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The Impact of New Drug Launches on Longevity: Evidence from Longitudinal, Disease-Level Data from 52 Countries, 1982–2001

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We perform an econometric analysis of the effect of new drug launches on longevity, using data from the IMS Health Drug Launches database and the WHO Mortality Database. Under conservative assumptions, our estimates imply that the average annual increase in life expectancy of the entire population resulting from new drug launches is about one week, and that the incremental cost effectiveness ratio (new drug expenditure per person per year divided by the increase in life-years per person per year attributable to new drug launches) is about $6750—far lower than most estimates of the value of a statistical life-year.

Keywords: life expectancy, longevity, mortality, pharmaceuticals, innovation, cost-effectiveness

JEL classification: I12, O33, O40

Longevity has increased throughout the world during the last half century. According to the United Nations, life expectancy at birth increased from 46.5 years in 1950–55 to 65.0 years in 1995–2000 (Figure 1).[1] The rate of increase in the last quarter of the 20th century was only half as great as the rate of increase in the previous quarter; still, life expectancy at birth increased 5.2 years from 1975–1980 to 1995–2000. Moreover, longevity in less-developed regions has grown much more rapidly than longevity in more developed regions (Figure 2). In the last two decades, the gap has narrowed by 3.5 years. Unlike per capita income, longevity is converging.

Until recently, there appears to have been a consensus among health economists (or at least authors of health economics textbooks) that the contribution of medical care to longevity increase and other health improvements has been quite modest. Consider these quotations from four textbooks:

> the empirical evidence indicates [that] the overall contribution of medical care to health is rather modest at the margin. . . education, lifestyle, the environment, and income [are] the major contributing factors (Santerre and Neun (2000:69)).

> increase in life expectancy [has] been much more influenced by economic development than improvements in medical care. . . the most important medical advances are being

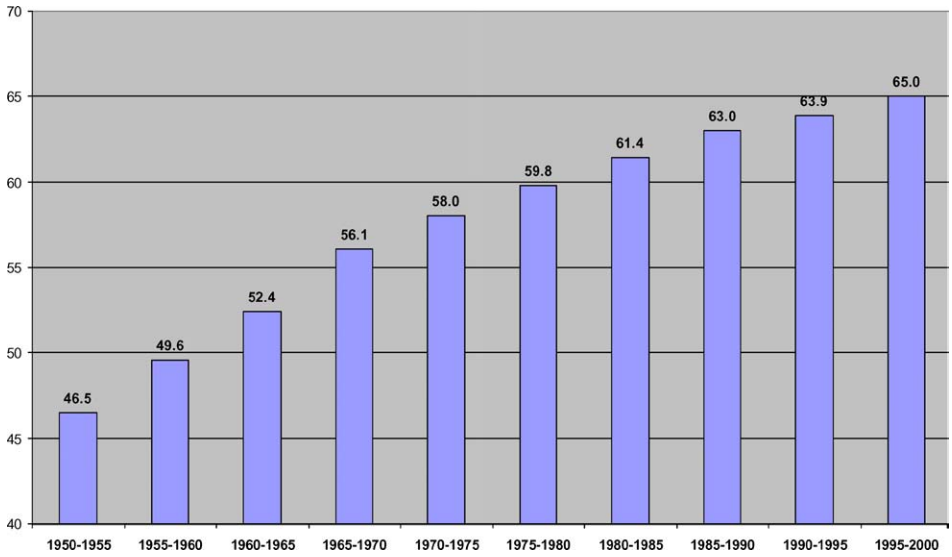


Figure 1. Life expectancy at birth, world.

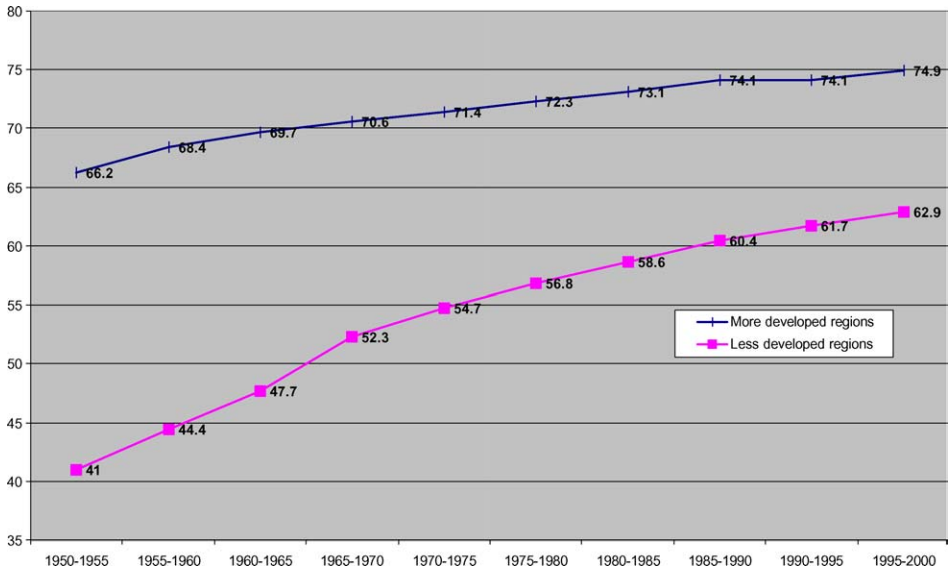


Figure 2. Life expectancy at birth, both sexes, by region.

> brought about by improvements in information technology, not pills and scalpels (Getzen (1997:330)).
>
> Research on the relationship between health status and medical care frequently has found that the marginal contribution of medical care to health status is rather small. . . any significant improvements in health status are more likely to originate from factors other than medical care. . . Factors that determine the level of health include income and education, environmental and life-style factors, and genetics (Henderson (1999:142)).
>
> The historical declines in population mortality rates were not due to medical interventions because effective medical interventions became available to populations largely after the mortality had declined. Instead, public health, improved environment, and improved nutrition probably played substantial roles (Folland, Goodman and Stano (2001:118)).

But some recent research has indicated that technological innovations in medicine have had important positive impacts on health. Cutler and McClellan (2001) reviewed case studies of technological change in the treatment of five conditions (heart attack, low-birthweight infants, depression, cataracts, and breast cancer) in the U.S. They concluded that "in most of the cases we analyzed, technological innovations in medicine are on net positive. Technology often leads to more spending, but outcomes improve by even more" (p. 23).

In this paper, we will perform an econometric analysis of the effect of new drug launches on longevity. Bresnahan and Gordon (1997) argue that "new goods are at the heart of economic progress." Investment in research and development (R&D) is a prerequisite for new good development, and the pharmaceutical industry is the most research-intensive industry in the economy. Drugs are much more research-intensive than most other goods and services utilized in the health care sector. As the data in the following table show,[2] in the U.S. in 1994 pharmaceutical industry R&D expenditure accounted for almost a third of total health R&D expenditure and more than half of industry health R&D expenditure.

Total health R&D expenditure	$32.9 billion
Industry health R&D expenditure	$17.1 billion
Pharmaceutical industry R&D expenditure (NSF estimate)	$9.6 billion
Pharmaceutical industry R&D expenditure (PhRMA estimate)	$11.1 billion

Moreover, according to the Global Forum for Health Research (2002), the pharmaceutical industry accounted for 42% of global health R&D funded by advanced and transition countries in 1998.

Clinical studies of specific drugs have shown that these drugs increase longevity. Here are three examples:

- Stenestrand et al. (2001) studied the impact on survival of statin treatment following acute myocardial infarction. They found that 1-year mortality was 9.3% in the no-statin group and 4.0% in the statin treatment group.
- Grier et al. (2003) found that adding two experimental drugs to the standard four-drug chemotherapy regimen has significantly improved survival in patients with non-metastatic Ewing's sarcoma, a highly malignant bone cancer of children and young adults. The overall survival rate increased from 61 percent to 72 percent for Ewing's sarcoma patients with localized disease who underwent the experimental six-drug chemotherapy.
- The journal U.S. Pharmacist (2002) reported that patients suffering from advanced metastatic melanoma who were treated with a combination of an investigational agent, Ceplene, and interleukin-2 (IL-2) had twice the survival rate as patients who were treated with IL-2 only. The patients were enrolled in a three-year study. The study also showed that the Ceplene/IL-2 combination significantly increased survival in a subpopulation group of advanced metastatic melanoma patients with liver metastases. The rate of survival in this group was six times that of the group given IL-2 only.

My objective is to assess the average or aggregate contribution of *all* new drug introductions. The data we will analyze cover all of the drugs introduced in, and diseases borne by people in, 52 countries during the period 1982–2001. Fortunately, launches of new drugs in these countries have been carefully tracked since 1982 by IMS Health.[3] Moreover, we can determine the (primary) disease associated with each new drug. Hence, we can measure the entry of new drugs, *by disease, country, and year*. Using data from the World Health Organization, we can also measure mortality (the age distribution of deaths) by disease, country, and year. Analysis of the relationship between new drug launches and mortality using longitudinal, disease-level data from 52 countries enables us to control, to an unusually great extent, for the effects of other potential determinants of mortality, e.g. education, income, nutrition, the environment, and "lifestyle".

The remainder of this paper is organized as follows. Section 1 outlines an econometric framework. Measurement issues and data sources are discussed in Section 2. Empirical results are presented in Section 3. Implications of the estimates are discussed in Section 4. Section 5 contains a summary.

1. Econometric Framework

We hypothesize that the age distribution of deaths from disease i in country j in year t depends on the cumulative number of drugs launched to treat disease i in country j by year $t - k$, and on other factors:

$$\text{AGE\_DEATH}_{ijt} = \beta \ln(\text{N\_DRUG}_{ij,t-k}) + \gamma \text{X}_{ijt} + \varepsilon_{ijt} \tag{1}$$

where

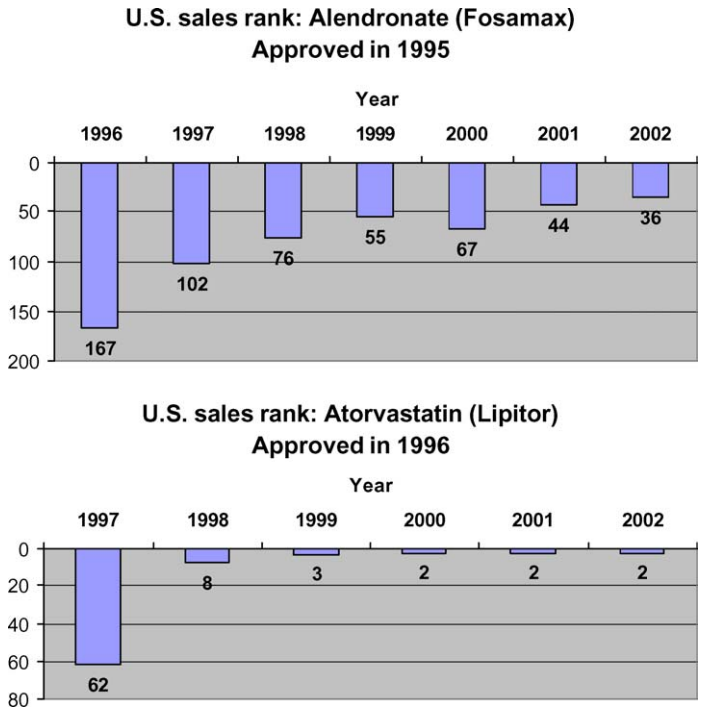
AGE_DEATH_{ijt} = a statistic based on the age distribution of deaths from disease i in country j in year t

$N\_DRUG_{ij,t-k}$ = the cumulative number of drugs launched to treat disease i in country j by year $t - k$

X_{ijt} = a vector of other factors (e.g. education, income, nutrition, the environment, and "lifestyle") affecting the age distribution of deaths from disease i in country j in year t

Equation (1) may be viewed as a *health production function*. AGE_DEATH is an indicator of "health output". N_DRUG may be viewed as an indicator of the level of medical technology.[4] We specify AGE_DEATH to be a function of the logarithm of N_DRUG because we hypothesize that there are diminishing returns to additions to the stock of drugs. In principle, it would be desirable to distinguish between the effects of drugs that provide substantial therapeutic advantages over existing drugs and the effects of other, less significant drugs. Drugs launched in the U.S. can be classified into these two categories, since the U.S. Food and Drug Administration designates drugs as either "priority-review" drugs or "standard-review" drugs. However, this classification is undoubtedly subject to error—it is made prior to the drug's review by the FDA—and it does not apply to drugs not launched in the U.S.

We specify a k-year lag in the relationship to allow for gradual diffusion of new drugs to consumers; we will estimate the model using different assumed values of k ($k = 0, 1, 2, \ldots$). The following data on the U.S. sales rank of two major drugs launched in the mid 1990s suggest the nature of the lag structure.



We hypothesize that many of the "other factors" (X_{ijt} in Eq. (1)) affecting the age distribution of deaths from disease i in country j in year t (e.g. per capita income, public health expenditure, and environmental quality) are invariant across diseases within a country and year, invariant across countries within a disease and year, or invariant across years within a country and disease. For biological reasons, people tend to die at younger ages from some diseases than from others in a given year, in all countries. For economic and other reasons, people tend to die at younger ages in some countries than in others in a given year, from all diseases.

Without loss of generality, we can decompose X_{ijt} as follows:

$$X_{ijt} = \alpha'_{it} + \delta'_{jt} + \theta'_{ij} + \nu'_{ijt} \tag{2}$$

where

α'_{it} = a fixed effect for disease i in year t
δ'_{jt} = a fixed effect for country j in year t
θ'_{ij} = a fixed effect for disease i in country j

Substituting (2) into (1),

$$\begin{aligned} \text{AGE\_DEATH}_{ijt} &= \beta \ln(\text{N\_DRUG}_{ij,t-k}) + \gamma(\alpha'_{it} + \delta'_{jt} + \theta'_{ij} + \nu'_{ijt}) + \varepsilon_{ijt} \\ &= \beta \ln(\text{N\_DRUG}_{ij,t-k}) + \alpha_{it} + \delta_{jt} + \theta_{ij} + u_{ijt} \end{aligned} \tag{3}$$

where

$\alpha_{it} = \gamma\alpha'_{it}$
$\delta_{jt} = \gamma\delta'_{jt}$
$\theta_{ij} = \gamma\theta'_{ij}$
$u_{ijt} = (\gamma\nu'_{ijt} + \varepsilon_{ijt})$

For example, suppose, as previous authors have argued, that environmental quality is an important determinant of AGE_DEATH, and also that environmental quality is correlated with N_DRUG. If environmental quality is invariant across diseases within a country and year, then its effect on AGE_DEATH is completely controlled for by δ_{jt}. If environmental quality varies across diseases, but deviations from country-year means are constant over time, then its effect on AGE_DEATH is completely controlled for by δ_{jt} and θ_{ij}. If environmental quality varies across diseases, and deviations from country-year means are not constant over time, estimates of β will be consistent as long as the deviation of environmental quality from its mean deviation from country-year means is uncorrelated with the deviation of $\ln(\text{N\_DRUG}_{ij,t-k})$ from its mean deviation from country-year means. The same argument applies to other potential determinants of AGE_DEATH (income, education, etc.).

While we can measure the stock of drugs by disease, country, and year, due to data limitations, we cannot measure the availability of medical devices (or of diagnostic and surgical procedures). If changes in the stock of devices are uncorrelated across diseases with changes in the stock of drugs, the drug-stock coefficient is unbiased. If changes in the stocks of devices and drugs are correlated (controlling for the fixed effects in Eq. (3)), the drug-stock coefficient could be biased. The direction of bias depends on the sign of the correlation. If the change in the stock of devices is negatively correlated across diseases with the change in the stock of drugs, the drug-stock coefficient is downward biased. Some evidence suggests that this correlation may indeed be negative. Lichtenberg (1996, 2001) presented evidence that use of newer drugs is associated with lower utilization of hospital care. Since use of some medical devices, such as stents and artificial hearts, requires hospitalization, drugs and devices may be substitutes rather than complements. Moreover, according to the Agency for Healthcare Research and Quality (2002), in 1999 the number of Americans using prescription drugs (172 million) was over eight times as large as the number with any hospitalizations (20 million).[5]

If pharmaceutical companies are more likely to launch drugs in product/geographic markets where they will have the largest impact on AGE_DEATH, then Eq. (3) could result in an overestimate of the average longevity impact of new drug launches. While this possibility cannot be entirely ruled out, there are reasons to doubt substantial overestimation of the average longevity impact. First, previous studies of the determinants of drug launch have not found any evidence that pharmaceutical companies are more likely to launch drugs in product/geographic markets where they will have the largest impact on AGE_DEATH: Danzon et al. (2003) and Kyle (2003) both found that market size (population) and the regulatory regime are important determinants of the probability of drug launch.[6] Second, if pharmaceutical firms tend to launch in markets where the benefit of launch is greatest, they are likely to launch in markets with the highest *total*, rather than *average*, longevity benefit. Suppose that the expected effect of a new leukemia drug on mean age at death in country A is 6 months, and that the expected effect in country B is 1 month. If 10 times as many people suffer from leukemia in country B as do in country A, then the social (and presumably private) benefits to launch in country B is higher, even though the benefit per patient is lower. Changes in AGE_DEATH reflect the average, rather than total, longevity benefit.[7]

2. Measurement

2.1. Drug Launches

We used data from the IMS Health Drug Launches database[8] to construct estimates of the number of drugs launched to treat disease i in country j by year $t - k$. This database has tracked new product introductions worldwide since 1982. In August 2001 the database contained over 165,000 records of individual product introductions between 1982 and 2001. Seventy-two countries are covered; many have been tracked since 1982. Data on product introductions is gathered from the IMS Health network of offices around the world and reflects the information on the product at the time of launch into each country.

Each record in the database contains the following information: the date and country of product launch, the active ingredient(s) of the product, a dummy variable indicating whether the product's ingredient is a new chemical entity (i.e. whether no products containing this ingredient have been launched anywhere before), and the therapeutic class of the product. The IMS therapeutic classification is extremely detailed; we recoded (aggregated) therapeutic classes into 11 therapeutic areas (e.g. nervous system drugs, respiratory drugs).

We constructed a list of all of the ingredients occurring in the database. This list contained information about two ingredient attributes: (1) whether the ingredient was a new chemical entity (i.e. was not launched anywhere in the world before 1982), and (2) the therapeutic area most frequently associated with the ingredient.[9]

We also constructed, for each country, a list of the active ingredients contained in products launched anytime during 1982–2002, and the first year in which that ingredient was observed in that country. We then merged the list of ingredients by country with the list of ingredient attributes. This enabled us to determine, for each country and therapeutic area, the total number of ingredients launched, and the number of new chemical entities launched.

The IMS Health Drug Launches database yields reliable estimates of the number of new (post-1981) drugs, but not of the number of old (pre-1982) drugs, or of the total (new + old) number of drugs. This is due to the fact that the launch data are *right-censored*: the IMS Health Drug Launches database does not cover products that were launched before 1982. Suppose that products launched in a country before 1982 contained a certain ingredient, but that no products launched since 1982 did. Provided that the products launched before 1982 are still on the market, that ingredient is still available to consumers, but we would not count it as an available ingredient. We can accurately measure the number of *new* drugs since, if an ingredient is identified by IMS as a new chemical entity, it could not have been launched prior to the initial launch date provided in the database.

If an ingredient is designated an NCE, then we can be confident that the date of the earliest observed launch of that ingredient in that country is the initial launch date. However, if an ingredient is not designated an NCE, then the date of the earliest observed launch of that ingredient in that country may not be the initial launch date—the ingredient may have been launched in that country prior to 1982.[10] In other words, NCE launches are guaranteed to be initial launches, but non-NCE launches may be either initial launches or re-launches; we suspect they are predominantly the latter.

To address the censoring problem, we will estimate two different models:

$$\text{AGE\_DEATH}_{ijt} = \beta_{\text{NCE}} \ln(\text{CUM\_NCE}_{ij,t-k}) + \alpha_{it} + \delta_{jt} + \theta_{ij} + \text{u}_{ijt} \tag{4a}$$

$$\text{AGE\_DEATH}_{ijt} = \beta_{\text{NCE}} \ln(\text{CUM\_NCE}_{ij,t-k}) + \beta_{\text{NON}} \ln(\text{CUM\_non} - \text{NCE}_{ij,t-k}) + \alpha_{it} + \delta_{jt} + \theta_{ij} + u_{ijt} \tag{4b}$$

where

CUM_NCE = the cumulative number of NCEs launched
CUM_non-NCE = the cumulative number of non-NCEs launched

In Eq. (4a), AGE_DEATH depends only on the cumulative number of NCEs launched, whereas in Eq. (4b), it depends on both the cumulative number of NCEs launched and the cumulative number of non-NCEs launched. We hypothesize that $\beta_{\text{NCE}} > \beta_{\text{NON}}$, i.e. that increases in the stock of NCEs increase AGE_DEATH more than increases in the stock of NCEs. While one might expect β_{NON} to be positive, or at least nonnegative, we can think of a reason why β_{NON} might be *negative*. Our basic hypothesis is that the greater the proportion of people consuming NCEs, the higher mean age at death will be. It is plausible that the proportion of people consuming NCEs is positively related to the number of NCEs launched and negatively related to the number of non-NCEs launched. Suppose, for example, that $\beta_{\text{NON}} = -\beta_{\text{NCE}}$; then Eq. (4b) reduces to

$$\begin{aligned}\text{AGE\_DEATH}_{ijt} = {} & \beta_{\text{NCE}} \ln(\text{CUM\_NCE}_{ij,t-k}/\text{CUM\_non} - \text{NCE}_{ij,t-k}) \\ & + \alpha_{it} + \delta_{jt} + \theta_{ij} + u_{ijt}\end{aligned}$$

AGE_DEATH depends on the *ratio* of NCEs to non-NCEs approved. The higher this ratio, the higher the probability that a person is consuming an NCE, as opposed to a non-NCE drug.

2.2. Age Distribution of Deaths

We obtained data on the age distribution of deaths, by disease, country, and year, from the World Health Organization (WHO) Mortality Database.[11] These data enable us to compute the fraction of deaths that occur above (or probability of survival until) certain ages, such as 55 and 65 years of age.[12]

We wish to provide estimates of the impact of new drug launches on *life expectancy* (at various ages, and for the population overall), as well as on survival probabilities. While complete life tables (which include life expectancies and survival probabilities) are available at the country level for various years, there are no *disease-specific* life tables, e.g. there are no published data on life expectancy of people with heart disease. However, we believe we can use aggregate life tables to translate our estimates of the impact of new drug launches on survival probabilities into estimates of the impact of new drug launches on life expectancy.

We obtained two different samples of country-level life tables: a time-series of decennial life tables for the U.S. for the period 1900–2000, and a cross-section of life tables for 191 countries in the year 2000. Each life table contains the following variables: life expectancy (years of remaining life) at age a ($\text{LE}_a, a = 0, 5, 10, \ldots, 100$), and the probability of survival from birth until age 65 (SURV65). The data suggest that SURV65 is a fairly good "sufficient statistic" for characterizing changes or differences in life expectancy. This is illustrated by Figure 3, which graphs life expectancy at two different ages (birth and age 30) against SURV65, using data from the 11 decennial U.S. life tables during the period 1900–2000. The R^2 of the regression of life expectancy at age 30 (LE_{30}) on SURV65 is .974, and the slope is 30.9, indicating that a .01 increase in SURV65 is associated with a 0.31-year increase in LE_{30}. The R^2 of the regression of life expectancy at birth (LE_0) on SURV65 is even higher (.997), and the slope is 66.0, indicating that a .01 increase in SURV65 is associated with a 0.66-year increase in LE_0.

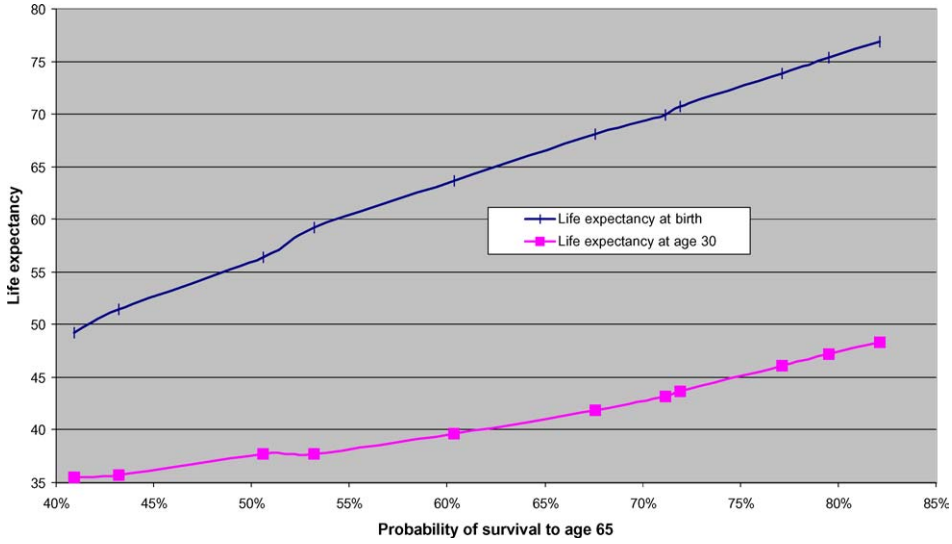


Figure 3. Relationship between life expectancy and probability of survival to age 65 U.S., 1900–2000.

We computed the regressions of life expectancy at each age (LE_a, $a = 0, 5, 10, \ldots, 100$) on SURV65, using both the time-series U.S. sample of life tables, and the cross-sectional international sample. The regression coefficients are plotted in Figure 4. The estimates yielded by the two samples are fairly consistent with one another. For example, the slopes of the age-0 U.S. and international regressions are 66.0 and 60.3, respectively, and the slopes of the age-30 regressions are 30.9 and 34.3, respectively.

Suppose that we estimate Eq. (4a), where AGE_DEATH_{ijt} is defined as PCT_GT65_{ijt}—the percent of deaths from disease i in country j in year t that occurred above the age of 65. PCT_GT65 is presumably a reasonable estimate of SURV65. Hence $\beta_{NCE} \approx \delta$ SURV65/δ ln(CUM_NCE). To estimate δ LE_a/δ ln(CUM_NCE), we simply multiply β_{NCE} by the regression coefficient shown in Figure 4. For example, using the U.S. estimate, δ LE_0/δ ln(CUM_NCE) $= 66.0 * \beta_{NCE}$.

In addition to estimating the impact of new drug launches on life expectancy at given ages, we can estimate the impact on the overall life expectancy of the population(LE_{POP}),[13] by calculating the weighted average of the regression coefficients shown in Figure 4, weighting by the share of the population in each age group. The resulting life-expectancy multipliers are as follows[14]:

	$\delta LE_{POP}/\delta$ ln(CUM_NCE)
U.S. time series, 1900–2000	$30.8 * \beta_{NCE}$
International cross section, 2000	$35.1 * \beta_{NCE}$
Mean	$33.0 * \beta_{NCE}$

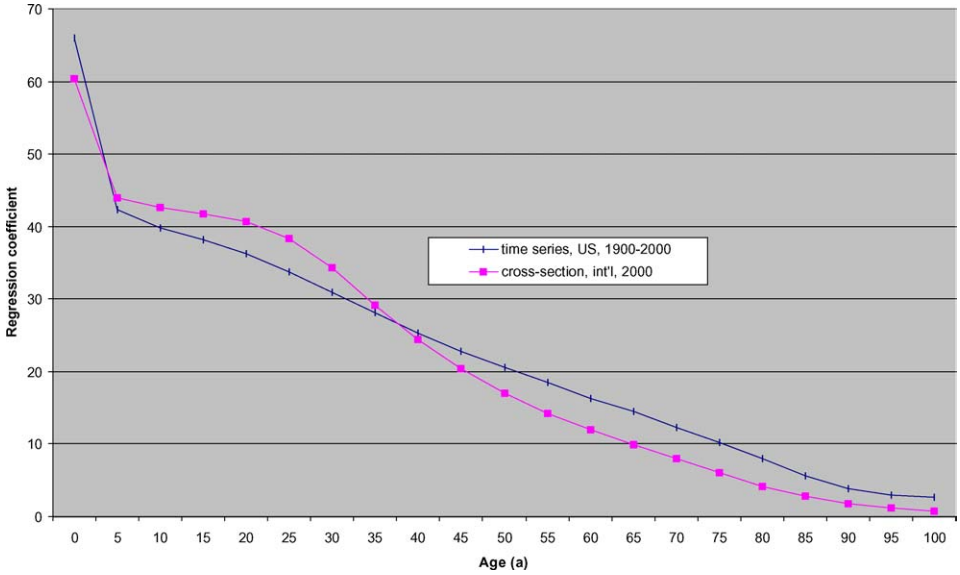


Figure 4. Coefficients from regressions of life expectancy at age a on probability of survival to age 65.

To convert an estimate of the effect of a change in ln(CUM_NCE) on SURV65 to an estimate of its effect on life expectancy of the overall population, simply multiply by 33!

2.3. Linkage of Drug Launches to Diseases

The drug launches documented in the IMS Health Drug Launches database are classified by therapeutic category. The classification system used by IMS is very detailed, but hierarchical. At the lowest (most detailed) level, there are more than 500 therapeutic classifications, e.g. prostaglandin antiulcerants (A2B3), and ACE inhibitor combinations with calcium antagonists (C9B3). At the highest level, there are 16 categories, e.g. Alimentary Tract And Metabolism (A), and Cardiovascular System (C).

The deaths documented in the WHO Mortality Database are classified by cause (disease), using the International Classification of Diseases (ICD).[15] Like the drug classification system, the ICD is very detailed, but hierarchical. At the highest level, there are 17 disease categories, e.g. Neoplasms (ICD10 codes C00-D48) and Diseases of the circulatory system (I00-I99).

The high-level IMS drug classification corresponds quite closely to the high-level ICD disease classification.[16] For example, cardiovascular system drugs obviously correspond to (are used to treat) diseases of the circulatory system. We defined 11 broad disease categories,

and classified drug launches and deaths into these categories as follows:

IMS drug class(es)	ICD10 codes	ICD10 disease class(es)
A Alimentary Tract And Metabolism	K00-K92, E00-E88	Diseases of the digestive system; endocrine, nutritional and metabolic diseases
B Blood and Blood Forming Organs	D50-D89	Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism
C Cardiovascular System	I00-I99	Diseases of the circulatory system
D Dermatologicals	L00-L98	Diseases of the skin and subcutaneous tissue
G Genitourinary System and Sex Hormones	N00-N98	Diseases of the genitourinary system
J General Anti-Infectives, Systemic; P Parasitology	A00-B99	Certain infectious and parasitic diseases
L Cytostatics	C00-D48	Neoplasms
M Musculoskeletal System	M00-M99	Diseases of the musculoskeletal system and connective tissue
N Central Nervous System (CNS)	F01-F99, G00-G98	Mental and behavioural disorders, diseases of the nervous system
R Respiratory System	J00-J98	Diseases of the respiratory system
S Sensory Organs	H00-H5, H60-H93	Diseases of the eye and adnexa; diseases of the ear and mastoid process

2.4. Descriptive Statistics

The IMS Health Drug Launches data indicate that 864 NCEs were introduced worldwide during 1982–2001. Figure 5 shows the number of NCEs introduced in each year. The annual number ranged from 34 to 59.

Figure 6 shows the distribution of NCEs launched, by principal therapeutic class. The four largest classes account for 54% of all NCEs launched. As shown in Figure 7, the distribution of *deaths*, by cause (each cause corresponds to a therapeutic class), is much more skewed. One cause—circulatory diseases—accounts for almost half (48%) of all deaths. The next three largest causes are neoplasms (27%), respiratory diseases (10%), and digestive/endocrine/nutritional/metabolic diseases (8%). The four largest causes account for 93% of deaths.

Table 1 shows the number of NCEs launched, by country, for countries covered in the database from 1982 to at least 2001. The three countries with the largest number of NCE launches (over 400) were Italy, Japan, and the U.S. Even in these countries, fewer than half of NCEs launched worldwide were launched. In six of the 40 countries—Malaysia,

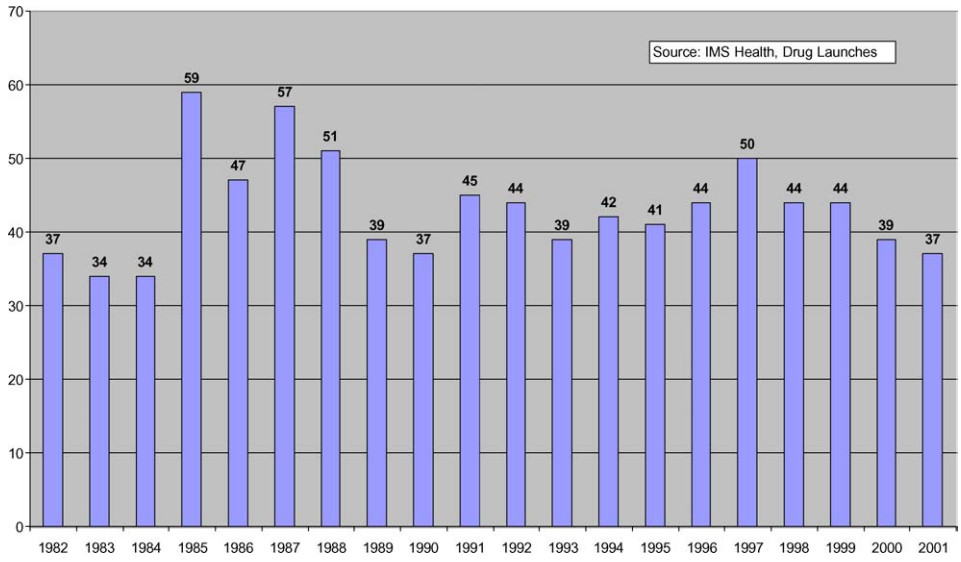


Figure 5. Number of NCEs launched, by year.

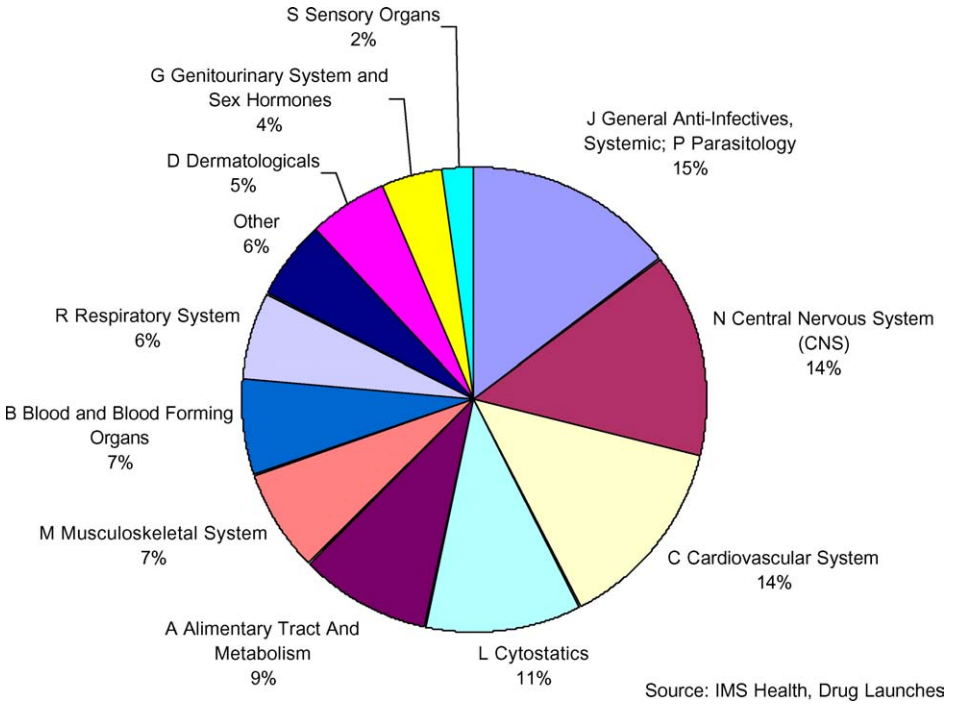


Figure 6. Distribution of new chemical entities launched, by principal therapeutic class.

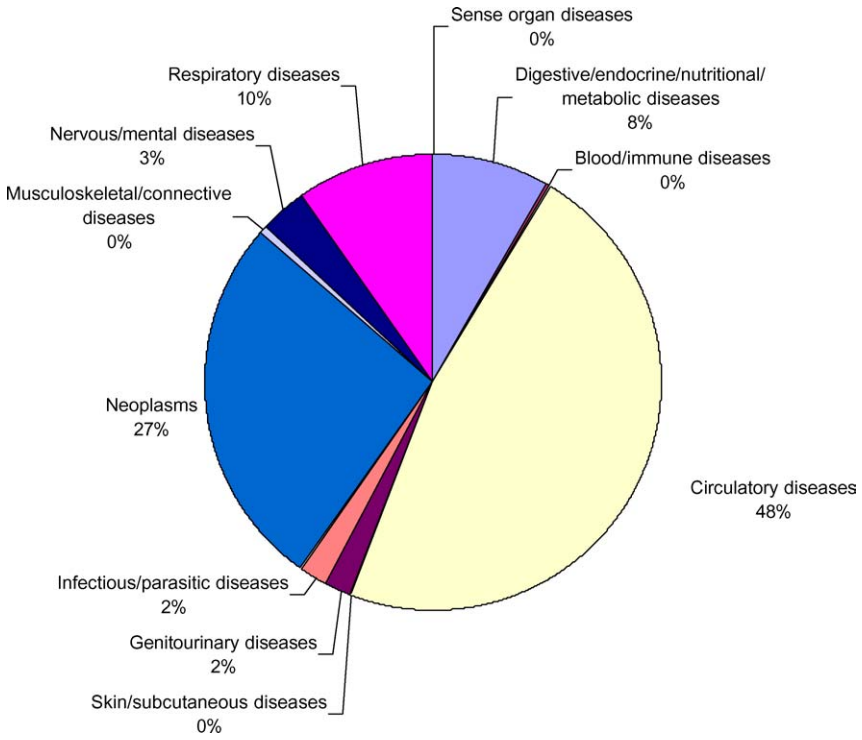


Figure 7. Distribution of deaths, by cause.

Egypt, Saudi Arabia, Singapore, Pakistan, and Indonesia—fewer than 200 NCEs were launched.

Table 2 shows the number of deaths, and the percent of deaths at age greater than or equal to 65, by country, in the most recent year for which mortality data for that country were available.

3. Empirical Results

Estimates of Eqs. (4a) and (4b), which explain the international variation in changes in the relative survival rates of different diseases ("difference in differences of differences"), are shown in Table 3. Estimates of β_{NCE} that are negative and significant signify that above-average increases in the relative number of NCEs launched to treat a disease in a country are associated with above-average increases in relative survival from that disease in that country. For example, between 1986 and 1991, four NCES for cancer were launched in Australia, increasing the stock from 7 NCEs to11 NCEs. This was an unusually large increase in the stock, in view of the number of cancer NCEs launched worldwide and the total number of launches in Australia (for all diseases) during that period. Therefore, one would expect

Table 1. Number of NCEs and non-NCEs launched, by country.

Country	Number of NCEs launched	Number of non-NCEs launched
ITALY	422	942
JAPAN	422	1193
USA	414	1000
ARGENTINA	373	1676
UK	373	604
AUSTRIA	350	699
SWITZERLAND	337	904
FINLAND	335	396
DENMARK	333	515
MEXICO	323	922
NETHERLANDS	310	448
SWEDEN	308	443
SPAIN	306	693
CANADA	299	990
IRELAND	292	478
FRANCE	290	766
BRAZIL	283	934
BELGIUM	282	533
GREECE	279	575
COLOMBIA	278	852
PHILIPPINES	277	555
THAILAND	272	911
CHILE	259	1032
TURKEY	241	754
SOUTH AFRICA	234	582
NEW ZEALAND	228	728
PORTUGAL	223	499
ECUADOR	220	750
ISRAEL	219	574
PERU	219	1026
VENEZUELA	215	647
HONG KONG	214	415
AUSTRALIA	213	682
INDONESIA	191	773
PAKISTAN	174	1089
SINGAPORE	171	229
SAUDI ARABIA	153	555
EGYPT	142	1037
MALAYSIA	122	249

Source: IMS Health, Drug Launches.

Table 2. Number of deaths and percent of deaths at or above age 65, by country.

Country	Year	Number of deaths	% of deaths at age GE 65
USA	1999	2,188,558	80
RUSSIA	2000	1,787,514	65
JAPAN	1999	875,172	81
GERMANY	1999	786,416	82
UK	1999	589,437	85
ITALY	1999	509,733	85
FRANCE	1999	448,640	82
MEXICO	2000	346,605	59
SPAIN	1999	343,186	85
POLAND	2000	313,275	74
EGYPT	2000	271,402	43
PHILIPPINES	1996	252,034	45
ARGENTINA	1997	224,694	71
CANADA	1998	198,312	82
SOUTH AFRICA	1996	184,197	41
SOUTH KOREA	2000	182,021	62
THAILAND	1994	148,426	29
NETHERLANDS	1995	122,692	83
HUNGARY	2001	121,727	72
AUSTRALIA	1999	117,829	83
COLOMBIA	1998	117,028	59
CZECH REPUBLIC	2000	101,022	78
BULGARIA	2000	99,898	77
BELGIUM	1996	93,679	84
GREECE	1999	88,621	84
SWEDEN	1999	88,061	88
PORTUGAL	2000	86,380	82
VENEZUELA	2000	77,011	56
CHILE	1999	68,566	72
AUSTRIA	2001	67,863	83
PERU	2000	61,086	58
SWITZERLAND	1999	56,582	85
DENMARK	1998	50,695	82
SLOVAK REPUBLIC	2000	48,622	75
FINLAND	2000	44,732	82
NORWAY	1999	40,393	87
ECUADOR	2000	37,794	56

(*Continued on next page.*)

Table 2. (*Continued.*)

Country	Year	Number of deaths	% of deaths at age GE 65
ISRAEL	1998	31,986	82
HONG KONG	2000	30,839	79
IRELAND	1999	30,180	83
MALAYSIA	1997	30,084	39
LATVIA	2000	26,971	72
PUERTO RICO	1999	25,965	72
NEW ZEALAND	1999	25,873	81
URUGUAY	2000	25,627	78
DOMINICAN REPUBLIC	1998	19,450	52
SLOVENIA	1999	16,481	77
SINGAPORE	2000	13,350	71
LUXEMBOURG	2001	3,239	82
KUWAIT	2000	3,040	44
PAKISTAN	1994	1,106	28

the cancer survival rate to have increased at an unusually high rate in Australia during 1986–1991, relative to the overall increase in Australian longevity and the global increase in cancer survival rates during that period. But between 1991 and 1999, the percentage increase in the Australian stock of cancer drugs was smaller than expected, in light of the number of cancer NCEs launched worldwide and the total number of launches in Australia (for all diseases) during that period. The stock increased 191%, from 11 to 32, whereas the *expected* increase in the stock was 458% (from 7.4 to 41.2 NCEs). Consequently, one would expect the cancer survival rate to have increased at a below-average rate in Australia during 1991–1999, relative to the overall increase in Australian longevity and the global increase in cancer survival rates during that period.

The dependent variable in all equations in Table 3 is the fraction of deaths that occurred at age 65 and over.[17] We chose this variable in part because it was the most widely available statistic in the WHO Mortality Database. All equations were estimated using data on 11 diseases in 52 countries over a maximum of 20 years (1982–2001). All equations included complete sets of country $*$ year, disease $*$ year, and country $*$ disease interaction effects. For example, the zero-lag equation ($k = 0$), which was estimated using 4678 observations, included 496 country $*$ year effects, 189 disease $*$ year effects, and 502 country $*$ disease effects. The equations were estimated via weighted least squares, using the number of deaths in that disease-country-year cell as the weight.

The first column of Table 3 shows the regression of AGE_DEATH_{ijt} on $\ln(\text{CUM\_NCE}_{ijt})$, i.e. a regression on the *contemporaneous* stock of NCEs, without controlling for the stock of non-NCEs. The estimate of β_{NCE} is positive and statistically significant, which is consistent with the hypothesis that NCE launches increase longevity. The second column of the

Table 3. Estimates of Eqs. (4a) and (4b).

Column	1	2	3	4	5	6	7	8	9	10	11	12	13
lag	0	0	1	1	2	2	3	3	4	4	5	5	6
β_{NCE}	0.0025	0.0023	0.0038	0.0036	0.0055	0.0053	0.0066	0.0063	0.0065	0.0062	0.0071	0.0068	0.0067
std. error.	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0010	0.0010	0.0010	0.0010	0.0010	0.0011
t-statistic	2.66	2.43	4.05	3.86	5.85	5.62	7.01	6.67	6.64	6.27	6.93	6.58	6.25
β_{NON}		−0.0029		−0.0044		−0.0040		−0.0018		−0.0006		−0.0010	
std. error.		0.0015		0.0015		0.0016		0.0016		0.0017		0.0018	
t-statistic		−1.9		−2.87		−2.55		−1.09		−0.38		−0.57	
$\beta_{NCE} - \beta_{NON}$		0.0051		0.0080		0.0093		0.0081		0.0068		0.0078	
std. error.		0.0018		0.0018		0.0019		0.0019		0.0020		0.0021	
t-statistic		2.83		4.38		5.02		4.29		3.46		3.72	
R-Square	0.994	0.994	0.994	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.995	0.995	0.995
Root MSE	1.831	1.833	1.808	1.811	1.780	1.782	1.765	1.769	1.777	1.780	1.807	1.808	1.828

The dependent variable in all equations is the fraction of deaths that occurred at age 65 and over. All equations were estimated using data on 11 diseases in 52 countries over a maximum of 20 years (1982–2001). All equations included complete sets of country ∗ year, disease ∗ year, and country ∗ disease interaction effects. For example, the zero-lag equation ($k = 0$), which was estimated using 4678 observations, included 496 country ∗ year effects, 189 disease ∗ year effects, and 502 country ∗ disease effects. The equations were estimated via weighted least squares, using the number of deaths in that disease-country-year cell as the weight.

table shows the regression of AGE_DEATH_{ijt} on both $\ln(\text{CUM\_NCE}_{ijt})$ and $\ln(\text{CUM\_non-NCE}_{ijt})$. Controlling for the stock of non-NCEs has very little impact on the estimate of β_{NCE}. The estimate of β_{NON} is *negative* and marginally significant, suggesting that, conditional on the cumulative number of NCE launches, the greater the cumulative number of non-NCE launches, the lower the probability of survival to age 65. This is consistent with the view that increasing the ratio of non-NCE to NCE launches reduces the fraction of people consuming NCEs, which in turn reduces longevity. The difference $(\beta_{\text{NCE}} - \beta_{\text{NON}})$ is positive and significant.

The remaining columns of Table 3 present regressions that are similar, except the regressors are *lagged*, rather than contemporaneous, values of the stocks of NCEs and non-NCEs. The third column of Table 3 shows the regression of AGE_DEATH_{ijt} on $\ln(\text{CUM\_NCE}_{ij,t-1})$, i.e. a regression on the stock of NCEs in the previous year, without controlling for the stock of non-NCEs. The estimate of β_{NCE} is about 50% larger than it is in column 1, suggesting that longevity is more closely related to the lagged stock of NCEs than it is to the contemporaneous stock, presumably due to gradual diffusion of NCEs following launch. The fourth column of the table shows the regression of AGE_DEATH_{ijt} on both $\ln(\text{CUM\_NCE}_{ij,t-1})$ and $\ln(\text{CUM\_non-NCE}_{ij,t-1})$. As before, controlling for the stock of non-NCEs has very little impact on the estimate of β_{NCE}. The estimate of β_{NON} is also about 50% larger than it is in column 2, as is the estimate of the difference $(\beta_{\text{NCE}} - \beta_{\text{NON}})$.

The fifth column of Table 3 shows the regression of AGE_DEATH_{ijt} on $\ln(\text{CUM\_NCE}_{ij,t-2})$, i.e. a regression on the stock of NCEs two years earlier, without controlling for the stock of non-NCEs. Once again, the estimate (and t-statistic) of β_{NCE} increases by about 50%. The sixth column of the table shows the regression of AGE_DEATH_{ijt} on both $\ln(\text{CUM\_NCE}_{ij,t-2})$ and $\ln(\text{CUM\_non-NCE}_{ij,t-2})$. The estimate of β_{NON} is slightly smaller, and less significant, than it was in column 4.

The remaining columns of Table 3 show estimates of the model for higher (3- to 6-year) lags between the stock of drugs launched and the age-65 survival probability. The estimate of β_{NON} is not significantly different from zero when the lag is 3 or more years.[18] As summarized in Figure 8, the estimate of β_{NCE} increases as the lag increases from 0 to 3 years, and then levels off. This suggests that it takes three years for new NCE launches to have their maximum impact on survival rates. We hypothesize that this is due to the gradual diffusion of drugs to consumers following launch.

If NCEs diffuse gradually following launch, this might be reflected in pharmaceutical *expenditure* behavior. An increase in the stock of NCEs is likely to result in an increase in per capita pharmaceutical expenditure, via both increased utilization and higher prices. From the OECD Health Database, we obtained data, by country and year, on per capita pharmaceutical expenditure, expressed in U.S. dollars, evaluated at PPP (Rx_expend).[19] After linking these data to the IMS Health Drug Launches data, we estimated the following equation for different values of k ($k = 0, 1, 2, \ldots, 6$):

$$\ln(\text{Rx\_expend}_{jt}) = \beta_{\text{expend}} \ln(\text{CUM\_NCE}_{j,t-k}) + \delta_t + \theta_j + u_{jt} \tag{5}$$

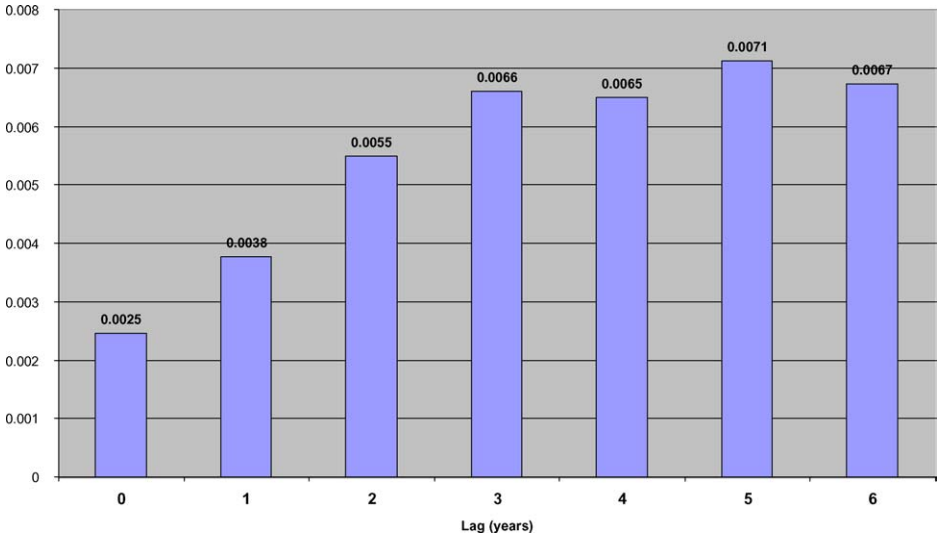


Figure 8. Estimates of β_{NCE} for different lags between stock of NCEs launched and longevity.

The estimates are shown in the following table.

lag	0	1	2	3	4	5	6
β_{expend}	−0.0087	0.0024	0.0145	0.0325	0.0421	0.0431	0.0400
s.e.	0.0132	0.0134	0.0135	0.0140	0.0161	0.0189	0.0230
t-stat	−0.66	0.18	1.07	2.32	2.61	2.28	1.73
p-value	0.5104	0.861	0.2849	0.0211	0.0097	0.0239	0.0848

For $k \leq 2$, β_{expend} is not significantly different from zero. This suggests that increases in the stock of NCEs have no impact on per capita pharmaceutical expenditure within two years. However, for $3 \leq k \leq 5$, β_{expend} is positive and statistically significant: increases in the stock of NCEs increase per capita pharmaceutical expenditure after three years. These results seem consistent with the time profile of the estimated effect of β_{NCE} (the impact of the NCE stock on survival probability). Estimates of β_{NCE} and β_{expend} at different lag values are plotted in Figure 9. It takes three to five years for an increase in the stock of NCEs to have its full impact on both pharmaceutical expenditure and survival rates.

4. Implications of the Estimates

Our estimates can be used to provide answers to several important questions:

- How much of the cross-country variation in longevity in a given year (e.g., 2000) is explained by international variation in the stock of NCEs launched since 1982?

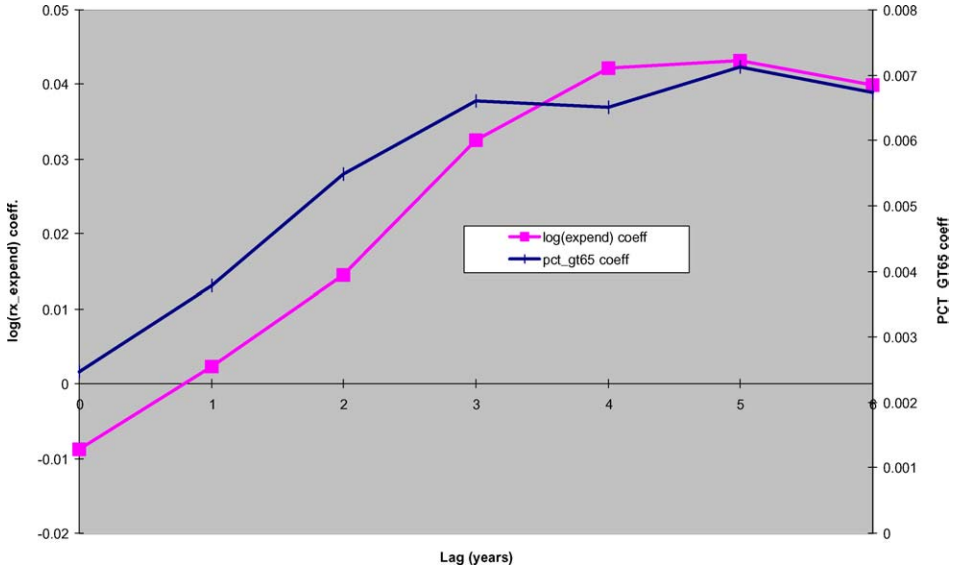


Figure 9. Estimates of β_{NCE} and β_{expend} at different lag values.

- How much of the long-run increase in longevity in the sample as a whole is due to the launch of NCEs?
- What is the cost per life-year gained from the launch of NCEs?

The last two questions can be answered under two alternative assumptions: (1) the estimates reflect the effect on longevity of new drug launches *per se*; and (2) the estimates reflect the effect of medical innovation in general.

To answer these questions, we will use the estimate of β_{NCE} from column 9 of Table 3, i.e. we will assume that $(\Delta\text{PCT\_GT65}_{ijt}/\Delta\ln(\text{CUM\_NCE}_{ij,t-4})) = .0065$. Recall that this estimate controls for all other factors affecting PCT_GT65 that are invariant across diseases within a country and year, invariant across countries within a disease and year, or invariant across years within a country and disease. Also, if we use aggregate life tables to translate our estimates of the impact of new drug launches on survival probabilities into estimates of the impact of new drug launches on life expectancy, as described above, then the effect of NCE launches on life expectancy at birth (LE_0) can be approximated by $(63.2 * .0065) = 0.4105$, and the effect of NCE launches on average life expectancy of the entire population (LE_{POP}) can be approximated by $(33.0 * .0065) = .2145$.

4.1. Cross-Sectional Differences

Heterogeneity with respect to NCE launches appears to explains very little of the international variation in longevity.[20] As shown in Table 1, the countries with the highest and lowest

number of NCE launches during the period 1982–2001 were Italy (422 NCE launches) and Malaysia (122 NCE launches), respectively. According to our estimates, the predicted difference in life expectancy at birth resulting from this launch differential is $\Delta LE_0 = 0.4105*\Delta \ln(CUM\_NCE) = 0.4105 * \ln(422/122) = .51$ years. This is only 9% of the difference between life expectancy at birth in Italy (78.7) and Malaysia (73.0) in 2000–2005.[21]

4.2. Time-Series Differences

In contrast, NCE launches appear to account for a significant fraction of the long-run increase in longevity in the sample as a whole. To measure this contribution, we adopted the following procedure. First, we inferred the average growth of PCT_GT65 from estimates of the year effects (δ_t's) from the following equation:

$$PCT\_GT65_{ijt} = \delta_t + \theta_{ij} + u_{ijt}$$

$(\delta_t - \delta_{1986})$ is an estimate of the change in the survival rate (and $33.0 * (\delta_t - \delta_{1986})$ is an estimate of the change in LE_{POP}) between 1986 and year t ($t = 1987, 1988, \ldots, 2000$), controlling for country $*$ disease effects. Second, we inferred the average rate of growth of CUM_NCE from estimates of the year effects (λ_t's) from the following equation[22]:

$$\ln(CUM\_NCE_{ijt}) = \lambda_t + \psi_{ij} + v_{ijt}$$

$(\lambda_t - \lambda_{1986})$ is an estimate of the change in the log of the stock of NCEs between 1986 and year t, controlling for country $*$ disease effects. Finally, the contribution of NCE launches to the increase in survival rates between 1986 and year t is equal to $(.0065* (\lambda_t - \lambda_{1986}))$, and the contribution of NCE launches to the increase in LE_{POP} is equal to $(33.0 * .0065 * (\lambda_t - \lambda_{1986}))$.

These calculations are summarized in Figure 10. Between 1986 and 2000, average life expectancy of the entire population increased by almost two (1.96) years. (The fraction of deaths that occurred at or above age 65 increased by 6 percentage points.) Our estimates imply that NCE launches accounted for 0.79 years (40%) of the 1986–2000 increase in longevity. The average annual increase in life expectancy of the entire population resulting from NCE launches is .056 years (= 0.79/14), or 2.93 weeks.

These results suggest that launch delays reduce longevity. Suppose that drugs tend to be launched much later in country B than they are in country A, so that country B's stock of drugs today is the same as country A's stock 5 years ago. The estimates imply that this launch delay reduces the average longevity of the entire population in country B by about 15 weeks. Danzon, Wang and Wang (2002) present evidence that countries with lower prices or smaller market size experience longer delays in access to new drugs.

4.3. Cost per Life-Year Gained from the Launch of NCEs

The cost per life-year gained from the launch of NCEs appears to be extremely low. OECD data indicate that in 1997, average per capita pharmaceutical expenditure in OECD countries

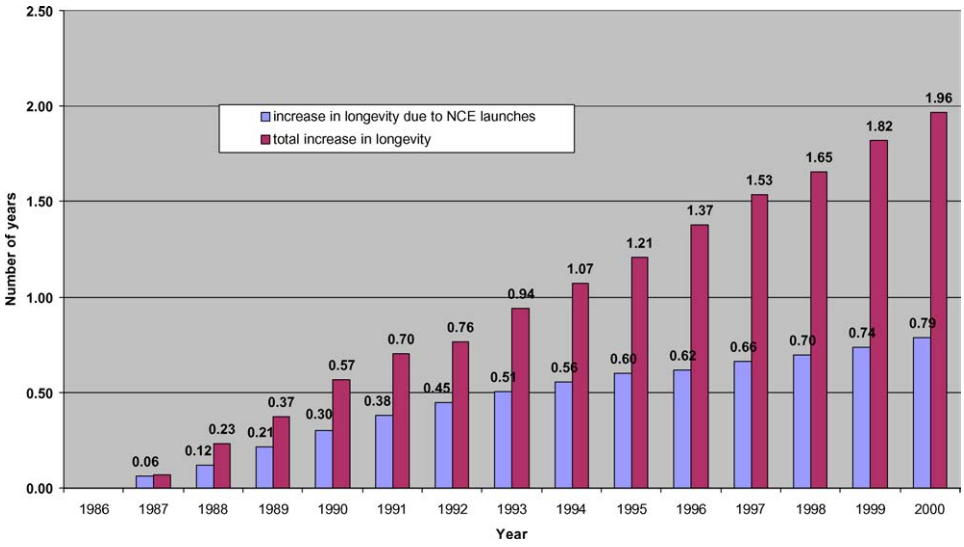


Figure 10. Contribution of NCE launches to increase in average life expectancy of the population since 1986.

was about $250. The average annual increase in life expectancy of the entire population resulting from NCE launches is .056 years. The ratio of these two numbers—pharmaceutical expenditure per person per year divided by the increase in life-years per person per year attributable to NCE launches—is about $4500.[23] This is far lower than most estimates of the value of a U.S. life-year (Nordhaus, 2003; Murphy and Topel, 2003).[24] Moreover, since the numerator includes expenditure on old drugs as well as on recently-launched NCEs, it probably grossly overstates the cost per life-year gained from the launch of NCEs. Data from the U.S. Medical Expenditure Panel Survey indicate that expenditure on "new drugs"—drugs that are less than 18 years old—accounts for approximately half of total drug expenditure.[25] This implies that the incremental cost effectiveness ratio—expenditure per person per year on new drugs divided by the increase in life-years per person per year attributable to NCE launches—is about $2250.

4.4. Effect of NCE Launches vs. Effect of Medical Innovation in General

As discussed above, due to our inability to measure the introduction of non-pharmaceutical medical innovations, these calculations might overstate the effect of new drug launches *per se* on life expectancy. Suppose that the estimated effect of new drug launches is capturing the effect of (country-disease-year-specific) medical innovation *in general* (the joint effect of new drugs, devices, and procedures) on longevity. Also, suppose that

$$\frac{\text{Effect on LE of new drug launches}}{\text{Effect on LE of all medical innovation}} = \frac{\text{Pharmaceutical R\&D expenditure}}{\text{Total health R\&D expenditure}}$$

As discussed in the introduction, U.S. pharmaceutical R&D expenditure accounts for about 1/3 of national (private + public) health R&D expenditure, and about 60% of industry health R&D expenditure. If only 1/3 of the estimated effect of new drug launches on longevity is attributable to new drugs (and the remaining 2/3 is attributable to other medical innovations), then new drug launches have increased longevity by about one week per year—about 13% of total longevity increase—and the incremental cost effectiveness ratio is about $6750.

5. Summary

Until recently, there appears to have been a consensus among health economists (or at least authors of health economics textbooks) that the contribution of medical care to longevity increase and other health improvements has been quite modest. But some recent research has indicated that technological innovations in medicine have had important positive impacts on health.

In this paper, we have performed an econometric analysis of the effect of new drug launches on longevity. Drugs are much more research-intensive than most other goods and services utilized in the health care sector, so new drug introductions account for a substantial fraction of medical innovations.

Our sample included data on virtually all of the diseases borne by people in 52 countries during the period 1982–2001. Analysis of the relationship between new drug launches and longevity using these data enabled us to control, to an unusually great extent, for the effects of other potential determinants of longevity, e.g. education, income, nutrition, the environment, and "lifestyle".

We used data from the IMS Health Drug Launches database to construct estimates of the number of drugs launched to treat eleven different diseases in each country in each year. This database has tracked new product introductions worldwide since 1982, and contained over 165,000 records of individual product introductions. We obtained data on the age distribution of deaths, by disease, country, and year, from the World Health Organization (WHO) Mortality Database. These data enabled us to compute the fraction of deaths that occur above (or probability of survival until) certain ages, such as 55 and 65 years of age.

We found that launches of New Chemical Entities (NCEs) have a strong positive impact on the probability of survival. The estimates indicated that it takes at least three years for new NCE launches to have their maximum impact on survival rates. This is probably due to the gradual diffusion of drugs to consumers following launch; data on pharmaceutical expenditure were consistent with this interpretation.

Launches of (older) drugs that are not NCEs—many of which may already have been on the market—do not increase longevity. Indeed, some estimates indicated that, conditional on the cumulative number of NCE launches, the greater the cumulative number of non-NCE launches, the lower the probability of survival to age 65. This is consistent with the view that increasing the ratio of non-NCE to NCE launches reduces the fraction of people consuming NCEs, which in turn reduces longevity.

Heterogeneity with respect to NCE launches appears to explains very little of the international variation in longevity. But NCE launches appear to account for a significant fraction of the long-run increase in longevity in the sample as a whole. Between 1986 and 2000,

average life expectancy of the entire population of sample countries increased by almost two (1.96) years. If we assume that our estimates reflect the effect on life expectancy of new drug launches *per se*, we may conclude that NCE launches accounted for 0.79 years (40%) of the 1986-2000 increase in longevity. The average annual increase in life expectancy of the entire population resulting from NCE launches is .056 years, or 2.93 weeks, and the incremental cost effectiveness ratio—expenditure per person per year on new drugs divided by the increase in life-years per person per year attributable to NCE launches—is about $2250. Previous authors have shown that countries with lower prices or smaller market size experience longer delays in access to new drugs; our results imply that launch delays reduce longevity.

It is possible that our estimates reflect the effect on life expectancy of medical innovation in general—new medical devices and procedures, as well as new drugs—although some evidence suggests that new drugs and other medical innovations are substitutes, rather than complements. If we assume that only one-third of the estimated effect of NCE launches is attributable to new drugs *per se* (pharmaceutical R&D accounts for about one-third of total health R&D), then we may conclude that new drug launches accounted for 13% of the 1986–2000 increase in longevity; that the average annual increase in life expectancy of the entire population resulting from these launches is about one week; and that the incremental cost effectiveness ratio is about $6750. Even this figure is far lower than most estimates of the value of a statistical life-year.

Notes

1. Referring to the U.S., Nordhaus (2002:17) estimated that, "to a first approximation, the economic value of increases in longevity over the twentieth century is about as large as the value of measured growth in non-health goods and services."
2. Sources: Appendix Table 4–31, National Science Board, *Science & Engineering Indicators—1996* <http://www.nsf.gov/sbe/srs/seind96/at04-31.xls>; Table A-8, National Science Foundation, *Research and Development in Industry: 1994* <http://www.nsf.gov/sbe/srs/nsf97331/tables/nsf94a08.xls>; Table 1, Pharmaceutical Research and Manufacturers of America, *Pharmaceutical Industry Profile 2004* (Washington, DC: PhRMA, 2004) <http://www.phrma.org/publications/publications//2004-03-31.937.pdf>.
3. Corresponding data on the launch of non-drug medical innovations (e.g. medical devices or surgical procedures) do not seem to be available.
4. In his model of endogenous technological change, Romer (1990) hypothesized the production function $Y = (A\ L)^{1-\alpha} K^{\alpha}$, where Y = output, A = the "stock of ideas", L = labor used to produce output, K = capital, and $0 < \alpha < 1$. The cumulative number of drugs launched (N_DRUG) is analogous to the stock of ideas.
5. Other unmeasured factors related to the quality of health care infrastructure could be positively correlated with availability of new drugs. For example, in the case of AIDS, a good system for diagnosing the disease and dispensing the treatments is essential for AIDS drugs to reach patients. AIDS drugs are not likely to be launched in a market until such infrastructure exists. However, AIDS is very insignificant in this sample: as shown in Figure 7, *all* infectious/parasitic diseases account for only 2% of deaths in the sample.
6. These determinants are likely to be well controlled for by the fixed effects in Eq. (3). Kyle found that firm characteristics (e.g. whether the firm was a domestic firm) and other factors also played a role.
7. Our procedure should produce unbiased estimates of the "effect of treatment on the treated", but not necessarily of the expected treatment effect for a randomly selected individual from the population.
8. IMS Health Drug Launches is now known as IMS Lifecyle New Product Focus.

9. A drug can be associated with more than one therapeutic area. For example, 6 products containing cefmenoxime were classified as infectious/parasitic disease drugs, and 5 products containing cefmenoxime were classified as sensory organ drugs.
10. Numerous products containing the same ingredient may be launched (e.g. by branded and generic firms) in a given country.
11. http://www3.who.int/whosis/whsa/ftp/download.htm
12. Notwithstanding the data shown in Figure 1, the dependent variable is not strictly non-decreasing. For example, the fraction of French people dying from digestive, endocrine, and related diseases who died after age 65 declined from 72% in 1987 to 69% in 1994.
13. $LE_{POP} = (\Sigma_a\ w_a\ LE_a)$, where w_a is the share of the population in age group a.
14. We used the age distribution of the U.S. in 1995 to construct the U.S. figure, and the age distribution of the world in 1995 to construct the international figure.
15. From 1982 to 1993, all deaths were classified using the ninth revision of the ICD (ICD9). In 1994, some countries began to report mortality data using the tenth revision of the ICD (ICD10). By 2001, most countries reported mortality data using the ICD10.
16. Establishing a correspondence between the two classifications at a more detailed level is far more difficult.
17. We also estimated models using the log-odds of survival until age 65, i.e. log(PCT_GT65/(1 – PCT_GT65)), and using a different age threshold (55 instead of 65). The results were qualitatively similar to those reported in the text.
18. The insignificance of β_{NON} suggests that the launch of generic drugs does not increase longevity. This might seem surprising, since generic launches might be expected to increase access and utilization of drugs. However Berndt, Kyle and Ling (2003) found that utilization of H_2-antagonist drugs by Americans *declined* following patent expiration; this may be due to the fact that branded firms cut back considerably on marketing efforts beginning several years prior to patent expiration. Moreover, the ratio of generic prices to branded prices may be much higher outside the U.S. than it is in the U.S.
19. Unfortunately, these data are not available by disease, and are only available for OECD countries.
20. Sample selection bias could conceivably lead us to underestimate the role of NCE launches in international longevity variation. WHO monitors mortality in 191 countries; IMS monitors drug launches in only 72 countries. Perhaps the number of NCEs launched in countries not monitored by IMS tends to be much lower than the number of NCEs launched in countries monitored by IMS.
21. As reported in the United Nations World Population Prospects Database.
22. Both this and the previous equation were estimated via weighted least squares, weighting by the number of deaths in that disease-country-year cell.
23. In France, the OECD country with the highest per capita pharmaceutical expenditure, 1997 expenditure was $421. Using this figure, pharmaceutical expenditure per person per year divided by the increase in life-years per person per year attributable to NCE launches is about $7518. (The average rate of new drug introduction in France was close to the average for all OECD countries.)
24. Estimates for developing countries are lower, but so are their drug costs. A World Bank study (Simon et al. 1999) of compensating-wage differentials in India implied a value of statistical life (VSL) of 6.4 million to 15 million 1990 rupees (roughly $150,000 to $360,000 at current exchange rates). This number is between 20 and 48 times forgone earnings—the human capital measure of the value of reducing the risk of death. Liu et al. (1997) estimated that, in Taiwan, the VSL ranges between US $413,000 and US $461,000, with a ratio of VSL to the present value of foregone earnings between 7 and 8.
25. Average spending on all prescription drugs by people age 18–64 was $255 in 1996. Expenditure on drugs approved after 1978 was $116, i.e. just under half of their total drug expenditure.

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