.6% in 1999 to 27.5% in 2010. The quantity-weighted-average fraction of products with molecules with missing launch years varies considerably across countries: it exceeds 40% for Thailand, the Philippines, and Indonesia, and is below 16% for Greece, Sweden, and the Netherlands.

$POST1980\%_{ct}$ = the quantity-weighted-mean fraction of products sold in country c in year t that were launched after 1980.

IV. Descriptive statistics

Descriptive statistics (population weighted) for 30 countries on the levels of variables in 2000 and 2009 are shown in Table 1. (Complete data on longevity, pharmaceutical use, and other variables, by country and year, are shown in Appendix Tables 1, 2, and 3, respectively.) The first part of the table shows statistics on longevity. Life expectancy at birth increased by 1.6 years, from 74.1 to 75.7 years, between 2000 and 2009. In 2000, life expectancy at birth ranged from 56.3 years in South Africa to 81.3 years in Japan. Life expectancy at age 65 increased by 0.8 years, on average. The probability of surviving from birth to age 75 increased from 59.8% in 2000 to 63.2% in 2009. Most of that increase was due to an increase in the probability of surviving from age 65 to age 75.

The next part of the table shows statistics on pharmaceutical use. In general, medicines in use tend to be quite old. In 2000, the quantity-weighted mean world launch year of drugs was 1946.5, i.e. the average drug consumed was more than half a century old. Moreover, this calculation excludes drugs with unknown world launch years, which tend to be quite old. The difference between the mean launch years of drugs used in 2000 in Indonesia (1928.0) and the Netherlands (1960.5) was over 32 years. The mean launch year of drugs increased by 4.7 years between 2000 and 2009. About 28% of the drugs consumed in 2009 had been launched after 1970; 18% had been launched after 1980, and 8% had been launched after 1990. Figure 2 depicts the quantity-weighted-mean fraction of products sold in 2009 that were launched after 1990 ($POST1990\%$), by country.

The remainder of Table 1 shows statistics on other variables included in our model of longevity. Mean real per capita GDP and years of schooling both increased modestly (by 4.4% and 5.8%, respectively) during the period 2000-2009. Mean real per capita health expenditure increased much more rapidly (by 32.0%).

Descriptive statistics (2009 population weighted) for 30 countries on 2000-2009 *changes* in variables are shown in Table 2. Coefficients of correlation between changes in two alternative measures of pharmaceutical innovation and changes in other variables in the longevity growth model are shown in Table 3. There is a significant correlation between the change in the fraction

of post-1990 drugs ($\Delta\text{POST1990\%}$) and just two variables: the log change in GDP per capita, and the change in urbanization rate. Both correlations are negative: countries with higher GDP growth had smaller increases in the fraction of post-1990 drugs. Table 3 also indicates that countries with larger increases in educational attainment had smaller increases in the quantity-weighted mean launch year of drugs consumed.

V. Empirical results

Estimates of the longevity change model (eq. (4)) are presented in Table 4. We analyze 8 different measures of the dependent (longevity change) variable: the change in life expectancy at birth and at ages 25, 45, and 65 (ΔLE0 , ΔLE25 , ΔLE45 , ΔLE65 , respectively), and the log change in the probability of survival from birth to 25, 25 to 65, 65 to 75, and birth to 75. For each dependent variable, we estimate two versions of the model: one in which $\Delta\text{VINTAGE}$ is the only regressor (in which the vector γ is constrained to equal zero), and one that includes the other potential determinants of longevity change (ΔZ) described earlier. We also include an additional regressor: the change in the log of the per capita *quantity* of prescription drugs ($\Delta\text{q_rx}$); $\Delta\text{VINTAGE}$ might be considered as the change in the average *quality* of prescription drugs.

In the models presented in Table 4, the measure of $\Delta\text{VINTAGE}$ is $\Delta\text{POST1990\%}$. After presenting these estimates, we will present (in Table 5) estimates of longevity change models based on two alternative measures of $\Delta\text{VINTAGE}$: $\Delta\text{POST1980\%}$ and $\Delta\text{LAUNCH_YEAR}$.

In model 1 in Table 4, the dependent variable is the 2000-2009 change in life expectancy at birth, and the only regressor is DPOST1990\% . The coefficient on this variable is positive and highly significant (p-value = 0.008), indicating that countries with larger increases in drug vintage had larger increases in life expectancy at birth. Model 2 includes the ten other potential determinants of longevity change discussed above. The coefficients on just two of these variables are statistically significant: countries with larger increases in unemployment had larger increases in life expectancy at birth (a finding consistent with those from some previous studies), and countries with larger increases in HIV prevalence had smaller increases in life expectancy. Controlling for the ten other potential determinants of longevity change *increases* the coefficient on $\Delta\text{POST1990\%}$ by about 32%. Figure 3 is a bubble plot of the correlation across countries

between the 2000-2009 change in life expectancy at birth and $\Delta\text{POST1990\%}$, controlling for changes in other variables.¹⁵ It indicates that the strong positive correlation is not due to a small number of outliers.

Models 3-8 are similar to models 1-2, in which the change in life expectancy at birth is replaced by the change in life expectancy at age 25, 45, or 65. In all of these models, the coefficient on $\Delta\text{POST1990\%}$ is positive and highly significant (p-value $\leq .001$). The only other coefficients that are statistically significant are on $\Delta\text{HIV_prev}$ in the ΔLE25 equation (model 4), $\Delta\text{health_expend}$ in the ΔLE45 equation (model 6), and $\Delta\text{urban\%}$ in the ΔLE45 and ΔLE65 equations (models 6 and 8). Controlling for the ten other potential determinants of longevity change does not reduce the coefficient on $\Delta\text{POST1990\%}$ by more than 19%.

In model 9 in Table 4, the dependent variable is the 2000-2009 log change in the probability of survival from birth to age 25, and the only regressor is $\Delta\text{POST1990\%}$. The coefficient on $\Delta\text{POST1990\%}$ is *negative* and significant. However, when we control (in model 10) for the ten other potential determinants of longevity change, the coefficient on $\Delta\text{POST1990\%}$ is far from statistically significant (p-value = .728). As discussed earlier, utilization of prescription drugs is much higher among the elderly than it is among young people, and only a small fraction of aggregate drug utilization is by young people. It is therefore not surprising that there is not a significant correlation between our measure of pharmaceutical innovation (which is based on drugs used by all age groups¹⁶) and the log change in the probability of survival from birth to age 25. There is a positive association between the log change in this probability and changes in per capita income, educational attainment, and the unemployment rate, and a negative association with the change in per capita health expenditure.

Models 11-16 are similar to models 9-10, in which the log change in the probability of survival from birth to age 25 is replaced by the log changes in the probability of survival from 25 to 65, 65 to 75, and birth to 75. When other potential determinants of longevity are included (in models 12, 14, and 16), the coefficient on $\Delta\text{POST1990\%}$ is positive and significant (p-value $\leq .020$). Countries with larger increases in drug vintage had larger increases in the probability of survival from 25 to 65, 65 to 75, and birth to 75. The only other coefficients that are statistically

¹⁵ Figure 3 is a plot of the residuals from the population-weighted regression of $\Delta\text{LONGEVITY}$ on ΔZ against the residuals from the population-weighted regression of $\Delta\text{POST1990\%}$ on ΔZ .

¹⁶ Unfortunately, the IMS MIDAS dataset does not contain any information about the age of pharmaceutical consumers, so it is not feasible to construct age-specific measures of pharmaceutical innovation.

significant are on $\Delta\text{HIV_prev}$ in the 25-to-65 and birth-to-75 survival equations (models 12 and 16), and $\Delta\text{urban\%}$ in the 65-to-75 survival equation (model 14).

In the models presented in Table 4, the measure of $\Delta\text{VINTAGE}$ is $\Delta\text{POST1990\%}$. Table 5 presents estimates of coefficients on $\Delta\text{VINTAGE}$ in the longevity change model (eq. (4)) based on 2 alternative measures of $\Delta\text{VINTAGE}$: $\Delta\text{POST1980\%}$ and $\Delta\text{LAUNCH_YEAR}$. To conserve space, we do not report estimates of the coefficients on all of the covariates included in these models. To facilitate comparison, panel A of Table 5 reproduces the coefficients on $\Delta\text{POST1990\%}$ in models 2, 4, ..., 16 of Table 4. Panel B of Table 5 displays the corresponding coefficients on $\Delta\text{POST1980\%}$ when that variable is substituted for $\Delta\text{POST1990\%}$. The coefficient on $\Delta\text{POST1980\%}$ is positive and significant (p-value $\leq .026$) in all models except the model of the log change in the probability of survival from birth to 25. Panel C of Table 5 displays the corresponding coefficients on $\Delta\text{LAUNCH_YEAR}$ when that variable is substituted for $\Delta\text{POST1990\%}$. Once again, the coefficient on $\Delta\text{LAUNCH_YEAR}$ is positive and significant (p-value $\leq .055$) in all models except the model of the log change in the probability of survival from birth to 25.

VI. Discussion

The estimates in Tables 4 and 5 indicate that life expectancy at all ages and survival rates above age 25 increased faster in countries with larger increases in drug vintage (measured in three different ways), controlling for an extensive set of other factors. Now we will use those estimates to assess both (1) how much of the global growth in life expectancy was due to pharmaceutical innovation, and (2) the extent to which international differences in life expectancy in 2009 were attributable to differences in drug vintage.

As shown in Table 4, for the 30 countries in our sample, between 2000 and 2009 population-weighted mean life expectancy at birth increased by 1.74 years, and POST1990\% increased by .050. The coefficient on POST1990\% in model 2 of Table 4 is 25.36. This implies that the increase in life expectancy at birth due to the increase in the fraction of drugs consumed that were launched after 1990 was $\beta \Delta\text{POST1990\%} = 25.36 * .050 = 1.27$ years. This is 73% of the actual increase in life expectancy at birth. Similar calculations can be performed for life

expectancy at higher ages, and alternative measures of vintage. The results are shown in the following table.

		Due to increase in drug vintage, based on vintage measure:		
<u>2000-2009 increase in life expectancy at:</u>	Actual	POST1990%	POST1980%	LAUNCH_YEAR
Birth	1.74	1.27	1.23	0.59
Age 25	1.17	1.36	1.33	0.63
Age 45	1.07	1.15	1.04	0.50
Age 65	0.92	0.87	0.76	0.37

When we use either POST1990% or POST1980% as the vintage measure, the increase in life expectancy at age 25 due to the increase in drug vintage exceeds the actual increase in life expectancy at age 25. This is possible because HIV prevalence and urbanization increased (Table 1), and the estimates in Table 4 imply that these trends may have reduced longevity. Moreover, obesity has increased (at least in OECD countries), and previous research (Flegal et al (2005)) indicates that this has also reduced longevity. Although per capita income and educational attainment have also increased, there does not appear to be a consensus among scholars about the effects of these trends on longevity growth, and the estimates in Table 4 and in other studies suggest that they have not made a contribution to survival gains among adults.

Estimates of the increase in life expectancy attributable to pharmaceutical innovation based on the POST1980% vintage measure are similar to, but slightly smaller than, estimates based on the POST1990% vintage measure. Estimates based on the LAUNCH_YEAR vintage measure are considerably smaller—less than half the size of estimates based on the POST1990% vintage measure. This may be due to the fact that world launch dates of many (old) molecules are unknown, so that LAUNCH_YEAR is a much noisier measure of vintage than POST1990% or POST1980%.¹⁷

To assess the extent to which international differences in life expectancy in 2009 were attributable to differences in drug vintage, we will compare the top 5 countries (ranked by POST1990% in 2009), as depicted in Figure 2, with the bottom 5 countries (ranked by the same criterion). As shown in the following table, the difference between these groups in POST1990% was 0.13.

¹⁷ Measurement error in the vintage measure is likely to bias its coefficient in eq. (4) towards zero.

	POST1990% in 2009	Life expectancy at birth in 2009
Top 5 countries (ranked by POST1990% in 2009): Netherlands, Greece, Italy, Portugal, Spain	16%	80.7
Bottom 5 countries: Morocco, Egypt, Colombia, Thailand, Indonesia	3%	71.6
Difference	13%	9.1

Since the coefficient on POST1990% in model 2 of Table 4 is 25.36, this implies that the difference between these two groups in life expectancy at birth due to the difference in the fraction of drugs consumed that were launched after 1990 was $\beta \Delta \text{POST1990\%} = 25.36 * .13 = 3.4$ years. This is 37% of the actual difference (9.1 years) between these two groups in life expectancy at birth.

VII. Summary

This study examined the impact of pharmaceutical innovation, as measured by the vintage of prescription drugs used, on longevity using longitudinal, country-level data on 30 developing and high-income countries during the period 2000-2009. The analysis was based on data drawn from several reliable databases: data on the utilization of over 89,000 pharmaceutical products from the IMS Health MIDAS database; life tables produced by the World Health Organization; and indicators of socioeconomic status, health expenditure, risk factors, and other variables from three World Bank databases and the OECD Health database.

The difference-in-differences estimation approach controlled for unobserved determinants of longevity that varied across countries but were constant (or very stable) over time, and for unobserved determinants of longevity that changed over time but were invariant across countries. We also controlled for a number of time-varying country attributes that some previous studies have indicated may be important determinants of longevity: real per capita income, the unemployment rate, mean years of schooling, the urbanization rate, real per capita health expenditure (public and private), the DPT immunization rate among children ages 12-23 months, and some risk factors (HIV prevalence and tuberculosis incidence).

We analyzed two types of measures contained in the WHO life tables: life expectancy at different ages (0, 25, 45, 65), and survival from age a_0 to age a_1 (birth to 25, 25 to 65, 65 to 75,

and birth to 75). The estimates indicated that life expectancy at all ages and survival rates above age 25 increased faster in countries with larger increases in drug vintage (measured in three different ways), controlling for an extensive set of other factors. The increase in drug vintage was the only variable that was significantly related to all of these measures of longevity growth. Controlling for all of the other potential determinants of longevity did not reduce the vintage coefficient by more than 20%.

Our measures of pharmaceutical innovation (which are based on drugs used by all age groups) were not related to the change in the probability of survival from birth to age 25. This is not surprising, since utilization of prescription drugs is much higher among the elderly than it is among young people, and only a small fraction of aggregate drug utilization is by young people.

Due to data limitations, certain risk factors (obesity, tobacco use, or alcohol use) could not be included in the model, but we showed that the increase in drug vintage was not correlated across OECD countries with the growth in these risk factors. It was also not correlated with a measure of non-pharmaceutical medical innovation: the growth in the overall quantity of advanced imaging equipment (CT scanners and MRI units) per million population.

We used the estimates of the longevity growth model to assess both (1) how much of the global growth in life expectancy was due to pharmaceutical innovation, and (2) the extent to which international differences in life expectancy in 2009 were attributable to differences in drug vintage. For the 30 countries in our sample, between 2000 and 2009 population-weighted mean life expectancy at birth increased by 1.74 years. The estimates indicate that the increase in life expectancy at birth due to the increase in the fraction of drugs consumed that were launched after 1990 was 1.27 years—73% of the actual increase in life expectancy at birth. Some estimates imply that the increase in life expectancy at age 25 due to the increase in drug vintage exceeds the actual increase in life expectancy at age 25. This is possible because HIV prevalence and urbanization increased, and our estimates imply that these trends may have reduced longevity. Moreover, obesity has increased (at least in OECD countries), and previous research indicates that this has also reduced longevity. Although per capita income and educational attainment have also increased, there does not appear to be a consensus among scholars about the effects of these trends on longevity growth, and our estimates and those in some other studies suggest that they have not made a contribution to survival gains among adults.

To assess the extent to which international differences in life expectancy in 2009 were attributable to differences in drug vintage, we compared the top 5 countries (ranked by drug vintage in 2009) with the bottom 5 countries (ranked by the same criterion). Life expectancy at birth in the top 5 countries (Netherlands, Greece, Italy, Portugal, Spain) was 9.1 years higher than it was in the bottom 5 countries (Morocco, Egypt, Colombia, Thailand, Indonesia). Our estimates imply that 37% (3.4 years) of this difference was due to the difference in drug vintage.

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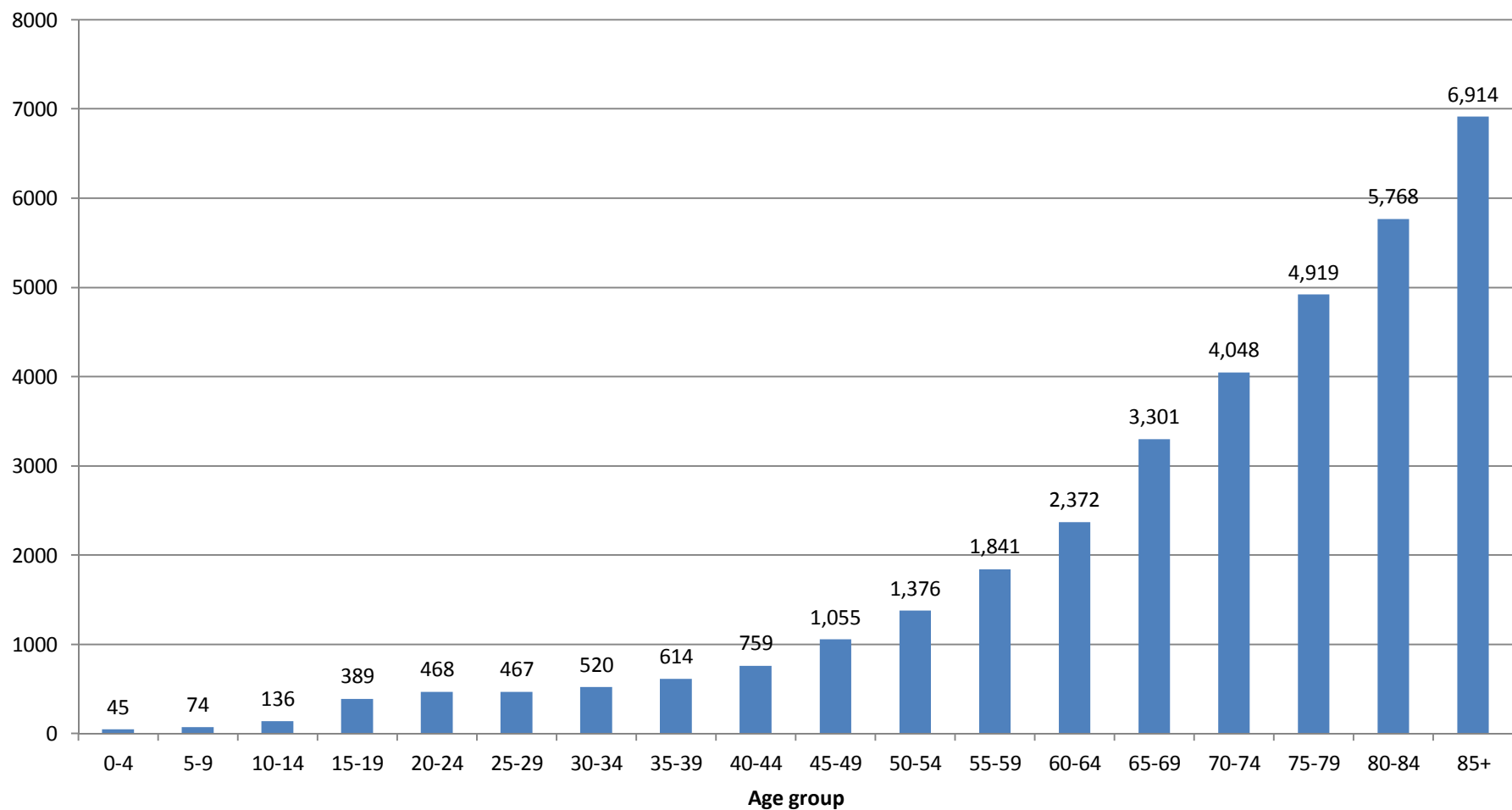
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Figure 1
Mean consumption of medicines (defined daily doses per thousand inhabitants per day), by age group, Denmark, 2011



Source: <http://medstat.dk/en>

Figure 2
Quantity-weighted-mean fraction of products sold in 2009 that were
launched after 1990 (POST1990%) , by country

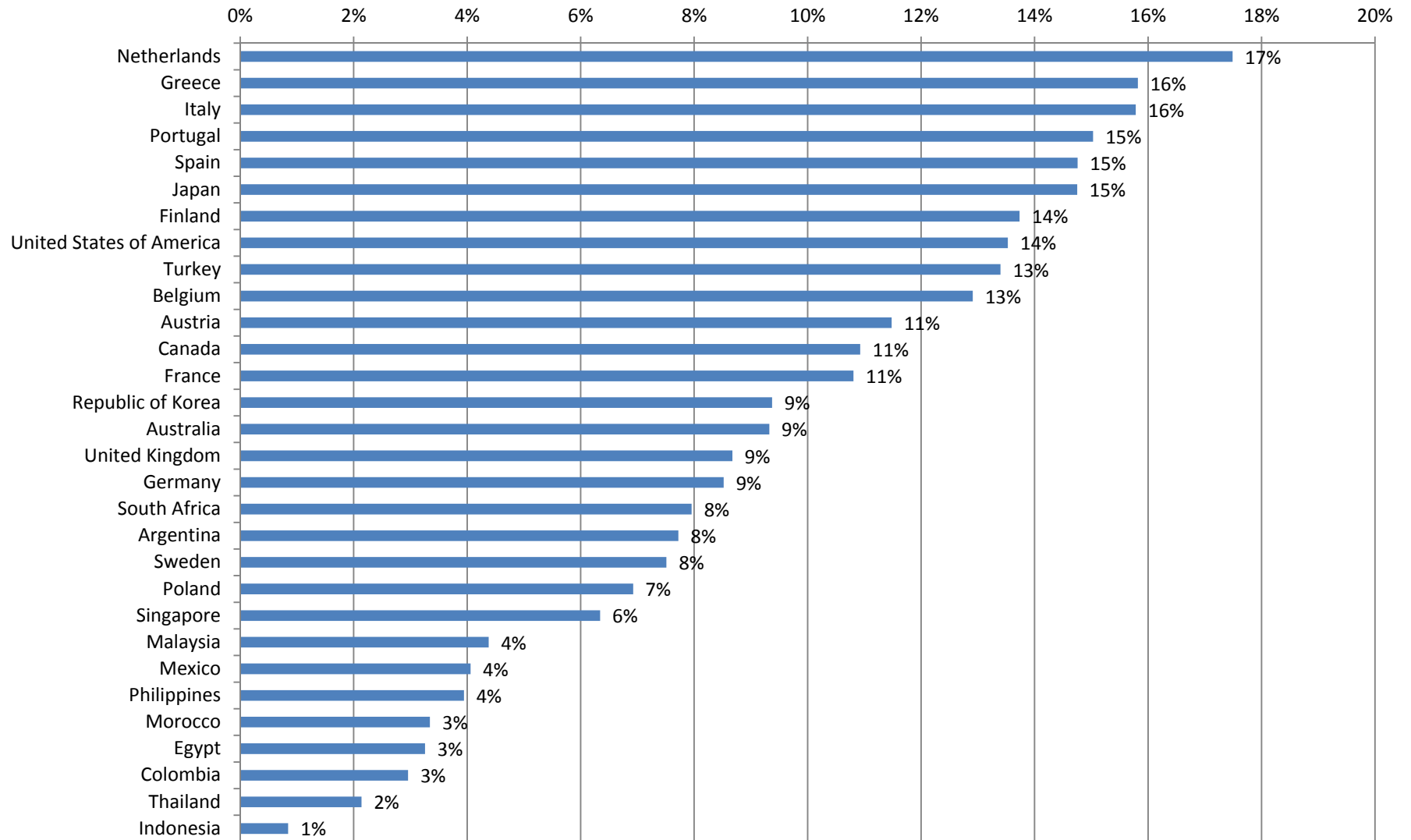
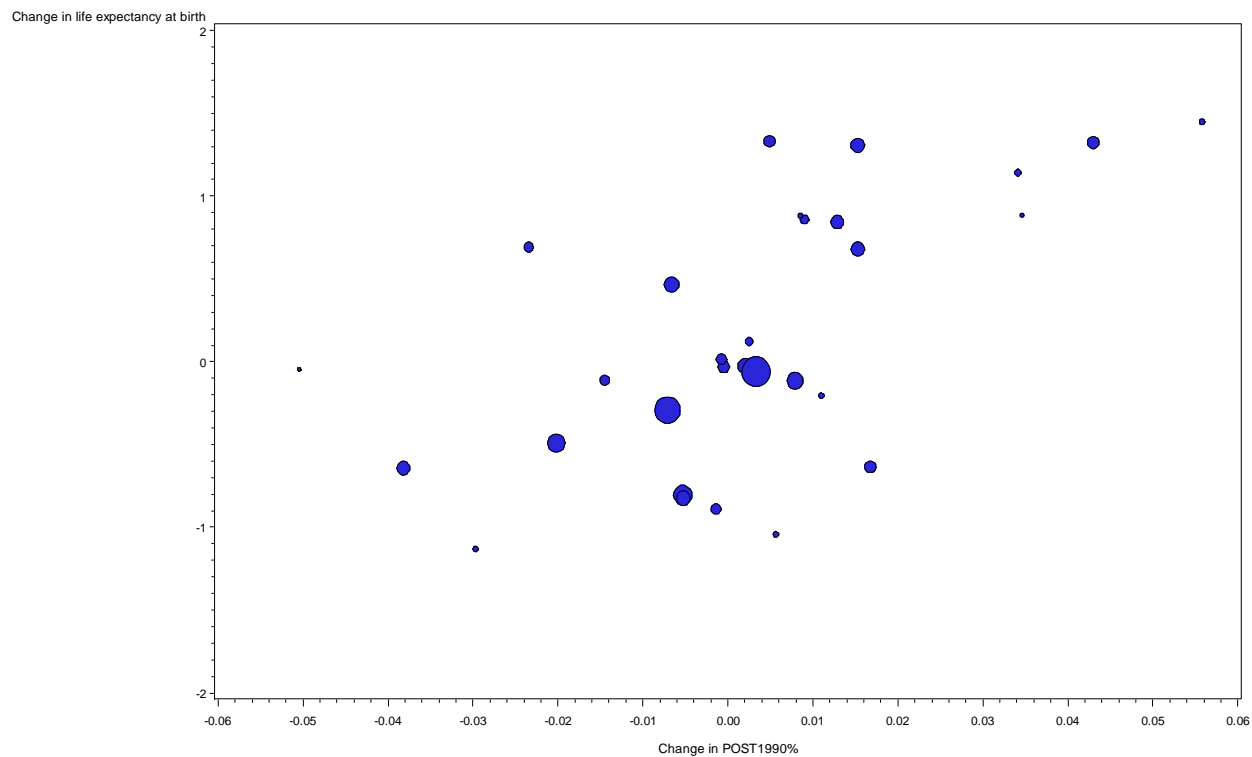


Figure 3

Correlation across countries between 2000-2009 change in life expectancy at birth and change in drug vintage, controlling for changes in income, unemployment rate, education, urbanization, health expenditure, immunization rate, HIV prevalence and tuberculosis incidence



Note: size of bubble is proportional to country population.

Table 1

Descriptive statistics (population weighted) for 30 countries: levels in 2000 and 2009

Statistic	MEAN		MIN		MAX	
	2000	2009	2000	2009	2000	2009
Year						
<u>Life expectancy at</u>						
Birth	74.1	75.7	56.3	54.5	81.3	83.1
Age 25	51.5	52.5	37.8	35.4	57.0	58.7
Age 45	33.1	34.0	25.1	25.1	37.7	39.4
Age 65	16.8	17.6	12.3	13.7	20.2	21.7
<u>Probability of survival from:</u>						
Birth to 25	96.5%	97.2%	88.4%	88.5%	99.1%	99.3%
25 to 65	81.0%	82.0%	53.0%	46.0%	89.0%	91.0%
65 to 75	75.0%	78.0%	57.0%	62.0%	85.0%	88.0%
Birth to 75	59.8%	63.2%	26.6%	25.3%	75.4%	79.3%
<u>Pharmaceutical variables</u>						
LAUNCH_YEAR	1946.5	1951.2	1928.0	1928.3	1960.5	1967.5
POST1970%	20.6%	27.8%	5.6%	8.3%	39.6%	49.8%
POST1980%	10.8%	18.2%	1.2%	2.6%	22.4%	34.5%
POST1990%	3.4%	8.4%	0.3%	0.8%	7.6%	17.5%
Per capita quantity of prescription drugs	773	848	129	145	1725	1744
<u>Other variables</u>						
GDP per capita (constant 2000 US\$)	\$15,684	\$16,379	\$773	\$1,089	\$36,789	\$37,766
Health expenditure per capita (constant 2000 US\$)	\$1,559	\$2,057	\$15	\$27	\$4,704	\$6,463
Public sector share of health expenditure	56%	58%	29%	36%	85%	80%
Unemployment rate	7.5	8.4	2.4	1.2	26.7	23.8
Prevalence of HIV, total (% of population ages 15-49)	0.7	0.8	0.1	0.1	16.1	17.8
Mean years of schooling, 15+	9.0	9.5	4.4	5.3	12.6	12.8
Incidence of tuberculosis (per 100,000 people)	79.6	85.0	5.5	4.4	576.0	971.0
Urban population (% of total)	66.0	69.4	31.1	33.7	100.0	100.0
Immunization, DPT (% of children ages 12-23 months)	88.4	92.2	71.0	63.0	99.0	99.0

Table 2

Descriptive statistics (2009 population weighted) for 30 countries: 2000-2009 changes

	MEAN	MIN	MAX
<u>Change in life expectancy at</u>			
Birth	1.74	-1.80	4.70
Age 25	1.17	-2.40	3.90
Age 45	1.07	-0.60	3.70
Age 65	0.92	-0.40	2.80
<u>Log change in probability of survival from:</u>			
Birth to 25	0.01	0.00	0.03
25 to 65	0.01	-0.14	0.07
65 to 75	0.04	-0.01	0.09
Birth to 75	0.06	-0.05	0.18
<u>Pharmaceutical variables</u>			
Change in LAUNCH_YEAR	4.85	-1.21	9.99
Change in POST1970%	0.07	0.01	0.15
Change in POST1980%	0.08	0.01	0.15
Change in POST1990%	0.05	0.01	0.11
Log change in per capita quantity of prescription drugs	0.17	-0.18	0.67
<u>Other variables</u>			
Log change in GDP per capita (constant 2000 US\$)	0.15	-0.03	0.35
	0.36	0.13	0.68
Log change in Health expenditure per capita (constant 2000 US\$)			
Change in Public sector share of health expenditure	0.02	-0.11	0.22
Change in unemployment rate	0.93	-7.90	7.50
	0.06	-0.50	1.70
Change in prevalence of HIV, total (% of population ages 15-49)			
Change in mean years of schooling, 15+	0.58	0.08	1.01
	3.24	-49.00	395.00
Change in incidence of tuberculosis (per 100,000 people)			
Urban population (% of total)	3.57	-0.44	10.58
	3.89	-12.00	13.00
Change in immunization, DPT (% of children ages 12-23 months)			

Table 3

Coefficients of correlation between 2000-2009 changes in measures of pharmaceutical innovation and changes in other variables in longevity model (2009 population-weighted)

	Coefficient of correlation with change in POST1990%	p-value		Coefficient of correlation with change in mean LAUNCH_YEAR	p-value
Log change in per capita quantity of prescription drugs	-0.120	0.529		0.071	0.711
Change in mean years of schooling, 15+	-0.238	0.206		-0.386	0.035
Log change in GDP per capita (constant 2000 US\$)	-0.590	0.001		-0.308	0.097
Change in unemployment rate	0.150	0.429		0.192	0.309
Log change in health expenditure per capita (constant 2000 US\$)	-0.296	0.113		-0.123	0.517
Change in public sector share of health expenditure	-0.300	0.107		-0.012	0.951
Change in immunization, DPT (% of children ages 12-23 months)	-0.017	0.931		-0.124	0.513
Change in prevalence of HIV, total (% of population ages 15-49)	0.106	0.579		-0.040	0.835
Change in incidence of tuberculosis (per 100,000 people)	0.051	0.789		0.026	0.891
Change in urban population (% of total)	-0.549	0.002		-0.525	0.003

Table 4

Estimates of models of longevity change, 2000-2009

Model		1	2	3	4	5	6	7	8
Dependent variable		change in life expectancy at							
		Birth		Age 25		Age 45		Age 65	
Regressor	statistic								
Δ POST1990% (change in quantity-weighted-mean fraction of products sold that were launched after 1990)	estimate	19.150	25.358	26.994	27.202	27.276	23.088	21.509	17.429
	t value	2.867	3.194	4.527	4.594	7.013	4.035	7.778	3.821
	prob > t	0.008	0.005	0.000	0.000	0.000	0.001	0.000	0.001
Δ q_rx (change in log of per capita quantity of prescription drugs)	estimate		-0.564		-0.908		-0.893		-0.677
	t value		-0.542		-1.171		-1.191		-1.134
	prob > t		0.594		0.257		0.249		0.272
Δ health_expend (change in log of real per capita health expenditure)	estimate		-0.045		1.918		2.568		1.913
	t value		-0.027		1.534		2.126		1.987
	prob > t		0.979		0.142		0.048		0.062
Δ public_health% (change in public sector share of health expenditure)	estimate		-1.471		-2.163		-2.486		-1.822
	t value		-0.681		-1.343		-1.597		-1.468
	prob > t		0.505		0.196		0.128		0.159
Δ gdp (change in log of real per capita GDP)	estimate		5.295		1.798		1.016		1.341
	t value		1.611		0.734		0.429		0.710
	prob > t		0.125		0.473		0.673		0.487
Δ unemp (change in unemployment rate)	estimate		0.159		0.065		0.062		0.052
	t value		2.755		1.508		1.490		1.566
	prob > t		0.013		0.149		0.154		0.135
Δ edu (change in mean years of schooling of people age 15+)	estimate		1.084		0.074		0.076		-0.131
	t value		1.866		0.171		0.181		-0.392
	prob > t		0.078		0.866		0.859		0.700
Δ DPT_immun (change in immunization, DPT (% of children ages 12-23 months))	estimate		-0.021		-0.030		-0.015		0.001
	t value		-0.648		-1.251		-0.659		0.073
	prob > t		0.525		0.227		0.518		0.943
Δ HIV_prev (change in prevalence of HIV, total (% of population ages 15-49))	estimate		-3.462		-3.302		-0.987		0.210
	t value		-2.880		-3.682		-1.139		0.304
	prob > t		0.010		0.002		0.270		0.764
Δ TB_inc (change in incidence of tuberculosis (per 100,000 people))	estimate		0.005		0.005		0.002		0.002
	t value		1.052		1.241		0.623		0.594
	prob > t		0.307		0.231		0.541		0.560
Δ urban% (change in urban fraction of population)	estimate		-0.126		-0.107		-0.126		-0.110
	t value		-1.547		-1.771		-2.154		-2.354
	prob > t		0.139		0.094		0.045		0.030
Intercept	estimate	0.775	-0.246	-0.194	-0.383	-0.305	-0.503	-0.165	-0.298
	t value	1.974	-0.424	-0.552	-0.888	-1.333	-1.205	-1.016	-0.895
	prob > t	0.058	0.677	0.585	0.386	0.193	0.244	0.318	0.383

Note: N = 30. Weighted least squares estimates, weighting by 2009 population.

Table 4

Estimates of models of longevity change, 2000-2009

Model		9	10	11	12	13	14	15	16
Dependent variable	log change in probability of survival from								
		birth to age 25		age 25 to 65		age 65 to 75		birth to age 75	
Regressor	statistic								
Δ POST1990% (change in quantity-weighted-mean fraction of products sold that were launched after 1990)	estimate	-0.118	-0.019	0.422	0.502	0.656	0.519	0.960	1.002
	t value	-2.438	-0.353	1.958	2.567	5.238	2.953	3.451	2.555
	prob > t	0.021	0.728	0.060	0.019	0.000	0.009	0.002	0.020
Δ q_rx (change in log of per capita quantity of prescription drugs)	estimate		0.006		-0.008		-0.007		-0.010
	t value		0.771		-0.318		-0.309		-0.189
	prob > t		0.450		0.754		0.761		0.852
Δ health_expend (change in log of real per capita health expenditure)	estimate		-0.030		0.033		0.049		0.052
	t value		-2.547		0.789		1.330		0.633
	prob > t		0.020		0.440		0.200		0.535
Δ public_health% (change in public sector share of health expenditure)	estimate		0.008		-0.034		-0.050		-0.076
	t value		0.521		-0.649		-1.037		-0.716
	prob > t		0.609		0.524		0.314		0.483
Δ gdp (change in log of real per capita GDP)	estimate		0.052		0.021		0.070		0.142
	t value		2.262		0.254		0.955		0.873
	prob > t		0.036		0.802		0.352		0.394
Δ unemp (change in unemployment rate)	estimate		0.001		0.001		0.002		0.005
	t value		3.250		0.929		1.698		1.681
	prob > t		0.004		0.365		0.107		0.110
Δ edu (change in mean years of schooling of people age 15+)	estimate		0.014		0.010		0.005		0.029
	t value		3.443		0.696		0.411		1.015
	prob > t		0.003		0.496		0.686		0.324
Δ DPT_immun (change in immunization, DPT (% of children ages 12-23 months))	estimate		0.000		-0.001		-0.001		-0.002
	t value		0.738		-1.776		-0.827		-1.153
	prob > t		0.470		0.093		0.419		0.264
Δ HIV_prev (change in prevalence of HIV, total (% of population ages 15-49))	estimate		-0.009		-0.114		-0.005		-0.129
	t value		-1.118		-3.861		-0.189		-2.166
	prob > t		0.278		0.001		0.852		0.044
Δ TB_inc (change in incidence of tuberculosis (per 100,000 people))	estimate		0.000		0.000		0.000		0.000
	t value		0.530		0.313		1.389		0.854
	prob > t		0.603		0.758		0.182		0.404
Δ urban% (change in urban fraction of population)	estimate		0.000		-0.002		-0.005		-0.007
	t value		-0.285		-0.783		-2.734		-1.657
	prob > t		0.779		0.444		0.014		0.115
Intercept	estimate	0.015	0.003	-0.008	-0.014	0.001	-0.003	0.008	-0.014
	t value	5.114	0.628	-0.647	-0.985	0.201	-0.228	0.477	-0.505
	prob > t	0.000	0.538	0.523	0.338	0.842	0.822	0.637	0.620

Note: N = 30. Weighted least squares estimates, weighting b

Table 5
Estimates of coefficients on Δ VINTAGE in longevity change model (eq. (4)) based on 3
alternative measures of Δ VINTAGE

Dependent variable		Vintage coefficient estimate	t Value	Pr > t
A. Vintage measure = ΔPOST1990%				
change in life expectancy at	Birth	25.358	3.19	0.005
	Age 25	27.202	4.59	0.000
	Age 45	23.088	4.03	0.001
	Age 65	17.429	3.82	0.001
log change in probability of survival from	Birth to Age 25	-0.019	-0.35	0.728
	Age 25 to 65	0.502	2.57	0.019
	Age 65 to 75	0.519	2.95	0.009
	Birth to Age 75	1.002	2.56	0.020
B. Vintage measure = ΔPOST1980%				
change in life expectancy at	Birth	16.247	2.50	0.022
	Age 25	17.519	3.38	0.003
	Age 45	13.673	2.70	0.015
	Age 65	9.972	2.48	0.023
log change in probability of survival from	Birth to Age 25	-0.012	-0.28	0.783
	Age 25 to 65	0.366	2.44	0.026
	Age 65 to 75	0.385	2.85	0.011
	Birth to Age 75	0.739	2.46	0.024
C. Vintage measure = ΔLAUNCH_YEAR				
change in life expectancy at	Birth	0.121	2.05	0.055
	Age 25	0.130	2.66	0.016
	Age 45	0.102	2.21	0.040
	Age 65	0.076	2.10	0.050
log change in probability of survival from	Birth to Age 25	0.000	-0.08	0.938
	Age 25 to 65	0.003	2.09	0.051
	Age 65 to 75	0.003	2.33	0.032
	Birth to Age 75	0.006	2.10	0.050

Note: All models include the following covariates: Δ q_rx (change in log of per capita quantity of prescription drugs); Δ health_expend (change in log of real per capita health expenditure); Δ public_health% (change in public sector share of health expenditure); Δ gdp (change in log of real per capita GDP); Δ unemp (change in unemployment rate); Δ edu (change in mean years of schooling of people age 15+); Δ DPT_immun (change in immunization, DPT (% of children ages 12-23 months)); Δ HIV_prev (change in prevalence of HIV, total (% of population ages 15-49)); Δ TB_inc (change in incidence of tuberculosis (per 100,000 people)); Δ urban% (change in urban fraction of population)

Appendix Table 1
Longevity data

country	year	population (millions)	Life expectancy at age				Number of survivors per 100,000 births until age			
			0	25	45	65	25	45	65	75
Argentina	2000	36.9	74.6	51.8	33.2	17.1	96,888	93,601	78,762	60,174
Argentina	2009	40.1	75.4	52.3	33.6	17.3	97,327	94,344	80,255	62,671
Australia	2000	19.2	79.8	55.8	36.8	19.1	98,600	96,481	88,014	73,053
Australia	2009	22.0	81.9	57.7	38.5	20.5	98,977	97,343	90,167	78,286
Austria	2000	8.0	78.4	54.3	35.3	18.2	98,660	96,577	85,570	69,381
Austria	2009	8.4	80.3	56.0	36.7	19.4	98,972	97,460	87,644	74,191
Belgium	2000	10.3	77.8	53.8	34.8	17.8	98,564	96,221	84,926	68,107
Belgium	2009	10.8	80.0	55.8	36.6	19.3	98,970	97,159	87,221	73,313
Canada	2000	30.8	79.4	55.3	36.1	18.8	98,699	96,848	86,932	70,789
Canada	2009	33.7	81.2	57.0	37.8	20.2	98,825	97,236	88,816	75,230
Colombia	2000	39.8	72.8	51.5	34.4	18.2	94,372	88,168	75,353	58,632
Colombia	2009	45.7	76.5	54.1	36.1	19.1	96,299	92,014	81,766	66,476
Egypt	2000	67.6	68.4	47.6	28.9	13.8	93,964	90,481	69,931	45,349
Egypt	2009	79.7	70.9	48.1	29.2	14.2	96,682	93,742	72,495	48,682
Finland	2000	5.2	77.7	53.5	34.6	17.7	98,798	96,125	84,570	68,141
Finland	2009	5.3	79.9	55.5	36.5	19.5	99,058	96,868	86,455	72,741
France	2000	60.8	79.3	55.2	36.3	19.5	98,726	96,192	85,176	70,748
France	2009	64.5	81.4	57.0	37.9	20.9	99,093	97,168	87,315	75,459
Germany	2000	82.2	78.3	54.1	35.0	18.0	98,818	96,742	85,339	68,171
Germany	2009	81.9	80.3	55.9	36.5	19.2	99,152	97,675	87,796	73,840
Greece	2000	10.9	78.2	54.2	35.0	17.5	98,595	96,606	87,062	70,822
Greece	2009	11.3	80.2	55.9	36.8	19.2	98,948	97,081	88,468	75,834
Indonesia	2000	213.4	67.9	48.0	29.7	13.9	92,510	88,495	71,185	47,710
Indonesia	2009	237.4	68.3	47.2	29.1	13.8	94,111	89,224	69,854	46,271
Italy	2000	56.9	79.4	55.2	36.0	18.5	98,828	97,013	87,865	72,398
Italy	2009	60.2	81.9	57.6	38.2	20.3	99,112	97,763	90,475	78,350
Japan	2000	126.9	81.3	57.0	37.7	20.2	99,030	97,363	88,606	75,363
Japan	2009	127.6	83.1	58.7	39.4	21.7	99,246	97,704	90,159	79,282
Malaysia	2000	23.4	71.6	48.1	29.7	13.9	97,574	93,658	74,738	49,272
Malaysia	2009	27.9	73.4	49.4	30.8	14.5	98,318	94,940	78,826	54,148
Mexico	2000	100.0	74.4	52.0	33.6	17.6	96,259	92,661	78,143	59,845
Mexico	2009	112.0	75.7	52.6	34.1	17.7	97,195	93,901	80,528	62,800
Morocco	2000	28.8	69.5	49.4	30.6	14.3	93,044	90,111	74,910	51,921
Morocco	2009	31.6	72.6	51.1	32.1	15.2	95,130	92,948	79,925	58,553
Netherlands	2000	15.9	78.1	54.0	34.7	17.4	98,801	97,061	86,375	68,547
Netherlands	2009	16.5	80.6	56.2	36.8	19.2	99,175	97,880	89,079	74,893
Philippines	2000	77.3	69.5	48.1	30.3	15.1	94,546	89,384	70,729	50,012
Philippines	2009	91.7	69.6	47.9	29.9	14.7	95,149	90,075	70,840	49,426

Appendix Table 1
Longevity data

country	year	population (millions)	Life expectancy at age				Number of survivors per 100,000 births until age			
			0	25	45	65	25	45	65	75
Poland	2000	38.5	73.9	50.0	31.4	15.8	98,272	94,779	77,124	56,110
Poland	2009	38.2	75.7	51.6	32.8	17.1	98,623	95,683	79,323	61,205
Portugal	2000	10.2	76.6	52.8	34.3	17.2	98,211	94,845	83,596	66,486
Portugal	2009	10.6	79.4	55.1	36.1	18.8	99,010	96,839	86,848	73,230
Republic of Korea	2000	47.0	76.0	52.0	33.1	16.5	98,579	95,846	82,586	63,494
Republic of Korea	2009	48.7	80.2	55.9	36.8	19.3	98,984	96,994	88,210	74,350
Singapore	2000	4.0	78.4	54.0	34.7	17.4	99,060	97,373	86,774	68,010
Singapore	2009	5.0	81.7	57.2	37.7	19.9	99,302	98,165	90,277	75,899
South Africa	2000	44.0	56.3	37.8	25.1	12.3	88,367	69,850	46,502	26,556
South Africa	2009	49.3	54.5	35.4	25.1	13.7	88,512	64,004	40,518	25,262
Spain	2000	40.3	79.2	55.1	36.1	18.8	98,752	96,452	86,788	72,031
Spain	2009	45.9	81.6	57.2	37.8	20.2	99,176	97,704	89,319	77,195
Sweden	2000	8.9	79.8	55.4	36.1	18.5	99,060	97,538	88,336	72,938
Sweden	2009	9.3	81.3	56.8	37.5	19.6	99,270	97,939	90,050	76,554
Thailand	2000	63.2	67.7	45.6	29.9	14.9	95,102	84,864	66,531	46,424
Thailand	2009	68.7	69.9	47.1	29.9	14.5	96,443	89,447	71,437	50,389
Turkey	2000	63.6	69.9	48.9	30.4	14.3	94,217	90,626	74,322	51,279
Turkey	2009	71.8	74.6	51.7	32.7	15.8	96,977	94,703	82,052	61,567
United Kingdom	2000	58.9	77.9	53.8	34.7	17.5	98,743	96,703	85,714	67,188
United Kingdom	2009	61.8	80.2	55.9	36.8	19.3	98,976	97,061	87,961	73,617
United States of America	2000	282.2	76.9	53.2	34.4	17.9	98,169	95,263	82,413	64,632
United States of America	2009	306.8	78.5	54.7	35.9	19.2	98,311	95,588	84,024	68,639

Appendix Table 2
Pharmaceutical data

country	year	SU per 100,000	mean launch year	post1970%	post1980%	post1990%
Argentina	2000	40	1950.2	28%	14%	3%
Argentina	2009	50	1951.3	30%	19%	8%
Australia	2000	121	1951.4	22%	14%	4%
Australia	2009	152	1951.3	23%	17%	9%
Austria	2000	102	1952.1	27%	14%	5%
Austria	2009	113	1959.3	36%	23%	11%
Belgium	2000	109	1956.9	35%	17%	5%
Belgium	2009	114	1963.4	45%	29%	13%
Canada	2000	107	1950.3	25%	15%	6%
Canada	2009	158	1952.8	26%	19%	11%
Colombia	2000	25	1938.7	12%	4%	1%
Colombia	2009	23	1938.8	16%	8%	3%
Egypt	2000	26	1944.4	14%	3%	1%
Egypt	2009	42	1949.8	21%	9%	3%
Finland	2000	102	1953.5	28%	17%	5%
Finland	2009	114	1961.4	38%	30%	14%
France	2000	173	1952.2	24%	12%	3%
France	2009	154	1956.1	31%	21%	11%
Germany	2000	127	1950.1	22%	10%	3%
Germany	2009	131	1959.1	32%	21%	9%
Greece	2000	81	1959.7	37%	20%	6%
Greece	2009	123	1964.0	43%	30%	16%
Indonesia	2000	17	1928.0	6%	1%	0%
Indonesia	2009	24	1928.3	8%	3%	1%
Italy	2000	84	1955.3	35%	20%	6%
Italy	2009	85	1965.3	46%	32%	16%
Japan	2000	148	1958.6	35%	22%	6%
Japan	2009	174	1964.8	46%	34%	15%
Malaysia	2000	16	1946.1	16%	5%	1%
Malaysia	2009	18	1948.8	20%	11%	4%
Mexico	2000	29	1943.0	15%	6%	2%
Mexico	2009	24	1941.8	17%	10%	4%
Morocco	2000	17	1946.0	13%	3%	1%
Morocco	2009	23	1952.0	21%	9%	3%
Netherlands	2000	62	1960.5	37%	22%	8%
Netherlands	2009	76	1965.6	46%	34%	17%
Philippines	2000	13	1938.7	11%	4%	1%
Philippines	2009	14	1940.2	15%	8%	4%
Poland	2000	98	1950.4	25%	9%	1%

Appendix Table 2
Pharmaceutical data

country	year	SU per 100,000	mean launch year	post1970%	post1980%	post1990%
Poland	2009	113	1958.9	36%	21%	7%
Portugal	2000	88	1960.5	40%	20%	4%
Portugal	2009	102	1967.5	50%	34%	15%
Republic of Korea	2000	108	1941.8	16%	6%	1%
Republic of Korea	2009	127	1951.7	30%	21%	9%
Singapore	2000	40	1949.6	19%	9%	3%
Singapore	2009	49	1953.7	28%	17%	6%
South Africa	2000	27	1946.9	16%	7%	2%
South Africa	2009	45	1951.5	25%	17%	8%
Spain	2000	107	1959.6	36%	21%	6%
Spain	2009	115	1964.2	43%	30%	15%
Sweden	2000	106	1951.3	27%	16%	5%
Sweden	2009	126	1955.8	33%	23%	8%
Thailand	2000	34	1934.6	9%	3%	0%
Thailand	2009	55	1942.3	17%	9%	2%
Turkey	2000	30	1950.5	27%	12%	3%
Turkey	2009	60	1960.4	39%	25%	13%
United Kingdom	2000	114	1951.4	20%	11%	4%
United Kingdom	2009	137	1955.2	29%	21%	9%
United States of America	2000	125	1951.3	25%	17%	8%
United States of America	2009	124	1959.1	35%	26%	14%

Appendix Table 3
Other variables

country	year	GDP	real per capita health expenditure	public sector share of health expenditure	incidence of tuberculosis	immunization, DPT (% of children ages 12-23 months)	prevalence of HIV, total (% of population ages 15-49)	unemployment rate	urban fraction of population	mean years of schooling of people age 15+)
Argentina	2000	\$7,696	\$689	55%	40.0	83	0.4	15.0	90.1	8.4
Argentina	2009	\$9,933	\$946	66%	28.0	87	0.5	8.6	92.2	8.9
Australia	2000	\$21,766	\$1,748	67%	6.1	90	0.1	6.3	87.2	11.1
Australia	2009	\$25,084	\$2,189	64%	6.3	92	0.1	5.6	88.9	11.8
Austria	2000	\$23,973	\$2,385	77%	16.0	81	0.1	3.5	65.8	11.1
Austria	2009	\$26,166	\$2,886	74%	7.3	83	0.3	4.8	67.4	11.2
Belgium	2000	\$22,697	\$2,039	68%	14.0	95	0.2	6.6	97.1	10.3
Belgium	2009	\$24,173	\$2,620	74%	8.7	99	0.2	7.9	97.4	10.9
Canada	2000	\$23,560	\$2,084	70%	6.4	92	0.2	6.8	79.5	12.6
Canada	2009	\$25,069	\$2,858	66%	4.8	80	0.2	8.3	80.5	12.8
Colombia	2000	\$2,524	\$172	81%	43.0	79	0.9	16.2	72.1	7.7
Colombia	2009	\$3,153	\$239	71%	35.0	92	0.5	12.0	74.8	8.4
Egypt	2000	\$1,476	\$80	40%	26.0	98	0.1	9.0	42.6	6.5
Egypt	2009	\$1,912	\$92	43%	19.0	97	0.1	9.4	42.8	7.5
Finland	2000	\$23,529	\$1,702	71%	12.0	99	0.1	9.7	61.1	12.4
Finland	2009	\$26,257	\$2,375	77%	11.0	99	0.1	8.2	63.6	12.7
France	2000	\$21,829	\$2,199	79%	13.0	97	0.3	10.2	75.8	8.7
France	2009	\$22,668	\$2,696	75%	9.6	99	0.4	9.1	77.6	9.3
Germany	2000	\$22,946	\$2,360	80%	13.0	90	0.1	7.7	73.1	12.3
Germany	2009	\$24,367	\$2,857	73%	5.1	93	0.1	7.7	73.7	12.4
Greece	2000	\$11,396	\$898	60%	7.6	89	0.1	11.1	59.7	8.7
Greece	2009	\$14,114	\$1,492	63%	4.9	99	0.1	9.5	61.2	9.4
Indonesia	2000	\$773	\$15	37%	189.0	71	0.1	6.1	42.0	7.1
Indonesia	2009	\$1,089	\$27	49%	189.0	82	0.2	7.9	52.6	7.9
Italy	2000	\$19,388	\$1,563	73%	8.9	87	0.3	10.8	67.2	8.7
Italy	2009	\$18,785	\$1,772	78%	5.4	96	0.3	7.8	68.2	9.4
Japan	2000	\$36,791	\$2,829	81%	36.0	85	0.1	4.8	65.2	10.9
Japan	2009	\$37,767	\$3,592	70%	22.0	98	0.1	5.0	66.6	11.5
Malaysia	2000	\$4,005	\$127	52%	95.0	95	0.4	3.0	62.0	8.8
Malaysia	2009	\$4,915	\$225	47%	83.0	95	0.5	3.7	71.3	9.6
Mexico	2000	\$5,817	\$295	47%	32.0	97	0.3	2.6	74.7	7.6
Mexico	2009	\$5,858	\$379	48%	17.0	95	0.3	5.2	77.5	8.3
Morocco	2000	\$1,272	\$53	29%	109.0	95	0.1	13.6	53.3	4.4

Appendix Table 3
Other variables

country	year	GDP	real per capita health expenditure	public sector share of health expenditure	incidence of tuberculosis	immunization, DPT (% of children ages 12-23 months)	prevalence of HIV, total (% of population ages 15-49)	unemployment rate	urban fraction of population	mean years of schooling of people age 15+)
Morocco	2009	\$1,797	\$94	36%	92.0	99	0.1	10.0	56.4	5.3
Netherlands	2000	\$24,180	\$1,924	63%	9.6	97	0.2	2.7	76.8	10.6
Netherlands	2009	\$26,247	\$3,144	70%	7.2	97	0.2	3.4	82.4	10.9
Philippines	2000	\$1,048	\$36	48%	329.0	79	0.1	11.2	58.5	8.7
Philippines	2009	\$1,307	\$47	37%	280.0	87	0.1	7.5	65.7	9.3
Poland	2000	\$4,454	\$246	70%	33.0	98	0.1	16.1	61.7	9.1
Poland	2009	\$6,332	\$465	66%	23.0	99	0.1	8.2	61.3	9.8
Portugal	2000	\$11,471	\$1,015	73%	47.0	96	0.4	3.9	54.4	7.0
Portugal	2009	\$11,591	\$1,244	73%	29.0	96	0.6	9.5	60.1	7.9
Korea	2000	\$11,347	\$543	46%	79.0	97	0.1	4.4	79.6	10.4
Korea	2009	\$15,463	\$1,070	51%	95.0	94	0.1	3.6	81.7	11.2
Singapore	2000	\$23,816	\$668	45%	50.0	98	0.1	6.0	100.0	8.5
Singapore	2009	\$28,932	\$1,196	39%	36.0	97	0.1	5.9	100.0	9.1
South Africa	2000	\$3,020	\$256	40%	576.0	73	16.1	26.7	56.9	7.4
South Africa	2009	\$3,692	\$338	37%	971.0	63	17.8	23.8	61.2	8.1
Spain	2000	\$14,422	\$1,040	72%	23.0	95	0.4	13.9	76.3	7.4
Spain	2009	\$15,539	\$1,486	73%	17.0	96	0.4	18.0	77.3	8.1
Sweden	2000	\$27,870	\$2,295	85%	5.5	99	0.1	5.8	84.0	10.6
Sweden	2009	\$30,838	\$3,084	78%	6.2	98	0.1	8.3	84.6	11.1
Thailand	2000	\$1,943	\$66	56%	137.0	97	1.8	2.4	31.1	7.3
Thailand	2009	\$2,531	\$106	78%	137.0	99	1.3	1.2	33.7	7.9
Turkey	2000	\$4,189	\$207	63%	46.0	85	0.1	6.5	64.7	5.4
Turkey	2009	\$4,969	\$335	75%	29.0	96	0.1	14.0	69.1	6.1
UK	2000	\$25,082	\$1,767	79%	12.0	91	0.1	5.5	89.4	9.6
UK	2009	\$27,645	\$2,706	80%	13.0	93	0.2	7.7	90.0	10.2
USA	2000	\$35,080	\$4,704	43%	6.7	94	0.5	4.0	79.1	11.4
USA	2009	\$36,706	\$6,463	45%	4.4	95	0.6	9.3	82.0	11.5