The question I'm raising today is about the past and future of innovation and if progress can be sustained. There's something in growth which I have called the curse of concavity. That's a fancy term for basically what you learned in Econ 101 which we called diminishing returns. The first thing you learn in economics is if you have a fixed factor, labour, and you keep piling on capital you keep growing but the rate of growth will slow down and eventually taper off — but the same is true for other forms of economic growth. So if you look for instance at what we call Smithian growth, what we call the gains of trade, which you learn in the second week of introduction to economics, it's quite clear that if two nations start trading with each other where they haven't before, as the trade expands they gain but the incremental gains keep declining. The same is true for the kind of growth you get from what Douglas North called improved institutions, namely better allocations of resources. So if you allocate the resources better you will get growth but as your allocations get better and better, eventually diminishing returns set in and so the question is: does this also hold for technological progress since 1750? Technological progress has become an increasingly important factor in economic growth. It has been argued that all the lowhanging fruits have been picked, in other words we have invented all the things that are important. . The argument basically

is that the amount of money that it takes to develop a new drug keeps going up or the number of new drugs per billion dollars spent is going down. So here is a counter paper by my friend Philip Aghion who's sitting right here and whom you'll hear from in a minute. They basically argue, no, this is wrong, because as they point out, you have to take into account the fact that it's technological change: not just at the level of a particular firm but old, tired firms leaving the industry while new, fresh ambitious firms are getting in, so voila, technological change will keep going on. Their question really is: is this low-hanging fruits metaphor really good? It has been the kind of metaphor that people feel is appropriate. My counterargument to that is that the growing scientific base of technology actually creates ladders and the ladders become taller and taller, so that what was once high-hanging fruits are now easier and easier to reach. What's more, the best fruits may be at the top of the tree and the tree is still growing. So that metaphor has now been beaten to death and I'm going to abandon it from now on. Now, can I be wrong? Well, of course, I can be wrong. I mean, we all know that historians should not predict the future but what I'm going to argue with you here today is that if we can understand a little bit about the technologically creative forces in the past and if — and that's a big if — the patterns of the past hold up, we will see that these

conditions hold with even greater force today. The basic idea is very simple. You partition the huge set of all ideas into two subsets: propositional knowledge (knowledge of what) as opposed to prescriptive knowledge (techniques). The great economic historian Nathan Rosenberg pointed out that science of course drives technology but that technology feeds back into science and so the dynamics of innovation really should be described as some kind of positive feedback loop between propositional knowledge and prescriptive knowledge. And as we know, positive feedback loops in certain conditions can actually diverge and keep growing with no end in sight, unless you impose some kind of ceiling. Here is one empirical regularity that I think history has demonstrated over and over: that new scientific tools and instruments, basically technology, often drives waves of scientific advances and that science advances because it has new tools and instruments with which it can do research. Here are a few examples I love to use to drive this home but I could produce as many as you want. [Galileo's telescope], [Robert Hook's microscope], [Evangelista Toricelli’s proto barometer], [Otto who was actually Lord Mayor of the city of Magdeorg, first vacuum pump], [Denise Papan's first model of a steam engine] It didn't actually do anything it was just a demonstration of how it worked but a few years after, the first steam engine is erected in

1712 in a place called Dudley Castle in England and you know every economic historian tells this in their introduction to economic history and this is of course an extremely sophisticated coreless beam steam engine. This was built in the middle of the 19th century and by that time it's clear that steam power has really reached a level that nobody ever imagined before. Here's something that's a little bit less well-known but perhaps equally important: the improvement in microscope technology was done in the 20s and 30s of the 19th century by a man called Joseph Jackson Lister, a very famous doctor and bacteriologist. But actually it was his dad who prepared things; so this is what he essentially built: the achromatic microscope objective. The problem he solved was that the early microscopes — although you could see things much better — were still distorting and caused by something called spherical aberration, which caused blurry images. So here you got Lister with his new microscope. It's not a well-known invention but it's actually critical because that innovation made it possible to clearly see cells and bacteria and find tissue structures, which was crucial for medical research and the net result is what I still believe was the greatest welfare enhancing discovery in history until then: the germ theory of disease.

So you can sort of see how new tools and better tools lead to major scientific breakthroughs. Now, of course, that feedback loop holds for theory for the 20th century and here is maybe the most prominent one: X-ray crystallography, which has led to at least 20 Nobel Prizes. Max Fona received a Nobel Prize in 1914 and William Henry Bragg won it the year after. Now, the most famous use of this technological breakthrough is of course Rosalind Franklin's 1953 use of crystal spectroscopy to help discover the structure of DNA. This is one of the truly towering discoveries of the 20th century. So what about today? Of course the tools we have available to us today dwarf anything we've seen in the past. [Lists a bunch of examples] I'm not going to list all the possibilities that AI provides to science but whatever else it will do to our society, it is clearly a fabulous research assistant. […] What kind of institutional environment supports innovation? I pulled out four items from a much longer list that I think matter most but people may disagree with that. The first is, and this is the economist speaking, we need incentives. Scientific and technological advances are not made by the population at large. They are made by what I have called the upper tail of the human capital distribution. This is the smartest, most creative people in society, who come up with these ideas, and the vast bulk of people just watch this and maybe they carry out the ideas, but the actual

insights come from very few people and they have to be incentivised. Secondly, we need a competitive, open, and free market for ideas. We don't want to live in a world in which the market for ideas is monopolised by something like the mediaeval Catholic church, the Communist Party in the Soviet Union or something like that. You want to have a great deal of diversity in the market for ideas in which people come up with new ideas all the time and they can advertise them as much as they want. Mind you, 99 out of 100 of these new ideas are public garbage but that is the nature of the process. Then third, I think what is important is freedom of movement: you really want to have a world in which creative persons and original thinkers should be able to move about to wherever they choose and wherever they can be the most productive. Finally, what you need is some kind of authority of a government, but the government should not be too controlling, as it is for instance in China and certainly as it was in the Soviet Union, but also not too absent, which is the direction in which the United States is moving — but a government that sort of sits in the middle and it guides and it advises and it regulates a little bit but it still lets the forces of free markets operate. I have argued at great length that these four conditions held increasingly in Europe between 1450 and 1750, the three centuries leading up to the industrial revolution. That is the kind of environment that led

increasingly to incredibly creative innovative people: Spinoza, David Hume, James Watt, Adam Smith, Antoine Lavoisier, and Leonhard Euler, [something indecipherable], Ludvig van Beethoven. These are all people who came up with brand new ideas in an environment that supported them, if not perfectly at least far better than anything in the past. The question is: do these conditions hold today? I would put it this way: the incentives in propositional knowledge in science are still there and they're stronger and larger and more pervasive than ever. The market for ideas today provides unprecedented rewards and incentives to successful intellectual innovators, particularly in science. We have hundreds of thousands of people who work in intellectual endeavours, most of them (but not all) in universities. So what we do is we offer them what most of these people need more than anything else, which is financial security, which is tenure and of course in research institutions you get things like named chairs. Then we have rewards and of course there's a whole pyramid of rewards at which the Nobel Prize and the Abel Prize presumably stand at the very peak, but there are many many other rewards, memberships in academies, and prizes for the best papers and the best books, and honorary degrees. The funny thing is these incentives are cheap relative to the benefits that these people bestow on humankind, and that is I think a critical thing. Of

course, in addition to all that there's name recognition, fame through mass media, and, perhaps most important, these things lead to peer recognition: many academics really want to be respected by their peers, by other people like themselves, and of course in addition for a very few you know there's lots of money to be made if they work in the right fields and get it right. Now, most of these incentives were already noticeable in about 1500, but in some ways the 20th century has done far better than anybody before. The Copley medal in England for engineering was established in 1738; in 1799 Count Rumford established the Rumford Medal, and the first winner of the Rumford medal was Count Rumford — clever — and so it goes. But most of these were still puny until about 1900. Then you get the Nobel Prizes in 1901, the Fields Medal in mathematics in 1936, and so on. We reward scientists today and yet they are sources of concern. One of them is what I call the dynamics of institutional adaptation: when technology changes, institutions have to adapt in various ways, and the problem is that they are usually slow to adapt. It takes decades until various parliamentary committees and political forces agree that some form of regulation or some form of control is necessary. And what evolutionary theory suggests is that adaptation to a changing environment is quite possible provided the changes in the technological environment are not too

fast and not too abrupt. A sudden discontinuous shock will lead to mass extinctions and catastrophe; we know this is true from evolutionary history and. So there's some concern that the acceleration in the rate of technological change in recent decades cannot be matched by institutional adaptation. What's more, the acceleration implied by the last 10 years' advances in AI and similar fields [suggests where] this is going to be a problem. Certain technological inventions have led to political polarisations, through social media for instance. This is something we haven't fully solved and it's not clear that we will be able to. The world is sufficiently fragmented and fragmentation has always been in many ways a force for good in the sense that nations were competing with each other and therefore nobody could feel left behind and that you know was true for Europe in the 17th and 18th centuries, and it's still true for the world. The problem I think is that fragmentation is also correlated with nationalism and that the likelihood of war is of course higher the more fragmented the polity is. So here is an interesting factoid: between 1500 and 2000 in Europe, there were only 60 to 70 years out of 500 in which there wasn't one major conflict in Europe. Of course the fragmented world today is not at peace and that is closely associated with economic nationalism, which gives us sanctions, tariffs, non-tariff barriers, and various sort of unwarranted state

support for strategic industries, and they seriously slow down progress. Then of course there's populism. Populism really is an anti-intellectual, anti-elitist movement and that's problematic because, as I said earlier, most progress is achieved by people in the very upper tail of the human capital distribution who are in many ways an intellectual elite. They may be university professors, top scientists but they are members of an elite. If society turns against those elites, you can see trouble on the horizon. That's particularly associated with autocracies and people like Vladimir Putin, Victor Orban, and similar. Then of course we are being threatened by xenophobia. Much progress has been achieved particularly in the US by engineers, scientists, people who came from many other countries. The three winners of the Nobel Prize this year were all born outside the US and did most of their work in the US, and that is quite typical. So there are then failures in the market for ideas; misinformation and disinformation proliferate, many of which lead to sort of crazy ideas that become more popular thanks to social media. There's a serious threat to the mobility of upper-tail human capital today due to policies, not just in the US but almost everywhere. Anti-immigration policies are a source of great concern. In conclusion, then, I don't think there is a place for unbridled optimism the way I felt about say two decades ago. I read the

papers too and the future of western industrialised countries is I think placed in the balance. As Sigmund Freud said, in one of the most masterly understatements of the 20th century, “While mankind has made continual advances in its control over nature and may be expected to make still greater ones, it is not possible to establish with certainty that a similar advance has been made in the management of human affairs.” No kidding, Siggy! The IMF has warned us against all these geopolitical risks. The most serious headwind that I'm scared of ladies and gentlemen is not national debt, it is not the ageing of the population: it's this stupidity the gods themselves contend in vain.

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