Informal Discussion Transcript

General Session I - The Advancing Frontier of Human Survival

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General Session I - The Advancing Frontier of Human Survival - Vaupel

TIMOTHY HARRIS: I'd like to introduce our keynote speaker, Dr. James Vaupel. Many, if not all, of you know Dr. Vaupel. He's the executive and founding director of the Max Planck Institute for Demographic Research. He's a scientific member of the Max Planck Society for the Advancement of Science, the German Academy of Sciences and a regular scientific member of the U.S. National Academy of Sciences. He's also a Fellow of the American Academy of Arts and Sciences. So, with that, Dr. Vaupel. (Applause.)

DR. JAMES VAUPEL: What I'd like to do today is to spend a few minutes talking about the advancing frontier of human survival, the fact that we're living longer. I'll try to put a special focus on the future of U.S. mortality. I'm very happy to be here because this is an important meeting in terms of thinking about living longer and longer and this is my first time here.

I want to go back historically 10 or 20 years and talk about three views about the frontier of survival. The first view was that there's a fixed frontier; in this view, life spans are limited and this view actually goes all the way back to Aristotle, who in 350 B.C. wrote an essay on the shortness and longness of life. Aristotle compared life to a fire burning in a home in the hearth where you put a certain amount of wood on the fire and lit the fire and

then if you didn't do anything, the fire would eventually die out, and he called that old age mortality or senescent mortality. The inevitable mortality was when the wood of your life burns out. The other possibility was you could throw sand on the fire or water on the fire and have premature mortality. So he distinguished in 350 B.C. between early death and late mortality or senescent mortality and premature mortality, which is the same thing that James Fries did in 1980 in his very influential article in the *New England Journal of Medicine*. This view was the dominant view from 350 B.C. up until very recently: that everyone is born with a maximum life span, you can do something about early death, but you can't do anything about your natural mortality from senescence. Many of you undoubtedly have heard about this view and some of you may subscribe to it.

The second view was, yes, there is a maximum length of life for every person and some people might have a maximum life of 80 and other people might have a maximum life of 100, but if you can figure out some secret, then you can evade this natural limit and you can live longer than your ordained number of days. The first major book on this was by Luigi Cornaro in 1558. He was a Venetian. He wrote a book called *The Art of Living Long* and it's in Italian. It's also translated as *The Secret of Longevity. A*nd what

was Cornaro's secret of longevity? Do you know this book? This book was the best-selling book in Europe for 300 years, after the Bible, the best-seller for 300 years. The secret of longevity is dietary restriction, so dietary restriction goes back to 1558 and people are still studying this dietary restriction idea, which seems to work for rodents.

Then there was a third view and the third view was that, YES, the frontier of survival is advancing! We just don't recognize it. This was alluded to earlier. We didn't have very good data 20 years ago about what was happening at mortality, at the older ages, at the oldest ages, so maybe something was, the frontier was actually advancing, we just didn't know it. So Ken Manton, Eric Stallard (Eric is coming to this meeting) and I wrote a paper about this in 1979 and we didn't have data then, we just proposed this as a hypothesis and the question was, "How could we get some data?" So I finally motivated myself to go to Sweden because if you want good data at very high ages, you go to Sweden. So I went to Stockholm and I went to the Statistics of Sweden, found a man called Hans Lindstrom and asked him if I could get some data on mortality after age 80, which hadn't been computerized, and he took me down into the basement and showed me all this data, and so I raised some money and hired him and for several years on Saturdays and

Sundays, he worked compiling this data and computerizing this data.

Finally in the early 1990s, we had some data, some accurate data, on what was happening to mortality at the highest ages, for the first time. So here is mortality at ages 85, 90, 95, for Swedish females. (Hans Lundstrom began by going back to 1900 and then later went back earlier and he stopped in the late 1980s). Here's the risk of death at age 85. I've updated this to the present. So you can see up until 1950 or so, there wasn't very much progress, but after 1950, there was a dramatic decline in the risk of death after 85; it went from 20 percent to under 10 percent, the annual risk.

At age 90, the same pattern and at age 95, the same pattern. Of course, it bounces around a lot because there weren't very many 95-year-old Swedes but you can see the dramatic decline from the level of something above .4 to a level of about .3. So, it's not true that nothing can be done about mortality at the highest ages; death rates at the highest ages, at least since 1950, have been substantially reduced. So this was replicated subsequently in many countries in large part because of the work done by demographers to establish the Human Mortality Database, John Wilmoth and Vladimir Shkolnikov. So here we have women ages 80 to 89 and men ages 80 to 89. First this is Sweden;

so we go from 1950, now I don't know if you can see the small print, but this is from 1950 until the present. Swedish death rates, the standardized death rate for octogenarian Swedish women, and you can see the steady decline. Here's the same pattern for French women, even more dramatic progress; here's the Japanese women, astounding progress; and here's the United States. Ken Manton and I wrote about this in the early 1990s talking about the U.S. survival advantage among the very oldest Americans, but at about the same time we published our paper, the United States was overtaken by France and Japan and there was a period of stagnation among older Americans for a while but then more recently this period of stagnation has ended.

I don't have the latest data here, this is from the Human Mortality Database, but if you look at the latest estimates, the U.S. trend is continuing to go down. Then here's a bunch of other countries.

For men, the same basic pattern but mortality is higher for males, of course, so these are the Swedish men, the French men, the Japanese men, the U.S. men. So again, a period of stagnation followed by, more recently, by progress and the U.S. males are doing about as well as anybody and then a bunch of other countries. So you can see there really has been a substantial decline in octogenarian

mortality.

How about nonagenarians, people in their 90s? Let's go through this together. So here's Sweden, some big decline but some leveling off recently; France no sign of any leveling off; Japan amazing progress. Even though the Japanese have the world's longest life expectancy, they're making very rapid progress in bringing death rates down at the highest ages. The United States, so again, a long period of stagnation for the U.S. women, followed by recent improvement and a bunch of other countries.

OK, so Sweden males, French males, Japanese males, U.S. males. The United States is different and sometimes American actuaries don't realize how different the United States is. The United States is part of the world, and events elsewhere in the world are going to influence events in the United States: the United States is not going to fall further and further behind the rest of the world. But there was a long period of time where there was a stagnation in the United States that was not found in other countries and here's a bunch of other countries.

OK, so, as a result of these dramatic declines in mortality at the highest ages, there was an explosion in the number of centenarians and supercentenarians. You know that this was alluded to earlier but let me just give you some detailed data about the number of females aged 100

plus in Sweden. This is from 1861 when the Swedish data are virtually perfect, so from 1861 to 1900 there were many years where there was nobody in Sweden who was above 100 and then there were some years where there was one or two people and then after 1900, there was a little bit of a rise, but even in 1975, there were only about 100 people in Sweden above 100 and then since 1970, this dramatic rise, it's still small, 1,600, but it's a dramatic rise. So you can see this is really an explosion in the number of centenarians and that's because the probability of living to 100 depends on your probability of making it to 80 and then your probability of making it from 80 to 100. Eighty is not certain and it's pretty good if you make it to 80, but to make it from 80 to 100 is hard. The dramatic reduction in mortality above age 80 has resulted in this explosion of centenarians. Bernard Jeune and I wrote an article about this; three-quarters of the growth in the number of centenarians is due to progress in bringing mortality down after age 80.

Let's look at the Japanese. Age 100, that's too young for the Japanese, here we'll look at 105 plus, 105 plus Japanese women. Have you ever seen anything like that? I mean it's virtually vertical, nobody and then virtually vertical. It's because of this, again because of this dramatic progress in Japan in bringing death rates down

after age 80.

OK, so a major discovery over the past two decades was the discovery of the advancing frontier of survival. A supplemental discovery was the frontier of survival is advancing because senescence is being postponed. That is, the increase of mortality with age is being postponed, it's not being slowed down, it's not being decelerated, it's being postponed. So let me show you some evidence for this. Well, let me ask you a question first: Compared with U.S. men 50 years ago, do 70-year-old U.S. males today suffer the same chances of death as 67-year-olds did then, 65-year-olds did then or 60-year-olds did then? That's a good actuarial question. You don't have to tell me now, write it down on a piece of paper, I'll give the answer in a second, but let me just show you some data first.

Here's a perspective on this postponement of senescence: The first paper on this was one by me and Lindstrom in 1992 and I expanded on it in *Nature* magazine in 2010. Consider the age when remaining life expectancy is five, when you really should write a will, or when your remaining life expectancy is 10 and then what is that age? So for Swedish women, the remaining life expectancy was around five; the remaining life expectancy of five occurred in the early 80s up until 1950 and now it's gone up close to 90 and you can see the same thing in the United States

and Japan. There's been a five- or 10-year increase in the age at which you have only five years left or 10 years left.

Then another way to see this, again using data for Sweden, is to look at the risk of death over age at different times. So here, here's the risk of death, the hazard of mortality, the force of morality for Swedish females from age 30 to age 90 in 1950 and it's on a log scale: Because mortality is pretty much Gompertz, it's linear. So you can see this more or less linear increase in Swedish female mortality in 1950 and here it is in 1980 and here it is in 2010 and one way to think about it is that mortality is being shifted down. Another way to think about it is mortality is being shifted out and if you think about it in terms of mortality being shifted out, you could take a look at the age when the risk of death is 1 percent; you might call that the start of old age when your chance of death rises above 1 percent. Well, in 1950 for Swedish women, it was 57 and in 1980 it was 63 and in 2010 it was 68. So you see every 30 years about a five- or six-year increase in the age in which your chance of death is 1 percent.

Instead of measuring things in terms of age, very often you should convert age to chance of death and think about things—at what age is your chance of death 1 percent,

at what age is your chance of death 10 percent—as a way of standardizing things across generations and in some sense, you could say 68-year-old Swedish women today have roughly the same health that 57-year-old Swedish women did 60 years ago. This is confirmed if you look at health statistics as well, but it's just more difficult; you can measure mortality more easily than you can measure health.

So to show you the answers to the question I gave you before, this is the equivalent age 50 years ago in terms of chance of death for people at different ages today. So if you look at age 70 today and then you look at U.S. males, so U.S. males 50 years ago at age 60 had the same death rate that U.S. males today have at age 70. So there's been a 10-year increase in this equivalent age of death, and if you look at the other numbers here, you can see something like a 10-year increase for these other countries as well and something like a 10-year increase at different ages as well.

So there's been roughly a 10-year, roughly a 10-year postponement of mortality, roughly a 10-year postponement of senescence over the last 50 years, roughly two years per decade. OK, so this is very important. Senescence is being postponed by roughly two years per decade.

In addition to the major discovery and the supplemental discovery about postponement, let me just go

back here and show you this. You see this is the important point, these curves are more or less parallel, they're not divergent; we're not slowing down the rate of aging, we're postponing senescence.

This advancing frontier of survival is part of a bigger long-term life expectancy revolution, so let me just briefly summarize the main evidence about the larger long-term life expectancy revolution. Some of you may know this but starting in 1840, how much has female life expectancy in the countries with the longest female life expectancy increased per day? Since 1840, one hour per day, three hours per day or six hours per day? Any one of these numbers are amazing, right? But which of these amazing numbers is right? OK and then since 1950, so this is since 1840, we have good data since 1840, since 1950 how much has female life expectancy, again in the countries doing best, how much has female life expectancy been increasing: An hour a day, three hours a day, six hours per day? Well, Jim Oeppen and I did this in an article in *Science* in 2002; we've updated it since then. Here's the record life expectancy in different countries; it starts in 1550 with English data. We have data based on skeletal remains before 1550, less accurate data but so far as we can tell, life expectancy in the populations doing the very best was something like 35 or 40 throughout human history up until

about 1800 and in many countries it was less than 35 or 40, 10 years less in the case of France, 15 years less in the case of Italy.

Around 1800, a revolution started to take place and life expectancy started to go up and here's looking at it from 1840. So now the graph starts at 1840 and the first dot, I don't know if you can see it, the first dot is for Sweden. Swedish women in 1840 had a life expectancy of 46 and then after 1840, a series of other countries had the world's longest life expectancy, and you can see the pretty regular rise and then recently it's been Japan, a very regular rise. The Japanese life expectancy now is above 86 for women and then if you plot a line through it, you can see that it's really very linear. The r squared is .992; it doesn't get much more linear than that. And what's the slope of the line? Well, it's two and a half years per decade. That's three months per year and three months per year is six hours per day. Life expectancy in the countries doing best has been going up by six hours per day since 1840 and also since 1950.

As I showed you before, the U.S. was a leader and then it lagged behind; now it's catching up again. But if you look at the countries doing best, six hours per day, it's really an amazing, amazing result. In some sense, you know, you don't (I'll give you some data on older people in a

minute) but in some sense, when you live 24 hours, you only have to count 18: You know, six hours are free every day. (Laughter.)

Here's particular countries. This is Sweden. So Sweden was the leader, it fell behind, it caught up, it fell behind again. Here's the Netherlands; again, a leader and then fell behind recently. Here's France; French life expectancy you can see was below 45 all the up until 1900 and then the French caught up, you can see World War I and World War II, the Spanish flu after World War I but the French are doing very well today. Here's East and West Germany; I show East and West Germany, West Germany in dark blue, East Germany in light blue. There was a divergence of the two and then following unification in 1990, East German life expectancy rapidly caught up with West German levels. So despite 40 years of communist rule, within a few years, life expectancy converged. And here's for the United States as well, and the United States you can see there's this dark blue curve, this leveling off and then beginning to rise, the start of increase recently.

Then in terms of predictions, how much is U.S. life expectancy likely to increase in the future and here's where I get on thinner ice, but the U.S. life expectancy today for males and females combined it something like 78. How much do you think it's going to increase over the

future and you can all come up with your estimate. Based on what I just showed you, if life expectancy is going up by two and a half years per decade and it's been going up recently by almost two and a half years per decade for men as well as for women, although men have lower life expectancy, two and a half years per decade, in 40 years, that's 10 years. So my prediction is 10 years, maybe a little bit less but more than eight. The Social Security Administration disagrees with this.

My argument is that the best way to forecast U.S. life expectancy is to extrapolate the long-term historical trend in the countries with high life expectancies because the United States is unlikely to fall further and further behind other countries; the United States is part of the world. And then to ask why might life expectancy progress be faster and why might it be slower, and balance those factors off against each other and see if you should increase or decrease the long-term extrapolation. This seems to me to be a sensible thing for actuaries to do. This is what actuaries like to do, it seems to me, you know, do a long-term extrapolation and then worry about whether the future is likely to be a little bit better or worse than the past.

If you do that, then you get three months per year, so you get 10 years, and the remaining life expectancy at age

65 might increase almost as much and let me show you some data about that. Here's the rise in record life expectancy at age 65 and you can see there was some progress in the 19th century and the early part of the 20th century, but since 1950, there's really been quite a steady rise. And look at different countries: so here's Sweden, here's France, a remarkable case of France, here's East and West Germany and the United States, you know, where there's been this leveling off. But if you look at these rates of improvement in life expectancy at age 65, it's not quite three months per year, it's more like two months per year, but it's accelerating, and so if life expectancy goes up by eight or 10 years at birth, it might go up by six years at age 65.

About a year ago, one of my Ph.D. students, Adam Lenart, came into my office and said, "Jim, suppose life expectancy is going up by three months per year every year on a period basis, how much is cohort life expectancy going up?" I said, "Adam, three months per year, right? If it's three months per year every year on a period basis, it's going to be three months on a cohort basis." "No, no, no, no, no, Professor Vaupel, no, it's four months per year and the reason is that if period life expectancy is going up by three months per year, then a newborn, by the time she gets to be 80, will at age 80 benefit from all that progress and

will have an even longer life expectancy at age 80 than you would project on the basis of the period calculations." So the cohort is taking advantage of the fact that they're more likely to live to a higher age and then have better chances after that age.

If you do the calculations with a simple Gompertz model, you get four months per year and Vladimir Shkolnikov checked this in an article [in] *Population [and] Development Review* empirically and, empirically for most countries, it's more than four months per year. So that's really astonishing, four months per year, phew. So if you just do the simple calculation, four months per year, take a newborn child, a newborn child a 100 years times four months, you know, then most Americans born since 2000 will celebrate their 100th birthdays, if we can extrapolate the past.

We did this for a number of different countries and cohorts, so babies born in 2000, babies born in 2005, babies born in 2010, again assuming four months per year progress. OK, now why did the United States do so badly? Well, there's a Select Committee of the Senate on Aging and Steve Goss and I were asked to testify before this select committee, this was a number of years ago, and I pointed out that the Social Security Administration's prediction for U.S. life expectancy in the middle of this century was

lower than current French life expectancy. This was 10 years ago and I said that President Bush would never allow U.S. life expectancy to fall further and further behind French life expectancy. (Laughter.)

As a result of this, the National Academy of Science was asked to organize a National Research Council committee on why the United States was doing so badly and of course you couldn't call the committee "Why is the United States doing so badly," so the committee was called "Divergent Trends in Life Expectancy" and the committee was headed by Eileen Crimmins and Sam Preston. I was a member of the committee and we identified three countries in which life expectancy had stagnated: United States, U.S. females recently, Dutch females and Danish females, and the males earlier. So the committee looked very carefully into why U.S., Dutch and Danish females experienced a stagnation of life expectancy and then the committee called all sorts of witnesses to testify about obesity and about smoking and about behavior and food and all sorts of other things and the committee wrote two books about this, available from the National Academy of Sciences' Press, and the committee concluded that—as one of my Danish colleagues said, he put it this way—there are four major reasons, smoking, smoking, smoking and a bunch of other things and that's what the committee concluded. And the same thing is certainly true

in the U.S. and is true in Denmark and, to a considerable sense, it's also true in Holland, that the stagnation is largely due to smoking.

I'm currently involved in a study, we're still writing this study, about the Danish stagnation, and Rune Johansen, the first author of the study, identified women born between 1920 and 1940, those women, as being the women who caused the stagnation, so what I suggested that Rune did was to look at period life expectancy in Denmark and replace the women born between 1920 and 1940 with Swedish women born between 1920 and 1940 and there's no stagnation. So almost 100 percent of the stagnation is due to what we now call the femme fatale generation, the women born between 1920 and 1940. And why were these women femme fatales? Because they smoked, that was the main thing, and they drank too much too.

Now Danish life expectancy, as these women die out, the Danish life expectancy is going up as fast as any country, as Sweden, so sometimes it can be major cohort effects. The resultant stagnation and these cohort effects to a large extent are due to smoking, but there's an underlying reason too. Why do people smoke? So why do women smoke? So I've been told it's because of pressure and stress and all kinds of things and part of it is social inequality.

In the United States, if you look at the counties of the United States and you look at the counties in which there is very high mortality, those are counties in which people tend to be poor or poorly educated, they smoke a lot, they drink a lot, they don't go to the doctor, they don't listen to the doctor. There's a whole syndrome of things associated with living in these counties, and these counties show a lot of social inequality. So I'll come back to that in the question-and-answer period if you'd like.

But anyway, let's take the United States versus France. So, Jean-Marie, you'll see France is doing very well. So U.S. life expectancy at birth, this is in 2010, is 81 for females, 76 for males and maybe a little higher today. The Social Security Administration, as I said, was projecting that the U.S. life expectancy at birth in 2050 will be less than the current French values of life expectancy, which are 85 for females and 78 for males, and it's really hard, it's very, very difficult to believe that U.S. life expectancy in 2050 could be less than French life expectancy today, especially since the most likely French values in 2050 are 95 for females and 88 for males. So will the United States really be under 85 for females and under 78 for males and the French more than 10 years higher? It's very hard to believe.

Mortality forecasts, based on expert judgment, have

been less accurate than extrapolation. In my studies of this field, what I've learned is never trust experts unless they have some numbers. Expert opinion is … well, you have to be extremely careful about expert opinion because experts know a lot about the past, but experts know very little about the future and experts over and over again have demonstrated a colossal failure of imagination to try to foresee what the future might bring, so I'm a firm believer in extrapolation.

Here's the picture that Jim Oeppen and I published 10 years ago in *Science* and we've updated it, but it's the same basic picture. The black line is the linear rise in life expectancy since 1840 and the horizontal lines are the experts' judgments about the ultimate limit to human life expectancy. So Louis Dublin in the early 1920s, he was an actuary at the Metropolitan Life Insurance Company, later chief actuary. Louis Dublin said no country in the world ever, ever will have a life expectancy more than 65, Ever. He didn't have data for New Zealand and New Zealand had a life expectancy of 65 two years prior to publication. So he tried again with Lotka, you know demography's Newton, Alfred James Lotka, he tried again and he said, they said life expectancy would never exceed three score and 10, ever, and it exceeded three score and 10 one year after publication. Then he tried again: It would never exceed 72,

and it exceeded 72 roughly at the time of publication. Then more recently, there's been a whole series of famous people and major organizations who are making predictions and in every instance, up until now, they've been exceeded or about to be exceeded.

The dashed red lines are the UN, the United Nation's projections and you can see they're getting better, they're going up and they're getting steeper but still they're consistently pessimistic. So, the experts have been consistently wrong.

One method, the best method I know of for testing an approach to forecasting life expectancy, is to put yourself in the past, say put yourself 50 years into the past and use a method to forecast life expectancy and then see what actually happens. So it's sometimes called historical forecasting. So you make an historical forecast in the year 1950 using this method and see what you get for year 2010 and compare it to what happened in 2010. Or you put yourself in 1920, or you put yourself in 1970, right? So you put yourself in the past, apply the method, see what you get and compare it to what actually happened. Every single method used by national organizations, all the methods used by actuaries to my knowledge have failed this test. One and only one method has satisfied the test; linear extrapolation is the only method that meets the test

for record life expectancy.

OK. Now it doesn't have to be true in the future but if you put yourself in the past, you put yourself in 1900, 1940, 1960, 1980, 2000, linear extrapolation will do better.

Now there are all sorts of arguments that the future is going to be different from the past and we can't use the past to project the future, OK, so fair enough. So the future will be different from the past. So if you put yourself back in 1950 and try to project, you wouldn't have foreseen what was going to happen in terms of cardiovascular disease in 1950, but it happened; if you put yourself back in 1930, you wouldn't have foreseen the revolution in antibiotics, but it happened. So all throughout history, the future has always been different from the past, but the future has been different from the past in such a way that we get this linear progress and I can talk a little later about why the progress is linear, but the fact of the matter is that progress has been linear.

So what's going to happen in the future? Well, one is that progress will be made against cancer and dementia and in developing genotype-specific therapies. Biomedical scientists tend to be too optimistic but in 10 years, 20 years, 30 years, there will be substantial progress.

Then there will be progress in rejuvenating tissues, first regenerating tissues and then rejuvenating tissues. There's been some progress already in rejuvenating, I mean, in regenerating heart tissues, bladder tissues, and then there will also be progress in replacing deleterious genes or giving you medicine that will negate the effect of the deleterious genes; this is already in the works. Again, not tomorrow but in 20, 30, 40 years, there will be substantial progress, probably, and then nanotechnologies. You know, eat a billion little nano-robots the size of a cell and they go around and fix your bones and kill cancers in 50 years and then maybe, maybe and if I was an actuary this is what I'd really be worried about, maybe we'll figure out how to slow down the rate of aging.

There are several thousand people in laboratories around the world trying to figure out how to slow down the rate of aging. They're working with yeast, nematode worms, fruit flies, rodents, and they're trying to figure out what can we do to slow down the rate of aging. You know, red wine, if you drink 200 bottles of red wine a day, you can slow down your rate of aging. So then they're trying to figure out how to encapsulate 200 bottles of red wine in one little pill, you know, the secret ingredient, or maybe there's some other chemical that can slow down the rate of aging.

Suppose we could figure out how to slow down the rate of aging. So if you could cut it in half, roughly speaking, life expectancy instead of being 80 would be 160 and this might happen in, I don't know, the lifetime of our children. So some people think I'm being very conservative when I do this linear extrapolation, they think it's likely to be much faster than linear extrapolation.

If you're in charge of long-run planning for a life insurance company, worrying about annuities, you have to worry about the fact that there might be a 1 percent chance that people are going to live to be 150, which would be pretty disastrous for annuities.

So, since 1840, as I said, every new generation there's been different kinds of progress made and the country in which the longest life expectancy was found shifted from Sweden to Japan, the causes of death shifted from infectious disease to chronic disease and the ages in which the progress was made shifted from childhood to old age, so we can see that here. This is the age-specific contributions to the increase in record life expectancy for women from 1850 to the present. And in the 19th century and the early part of the 20th century, almost all the progress in increasing life expectancy was due to progress in childhood; you can see the effect in infancy and childhood, early adulthood. Almost no progress at older ages.

Then in the middle decades, progress in the middle ages and now recently most of the progress—look at the last column—most of the progress is due to reductions in death rates after 65 and the biggest contribution is reduction in death rates after age 80. So something can be done about old age and that's why life expectancy is increasing.

So, this linear rise in life expectancy is truly remarkable, given the fact that the country has changed, the nature of the causes of death has changed, the ages have changed, but still we get this linear progress. And so a big question is why the progress has been linear. I have some explanations but no totally convincing explanation, but the fact is it's been linear. So my argument is that because, ever since 1840, future progress has been different from past progress, but this has been taken into account in the linear rise and because experts have a failure of imagination, they can't foresee what's coming very well, then the best strategy is to extrapolate and the extrapolation takes into account all the unforeseen advances and shocks of the past. So sometimes people say, "Jim, how about obesity?" I say, "Well, put yourself back in the 1900s and say how about smoking?" You know the smoking epidemic was vastly worse than the obesity epidemic is likely to be and despite the smoking epidemic, life expectancy went up three months per decade. Obesity will

slow the rise a little bit but it's not going to reverse the rise. The National Academy of Science's committee considered that very carefully.

Again, the straight line is the record, the horizontal lines are the experts. So let me stop there, thank you very much. (Applause.)

TIMOTHY HARRIS: We're going to open things up for questions now. I did want to make a comment, though. I do take that one little pill you're talking about, I take Resveratrol supplements.

DR. JAMES VAUPEL: Mm-hmm (yes), OK, OK, maybe it works, I hope it works.

TIMOTHY HARRIS: I'll let you know later. So, do we have any questions from the audience for Dr. Vaupel?

DR. JAMES VAUPEL: I gave a short talk to leave plenty of time for questions.

TOM BAKOS: Yes, you like straight line projections.

DR. JAMES VAUPEL: I don't like them; it's just empirically correct.

TOM BAKOS: Well, you think they work. (Laughter.) I'm Tom Bakos, I'm sorry. And so my question is: How far are you willing to go with that straight line? You know, it looks like you're willing to accept the fact that there is no limit on human life span.

DR. JAMES VAUPEL: Well, see, it would take a long time to

verify that humans could live forever, right? It would take a very long time. (Laughter.) So it's not going to happen tomorrow, I mean nobody is going to live forever tomorrow and so my prediction is that life expectancy has been going up by two and a half years per decade since 1840 in the countries doing best, that's the frontier, and if it's been going up two and a half years per decade since 1840, it's likely to continue to go up by two and a half years per decade in the future. I don't know how many decades into the future, I just think that that's the best guess for the immediate future, for the next few decades. OK, when life expectancy gets to be 100, will it keep on going up? I don't know, I really don't know but I'm pretty sure—no, I'm not pretty sure, but a judicious guess—given the record of the past, is that it's likely to go from 80 to 100 over the next 80 years.

TOM BAKOS: Yeah, I asked the question because I had done a projection like that using a straight line. The statistic I projected was an actual-to-expected ratio and I looked at the Society of Actuary's mortality studies relating mortality to a standard, and, of course, my graph was going down like this and so I was able to project, using that straight line projection, I think that we would be immortal by the year 2030 because that would be when the actual expected ratio was 0. So I kind of did it in a humorous

vein but it seems like maybe there's something way out in the future that we don't know.

DR. JAMES VAUPEL: I agree completely with you.

TIMOTHY HARRIS: Well, this was, I wrote a book on living to 100 and beyond and Tom wrote the forward for that book and he put this chart in there and he showed the year at which we achieve immortality in this chart.

DR. JAMES VAUPEL: No, I agree with you completely. When I forecast things, sometimes I use an exponential projection, sometimes a logistic. You know, it depends on the nature of the data and the measure; I think you have to keep very careful track of what's happening. There's been no evidence whatsoever of any slowing of this two and a half years per decade. If there starts to be evidence of that, then we have to change our minds. For a long period of time, life expectancy, as I said, hovered between 25 and 35 in most countries, and then around 1800, 1840, it started to go up. Maybe there's going to be a long period of time where it hovers around 100, I don't know. But just as a serviceable approach to the next few decades, the linear extrapolation of life expectancy, not of some ratio, but of life expectancy, would have worked if you had done that 50 years ago or 100 years ago in making your projections, that's my only argument.

TOM BAKOS: I love your optimism.

DR. JAMES VAUPEL: I'm not optimistic, you know, Aubrey de Grey is optimistic. No, I'm in the middle, I'm in the middle. There are many people who are much more optimistic than me. There are many people who think that we're going to have a breakthrough in slowing down the rate of aging soon and if we could slow down the rate of aging as I said, then life expectancy could really go up fast. If these people are right, then I'm pessimistic. I don't want to be an optimist or a pessimist; I have an exuberant personality but I'm not an optimist. (Laughter.) So, I think Jay was next.

JAY OLSHANSKY: Actually, Jim, I'm one of the optimists who, as you know, I'm working very hard to accelerate research in the field of aging to slow it down, to achieve the very thing that you're talking about in terms of accelerated improvements. But, you know, we published a paper just earlier or I guess late last year looking at the demographic effects of decelerated aging and the rise in life expectancy actually was not exponential, it was not dramatic. It was actually relatively small, it was a little bit faster than the middle range assumption from the Social Security Administration. But that actually wasn't my question. My question is you know Sam Preston, just a few weeks ago, published an article on demography, looking at the effects of smoking and obesity, forecasting forward,

and he came to the conclusion that life expectancy for females would rise about 9/10^{ths} of one year between now and 2040 and for, let's see, what did I say for females, yeah so a little bit less than one year per decade, yeah it was .8 for males, .9 for females, it was dramatically slower than what you just presented and I'm wondering what Sam did wrong. (Laughter.)

DR. JAMES VAUPEL: That's a good question. First of all, Jay, in terms of your first comment about the slowing of life expectancy, if you slow the increase in mortality with age enough, then people live a lot longer, so it depends on your assumption. In terms of Sam's analysis, and I have the highest respect for Sam and I think his analysis is certainly in the range of credibility, he based his analysis on the analysis of U.S. data and my estimate of two and a half years per decade is based on the analysis of international data and the main disagreement that Sam and I have is that. And it's not a serious disagreement because we talk about it and we agree that each of us could be right. The main disagreement we have is how much weight should you give to the U.S. data versus how much weight should you give to the international data. Will the United States continue to fall behind France? Will the life expectancy gap between the United States and France rise to a decade? Sam thinks, yes, it could and I don't think it

will, but I think his estimate is possible. I think Social Security is too low, but his is possible.

TIMOTHY HARRIS: Dale, I think you're next.

DALE HAGSTROM: I just thought the actuaries in the room would be interested in the results of a calculation that they may be thinking about. Tom would humorously project the Q's linearly, going down to zero and then beyond to negative rates (so that we have the zombie return of the insured population). I, on the other hand, will take a more plausible interpretation of compounding annual improvements occurring over the next 40 years for every age, by which time the new 65-year-old's life expectancy will be 10 years longer than whatever it is today. Based on a U.S. life insurance valuation basic table, I figured out the life expectancy at 65 and asked what constant rate of geometric improvement, for every age uniformly from 65 out to 120, for every year, would be needed so that 40 years from now the life expectancy for the 65-year-old calculation would be 10 years more than it is today. The answer is that a 2.85 percent annual improvement is needed for every age from 65 up through 120. While plausible, it is higher than it's been in the U.S. for those ages during most years. I just figured people would be interested in having that reference.

DR. JAMES VAUPEL: No, no you're absolutely right. I've done

a similar calculation and I got 2.5 percent but the same, roughly the same as you did, so the question is, is a 2.5 percent improvement plausible? And at younger ages, we've had more than 2.5 percent increases, so my thinking is that this postponement of aging that I talked about means that the rates of improvement we've been seeing at younger ages will become rates of improvement at older ages. If 80-year-olds today are as healthy as 70-year-olds were 50 years ago, then we might be able to start making faster rates of progress for the 80-year-olds than we did in the past.

Also if you look at the time trends in rates of improvement, for example, at age 80, the rate of improvement at age 80 was 0 in the first part of the 20th century and it has gradually accelerated up above 1 percent today, and then if you extrapolate that, it's possible the rates of improvement at age 80 might be comparable to the rates of improvement at age 60, right? But I agree with you, that's the assumption, something like 2.5 percent is required. If you have something like 2 percent, you don't get 10 years, you get eight years, but you need something like that, yeah.

TIMOTHY HARRIS: I think the back microphone is next.

MATT DAITCH: We've had a lot of discussions about your theory in our company so it's actually kind of a little thrill to actually meet the person who we have been

debating that theory for a long time. But my main question is those extrapolations are based on life expectancy at birth and we've been doing a lot of discussions about older age and a lot of the improvement that's created that straight line had to do with the treatments of infectious diseases, infant mortality, for women, it's when they're giving birth and therefore implied. If you're saying that a lot of that improvement has already happened, most of the improvement has to happen at older ages, in order to continue that linear extrapolation. When you get to the best in class, they need to have improvement that's never been experienced before and then the ones who are behind who have to converge have to get improvement that's even higher than that. So you're talking about, what's implied in that theory, is improvement rates that have never been seen before and then a lot of the, also the issues we had that we were concerned about was with Japan. There's been a lot of data that's showing that there's a lot of, that the data is incorrect, that people are committing fraud in not reporting deaths so that they continue to collect their, their beneficiaries can collect their pension benefits, so I guess the question is, is that, would it have been better, you know, what would have been the analysis if the focus was really at life expectancy at say age 65 versus at 0? Would there be a very big difference as far as comparing

the different countries and would your data, as far as the improvement rates that would be needed or that would be seen, would that change a lot?

DR. JAMES VAUPEL: Yeah, OK, so anyway to answer your question briefly, I showed a table which showed that you're absolutely right. Before 1950, most of the progress in increasing life expectancy was due to adult and childhood mortality. After 1950, most of the progress was old age improvements. Recently the single most important age category is 80 plus in terms of improvements in life expectancy. In terms of your second part of the question, it's what I just answered, yes, it does imply that you need rates of improvement at age 80 comparable to rates of improvement at age 50 or 60 today. And in terms of Japan, if Japan never existed, then we'd have France; if France never existed, we'd have Italy; maybe they cheat in Italy, but if Italy never existed, we'd have Germany, they don't cheat in Germany, never, you know. (Laughter.) So this is not analysis based on a single country. The Japanese have two registries; they have one registry that's used locally to distribute benefits and people sometimes cheat in that registry. Then they have a vital statistics registry, a separate registry and my understanding is that that's extremely accurate, but we have someone here, Jean-Marie Robine is an expert on this and he can testify, you can

talk with him but the Japanese data are good, I have been told. Michael Poulan's also an expert on that, the Japanese data are good, very good and much better than the U.S. data, much, much better than the U.S. data, but we still are backed up by France, by Italy, Germany and many other countries.

TIMOTHY HARRIS: OK, the front mic. I think we're going to go front back, front back, front, back right now.

DOUG ANDREWS: Doug Andrews, University of Waterloo. You talked about how the rate of mortality was the same but moving out at say five-year bands and so on, but you glossed over the question of whether the health status was the same at those ages. And in terms of health costs, it is a significant factor whether health is the same or not and would you like to comment on that?

DR. JAMES VAUPEL: Yeah, this is a question I've devoted a lot of time to and a lot of other people have devoted a lot of time to this as well and again, Jean-Marie Robine who is here is one of the leaders of international studies to determine what's happening to healthy life expectancy. There are several other people who have questions so I'll try to be brief, but I could spend an hour on that. I wrote an article about it that came out in the *Lancet* two or three years ago, a review article. We looked at 300 articles and reviewed the different articles. I like

working with death because you can measure it accurately; it's very hard to measure health, very hard, and you can ask somebody how do you feel, men feel better than women and they die younger. (Laughter.) You can ask somebody, you know, can you do something and they say, yes, I can walk 100 meters and then you ask them to walk 100 meters and they can't. It's really hard to measure health, and different people in different countries respond differently; it depends on whether you ask somebody after they had a drink of red wine or before they've had a drink of red wine. So there have been a lot of studies showing that it's really difficult to measure health; that's point one.

Point two: Some indicators of health are getting worse, no question about it. There are more people around today who have pacemakers than there used to be, there are many more people around who have artificial hips and artificial knees than there used to be. There are more people who wear bifocals than there used to be. Is this a sign of success or a sign of failure? So if you look at the prevalence of people with cardiovascular disease, there is a higher disease prevalence but these people are alive because of pacemakers and beta blockers and statins and blood pressure-reducing pills and so on; they're alive instead of being dead. Is it better to be alive at a pretty

good state of health or to be dead without heart disease? So you really have a hard time; it's very difficult, it's very, very difficult to study this.

What we decided to do was to look at (this review article covers all of this) the really expensive older people that are people who need care from somebody else, people who can't take care of themselves and again, studies differ from country to country. We did a very careful study in Denmark. Part of the problem is to get accurate information, you have to have data on everybody, but when you do a survey, people who are too sick to participate are not in there, or if you do a survey in hospitals, only sick people are in there. So in Denmark, because of the central person registry system, we have data on everybody and so you could look at how many people in Denmark need care and it's being postponed to higher ages, just like mortality. There's still a need for lots of care when you get within five years of death, but five years of death is getting to be higher, a higher and higher age. And we also looked at measures of dementia, and the same thing, people still get demented when they get to be old enough, but it's being postponed and we had an article in the *Lancet* three or four months ago, about the postponement of dementia. It made the first page, right-hand column top of the *International Herald Tribune*, *International New York Times* and so you can

find that. So, anyway, the *Lancet*, *Lancet* four or five months ago about the postponement of dementia, so will there be an increase in health care costs? Well, the baby boomers are getting older so that alone is going to increase health care costs but will there be an increase in health care costs because people are sicker? I don't think so; I think it's going to be a postponement.

TIMOTHY HARRIS: Back mic.

DAVE SANDBERG: My question has to do with data for the ultimate ages as opposed to data about the life expectancy and the averages moving over time. I'm curious as to what kind of data is there on the actual realized ultimate ages changing? Does this mean that while life is limited to 120 eventually, we're all going to get to age 120?

DR. JAMES VAUPEL: Yeah, Jean-Marie Robine, who I mentioned twice already but who is here, he and I, he knew, personally knew, Madame Jeanne-Louise Calment, the world's oldest recorded person. She died at 122 $^{1}/_{2}$ and he took me to visit her twice and she's the record holder and she died at 122 $^{1}/_{2}$ and she died 15 years ago, in fact, yeah, more than 15 years ago and nobody has lived that long since. But the people who study extreme values, there's a whole statistics of extreme values, know that extreme values really fluctuate, you know, the height of floods and the temperatures and so on. Look at the temperature here and

there, there's these really big fluctuations. And so it's very hard to see a regular pattern in extreme values; you know, some extreme value might be constant for a while and then jump and be constant for a while. So what Jean-Marie Robine and I have done is to set up something called the International Database on Longevity and we look at data on supercentenarians, people who are 110 years old and older. Most alleged supercentenarians are liars so you have to get birth records, right, so we get birth records and so we try to have a really good statistical sample and the number of people who are 110 and older is doubling every five years, so there's really been a very rapid increase. So even though the 122 1/2 has not been broken, there are many, many, many more people getting to be more than 110. So far as we can tell, there was nobody who was 110 or more in 1930 anywhere, and then there was one person and then subsequently there's been more, but now, now there's many hundreds, I think something like 800 today in the countries that we're looking at. So there's really been a radical increase at the oldest ages, but not the extreme.

TOM PERLS: Hi, Jim, I'm Tom Perls, I'm the director of the New England Centenarian Study, and an expert without data so maybe I should just sit down. But, in, a long time ago you talked about a model of aging kind of being similar to a car or an airplane that they're built for a particular

distance and after that they kind of quickly deteriorate. And along the same lines, and, of course, there are Fords and there are Volvos and Volvos go a lot further and maybe those are supercentenarians. And then there's the Seventh-day Adventists who have given themselves this optimal set of health behaviors that I think we should all be striving for and they live to this remarkable average life expectancy of about 10 years greater than the rest of us. And so I wonder in light of your idea of the car or airplane only being able to go a certain distance and then they die off, and the Seventh-day Adventists really pushing it to the limit in terms of optimizing their environment, if we're not fast approaching a point of diminishing return that with our current environment we can really only go so far? And then you had a slide that said, OK, well, and I don't know if you meant to say this, but really to go much further than where we are now, we're going to need the nanobots and the Resveratrol and what have you. So I guess my question is, first, are the people who are proposing that there's going to be nanobots nuts and therefore that's just not going to happen? And if that's not going to happen, don't you need something like that to be able to invoke that half of the girl babies born today are going to live to 100 if there really is a point of diminishing return, maybe around 90, after which you know we have

optimal behaviors? Oh, and the other thing is if there were nanobots, what portion of our population would have access to something so incredibly expensive and out there?

DR. JAMES VAUPEL: OK, that's a long complicated question, Tom, but first I don't deserve credit for the analogy with automobiles, I think Jay Olshansky probably does, but anyway it wasn't me, but I did study automobiles, I did a big study of automobile mortality, I mean, why not? The question is the pattern of mortality for humans, does it hold for other kinds of animals, does it hold for plants, does it hold for complicated pieces of equipment? So I've also done a study of light bulbs that's a simple kind of equipment. But, anyway, for automobiles, mortality goes up more or less exponentially and reaches a plateau after age 10, about age 15. There's a plateau and of course the plateau, how long it takes to reach the plateau is different for different makes and some makes as you said, Chevrolets don't live as long as Cadillacs but there is a more or less exponential increase followed by a plateau so the pattern for, and there's some lemon mortality too, some infant mortality for cars, so it looks remarkably similar to human mortality.

Why do you get a plateau for cars? Well, because those who have old cars take care of them and they might also be old themselves, right? And don't drive so much. So I don't

think there's any evidence for the falling apart of cars or humans at some age. In terms of the analogy to cars, it's not at all clear to me that there's analogy to cars or how long it takes to run a mile, it seems you know what the new record is going to be, will it ever be zero? I don't think those analogies make a lot of sense, and I think we have to look at the data themselves.

If I was going to make an analogy to a human body, I wouldn't compare a human body to a car, I'd compare it to a house or a building and if you keep on repairing the house, then you can keep the house alive for a long time. I live in a house that was built in 1659 and the house is still there, but it needs a lot of repair.

In thinking about life expectancy, there's two very important aspects: One is what's the average in a population and why do some people live longer than the average and so these are two very different issues. So if you do everything right—and based on all the work that I've done on this, other people have done on this—I've come to the conclusion that if you do everything right, i.e., if you listen to your mother, you know you wear a hat, you wear a coat, you have breakfast, you sleep eight hours, you have fun but not too much fun, if you listen to your mother, you might live 10 years longer than average, but it's hard to live much more than 10 years longer. You know,

you can if you're lucky. So the important thing is what determines the average and then we'll have a distribution around the average. What determines the average? The data I showed indicates the average is going up, so as the average is going up and if senescence is being postponed, there will still be a bell-shaped curve around the average but the numbers will get higher and higher.

The last part of your question concerned we're going to need breakthroughs to achieve higher levels of life expectancy and that's right, we're going to need breakthroughs. Breakthroughs were required to go from 45 to 60, breakthroughs were required to go from 60 to 80, and breakthroughs are going to be required to go from 80 to 100. The people in the past did not foresee the breakthroughs, they happened, they didn't foresee them. People were very pessimistic because they didn't foresee them, but we managed to control infectious disease by and large, we've managed to reduce chronic disease a lot, even though this was unanticipated. So I think there will be some future breakthroughs. I don't know what they're going to be; little robots, that's one possibility, genetic technology is another possibility, regenerative medicine another possibility, but I only have a vague understanding of this. There's probably going to be some breakthrough that nobody has any idea about and you just have to take

that into account, given the record of the past. But I agree with you completely, we're going to need breakthroughs, new breakthroughs, just as we had to have breakthroughs in the past.

Now in the past, there have been breakthroughs and these breakthroughs have been very expensive to begin with and then they become cheap, so to begin with, rich people benefit and then everybody benefits, so that's my prediction about the future but again, just extrapolating the past.

TOM GETZEN: Hi, I'm Tom Getzen, from the International Health Economics Association and my question is about expertise and expert judgment and I'm an expert on forecasting medical costs, expenditures, you know lots of experts in the room and I strongly agree with your statement about expert judgment [is] generally less accurate than extrapolation. Every time I adjust my model, not every time, but almost always, it gets worse but not better. I actually went and talked to a bunch of people who study forecasting; it's not just actuaries. This is almost all experts that their judgment is worse. So my question is, why? How come if we're supposed to be data-driven scientists and demographers, we spent 50 years more in love with our own expertise than connecting the dots? And how do we expect somebody whose idea of expertise is they read an

article in *USA Today* to do that same thing and figure out this is what the data says?

DR. JAMES VAUPEL: Yeah, I don't have a deep answer. My basic answer is that experts are very good at what they know and what they know is about the past, so that they're very good at understanding what's the developments of their field up until now, and they're very good at knowing what the current state of their field is. Where the experts have a failure is being able to imagine something that nobody knows anything about in the future and you can't expect experts to know about something that nobody knows anything about. There was an article in the London *Economist* at the beginning of the 20th century saying that horse manure was going to put a limit to the growth of the city of London and the experts didn't have any idea about automobiles, you know, and buses, so, and you can't fault them for that. You can't expect experts to foresee something that nobody knows anything about, so what you can expect experts to do first of all is to be a little bit more modest. A lot of experts make their living by being immodest. And the other thing is that you can expect experts to say, listen, if I put myself back 50 years or I put myself back 100 years, I would be making very bad forecasts using my method. What actually happened is closer to some sort of extrapolation of the past and let's just recognize that we don't know what's

going to happen in the future and the record of the past takes into account all the shocks, all the breakthroughs, all the disasters, all the good things that we don't anticipate and let's rely more on the extrapolation and less on our own personal opinions. That's my view. You agree? Good, OK.

TIMOTHY HARRIS: Front mic.

JOSEPH LU: I am the head of longevity risk team at Legal & General. Our job is to work out the best estimate and stressed scenario for longevity risk for an annuity portfolio. My question relates to mortality improvements at higher ages. I'll probably begin with an analysis by the CMI, the Continuous Mortality Investigation Bureau, in the U.K., that they have looked at international data and published that they have observed a reduction in mortality improvement rates with increasing ages. This coincides with a practice of having a forecast in mortality improvement rates with a tapering effect with increasing age. For example, they may have 2.5 percent of mortality improvement rates for the future up to age 90 and that 2.5 percent may reduce to say 0 percent at age 120. What's your view on that in terms of historical observation as well as using that to forecast? I ask this question because this assumption can be financially material. It's for above age

90 or 100; many people may not pay much attention to that but financially that can be material.

DR. JAMES VAUPEL: Yeah, thank you. So it's absolutely true that if you look at the rate of improvement in mortality by age, as you get up to higher and higher ages, the rate of improvement slows down. But if you look at it not cross sectionally in some year and if you look at it over time, so you look, for example, at the rate of improvement at age 80, the rate of improvement at age 80 used to be very, very low and now is quite high, above 1 percent, so you have to combine the dynamic change over time together with the change over age, you have to put the two of them together. One way to do that is to recognize that age is no longer what it used to be. It used to be, say, that person is 60 that meant something, right? But a person who was 60 50 years [ago] is completely different, on average, than a person who is 60 today. So as I mentioned in my talk, another way to look at this is to look at the age when the force of mortality is 1 percent or the age when the force of mortality is 10 percent and look at the rate of progress, at the age when the force of mortality is 1 percent, and you'll discover that the rate of progress is fairly constant and pretty high and the rate of—it's just that the age is going up and so—the rate of progress is going up at higher and higher ages. Another way to do it is

to look at the rate of progress when the remaining life expectancy is 10 or the rate of progress when the remaining life expectancy is 20, and once again, you'll find a much more linear, much more constant pattern than if you look at age per se, so I think we have to move beyond age, we have to recognize that senescence is being postponed to higher ages and therefore, age 80 is like what age 70 used to be, which is like what age 60 was earlier and not base our calculations purely on age but rather base our calculations on the level of mortality at some age or the remaining life expectancy at some age. That would be my suggestion.

Another way to do this, to try to get beyond age, is to develop methods of forecasting that free yourself from looking at age-specific forecasts but put it in a broader context and there are some new methods that are being developed, where, for example, you look at the whole surface of mortality over age and time and try to see what the developments are, taking into account both the time dimension and the age dimension, so I think there are some possibilities for better forecasting methods.

JOSEPH LU: But looking at cohorts solves some …

DR. JAMES VAUPEL: Yeah, cohorts, for example. As I mentioned before, there definitely are cohort effects in some populations, but to try to, I wouldn't. What I would suggest is that we look at the whole surface of death

rates, so we take into account time and age, not just cohorts, not just periods, but the whole surface and try to project the surface forward.

TIMOTHY HARRIS: OK, Sam, is next, but we're not going to have time probably for the third person in line there, we've got a pretty tight schedule and I think we're going to run over a few minutes. Sam, go ahead.

SAM GUTTERMAN: My question relates to social inequality. Over the last 20 or more years, inequality, however you measure it, has diverged in many parts of the world, whether in terms of income, wealth, education, access to certain health care, etc. What affect does that divergence have on linear extrapolation?

DR. JAMES VAUPEL: Yeah, I've looked carefully at this and I wrote an article about it in the *British Medical Journal*; there's a very high correlation, not .992, but like .8, .9 between a measure of inequality in life spans—so this is not socioeconomic inequality but just inequality in the length of live—compared to the average length of life. So if you measure life disparity in terms of how different are people's life spans and compare it with life expectancy, you find a strong relationship between life disparity and life expectancy. And the reason is, the main reason is, the people who are best off in a country tend to have life expectancies that's close to the world's record, you know

close to the best you can do and so why is the life expectancy in the country below that? Well, life expectancy in the country is below that because it's pulled down by all these subpopulations that have lower life expectancy. So if you want to be close to the top, if you want to be a world life expectancy leader, almost everybody in your country has to have a high life expectancy. If you have subgroups that have low life expectancy, it brings the average down, and that's what's true in the United States. The people in this room probably have a life expectancy close to Japanese people, and the reason that U.S. life expectancy is lower is because there are people in the United States with life expectancies of 50 or 60, you know, some subgroups 70.

In the article in the *British Medical Journal*, what we demonstrated was that the improvements in life expectancy in different countries is largely driven by reductions in early death, so saving people's lives, saving the lives of people who died earlier than life expectancy rather than saving the lives of people who died after life expectancy. So it's by reducing early death that you can improve the life expectancy in a county, and I think this is, if I was going to be a public policy advocate, I would advocate spending more of the U.S. health resources on saving, averting early deaths, in terms of improving the health of

the population, improving equity in the country and also improving life expectancy.

TIMOTHY HARRIS: Jean-Marie.

JEAN-MARIE ROBINE: Jim, somewhere in the middle of your presentation, one slide was showing the mortality rates by age in Sweden 30 years apart or 50 years apart, I don't remember exactly, and the curves were almost parallel and I think even you added they are not divergent. And in your last slide, maybe the last sentence, you said maybe in the future we can slow down the aging process. So, as you know, we are using a slightly different method than you, in studying the compression of mortality, but what we observed, in fact, not in Sweden but in most countries, is over time, the rate of aging is increasing and it seems that, in fact, the curves are not in parallel but are converging and the aging rate used to be around 8 percent in the past is now in many countries between 12 and 14 percent, this is the rate of increase in mortality by age, by single age. It means that we are postponing, we are totally agree with you, the mortality. But at the same time that we are postponing the mortality, we are accelerating the mortality rate and when we are talking with our colleagues working on dementia, they are telling us that if you are able to postpone dementia, what they are observing among the better educated people, they are also observing

that after the onset of dementia, the course of the disease is much faster. So people are getting demented later, but after that, they are deteriorating much faster and the period of life with dementia is really compressed. So my question is, really, do you think that in the future the mortality rate of the curve can start diverging and to age slowly, more slowly?

DR. JAMES VAUPEL: Thank you. I am not engaged in research in slowing down the rate of aging, but a lot of people are doing such research and I was just pointing out the fact that maybe they'll succeed, but they haven't so far. You're absolutely right, and, in fact, if you just look at the data, you just look at the raw data, it appears that the rate of aging is somewhat increasing over time. So what's the rate of aging? So, if you take the derivative of the force of mortality and divide it by the force of mortality, so the relative derivative of the force of mortality, the percent that the force of mortality goes up with age, that tends to be increasing and as Jean-Marie pointed out, a few years ago, perhaps 100 years ago, it was 8 percent per year at older ages and now in Japan it's 12 percent per year. Well, this result is because of bad models. When you get that result, you're fitting a Gompertz curve, a times e to the bx, but historically and at younger ages, mortality is not Gompertz, it's closer to a Makeham curve, a times e to

the bx plus c. And if you forget about c and fit a times e to the bx, your estimates will be wrong. But c is actually important and c is getting to be smaller and smaller. Then you will get what appears to be an increasing rate of aging, because your model is mis-specified. You haven't taken into account that the rate of aging should pertain to senescent mortality, it should not pertain to all-cause mortality, so you should subtract out morality not due to senescence. If you do that, the rate of aging is much more constant over time, much more, much closer to 12 percent. The other factor that's left out in these models is the fact that populations are heterogeneous and that some people are stronger, healthier, more robust than other people and when you get to high ages, when only a small fraction of the population is still alive, the people who are still alive tend to be exceptionally robust. And they're not the same as the people who died: you're comparing apples and oranges when you're comparing robust people at age 100 to a mixed population at age 80 and you have to control for that as well and when you control for those two factors, you get more than 12 percent, even historically, you get, in fact, you get 14 percent. OK, but anyway, more work needs to be done on this. In *Nature Magazine* a couple years ago, I published the hypothesis that the rate of senescence, the rate of increase in

mortality due to senescent causes, not all causes but senescent causes, is about 14 percent per year, is about 14 percent for everybody and has been 14 percent forever, you know, for hundreds of years.

In terms of the progress of dementia, yeah, as you know, you're an expert on this, it's very hard to diagnose dementia, there's a mini mental exam you can use but it's difficult and well-educated people can trick you in this exam and there are different results from different countries. The Danish results don't show this precipitous increase in mortality following diagnosis of dementia, so it may be true, but I'm skeptical until we have more data about it.

TIMOTHY HARRIS: OK, well, thank you. That's it for the questions and let's thank Dr. Vaupel for a very exciting presentation. (Applause.) And it's break time now. I did want to mention that for enrolled actuaries, you can go ahead and start leaving but for enrolled actuaries, for those sessions for which you can receive CE credit, there will be signup sheets outside, because you guys have to sign up. The rest of us don't. Thank you.