Age and Great Invention

by Benjamin F. Jones.

in *The Review of Economics and Statistics* 2010 92(1):1-14.

Research Digest by Matthew Clancy

Findings

The average age at which 544 Nobel prize winners in Physics, Chemistry, Medicine, and Economics do their prize-winning work increased by 7.8 years over the course of the 20th century, when adjusting for field and country of birth.[1] The average age at which 286 great inventors made their big breakthroughs rose by 8.2 years over the 20th century, again adjusting for field and country of birth.[2]

Part of this increase appears to be due to the general aging of the population. But it's not the most important driver. Jones develops a model of research/inventive productivity over a lifetime (e.g., how likely are you to develop a good idea at age 25, 30, 35, etc.), which he calibrates using data on the age at great invention and the age distribution of the population. This model lets him separate out how much of the change is driven by *delays* to getting started at research, how much is driven by higher research productivity late in life, and how much is due simply to the greater share of older workers in the population as time goes on. Greater research productivity late in life doesn't seem to explain any of the above increase. The greater share of older workers in the population accounts for about 3 of the 8 year increase. Delays in the onset of research account for about 5 of the 8 years.

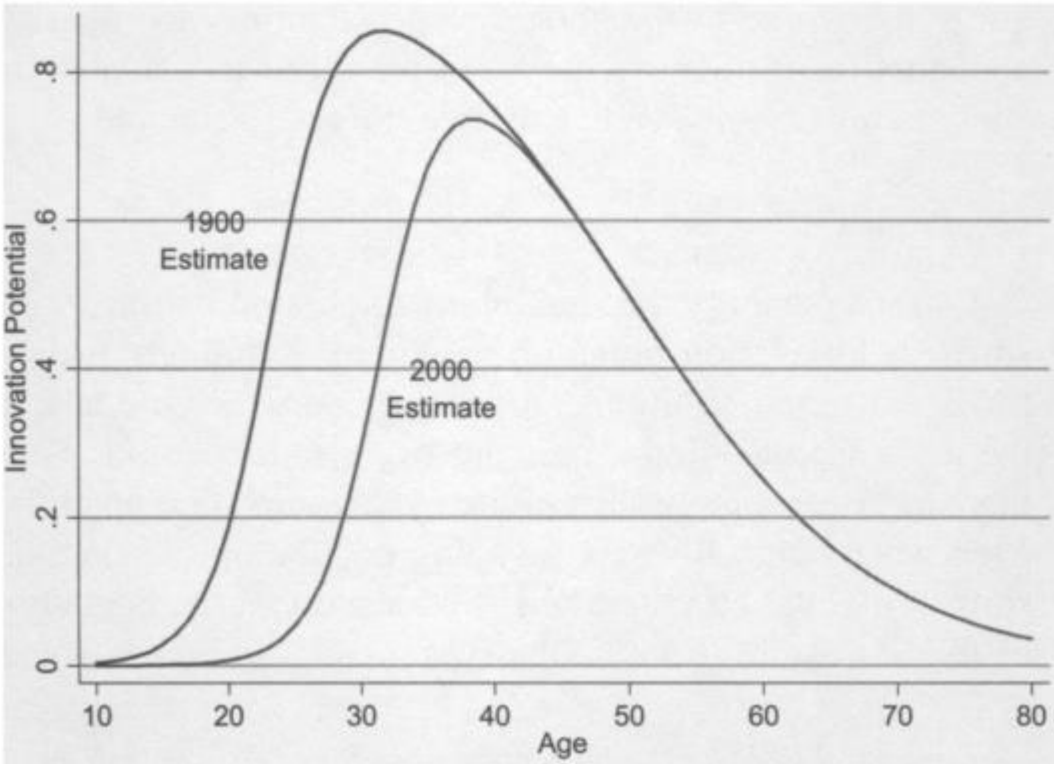
Figure 4 clearly illustrates this. The figure uses Jones' calibrated model to illustrate the probability of a great invention being discovered by someone at each age, given the population profile of scientists/inventors in 1900 and 2000. This diagram indicates the increase in age is driven by a massive decline in the probability of great invention for those aged 30 or below, with little to no change for the probability of coming up with a great innovation after age 30. For some reason, inventors have stopped inventing things while they are young, even though this used to be one of their most fruitful periods of discovery.

---

[1] Table 1, column 3

[2] Table 1, column 6

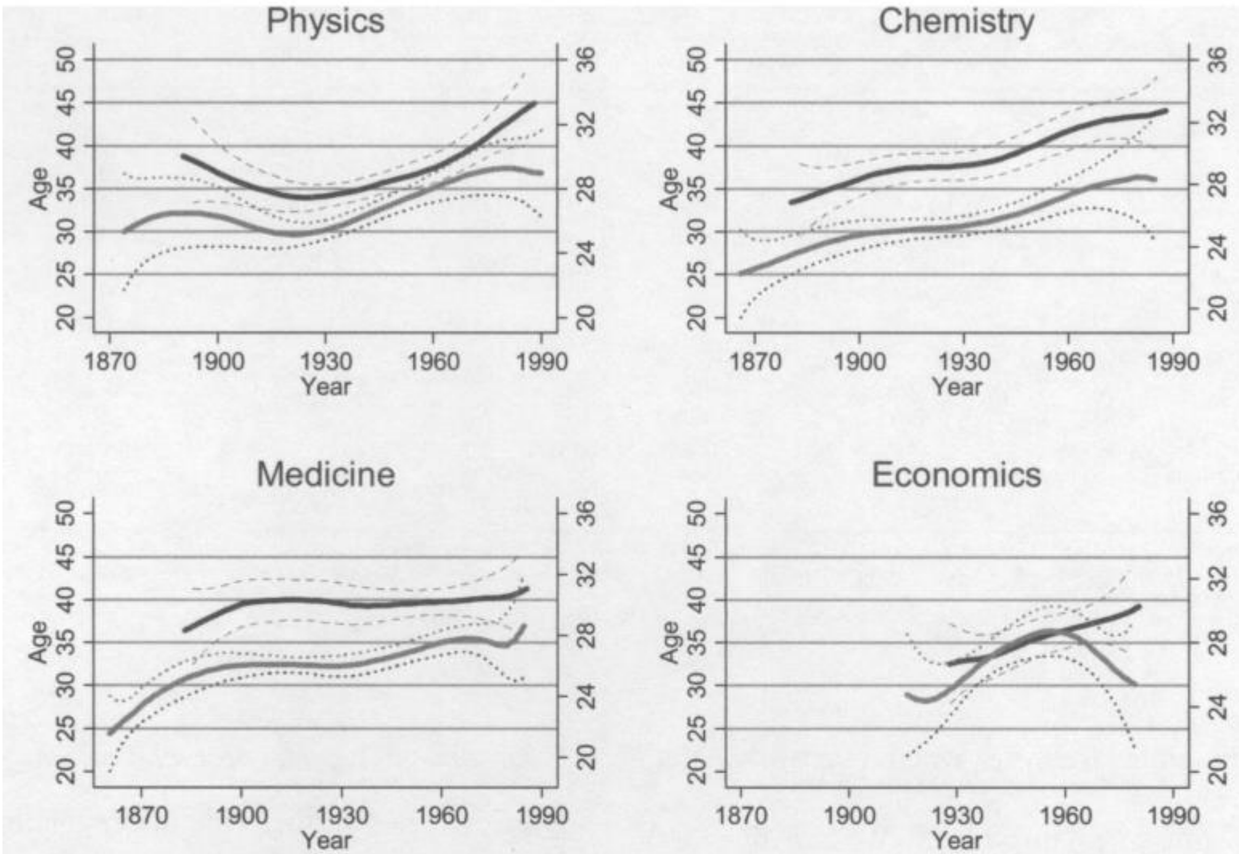
FIGURE 4.—MAXIMUM LIKELIHOOD ESTIMATES FOR THE POTENTIAL TO PRODUCE GREAT INNOVATIONS AS A FUNCTION OF AGE



Note: This figure plots the estimated shift in relative innovation potential (using column 1 of table 2). See the discussion in section 5A.

Jones next shows that the age at which scientists have finished their highest degree has increased by about 4 years in a century. In other words, the increase in time spent on education and training is quite close to the 5-year increase not attributable to an aging workforce. Moreover, as indicated in Figure 5, looking field by field it is clear that the age of terminal degree follows a similar trend as the age of Nobel prize winning work, including a notable dip for physics around the time of the quantum mechanics revolution.

FIGURE 5.—AGES AT PHD AND ACHIEVEMENT OVER TIME, BY FIELD



Dark lines, left axis – age of Nobel prize winning work. Light line, right axis – age of final degree.

Lastly, Jones considers a natural experiment that interrupted the training of some researchers during the 20th century: World War I and World War II. Researchers still in school when these wars broke out had an unusually sharp and discrete interruption to their studies. On average, it took an extra 2.8 years for scientists to complete their degrees,[3] if they had their studies interrupted by the wars. The average increase in their age of great achievement also increased by 2.8 years.[4]

Discussion

One way to interpret Jones' data is that a certain amount of knowledge and training is a necessary prerequisite before you can make new discoveries, and that the time required to obtain this training has risen by 4-5 years (over a century). This may be because the quantity of knowledge that is a prerequisite to making new discoveries has grown. This pushes back the age at which great inventions are made. Furthermore, Jones' calibrated model suggests the impact of longer training is not simply to push all research activity by 5 years, but rather to truncate the life of

[3] Table 5, column 4
[4] Table 5, column 6

invention. It's more like scientists simply have 5 fewer years in which to do research, and the years lost tended to be particularly active ones in the past.

Data

Jones uses biographies of Nobel prize winners published on the official web site of the Nobel Foundation (nobelprize.org) for data on 547 winners in Chemistry, Physics, Medicine, and Economics over 1901 to 2003. He is able to determine dates of birth, country of birth, and dates of the winning contribution for 544 of these winners. In 75% of cases, the official Nobel biography gives a single year in which the winning contribution occurred. In the rest of cases, the Nobel citation encompasses a body of work that spans multiple years and Jones uses the midpoint between the first and last year of contribution. Jones notes this assumption is not crucial to his findings. In a few cases, additional sources were consulted to pin down the year of contribution.

Jones uses two technological almanacs to derive the birth date, country of birth, and date of great invention for 286 twentieth century inventors. These technological almanacs compile major technological advances across many categories: electronics, energy, food, agriculture, materials, tools, and devices. Example inventions include various forms of jet engine, the personal computer, radio, and plastic materials.

To estimate his calibrated model of productivity, Jones uses data on the distribution of ages in the US census. He variously uses the entire US population, the population of those active in the labor force, and the population of professional scientists and engineers. Because the sample is so small for the last category (especially in early years), Jones applies some statistical smoothing techniques.

Methodology

Jones uses ordinary least squares estimation to find (1) the change in age of great invention, (2) the change in age of final degree, and (3) the impact of the World Wars on age of final degree and age at great invention. His regressions have the general form:

$$a_i = \alpha + \beta t_i + \gamma X_i + \varepsilon_i \tag{1.1}$$

where a_i is the age of individual *i* when they made their great invention or finished their terminal degree, and t_i is the calendar year in which individual *i* made their great invention or finished their terminal degree. The term X_i includes controls such the country of birth, the field of the work, and in some specifications the presence or absence of a World War during an individual's educational years. Separate regressions are run on the population of Nobel prize winners and great inventors. All results reported in the findings reject the null hypothesis that the actual variable of interest is zero with at least 95% confidence.

To estimate his calibrated model of the productive lifecycle, Jones specifies a model combining real data on the population of the workforce with various unknown parameters. This model, once parameters are fed into it, makes predictions about the probability a given great discovery is made by an individual of age *a* in year *t*. He then uses maximum likelihood estimation to choose the value of unknown model parameters which best fit the actual data on age at great invention across the 20th century. Once he has chosen parameters for his model, he can use it to generate the probability a great discovery is made at every age, for any year in his data set.

The basics of his model have this form:

Pr(discovery made in year *t* by age *a* inventor) =

(share inv. pop. with age *a* in *t*) x Pr(in year *t,* age *a* inv. makes a discovery)

The left-hand-side variable is empirically given by the data, since we know the age at invention for every discovery in each year. The first right-hand-side variable is also given by data on the share of the US population at age *a* in every year. The second right-hand-side variable is estimated though.

$$\Pr(\bullet) = \left[1+\exp\left(-(a-\mu_0-\mu_1 t)/\omega\right)\right]^{-1}\left(1-\left[1+\exp\left(-(a-\theta_0-\theta_1 t)/\rho\right)\right]^{-1}\right) \tag{1.2}$$

where exp(.) is the exponential function. This equation has a number of unknown parameters (all the greek letters), which are chosen by maximum likelihood algorithm to best fit the data. To interpret this function, the most important terms are buried in the exponential functions.

Inside the first set of braces we see:

$$a-\mu_0-\mu_1 t \tag{1.3}$$

When the age *a* rises relative to $\mu_0+\mu_1 t$ then if you carefully follow the chain of effects, it has the impact of raising Pr(in year *t,* age *a* inv. makes a discovery). The term $\mu_0+\mu_1 t$ can be thought of as a measure of how old a scientist must be before he has a high probability of making a great discovery. Since $\mu_0+\mu_1 t$ includes *t*, we can have this effect rise over time. It turns out the values of μ_0 and μ_1 that best fit the data imply this age has risen by about 5 years over the 20th century.

Inside the second set of braces we see:

$$a-\theta_0-\theta_1 t \tag{1.4}$$

When the age *a* rises relative to $\theta_0+\theta_1 t$ then if you carefully follow the chain of effects, it has the impact of lowering Pr(in year *t,* age *a* inv. makes a discovery). The term $\theta_0+\theta_1 t$ can be thought of as measure of how old a scientist can get before their probability of making a great discovery falls sharply. Since $\theta_0+\theta_1 t$ includes *t*, this lets Jones see if scientists have longer working lives over time. In this case, no, it turns out the values of θ_0 and θ_1 that best fit the data do *not* imply the age at which great invention "stops" has risen over the 20th century.