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Interview by Matt Hourihan,
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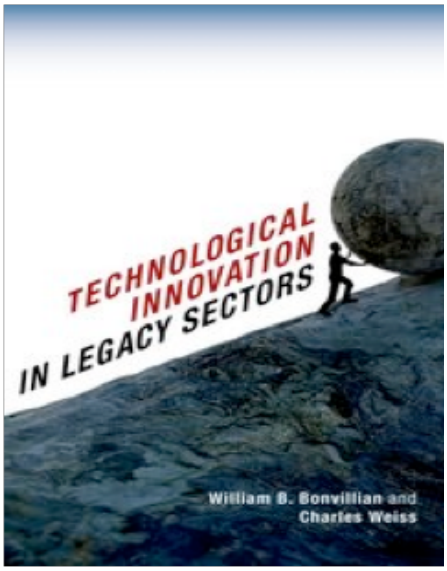
on 12/16/15 with authors
William B. Bonvillian and Charles Weiss
about their new book
Technological Innovation in Legacy Sectors
(Oxford University Press, released September 2015)



So why focus on legacy sectors? What's the importance?

Bonvillian: When we began this book, we began realizing that there's this phenomenon in the U.S. economy. The U.S. is good at creating new frontier technologies. To use a phrase in the book, we tend to take our "technology covered wagons" west and open up new frontier areas. In our lifetimes of course, the IT revolution is a perfect example of that. The biotech revolution is similar. We find open spaces that haven't been previously occupied and we create new technologies that will fill them.

The problem with legacy sectors is different. Legacy sectors are the complex, established parts of the economy. They probably amount to, we estimate, somewhere around 80 percent of the economy, but certainly well more than half. They include areas like fossil fuel, manufacturing, the electric grid, the construction sector, transportation, agriculture, defense. Bringing innovation into them is a more complicated proposition because they're "occupied" already with existing technology systems. So if you're going to land new technologies in these established sectors they've got to parachute in, and they're going to get shot at often on the way down.

The U.S. has this tendency of wanting to do biotech, not go back and fix the healthcare delivery system. It would rather move on than fix what it's got. This is a problem in an economic sense because, by creating stumbling blocks to the entry of innovation in our established sectors, we artificially limit our ability to grow and therefore to create better economic well-being in our society. In addition to that,

there are these big societal problems: climate change; jobless innovation; healthcare delivery. These are big societal challenges that you can't deal with unless you tackle these legacy sectors.

Some who work in the sectors Bill mentioned would probably argue that we *have* seen innovation in these sectors. For instance, thermal efficiency of natural gas turbines is substantially higher today than it was a few decades ago. But you're talking about more disruptive innovation. What are the concerns and barriers regarding more radical technological developments?

Weiss: Well the defining characteristic of a legacy sector is a well-established, well-defended paradigm, which is partly technological, but also is multidimensional. It's got an economic, a political, a legal, an institutional dimension. If a given innovation fits that paradigm, it can go very nicely. Fracking…is going very well because it fits the prevailing fossil fuel paradigm, whereas solar and wind and conservation face very serious obstacles, which put a disproportionate pressure on the innovation system.

Bonvillian: What we found was that there are certain kinds of characteristics that are typically shared by many legacy sectors. For example: pricing that doesn't reflect externalities. An established infrastructure that's locked in and very hard to change. There are public expectations that come to bear here: public expectation of very low energy prices, very low gasoline prices. There are career paths, and curricula. There are regulatory requirements that tend to lock in certain kinds of legacy sector tendencies. All of these sectors are defended by powerful vested interests.

And then, in turn, there are a series of market imperfections, and these are more technical terms in economics, but issues like perverse subsidies, and network economies, what we call "lumpiness," which are these major sectors [in which] you have to operate at a certain scale to gain entrance. We have a financing system that's not geared to the introduction of disruptive technologies. It tends to be pretty short term – venture capital is typically five to seven years.

Weiss: The particular difficulty about introducing disruptive technological innovation into legacy sectors – innovations that don't fit the paradigm – is that you have to think simultaneously of changes in policies and institutions, *and* of technological innovation. This is not the typical way the U.S. goes about thinking about innovation. We normally think of innovation as flowing from research. The particular case of legacy sectors [is that] you have to think about policies and institutions *in parallel* with research, and you typically require government intervention over and above the support for research, *or* strategic thinking on the part of the private sector or foundations or NGOs that think through the obstacles to disruptive innovation…In the private sector, I think you can see it with driverless cars. Here the car companies and some of the computer companies – Google – are not only thinking through what it would take to have a technically safe and operational driverless car or driverless truck or driverless caravan…but they're also asking themselves what are the changes in financing, in insurance, in liability, in legal structure, in licensing structure, in highway and transportation systems design. You can see the change agents forming in a collaboration between government and the private sector.

The major challenge of this book was to develop a framework for thinking about the problems of innovation, of research, *and* of obstacles to the introduction of disruptive innovation, all at the same time.

And you don't just look at technology-based sectors – you also examine service sectors, like higher education and healthcare delivery. What are some of the challenges and opportunities in these?

Bonvillian: Turning to higher education, some have argued that the last major systemic change in higher education was development of the book. Obviously it's a more complicated story than that, but this is a pretty slow moving system, and the introduction of significant change is a very gradual process, because there are a series of these classic legacy sector problems that afflict higher education. There is an established infrastructure in higher education, whether you characterize that as colleges and universities, or textbooks, and it's hard to introduce new models. There are public expectations about higher education. There are what some would characterize as perverse pricing, i.e. very high and rapidly rising cost. There is very limited R&D conducted on education.

We look at one interesting, potentially disruptive set of changes, which is the introduction of MOOCs, massive open online courses that began to be introduced around 2012 and 2013. There are some things that online education can do, frankly, better, in terms of delivering education and learning, than the existing system. But there are of course things that online can't do. So we argue in the book in the end that a blended model is preferable...The risk in higher education is that universities and colleges will add portfolios of MOOC courses and think they've checked the box. They won't necessarily look at the blended model because that means changing the existing legacy sector system, not just adding an additional feature on the side. So that's the big challenge in higher education – a disruptive innovation is on the way, it's arriving, it's starting to land after a long time in coming. But will the potential of that, and the opportunities for learning it creates, be fully implemented into the established system?

Even though DOD has all the hallmarks of a legacy sector, you use it as a case study of a successful innovation system, which may surprise some readers. What were the key ingredients to DOD's success on this?

Weiss: Defense is a very interesting chimera. You have the services, which are devoted to the short- and long-term problems of their mission as defined. And then, [you have] different mechanisms whose function is to push disruptive innovation and that's their job. It used to be a particular individual like Admiral Rickover[1] or General Schriever[2], and now DARPA [the Defense Advanced Projects Agency] has institutionalized in this function.

Bonvillian: It's an important question because the Defense Department, which is frankly one of the most notorious bureaucracies in the history of the United States, has been able to introduce technological innovation in some very interesting and important ways. And to some extent it offers a model of how to organize within a legacy sector to accomplish technological innovation.

The example we look at is something called the Revolution in Military Affairs [RMA] that occurred in the 1980s and 1990s. To set the stage, following the end of the Vietnam War…there was genuine worry about the capability of the U.S. Army to provide a sufficient deterrent and barrier to a reviving Soviet

[1] Admiral Hyman Rickover, USN, led the development of atomic submarines.
[2] General Bernard Schriever, USAF, led the development of ballistic missiles.

Union and their forces in Eastern Europe. And the leadership of the Defense Department at that time – Harold Brown[3] and Bill Perry[4], noteworthy Defense leaders – thought, 'Look, we're not going to deal with this massive disadvantage we have in manpower and equipment by matching the manpower. We're going to have to match it through technological innovation.' And they began a series of efforts to develop breakthrough defense technologies around issues like precision, around stealth, around UAVs [unmanned aerial vehicles]. The services were not interested in those technologies. But DARPA and other elements within the Department were able to press these technologies forward, and eventually they went into place.

How did it do this? Chuck mentioned the important role of DARPA. Unless you have innovations available to feed into your legacy sector system, there will be no innovation, and DARPA has played a role in driving the core innovations that helped create this RMA possibility. But that doesn't mean that these are implementable. In turn, there had to be change agents within the Department ready to press these changes into the services and nurture the technologies through development. I've mentioned Harold Brown and Bill Perry were certainly critical, but there were a series of other leaders and in subsequent Defense Department leadership circles prepared to help press these advances through.

Weiss: And also procurement capability, which is the critical thing for DOD. Just to finish the DARPA story: When you have this integrated system, where you're both the developer and the purchaser, the management of DARPA becomes a big challenge, because everybody has to understand what DARPA is about. DARPA is not about the immediate problems of the services. It's about the long-run potential for application of breakthrough technology. The director of DARPA has to have special relations with the services so that they understand what his/her job is, but also the Secretary of Defense has to defend [DARPA] against inevitable pressures.

Bonvillian: So the Defense Department gives us a lesson on how to change a legacy sector. You need the front-end innovations, and DARPA has been what we can call a change agent on the front end of the system. But on the back end of the system where you're moving towards implementation, there are leadership and institutions within DOD that have also been prepared to press the change and the technological innovation opportunities into actual implementation.

That's one model; but it's only applicable in a particular kind of setting. Obviously other legacy sectors are market-oriented, and very different. But this is where other models could come into play, you argue.

Bonvillian: We paint five models of the innovation dynamics. Two are familiar to the science and technology policy and innovation community. The first we can call the "pipeline" model: that is a technology-push, technology-supply model. Often, federally supported research will *push* the products of basic research towards the marketplace. That's the dominant model underlying U.S. innovation policy – that's the way we think most things work. But obviously industry is a huge factor in innovation. That

[3] Secretary of Defense Harold Brown, a scientist and former president of Caltech, was secretary from 1977-81.
[4] William Perry was a mathematician and engineer and Undersecretary of Defense for Research and Engineering from 1977-81; he subsequent served as Secretary of Defense from 1994-97.

model the literature calls “induced.” That’s a technology-pull, demand-pull model. Industry will spot a market opportunity and will move technology advances – which are often incremental, to meet those market demands and opportunities.

So those two models are pretty well understood in the system. We propose actually three more. The third model is the “extended pipeline” model that we referenced earlier. That is the way the Defense Department works, to a lesser extent the Department of Agriculture works. A fourth model we call “manufacturing-led,” and this is a second new model we’re proposing here. America thinks of innovation as revolving around R&D, but it turns out that production – particular initial production of a new technology – is a very sophisticated innovation-oriented stage. It’s very rich on creative engineering…Some countries are very strong at this. Germany is very strong in manufacturing-led innovation, [and] Japan’s invention of the whole quality manufacturing system that it implemented. Taiwan, Korea, and now China – these are all examples of manufacturing-led innovation.

And the fifth model [we call] “innovation organization.” Chuck and I argue in the book that this model encompasses all of those four models, that in order to bring innovation into legacy sectors you’re going to have to be able to move all four models, not one of the above, taking into account the broad context and structure of a complex, established legacy sector where you’ll need all those elements to really bring change.

The idea behind all this is to craft policy responses that orchestrate between these different modes of operation, essentially, and to avoid limiting your paths of action given the special challenges in legacy sectors, is that right?

Weiss: Sometimes you use technology-push, sometimes you use demand-pull, sometimes you want to innovate on the manufacturing side, sometimes you want to just let nature take its course after the research, sometimes you want to be involved in the entire innovation process and you have to think about all the problems you expect to happen along the way. The model of stealth and precision strike and drones, which involves creating the technology and then seeing it through, has to be modified when you’re not in charge of procurement, when procurement is a function of markets.

We lay out a framework which would have to be modified from sector-to-sector but the idea is the same. First you have to strengthen the front end, which may often mean creating or strengthening existing innovation institutions. You have to be sure your researchers are both isolated from immediate pressures *and* linked to the ultimate decision-makers so that they understand the problems that the sector has to solve, and also have receptive decision-makers for when the ideas come out, which Bill calls “connected” science and technology, which is a good word for this.

Then you have to think through the launch paths of these technologies you’re trying to promote. And when you start thinking through the launch paths, you’ll start to see obstacles that have to be overcome: infrastructural or institutional or public conceptions or legal. It doesn’t pay to have the technology ready to roll, and then say “Oh my heavens, we have to deal with the legacy aspects of the sector.” After you’ve thought through the technology launch pathways, you realize the areas of support or public policy change that are going to be needed to overcome these obstacles.

And all this is taking place against the broad background of the context of innovation. One feature of the U.S. that I think is insufficiently appreciated is the role of the innovation context. We spend a lot of time worrying about our innovation system, but what really makes innovation flow in this country are broader issues of culture, of acceptance of risk, of reward to merit, of relative indifference to where you come from, what your religion is, what your color is, who your father was. This sets us apart. There are a lot of countries where if you start a company and go broke, you're a black sheep forever. In Silicon Valley, you start two companies and they both go broke and you come to the venture capitalist with a third idea and it's a good idea, he's likely to figure well, you learned something from the first two mistakes.

This is no small task you're setting out for policy practitioners. But in the book you argue it's a task that's already moving forward with regard to advanced manufacturing, in response to the long-term relocation of manufacturing overseas. Walk us through that response.

Bonvillian: Manufacturing is particularly interesting because it's a legacy sector, but it's also one of the models of innovation dynamics…If manufacturing is actually an important part of the innovation system, we're creating a problem that could be "produce there, innovate there." Because in the process of moving part of the innovation system abroad to these offshore locations, we're affecting our overall innovation capacity and capability.

So what's the policy response here? We're probably going to have to innovate our way into greater efficiencies and productivity. That means the five-step process Chuck laid out becomes very relevant to advanced manufacturing, and in fact we're starting to move through those steps. We can start to see a series of new technology paradigms that are starting to evolve in manufacturing that could be transformative and enable much higher efficiency in the U.S. system. For example: 3D printing is now moving apace, it's a whole new kind of production system. Advanced materials may enable a very different kind of product set. New digital and sensor technologies can be introduced at every phase of the production process to make it smarter than it already is.

Can the U.S. move to implement those on the front end of the innovation system? We're doing several things in that regard. We're starting to coordinate better. We're now creating a series of manufacturing institutes which have a role on the front end but also in the implementation end. These manufacturing institutes are modeled on the German Fraunhofer Institutes[5]…We're developing a series of support policies tied to those different paradigm launch pathways, and we're also looking at gaps in the system. We're introducing new kinds of workforce education and apprenticeship programs, we're taking a series of institutional steps in parallel that help to fill those innovation gaps.

It's a much more complicated model than anything we've tried before. This involves collaborative organization across the private sector between small, midsized, and larger firms, and it also involves integrating university expertise, and tying some federal funding to provide leverage here with private

[5] Germany's Fraunhofer organization supports a network of 60 regional institutes for applied R&D, bringing together advanced engineering expertise with small, mid-sized and large firms around manufacturing technology and process challenges.

sector funding and state funding, because these institutes are shared by all three sets of partners. But on the other hand, legacy sectors require complex organizational solutions.

Weiss: The convening power of government is important here. Not just the programmatic or financial, but the government convenes a meeting, people talk to each other that might not otherwise, which means there has to be conceptual leadership that at least identifies the problem and identifies who has to be part of the solution, to bring them together. It doesn't mean you are the solution, it means at least you have the wit to bring the right people together, and get each to do what they have to or promote the idea that each has a role to play.

Where Does NIH, NSF fit in? Discovery science agencies?

Bonvillian: These are agencies that were organized around what we call the pipeline model…In the multi-decade history of the evolution of U.S. R&D agencies, many have added to strong foundational basic research capability – which of course remains critical – by adding new dimensions. So for example, a lot of the Defense Department's capabilities developed coming out of the Cold War and the Sputnik challenge. An organization like DARPA came along at that time requiring what we can call a more full-spectrum kind of model: an extended pipeline model that undertook the research all the way through development and potential initial market creation, so they broke from a basic research mold long since.

The next great period of change in R&D agencies was around the challenge from the Japanese development of quality manufacturing in the '80s and the great challenge that both Japan and Germany offered to the success of U.S. innovation at the time. And we developed things like manufacturing extension centers, the Bayh-Dole Act which brought universities into commercializing technologies for the first time, the Advanced Technology Program. The SEMATECH model came out of that same period, as a response to a challenge on the computer chip side. Since then, the energy challenges have pushed a number of new institutional elements at the Department of Energy. ARPA-E is a strong example. The Department of Energy is sponsoring manufacturing institutes because unless they drive the production costs down of new energy technologies they'll never enter the marketplace.

The latest challenge has been around advanced manufacturing, we've talked about the new manufacturing institutes there as well as some other organizational models that are coming about. So you're seeing change in our more traditional R&D agencies as they need to accommodate additional challenges. That doesn't mean their fundamental research portfolio doesn't remain critical – it does. But there are additional pieces that can get added on here. Even an organization like NSF – a classic basic research agency – has very strong engineering programs and has engineering research centers and a series of related programs that enable it to expand its reach.

[Weiss: And that's a good point to close on – about structural and organizational change to meet evolving legacy sector needs. Thanks very much, Matt…]