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**WILLIAM
BONVILLIAN:**

So I just want to go back through class five, because it's kind of foundational for the ideas that come up in this class. So just very quickly, David Hart taught us about the ideologies behind US innovation. And he takes a look at really the 1920s ideology around science and technology policy. And as we discussed, the same debates are with us.

And the leading ideologies, we could call them, are the associationalists, which we would now translate as public-private collaborations, versus conservative, which, you know, there is no federal governmental role except in the national security territory. And then the national security rationale, which I would argue is, do whatever it takes to establish national security based technologies. These ideologies fit the US than honestly fit other countries, but they are a significant part of the story about how policy has evolved in science and technology.

Then we had a long dissertation on Alfred Loomis and the beginning of the Rad Lab at MIT, which we argued was really a foundational model for how the US R&D system is going to get organized. So that's taking place right here, and Loomis really designs a system that teaches us a lot about how we're going to organize R&D.

So flat, non-hierarchical, team based, very cross disciplinary, collaborative, keep R&D out of uniform and out of uniform bureaucracies. Keep it out of the civil service. Create a kind of flat, non-hierarchical system that enables maximum exchange of ideas. Vannevar Bush at the end of the war writes *The Endless Frontier*, and that's the foundational document for US R&D.

And what he's concerned about at the end of the war is salvaging some federal role in science. So the growth of the federal role in science in the course of World War II was profound. As I mentioned in class five, MIT receives 80 times more federal funding in the course of World War II than it does in all its previous 80 years of history. And that story is not unique. Other universities are having comparable experiences.

So that's when the federally funded research university begins. And that's, obviously, a foundational model in the US system. Vannevar Bush wants to salvage it. So in the midst of a

kind of a huge rapid scale down to the defense establishment at the end of World War II where everything is being canceled, he works with Franklin Roosevelt to keep a federal government research focus in basic research.

Peter Singer reminded us of how productive that system has been. So his paper on 22 examples of federal R&D that translated into major technology sectors-- so Peter argues that that basic R&D model has, in fact, yielded enormous technology development. That's not an easy thing to trace. What are the originating scientific advances in a 20 year project towards technology advance, or perhaps longer. But Peter kind of did what we called genealogical research to figure out what the core elements were.

But it's there. So it's not that Vannevar Bush's basic research model in itself is bad or wrong. But it's an important one. And William Blanpied told us the story of NSF. So the second Vannevar Bush story is-- story one is support basic research. Story two, how are you going to organize science in the federal government?

And his vision was there was going to be one tent. And science was going to fit under one tent. You wouldn't have a multitude of agencies. He was not successful in pushing that argument, remember. Because Harry Truman vetoed the National Science Foundation law that he proposed. Because Vannevar Bush wanted scientists alone to control science and left out a significant role for the executive branch. So it got vetoed.

And therefore, NSF didn't really get stood up for another five years. So other agencies pop up in the void. So that, in turn, meant-- this kind of funny accident of time meant that the US was going to have a very decentralized system of a multitude of agencies working on science and research. That's how it happened.

And Blanpied lays out that debate for us. We then looked at Donald Stokes as the kind of closing reading last week. And Stokes's book, *Pasteur's Quadrant* is something of a classic in the science policy literature.

And Stokes argues that Vannevar Bush saddled the country with a disconnected system. All very well and good, but he missed a crucial quadrant. He missed the quadratic of use-based fundamental research. In other words, you have an idea about what you want to achieve. But you use basic research to get there. He argues that Pasteur's quadrant-- because Pasteur is out to save kids in France from bad milk, he knows what he wants. But he goes back and develops microbiology to get there.

So Stokes's argument is Vannevar Bush focuses us on curiosity driven basic research. He missed use-based basic research. And that was a big gap in the system.

So what that meant in the US was that we would be good at the basic research. We would have a disconnected system. It would be hard to do the implementation stages to achieve the technology advances here. And we have seen that again and again. The US would often originate the foundational technologies. I was just working on lithium ion batteries. A lot of those early advances came out of the US. It was not commercialized here.

So Vannevar Bush, of course, understood connected science, because he created that in World War II, a brilliantly connected model. I would argue that what he was trying to do was salvage what he could at the end of the war. But Stokes critiques him essentially argues that we got a disconnected system out of this. And that was very problematic for the ability of the US to stand up subsequent follow on technology advances. And we've seen that again and again.

So that's a look at some of the foundational issues on how we organize science and R&D in our system. And today, we're going to take a really deep look at what we could call the valley of death problem. In other words, it's precisely this problem that Stokes talked about, the disconnect between the research stage and late stage development. And we're going to-- the Branscomb and Auerswald reading will lay that valley of death problem out. And then we'll talk about actually how the US is actually on the side running all parallel universe of much more connected defense research. It's a very different system. So we have two very different innovation systems that the federal government is supporting. And we'll go through those two models.

So who's got got Branscomb and Auerswald, which of you three? Matthew, you got it? OK. That's Lew Branscomb, a noted professor at the Kennedy School, now emeritus. He was vice president and chief scientist at IBM. He was a director of NIST, a noted physicist working in the atomic molecular fields. He won the National Science Foundation's Vannevar Bush award, appropriately enough, which is its top award. A remarkable and lovely and wonderful guy, and a real kind of statesperson of science who used to help young kids like me and help us learn the system.

And his colleague, Phil Auerswald, is now on his third or fourth book, and has gone into the field of innovation policy in a deep way, and is a real contributor in that field as well. So Phil is

a spokesman in his own right at this point. He teaches at George Mason University, which has a strong science and technology policy group.

So those are our authors. And let me just go to the charts. This is a chart that was used in the House Science Committee. And it wasn't-- the term, valley of death, between, again, research and later stage development-- that wasn't a term that Branscomb and Auerswald invented. It kind of came into currency, however, in the time period in which they're writing.

And the idea here is-- it's a very simple one, that you've got one set of institutions working on basic research. You've got another set of institutions working on the later stage, applied side, later stage development in particular. And there are very few bridging mechanisms in our system across this gap between the two.

So as we tried to understand innovation 20 years ago, this was the major idea in the system. And it comes right out of Stokes's thinking. We're seeing this. And what's happening at the time is that Japan has created this brilliant quality manufacturing system. It amounts to a real innovation wave in itself. The US misses it and then loses leadership on two huge industrial sectors, autos and consumer electronics as a result of getting this wrong.

So this is another chart of the same thing. This is more of a pipeline chart. And arguably, Vannevar Bush set up the pipeline model where the federal role was going to be dump basic research into the end of this innovation pipeline. Mysterious things will occur. Great products will emerge at the end. That's essentially the organizational model for US civilian R&D.

This is a way to try and understand what's going on within that pipeline and who the actors are that can influence different stages, who can do the bridging. And what Branscomb and Auerswald set out is-- there's basic research. There's the proof of concept invention stage. Then there's technology development. Then you move on to product development and production and marketing.

And then helping at these different stages are different actors. So the basic research agency's here. And maybe they'll help you get to the proof of concept stage. But they're not going to reach beyond that. But then angel investors, sometimes corporate allies, sometimes the small business innovation research program that we've talked about-- that might help you move from here to here.

Venture capital, they point out, doesn't really come to bear in this stage. Venture capital, as we

talked about in the first class, is really only interested in supporting your technology if it's only about two years away from actual production. So they're not going to help you, by and large, with the exception of the biotech area, bridge across this kind of gap territory. When you get to here, there's corporate venture, and equity, and commercial debt that will help you. But they argue that this is the gap in the system.

But they also note, it's not a pipeline. It's much more complicated. And in the end, they adopt this phrase, a Darwinian sea between a struggle for life and a sea of technical and entrepreneurship risk. Because things don't move smoothly down the pipeline. You'll get to proof of concept stage and realize you've got to rethink it. You go back here. And then maybe you get to here and then you realize, well, I'm not going to be able to get to product development. I've got to go back to there.

In other words, it's a much more convoluted process with a lot of iterations and feedback in that system. So they argue, in the end, it's more like this. The innovation and new business on one side, research and invention on the other, and this kind of struggle, in a Darwinian sense, going on between the two. But frankly, a pipeline model is much more convenient and easy to understand, even though we should all know that it overstates the model, that it's really more like a Darwinian sea.

And then they go through what are the funding sources and note, really pretty limited funding sources that are available for that bridge over the valley of death. It's a pretty limited panoply. So why don't we leave that there. And I'll turn it over to you, Matthew.

AUDIENCE: I think the summary was pretty comprehensive. So I mean, most of the questions that I had really focused on that stage theory, that early stage technology development. As you could say, it's the Darwinian sea or the valley of death. And one of the questions I wanted to ask here was-- we saw a lot previously about metrics to measure how much we're putting into basic research. And then we also have all the economic indicators on the other side. Right now, is there any good way to measure just how effective a country is at actually translating technologies that are being developed into commercialized products?

AUDIENCE: Could you rephrase the question?

AUDIENCE: Sure, yeah. So I mean, could you imagine any good way to-- or any good metric to measure just how effective-- or would it even make sense to measure how effective a country is kind of traversing that valley of death? Because there's a lot of metrics in terms of just how much

we're spending on one side on basic research. And then on the other side you have economic indicators, productivity.

AUDIENCE: Well, one idea for that could be the sheer number of startups that are produced, which was something that I think one of the later readings had mentioned. Or you could just look at the success rate of startups. So how long does it take for them on average to foreclose, or just to go bankrupt, or to just-- how many of them do so? And how many of them are able to actually produce a viable product? Et cetera. You could measure something along the lines of that.

AUDIENCE: Longevity and percentage of-- make it through first year, five year, 10 year.

AUDIENCE: And I think it would be important also to measure how much of that value you actually capture as a country. You have countries like Israel where you have tons and tons of startups, but they all end up getting exported. They don't stay in the country, because all of the venture financing is in the US.

WILLIAM BONVILLIAN: There's another possible measure too, Matthew. It's probably on your list. Patents. And patents have to list the scientific research on which they draw. So you can actually go into the patent literature and understand the scientific advances behind the patent application.

But of course, many patents sit completely unused. They go on the shelf. So it's just-- the total number of patents doesn't necessarily tell you much.

AUDIENCE: Look at the citations on the patents--

WILLIAM BONVILLIAN: Yeah, but it does tell you what the early stage research was, often, that's behind them. And look, the amount of early stage research that's being cited in patent applications has been growing profoundly. So we know that some of this research is getting out of the left hand side of the pipeline out the end of it. So it's important from that perspective. Other indicators?

AUDIENCE: I think there's also something to say for maybe the economic impact per capita. Really assessing, how much does the innovation end up impacting the country's well-being? And how do individuals-- whether or not individuals benefit from it who are regular citizens, rather than just the industry capturing that profit. I think there's something to be said about establishing a metric for impact as well that's based specifically on per capita or per citizen in order to make it sort of comparable to other countries and the resources that they have available to them or not.

AUDIENCE: So you're saying non-monetary results.

AUDIENCE: No, I think they can be monetary results too. I mean, the regression analysis is going to be more complicated. But I feel like if you do measures of well-being, both on economic impact and also on well-being sort of statistical measurements on, say, like-- I mean, I know people measure happiness now. That could be a really interesting impact. And I know that you could do that-- for example, when we need biotech, the people who you're impacting, do they feel like their lives any better as a result of your invention, in addition to the economic benefits of your advance.

AUDIENCE: Yeah, I would say no. I think it was polio, that somebody discovered it, and then just kind of gave it away. So that has a big impact. You make a lot of money, but it was important to [INAUDIBLE].

WILLIAM BONVILLIAN: The issue here is that often that social impact is going to take a very long time to evolve at scale. So if you're willing to take a long-term look to reach a level of a reasonable assessment, it's going to be a very extended period.

AUDIENCE: It's such a difficult metric.

AUDIENCE: What metric do you have for measuring it, too? Because you can say, oh, I have x amount of Apple stock, and I've made x amount of dollars. And that's improved my assets over this many years.

WILLIAM BONVILLIAN: Well, you're driving at its societal impact, right?

BONVILLIAN:

AUDIENCE: But then how do you measure--

AUDIENCE: But it could also be specifically in technical advances. Like I wouldn't say necessarily, from an investment standpoint, that I would care so much about the happiness of the stakeholder or the shareholder, specifically.

AUDIENCE: But I was going to go on to say, how do I measure how much this has improved my life, when you get into issues with measurement. It's complicated.

AUDIENCE: When it comes to a measurement, like you can have the best invention, but you don't win. You know what I mean? Like you can come up with something that's really great, but if you're not a

great executioner-- like for Fitbit, I met the guy who now works for Google X, and he created the Fitbit, but way better and had way more customers. But because he didn't raise a round of funding before the economic collapse, the product never got to market.

So it might just be chance, right? So Darwinian sea is a good example. Your research can be really good. It can be really compelling. You can be a great team. But there's a lot of other factors that we don't take into account, a lot of hidden variables.

WILLIAM How about another question, Matthew?

BONVILLIAN:

MATTHEW: Yeah, actually one thing that kind of a lot of people caught on to was-- so Branscomb and Auerswald, they detail three main challenges to crossing the Valley of Death. And the three challenges were motivation on the R&D side, to reducing that to practice, trust between the technologist and the business manager.

And then the third is the sources of funding for entrepreneurs. And focusing in on that trust or understanding even between the technologist and the business manager, someone asked, is there value in maybe changing the way we educate people, or having more joint technology in business degrees or courses of study to help bridge that gap?

WILLIAM Matthew, I can give you a hint. You can ask the person who wrote the question to respond.

BONVILLIAN:

MATTHEW: He's double major, or--

WILLIAM No, which one of the students who wrote the question that you're drawing on, you can call on

BONVILLIAN: them.

AUDIENCE: It was a lot at once.

WILLIAM It was you?

BONVILLIAN:

AUDIENCE: So if you have an answer, just like, it was a lot at once.

MATTHEW: Yeah, so what do you think the value would be in maybe restructuring the way we do education or offering more interdisciplinary degrees in maybe, say, science or engineering and business to help bridge that gap?

AUDIENCE: I would look into the top most successful technologists right now. So like Zuckerberg was psychology and computer science. I think Larry Ellison, he was medicine, but then he switched and then went to Silicon Valley. Elon Musk was economics and physics. So I don't know if that's a good answer.

AUDIENCE: So frankly, I'd say you're in support of it, because a lot of these people that were successful. Of course, correlation does not imply causation. So just because Mark Zuckerberg happened to use computer science and psychology, it doesn't mean that--

AUDIENCE: But I was trying to-- the education, in terms, like, has there a bit a really, really great technologist who was just pure science, or like just one?

AUDIENCE: Maybe 100 years ago.

AUDIENCE: I think during the transistor era, there was a lot of great technologists that could execute well, like Bardeen, Shockley. And then that's where Intel started.

AUDIENCE: Well, I don't know about Shockley.

AUDIENCE: Yeah, he didn't take the credit, but he was still there.

WILLIAM BONVILLIAN: Well, that's next week's story, or two weeks from now story. No, next week-- right, sorry. Luyao, you asked that question? So do you want to oppose? Do you want to give us an answer or your thoughts?

AUDIENCE: Like to me, I realize the American system is more flexible and allows you to take cross-disciplinary course. But from my home university, like England has really kind of narrowed choices for each student. So you see less students choose a double degree or double major courses. I do think that plays an important role in the development of innovations in the States. This is a cross-country comparison.

WILLIAM BONVILLIAN: As you all know, there's lots of MIT students who are doing business minors and engineering or science degrees, and lots of entrepreneurship courses that people from both sides are taking. So I think it's a development that's starting to occur. Matthew, do you have a closing thought on Branscomb and Auerswald for us?

MATTHEW: I can give a personal--

WILLIAM Please.

BONVILLIAN:

MATTHEW: I actually am a mechanical engineering and business minor. And I do think it's really valuable. At the same time, I think specialization is important to keep, because I know I'll never take as in-depth mechanical engineering classes as people who are just that studying that throughout their four years here. But I do think having more people with interdisciplinary degrees can help transition that gap.

WILLIAM
BONVILLIAN: Great, thank you. All right, so we're going to push along to our next reading here. And Vernon Ruttan is another one of our great growth economists. Ruttan taught at the University of Minnesota. And he really develops the whole concept of induced innovation. In other words, how does industry innovate, is really the problem he's looking at. Obviously, it's not just government agencies for sure. Industry does the great bulk of the innovation.

So he studies induced innovation through his whole career, and develops a whole set of thinking about that doctrine. And then towards the end of his life, because he dies only a couple of years after writing this book, he goes back and looks at the Defense Innovation system. So he's looking at where these big strands of the American economy come from, things like aviation, space, electronics, nuclear power, computing, the internet. And I wouldn't say he stumbles, but he focuses on the Defense Innovation system, and starts to lay out for us what that's like.

So we've just talked about the Vannevar Bush basic research only, peer-reviewed, basic science agency model that we tend to think of when we think about US R&D. That's the dominant model, certainly on the civilian side. But then there's this whole parallel universe that's organized in a very different way.

And he goes back and traces the history, and has this very provocative title-- *Is War Necessary for Economic Growth?* Because the big innovation waves of the latter part of the 20th century, frankly, came out of that Defense Innovation system. Those are the big ways that I just listed. So what's going on here?

And Ruttan tells a very interesting story that-- this didn't happen yesterday. He tells the story of the development of interchangeable machine-made parts, which, as you all know, is the core initial step towards mass production. And that gets developed in the United States. And how does it get developed? It gets developed by the War Department.

And the War Department is, essentially-- you think of the early 19th century, muskets are made by hand. They're made by blacksmiths. Armorers they were called. And every army had to bring along a whole group of armorers to constantly keep its muskets repaired. And every time a part would break down, they'd have to make a new part. So they'd have to pull out their forge and their anvils and their hammers, and then model that part exactly so it would actually fit. Because no two parts were the same. They were not interchangeable.

So Eli Whitney has a vision for interchangeable machine-made parts. Why Eli Whitney? You've heard of the cotton gin, of course, one of the key early 19th century simple machines that launched the industrial economy in the United States. But Whitney's got a big problem with the cotton gin. Anybody can make one.

You can see this thing, and any decent mechanic all over the country could essentially replicate it. So he's faced with massive patent violations. And he's handling lawsuits all over the country. He can't manage this. So he has this remarkable invention, but he can't capture any revenue off it. So being a good US industrialist, what do you do?

The War Department bailout, that's what you do, right? So he goes to his friends and colleagues in the War Department and paints this vision. Why make muskets by hand? I'll give you interchangeable machine-made parts. We'll drive the costs through the floor. And you won't have to have these armor trains dragging down the speed of your armies. We'll just have a bunch of parts in boxes. And you'll just snap them in, and they'll be interchangeable.

It's a wonderful vision, and he sells it to the War Department. And guess what? He gets something that's the equivalent of a cost-plus contract, every industrialist's dream. Whatever you need to spend, spend it. It's consistent with our contract terms. So he turns his factory in North Haven, Connecticut, just north of New Haven, into an attempt to develop interchangeable machine-made parts.

He doesn't quite get there. This requires really creating the whole first generation of machine tools. And he isn't quite able to pull it off. You have a whole new way of organizing the workforce around division of labor and around specific differentiated tasks for the workforce. So it carries all kinds of organizational implications with it, so that each part of the labor force is mastering one set of tasks related to a production system.

All these things are starting to happen in that North Haven facility of his. And there's now a

museum setting that's around this, so you can go tramp the sites where all this was happening in North Haven. But he doesn't quite pull it off.

But meanwhile, there's two armories, one in Harpers Ferry, West Virginia, and the other in Springfield, Massachusetts. And these armories are pursuing the same project, because it's so key to the War Department. It's an absolutely critical technology capability the War Department needs.

And the story that Ruttan picks up is the story of John Hall, who runs the Harpers Ferry arsenal. And over an extended period of time, over many, many years, he eventually perfects the machine tools that will enable the creation of these interchangeable machine-made parts. And it's a remarkable story. And only the long-term patience and capital of a government agency is going to tolerate this kind of 20-year project.

Interesting, the minute he gets it done, other industrialists understand what the accomplishment is. So Congress forces Hall and the Army to throw the patent essentially into the commons and be accessible to others. So that stands up the whole early industrial economy of New England, building these simple machines.

So you can go to Connecticut towns, Massachusetts towns, which are blessed with fairly small, slow-moving water power, because that's the power source, that moves fairly steadily. It doesn't flood a lot. This is an ideal region for water-powered energy do the building here to power the mills.

AUDIENCE: So you said John Hall goes and makes the patents open to the public?

WILLIAM BONVILLIAN: Well, the Congress force-- Congress passes legislation that precludes the Army and Hall from having the patents. In effect, they make them available to others. That turns out to be of great benefit, because then this interchangeable machine-made parts model can get picked up by everybody.

AUDIENCE: I guess it would be a huge benefit of the country. But then people like John Hall, doesn't it give them a pretty strong incentive not to do something like that?

WILLIAM BONVILLIAN: Yes, it would give someone a pretty strong incentive not to spend 20 years of their lives working on this stuff, yes. But of course, he is working for the military. So it's not as if he would capitalize alone on this. But overall, it's a positive. And the power of those New England companies to get their congressional delegation to kind of take that patent away and put it out,

it's an important political lesson. It was just too valuable for the Army to own it.

So this creates the Connecticut River Valley of all these small, simple machine industries. Clocks are famous in New England. Muskets are famous up and down the Connecticut River Valley. All these kind of early fairly simple machines get built here, and that's the New England industrial economy. That is the first place the US to really-- obviously textiles are developing in parallel, including in Massachusetts.

But this system of other hard technologies and simpler machines starts to take off pretty explosively. So the lesson here that Ruttan is pointing us towards is how the military can operate and the private sector can't operate. The military is willing to take a couple of decades-long effort and spend whatever is needed to get that technology perfected, because they really need it.

Those risks are too high and the cost is too high for the private sector to manage. So that's his underlying point here, that the military is going to be able to do things that the civilian sector is not going to be able to do in the technology standup process. We skip time, right?

I always try to provide some MIT material in the class. And this is Whirlwind, right? Mainframe computers had been created by the late '40s, early '50s. So there are a number-- you can number them on one hand, but there's a number being stood up around the country, particularly coming out of Mauchly and Eckert. And the UNIVAC generation machines came out of the University of Pennsylvania Engineering School.

But MIT, of course, wants to play in this game. So Jay Forrester, a great MIT technologist, persuades the Navy to develop a mainframe flight simulator. Now, the problem with having a flight simulator is that it has to operate in real-time. So the other mainframes tended to be gigantic calculators. This thing is different. And to operate in real-time, you have to have memory. And Forrester and one of his graduate students create the magnetic core memory that's part of this Whirlwind system.

Now, this is a time also of Defense cutbacks. So the Navy actually pulls the contract on the Whirlwind system. But also at MIT is a professor named George Valley. And George Valley was a veteran of the Rad Lab in World War II, teaching at MIT. And he comes to the realization that the Soviet Union has developed a bomber fleet of sufficient long-range that they could undertake a first strike with atomic weapons, because they developed the atomic

bomb in 1949. And there was nothing, nothing standing in their way. We would have no idea they were coming until it was too late.

So Valley is an advisor to the Air Force. And he gets the Air Force in particular are really concerned about this problem. And boy, is it a real problem. It's a real problem. So Valley persuades the Air Force that they're going to have to stand up a whole new airborne warning defense system. What's he going to do?

It's an incredibly complex network. It's going to have to get stood up all across, like, the Arctic and out into the North Atlantic on ships. And there's going to have to be planes with radar systems flying. And there's going to have to be radar installations all over northern Canada. In effect, they're going to have to build a radar interception network.

And then these varying messages are all going to have to come to a single place. And you don't have a lot of time here. And the messages have got to be understood, and then transmitted to decision-makers to make a decision on what they do. It's a really complicated problem.

So Valley realizes, I'm going to need a computer. He's walking around MIT, where else but the Infinite Corridor. And he bumps into Forrester, and discovers Forrester is actually building a big computer, Whirlwind. And Valley says, we need it for this new early warning defense system.

And he enlists Forrester, who's over here. Because it's real-time computing, it's different. It's not just a big calculator. Look at this lady sitting in front of a keyboard with a cathode ray tube. That's this. That's this thing. That's not a standard mainframe from ENIAC or UNIVAC. That's this thing, right? That's what they stumble on to.

And look at this. Here's an Air Force corporal sitting in front of the cathode ray tube. Signaling is coming in. You guessed it-- signals across telephone lines. So the radar signals are being sent to a central location across telephone lines. He's got this kind of gun in his hand. It's like an electronic gun. It's the mouse. That's what it is. You point on it, you get a readout of what the signal means.

So here it is, like in the early '50s. That's Whirlwind. That's SAGE. Lincoln Lab has to get created to really drive the research, because it's not just going to happen in professors' labs in MIT. MIT starts to make these computers, and decides, we don't want to be in the computer

business. So the contract is given to IBM to make the computers. And that becomes IBM 700 series, it's first really big important set of computers. So you begin to get an idea of the ramifications of pursuing this Defense project at the scale that the Air Force is willing to pursue it at.

I'll just tell you one more story. At the end of World War II, there's two countries that are making a lot of progress on computing. The British have made a lot of progress at Bletchley Park on computing, because they have to cope with the U-boat threat. And they have to decipher these incredibly complex Enigma signals that the German communication system relies on.

It's really quite capable cryptography. And they develop computers to be able to break those signals down. So the British are going well. And they share a lot of that information with the US, and we develop comparable encryption capability.

End of World War II, Britain dismantles its war machine, cancels its nascent computing operations. There is one company in Britain that picks up computing. It's a tea biscuit company. At 4 o'clock, everybody's got to get tea. And at 4 o'clock, everybody's got to have fresh tea biscuits right there in the tea shop.

It's a very complicated problem. It involves incredibly complex railroad time schedules and analysis of delay and delay factors. And they need a computer, so they take the wartime computers the British have been developing. And they develop this whole computing system for getting tea biscuits throughout the British Isles at 4 o'clock in the afternoon at all the tea shops. That's one development project.

The other development project on the other side of the Atlantic is the United States Air Force. They're beginning to develop missile technology and ballistic missile technology. And boy, does that require computing. Getting those trajectories right really requires computing. Who does the IT revolution, the tea company or the US Air Force? Who wins? You can only guess. So that's how these things happen.

There's often foundational stories. They're pretty key here. But you get that rough comparison of what you're up against, if you're the British tea company trying to develop computing versus the US Air Force. The US Air Force is doing this stuff-- magnetic core memory, the mouse, the cathode ray. They're putting all these pieces together that become foundational.

The Whirlwind project becomes the SAGE project. And that becomes really critical for a lot of early computing, particularly real-time computing. The Defense Department goes on to semiconductors. It goes on with key work in all kinds of semiconductor technologies. It goes on to supercomputing, leading that, all kinds of advances in software. When we talk about DARPA, we'll talk about the development of personal computing in the network and the internet.

But it's a powerful story of this Defense Innovation system and the role that it plays in the US economy in the second half of the 20th century. So which of you has got-- Matthew again, all right. You're up.

MATTHEW: Yeah! so there are definitely a lot of examples that Ruttan gives. And his thesis was that maybe these technological developments would have happened anyway, but that urgency of war made these happen a lot faster. And you see the DOD becoming, in his eyes, the major organization that's kind of funding this technological development. So I think the one question we really need to ask is, is war necessary for economic growth?

WILLIAM BONVILLIAN: That would be the foundational question at the least. That's a great question. I mean, it's a great question.

AUDIENCE: Well, I have a counter question to that. Maybe rather than war, maybe what's really required is DOD funding. Throughout a lot of this, granted, there was a lot of Cold War paranoia that was fueling this. And that was fueled on all these advances. But you could still paint a lot of the problems that face us today as national security risks.

And then you could get a similar level of urgency. Even though we're not technically at a war with, say, the climate, you can't really shoot that. And you kind of need it to live. So maybe it's less about war and more just a sense of priorities.

AUDIENCE: I think that's a really good point. Pretty much every presidential campaign debate I've ever watched, there's always the essential question they ask, where they're like, oh, what's the biggest risk that you think is facing our nation today. And often one of the answers is climate change. So I think that might be a really key part of rephrasing or reorienting our perspective to maybe start re-allocating funding towards what is necessary for the welfare of the nation that might not always be another nation's intentions.

AUDIENCE: Yeah, I think he used it as a provocative title. But it should have actually been called, *Is the*

Threat of War Necessary for Economic Growth, because I think there's a stronger argument for that. Yeah, threat makes us put funding into national security technologies. Also we've talked a bit about Japan's manufacturing innovation. And I don't think that was spurred by war or the threat of war. So it's caveats.

WILLIAM BONVILLIAN: Yeah, and you make an important point here, too. Which is, the US is pretty unique in putting national security at the center of its innovation system. Other countries don't do that. For sure, Japan doesn't. For sure, Germany does not at this stage. So other countries have other organizational motivations than, as you put it, the threat of war. But it's a powerful one in our country.

AUDIENCE: Yeah, that's the other point I wanted to make, is that I think Ruttan was very United States-centric just throughout our entire reading.

MATTHEW: So with that in mind, is there anything to worry about the \$54 billion cut to science and basic science research, and reallocating that towards national security defense, if that's going to go to the DOD anyway?

AUDIENCE: Well, I guess I could get a job flipping burgers.

WILLIAM BONVILLIAN: I don't think the \$54 billion will necessarily go into Defense R&D. And obviously, the entire \$54 billion didn't come out of the domestic side either, but there are very significant cuts to US science on the civilian side. I don't think they're going to be offset by corresponding increases on the defense side. We should be so lucky.

But I think, Matthew, you're driving an interesting point. Suppose there's no war, right? What's the motivator we're going to use to drive a technology advance?

MATTHEW: I think one person mentioned in their question if maybe international competition could replace kind of that sense of urgency.

AUDIENCE: Yeah, I think it's just a question of, what are your priorities at the current moment, and what can you make urgent enough just to justify kind of large-scale, huge, not just funding, but reorganization around maybe computers or key principles. And so in this case, I guess it was a threat of war. But you could probably argue, around the time of-- man, I'm forgetting. But there's probably some public health epidemic that you could argue that would have spurred massive bioresearch in that area.

And I think that can also happen internationally. So you think maybe the development of an epidemic in a different country could also spur bioresearch in other countries to supplement or help. And so I think we could even generalize even further and just say, is threat necessary for economic growth?

AUDIENCE: I think the big point about war is that you're a kind of centralizing everyone towards a common cause. So I think a lot of the initiatives nowadays, like the Cancer Moonshoot or even the push around getting a drug out there for CF, like those targeted initiatives towards a certain cause, I think those could be one way to target the need for development in a certain area, in times of peace, where you don't have a war impending.

AUDIENCE: One thing I thought was interesting, especially when people were discussing the increase in DOD funding, despite the fact that we're not really in a World War II era of war, I've noticed that-- how much of MIT's funding is DOD? It's like half, right?

WILLIAM No.

BONVILLIAN:

AUDIENCE: It's not.

WILLIAM Not close.

BONVILLIAN:

AUDIENCE: Oh, it might be just the Nuclear department then, which makes sense.

WILLIAM Yes, that makes sense. I don't know. It's like in the 18% range of federal research funding. So

BONVILLIAN: NIH and DOD are just about equal at MIT, in terms of originating research funding for the university. MIT tends to be somewhat higher in defense research than most universities. It's not close to half.

AUDIENCE: So the point that I wanted to make, though, regardless of the exact number, I'm sure that a lot of DOD money is spent on things that don't necessarily have applications of, say, building a better tank or a better missile or anything like that. So just because some things have the label and are under the Department of Defense, that does not necessarily mean that they're going strictly toward learning how to fight a new enemy. I'm just curious what your thoughts are.

AUDIENCE: Can you rephrase that?

AUDIENCE: OK. So MIT, we don't really research building better guns and bombs, right?

WILLIAM Correct. And we don't do classified research either.

BONVILLIAN:

AUDIENCE: Yeah. So just because we have a lot of DOD funding coming our way, it does not necessarily mean that we're researching better ways to kill people or to keep ourselves from being killed.

AUDIENCE: Does that funding come to MIT the institute, or Lincoln Lab as part of MIT?

WILLIAM So Lincoln Lab is a separate entity from MIT and, in fact, undertakes a lot of Defense work.

BONVILLIAN: But it is defense, not offense, is kind of a general rule that they apply.

AUDIENCE: So that 18% doesn't go to just MIT.

WILLIAM I'm not counting Lincoln Lab in that.

BONVILLIAN:

AUDIENCE: So my thought on that is basically just that, you're taking this money, but it's not necessarily trying to make us a better war machine.

WILLIAM So Max, in our reading of Glenn Fong, which I think comes next, we're actually going to derive after this exact point. So we can really lay out some of those nuances when we look at his piece. So Matthew, do you have a closing thought for us on Vernon Ruttan?

MATTHEW: I think I thought very similarly to other people here, that it seems more than war itself. A sense of urgency and threat, whether it's military or health-related, that's really what drives us.

WILLIAM Right. And that'll drive a societal, scaled-up effort, those kinds of concerns. I think you're

BONVILLIAN: absolutely right.

AUDIENCE: My main concern with this piece was like, you're overspending to move very quickly, which isn't really great. But also right after-- like once your initiative is done, that's like saying, yeah, I'm going to diet up until Friday, like right after you kind of go all out. So I wonder if these things, if you move the science forward very quickly, and then people just kind of drop it after. So there's this kind of lost cause, and they don't advance it. Because also, like for most technologies, like we can't do certain technologies that we would have been able to do 50 years ago, because the experts in that kind of thinking are not here anymore.

AUDIENCE: I had a quick operations question for Bill. When it comes to increasing R&D funding for agencies like DOD, is it the Congresspeople and Senators acting sort of in an executive capacity for their districts, or is there pressure from the district to sort of increase the policymaking for that, in terms of national defense? So I guess I'm asking, are legislators acting autonomously in defense of the country, or is there pressure coming from their districts, as well?

WILLIAM BONVILLIAN: So members of Congress tend to be much more concerned about defense spending that's part of big acquisition programs. Who's going to get the next award for the next Air Force aircraft? That's significant scale. R&D spending tends to be at a much more modest scale. And Congress itself has eliminated the appropriations earmarking system. So members can no longer go into bills and stick money in for projects in their district. That system has really been significantly-- I wouldn't say it's been eliminated, but it's been significantly reduced. So the Congress itself, to some extent, has reformed itself.

Now, the problem for that is that it gives members much less at the stake in federal expenditures. If they can't affect what's going on in their own district, why should they care what federal appropriations levels are? So it's a two-edged sword here. But by and large, members of Congress have stayed out of R&D. They don't really touch DARPA. They certainly don't touch NSF. They don't touch NIH. And part of this is that the amount of funding awards for a research project are relatively modest and really don't affect anything at scale. What they worry about are these larger acquisition projects.

AUDIENCE: Was that also the case for the [INAUDIBLE] observation that Ruttan undertook?

WILLIAM BONVILLIAN: I'm not sure I follow you.

AUDIENCE: Was it the pre-earmark era? Was it present [INAUDIBLE] observation?

WILLIAM BONVILLIAN: Right. The earmark era is only in it in the last four or five years.

AUDIENCE: So then Ruttan was operating under that system.

WILLIAM BONVILLIAN: Yeah, but again, there wasn't very much earmarking of R&D funding, which is really what-- he's focused on the innovation system.

OK, so Glenn Fong-- and he starts his piece with a quote from a former White House chief of staff, John Sununu of New Hampshire, who states, "We don't do industrial policy," in the US. And Glenn takes that line on and essentially proves otherwise, that we actually are operating, at least through the defense sector, with what can only be viewed as a pretty significant industrial policy. So how does case studies of various agencies. It's not all defense. He also looks at Commerce and NIST.

But he concludes that the significance of the governmental role, particularly on the defense side, is really quite strong. And that because of the volume of the spending, in particular, that's particularly powerful on the defense side. And he argues that there are about four models to drive it. The question, Max, you were asking about, there's about four models by which DOD undertakes its spending that happen to have spillover effects into the civilian sector.

So one model is what he calls the byproduct model. Military R&D will have unintended spillovers into the commercial sector. And he cites ARPA-NET as an example of this. In other words, when DOD is setting up the internet, the ARPA-NET, for its own internal purposes, it's a defense communication system, and a communication system between the early computer science departments that DARPA has been supporting.

It's a way for them to communicate and transfer data amongst themselves. They're not envisioning that this is going to be the standard form of communication of the 21st century. They were thinking about a much more immediate problem. But the byproduct is that we create this massive economic sector.

Then there's an intentional spinoff model. So commercial spinoffs get expressly contemplated during the program planning around an R&D initiative. And [? E-side ?] strategic computing and VHSIC as examples where DARPA know that what it was going to create in the computing sector was going to benefit all parts of the computing sector, not simply DOD. But the gains were significant enough for DOD that it was really important to pursue this.

And in fact, DARPA and the IT revolution in general consciously worked on standing up a lot of these technologies in the civilian sector. Why is that? Because the Defense Department is often quite good at standing up the early prototypes of a pretty radical set of technologies. But they don't have the follow-on capital that the civilian sector can muster, a big financing follow-on capability.

So DARPA consciously understood this, realized there was going to have to be huge

incremental advances in the technologies it was standing up. It would help create the model, make it available in the civilian sector, on the assumption that a rising IT sector and financial support system would come in and scale this up. It would radically drive the price down, enabling DOD to buy the technologies back at a fraction of the cost and with much greater capability than their own system would be able to do this.

So DARPA's decision to stand up a lot of the IT revolution around computing on the civilian side comes from a pretty conscious effort to understand the dynamics of what was going to be. And they all understood it to be a very large potential economic sector. And how DOD could be the initiator and then leverage off what were going to be much higher investments on the civilian side. So for example, for a long period of time, DOD would be the initial market.

So when we talked about how Kilby and Noyce developed the integrated circuit, the core breakthrough technology in semiconductors, and really in computing, the only customer for the first four years were the Defense Department and NASA. So the Defense Department carried all those advances through the first four years of new generations of advances for integrated circuits. It wasn't until four years later that a civilian sector started to evolve. So DOD can play this initiator model. And what Glenn Fong is driving at here is, that's an intentional spinoff model that works well for DOD.

Also, DOD has an explicit dual use model. So a defense project could have the explicit goal of developing a military technology and a civilian technology in parallel. And advances in lithography in semiconductor etching are a pretty good example of that. High performance computing, which Al Gore helped to originate and pass the original legislation before, these were going to have benefits on the military side big-time, but obviously corresponding big benefits on the civilian side.

And then kind of the fourth model, Glenn points out, for how DOD thinks about its role in the economy and intervenes in the economy and has, in effect, an industrial policy, is what he calls the industrial base model. So sometimes, DOD is going to decide that it must have an industrial base in a particular sector, and will consciously support the development of an industrial base in the civilian sector. The best example of this I know of is that both the Navy and the Army, in the early days of aviation in the 1920s and '30s, are consciously attempting to create a very strong civilian industrial base in aviation.

Because they know how powerful and important that's going to be. So Admiral Moffett, who

was leading the Navy's early aviation program, carefully makes sure, in the appropriations process, the congressional appropriations process, that there are a multitude of projects for engine makers, for airframe makers, for different types of aircraft. So that he's going to start to stand up a whole industrial base and aviation. It's done very consciously. I think that's the best example.

But there are other examples like that, too including in the IT side, such as Semitech. When Japan came very close to capturing leadership in the semiconductor sector-- and we talked about this in the manufacturing class-- DOD intervenes. So under President Reagan, DARPA jumps in here and cost-shares the development of new advanced manufacturing approaches in semiconductors, so that the US could get back into that game. Japan had figured out better processes, better production systems, more efficiency, higher quality in semiconductor fabrication.

The US had missed these. This was a conscious attempt to keep up, because the Defense Department felt it had to have an industrial base in semiconductors. So these are four ways by which DOD is willing to intervene. It will not intervene just for straight economic competitiveness reasons.

So getting back to our conversation earlier, Max, it's not going to do something just because it will help US competitiveness. It will only do it if it can find one of these very close military needs associated with it. And these are the four models they use. Who's got the Q&A on this, Chris? I think we're Through. Yeah, we're through this. Why don't you lead us off in some Q&A. And Max has got a question, too.

AUDIENCE:

Sure. So as we just went through pretty briefly, he mentions a lot of different models and different agency projects that have been kind of case studies of opportunities that the DOD largely has used to advance technological innovation, somewhat indirectly. So maybe we could start off by discussing, which model do you guys think is most effective? Do you think it changes when you consider different industries or different focuses? And how applicable is this kind of structure to present day?

AUDIENCE:

I think what's really cool about all these is they're separated by intent, really. So if you're intending to have a sort of dual use-- it's probably easier to see the bottom two than the first one. But the dual use and the intentional spinoff are pretty strong arguments for how DARPA projects could be effective and useful and why you should advocate for them. It'd be pretty

hard to do the byproduct model with that sort of intent for spinoff, just because you have absolutely no idea of how that's going to turn out.

But because they're separated by intent, I think it's pretty fair to say that, depending on what sort of project you're looking at, you're going to see which model is going to be better. And it's nice that you can do that from the get-go. When you start the project, you can kind of see where that's going.

AUDIENCE: So just personally, it seems like some of these might be hard to kind of create a project around, oh, I'm going to have unintended spillovers into the commercial sector. In some sense to me, it seems like a bit like post-classification of what has been done. So thinking about the DOD as they're trying to fund projects, what do you think are their main priorities, in terms of potential commercialization and potential kind of benefits that way, and also benefiting their military efforts? What do you think is that balance, and what kind of characteristics would they be looking for in, maybe, a funding proposal?

AUDIENCE: Well, I'd say one characteristic that they look for and definitely emphasize would be superiority over other countries who are working in similar fields. So with the semiconductor thing, the moment they saw, hey, Japan's doing this, they're like, oh no. OK, now we need to get on this. What was the direct implication? That was my question, by the way.

WILLIAM Semiconductors?

BONVILLIAN:

AUDIENCE: Yeah.

WILLIAM [INAUDIBLE] for the computing system.

BONVILLIAN:

AUDIENCE: OK. Because you said the DOD does not support different industries unless it has a direct national security application. So I guess I'm just trying to figure out how we could implement these ideas today, so that we could, I guess, boost our current innovation system.

AUDIENCE: I don't know if it would be military-based, but you just go with a focus point, have that kind of military ideology of like, we need to get here by X amount of time. And let's put these efforts and try to think more as a system, rather than different departments. But you would put initiatives. Like in private capital that's been happening recently, like [INAUDIBLE] made a private initiative to cancer and certain diseases. But if you have a national effort-- I don't know.

I wasn't alive during this, but I think during the '70s, during the Cold War, there was a huge initiative for science and rockets. I don't know. You probably know. I haven't seen a [INAUDIBLE] this.

WILLIAM We'll get into that in a later reading today.

BONVILLIAN:

AUDIENCE: But I think definitely having a strong national interest, but not just financial incentives. Because from a management perspective, people have different ideas of what's good and what they want out of life. So I would do financial incentives, social incentives, in terms of, you solve this problem, you're a superstar. Kind of like an Einstein, it'll get you on TV. And then also educational, in terms of like, oh, these are our star students, from five years old, 10 years old, 15 years old, so they're part of the community.

And that's probably how I'd do it. And getting rid of egos, like finding a way to do that in a system, that's how I would think about it. But I'm interested in what policy people think, people who focus on policy. I don't know policy. Have there been policies in the past that do something similar?

AUDIENCE: Well, apparently, right?

AUDIENCE: I mean outside of this.

WILLIAM Martin, you're laying out a whole new set of initiative drivers here. And it's an interesting list.

BONVILLIAN: And in fact, in the Sputnik era, which we'll talk about a little bit, we do see a tremendous focus on education, for example, and training, and the importance of being a scientist. Those all come to the forefront in American society for a reasonable period of time.

AUDIENCE: And coming back to what I was actually saying, because it's less obvious, or at least it's not as advertised to the American people, that, in a lot of aspects, we're not really doing all that well, like education or in manufacturing. Because it's not advertised as much, perhaps that's why maybe we spend some time resting on our laurels from the '70s or whatever. And maybe that's why we're progressing less quickly in other places.

AUDIENCE: To bring in the question you asked earlier, Chris, I really like the diagram, I guess, he poses on page 161. I guess I can zoom into it on my computer, where he essentially shows where each of these fit on the models. And I like this trend line was in between intentional spinoff and

explicit dual use. And I appreciate that in particular, because I think it really highlights-- and even within the context of him choosing those as case studies-- a point that he had made towards the beginning on structural attributes of the United States.

And he argues something along the lines of, structural attributes determine industrial policymaking capabilities. And the US has deficiencies in industrial policymaking, because we don't care, or rather because we don't put an emphasis on creating that policy explicitly. And I guess I question how much of that is, I guess, a cultural barrier almost, that we have, or a perception barrier, more so than a policymaking barrier.

Because if policymakers don't conceive of themselves as change agents, maybe-- was there a reading in this concept for this week that-- was it yours, Bill, the fifth reading? Yeah, that talked about changing, because if policymakers don't see themselves as change agents within the economic context, and they feel like that should be left up to private markets, then they might not feel like it is their position or even something in their area of expertise to promote industrial policymaking as a key to economic growth.

But if, I guess, someone were to articulate-- or maybe, Bill, that was you. Maybe that was your position in the Senate, right? If there was someone who was clearly articulating the link between industrial policymaking and economic growth as of the utmost importance, then maybe they would do it more often. So I think that's where that diagram that he draws is really important in establishing that trend line between intentional M off modeling and the explicit dual use model. Because it is perhaps precisely trending towards explicit dual use that you can convince policymakers to invest in R&D, and not in basic research and not explicitly at the hands of the market.

WILLIAM Chris, do you want to react?

BONVILLIAN:

AUDIENCE: Yes.

AUDIENCE: That was a lot.

WILLIAM No, go ahead, go ahead.

BONVILLIAN:

AUDIENCE: Oh, no, go ahead. I'm still trying to gather my thoughts.

WILLIAM BONVILLIAN: Yeah, no. I'll say just a couple words, then Rasheed and then, Chris. Industrial policy is a negative term in the United States. And what it's come to suggest is that the government is playing a role, intervening in the marketplace to pick, as the phrase goes, winners and losers-- in other words, who's going to be the successful firms and who's not. And what Glenn is arguing is, like it or not, as the military moves into these very applied areas in the IT revolution, it is playing an industrial policy, industrial organizational kind of role, like it or not.

And even though we deny we have industrial policy in the United States, Glenn is arguing, look, as a practical matter, the Defense Department definitely has tendencies in this direction. So this is a debate about pros and cons of industrial policy. I think Glenn is arguing, you want to see these technologies stood up, you're going to have to think about how you're actually organizing to implement them.

AUDIENCE: As a quick followup, do you think that he would argue that calling it by its name is important? Rather than having these sort of disambiguations about research and development funding, we really talk about it in an economic sense as industrial policymaking. And if we call it like it is, then perhaps we would sort of destigmatize market interventions, at least in this context.

WILLIAM BONVILLIAN: You're right. We invent a lot of phrases to not use that term. For example, in the civilian research side, when the Advanced Technology Program is being put together that funds industry-applied research projects, the argument is, this is not industrial policy. We are funding pre-competitive research, which is going to land and be accessible to a number of firms. So we're not particularly picking one firm as opposed to another. We're funding pre-competitive research that will benefit all.

And that's not a bad theory. There are issues, as Charles Shultze taught us, about governmental intervention and industrial policy. This is not a simple landscape. It's rife with problems. We'll get to In-Q-Tel as soon as we take a break. But that's the ultimate interventionist governmental mechanism. But Rashid, go ahead. You had a point.

AUDIENCE: There are two things that are separate. I think one, very quickly, is DARPA. I think it was in one of the readings. They do actually, at each stage of their project development, they sort of kind of have you hash out just a white paper, identifying what would be the potential commercial impacts of this research if it were to go to market. So they have sort of staged places where they're thinking about, how are we going to transition in toward to this byproduct intentional spinoff in an explicit dual use.

Because they realized like, yeah, we're doing research, that's great for us. But obviously, this is going to have benefits elsewhere. But I think what's important is DARPA actually has stages where they identify, and they make you sort of write it out. And it's not punitive or binding. But they say that they're thinking about, how are we going to actually transition this defense research into commercial applications? And that's really important. Because they're kind of speeding through a lot of steps here in the R&D space, by putting so much money in it, doing these high risk, high reward opportunities.

But they're thinking actively about how they're going to benefit the consumer and commercial efforts. And then two, I think policymakers as change agents is pretty key. And Martin and Steph kind of hit on it a little bit. But I think it's just a different way of thinking. And maybe it's just calling it like it is. Maybe it's just saying, industrial policy or kind of adopting these methods, without-- so adopting the best of what we like about industrial policy, which is this byproduct model and all these things, without really getting into picking winners and losers, sort of this In-Q-Tell kind of mechanism here.

And I think it might be a little bit easier to decide what we like about industrial policy if we just call it industrial policy instead of just avoiding market intervention as a term entirely. Like if you just decided, yes, it's a market intervention, and yes, we're doing industrial policy, but we want to do this kind of market intervention and this kind of industrial policy, instead of kind of masking it with ambiguous terms, things might get a little easier.

And then third, I think the call for things is a nice way to get around this. So I think there's a lot of examples about the government putting out calls and initiations. And even DARPA kind of does this, where they initiate calls. They say, we'd like to do research in this particular area, or we'd like to solve this particular problem. And it's not a way to pick these winners and losers and decide who does it.

But like, the person who comes up with the best proposal and can prove that they can meet these staged deadlines will win in the end. And it's a pretty tried and true method you see in things like that. But it's just like, are we giving room for policymakers to make these same judgments and put out these calls for advancements in R&D funding and all these other things, with these staged metrics.

WILLIAM

So Chris, do you want to give us some closing thoughts on Glenn Fong's work?

BONVILLIAN:

AUDIENCE:

Sure. So I guess the general theme that we've been talking about is that industrial policy in the US is kind of obscured or hidden behind these programs, by the DOD. And they're only manifested when innovations are really pushed towards that explicit competitiveness. And he claims that increasing US capacity to undertake these programs is directly relevant to economic competitiveness. Which is interesting, because this is kind of in direct contrast to what we've been talking about in some of the past lectures, that there's this post-war paradigm, that they're focusing government R&D to basic research. Or I believe he calls it like mission agency.

So I think this is a pretty interesting reading. And also, I guess, a side point was that, one thing that came up for me was this kind of conflict between a focus on economic competitiveness and more I guess social impacts or ramifications that could result. Like he mentions a couple of times that, like welfare policies and stuff aren't considered economic competitiveness. And using those as metrics isn't exactly a good way to look at competitiveness.

And I thought that was a really interesting way to kind of segregate, I guess, the impact of these kind of programs. And obviously, they're two very different things. And DOD probably has to stay out of it. And just like we've been mentioning, can't really pick winners or losers. But yeah, I thought that was another interesting kind of subtext theme.