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Sonia Ben Ouagrham-Gormley. *Barriers to Bioweapons: The Challenges of Expertise and Weapons Development*. Ithaca: Cornell University Press, 2014. ISBN: 978-0-8014-5288-8 (hardcover, $39.95).

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Introduction by Lynn Eden, Stanford University, Emeritus

Sonia Ben Ouagrham-Gormley's outstanding *Barriers to Bioweapons* demonstrates that while it may be relatively easy to pick your poison, there are very significant barriers to manufacturing it. Her main argument, as our reviewers so clearly explain, is that making bioweapons—that is, 'weaponizing' biological agents such as anthrax, smallpox, plague, and many others—has been far more difficult to achieve than is generally understood. And this is true whether these are small groups intent on creating terror or nation-states working at far larger scales of destruction.

Ben Ouagrham-Gormley neatly and richly organizes her arguments in terms of 'endogenous variables,' the immediate environment in which knowledge is created, and 'exogenous variables,' the broader political and organizational context.

Endogenous variables include the program's structure and immediate organization of work, the style of management (for example, trust or tyranny), and the social context (for example, consistent or inconsistent team skills, translatable or incommensurate technical languages)—all of which can affect the use and transfer of tacit knowledge, which greatly affects the ability to solve problems.

Exogenous variables include the degree of foreign technical assistance and the capacity of the state to absorb that assistance, the managerial abilities to integrate the myriad aspects of a large program, the priority of the program to political leaders, and the resources available to the program (12-13 and chapters 2-3).

Ben Ouagrham-Gormley argues that in the Soviet Union, the rigidity of central planning, economic scarcities, political interference, and the constraints of secrecy led to a focus on 'correct' procedures and even to faking results (118). Despite the inefficiencies, even after signing the international Biological Weapons Convention in 1972, the Soviet Union produced "'hundreds of tons' of anthrax bacteria and scores of tons of smallpox and plague viruses."[1]

By contrast, in the United States, lack of unified management, very poor coordination and integration, multiple reorganizations (83-84), and generally low priority, led to an anemic bioweapons program (83-85). The U.S. signing of the Biological Weapons Convention ended the program.[2]

Ben Ouagrahm-Gormley's 'variable' framework works well, especially for the systematic comparisons of national bioweapons programs that structure *Barriers to Bioweapons*.

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[1] "'Hundreds of tons' … plague viruses": Tim Weiner, "Soviet Defector Warns of Biological Weapons," *New York Times*, 25 February 25 1998. On international agreements and biological warfare programs more broadly, see Gregory D. Koblentz, *Living Weapons: Biological Warfare and International Security* (Ithaca: Cornell University Press, 2009). On smallpox, see Jonathan B. Tucker, *Scourge: The Once and Future Threat of Smallpox* (New York: Grove Press, 2001); and see his other excellent policy work on chemical and biological weapons.

[2] For an historical and theoretical explanation of the changing but generally low priority of bioweapons in the United States, see Frank L. Smith III, *American Biodefense: How Dangerous Ideas about Biological Weapons Shape National Security* (Ithaca: Cornell University Press, 2014).

Implicitly, she uses what organizational sociologists call an 'open systems' approach. Even with a high degree of secrecy, organizations are not entirely "closed … sealed off from their environments, but are open to and dependent on flows of personnel, resources, and information outside.... [E]nvironments shape, support, and infiltrate organizations."[3]

The four reviews that follow very ably explicate Ben Ouagrham-Gormley's more specific questions and arguments, and I will not repeat their points here.

The reviewers place Ben Ouagrham-Gormley's work in the context of the literature on nuclear power and nuclear weapons, and note that she impressively draws from multiple literature, including business school case studies, anthropology, and organizations and management. They also note that she contributes to the fields of political science, public policy, and policy assessment, and to the study of expertise and, especially, tacit knowledge. They agree that *Barriers to Bioweapons* significantly broadens policy-relevant scholarship on the proliferation of deadly weapons well beyond the historically dominant focus on nuclear weapons. They agree that the empirical work is outstanding and find particularly noteworthy the personal interviews of participants in the Russian bioweapons program, and also in the U.S. program.

To these strengths, I would like to add three others: first, *Barriers to Bioweapons* is well organized and very well written—a model of rich empirics and theoretical sophistication. Second, Ben-Ouagrham-Gormley successfully tackles a large and hard problem: showing how state structures and processes shape specific technical and scientific outcomes. Third, in addition to her excellent discussion of tacit knowledge, Ben Ouagrham-Gormley writes with great insight about knowledge reservoirs, knowledge transfer, and knowledge loss in and across organizations.

Of course, the reviewers raise hard questions, find shortcomings, and suggest further research that can be done. I leave it to readers of these reviews and of *Barriers to Bioweapons* to ponder these critiques for themselves.

In what follows, I briefly add to the reviewers' mapping of *Barriers to Bioweapons* onto other literature, in particular, science, technology, society, and also organizational behavior. I conclude by sketching very recent and quite possibly revolutionary change in biotechnology and ask: will Ben Ouagrham-Gormley's arguments continue to hold? And, how would we know?

There are many ways to contextualize changes in science and technology, including the interactions of inventors and the public, interactions within and among expert communities, and the effects of organizational goals and routines on innovation.

Ben Ouagrham-Gormley's questions force her to take a different tack and to work on both very large and very small scales: how to characterize the effects of different states' structures and processes on varying technical and program outcomes. She very successfully meets this challenge. We have seen above how her well-ordered

[3] W. Richard Scott and Gerald F. Davis, *Organizations and Organizing: Rational, Natural, and Open System Perspectives* (Upper Saddle River: Pearson, 2007), 31. Many organizational sociologists have migrated to business schools and work in what is termed 'organizational behavior.'

and deeply knowledgeable analysis enables her to compare the programs of the Soviet Union and United States.[4]

In working on both scales, Ben Ouagrham-Gormley is in small but excellent company. A recent exemplar of work—in the nuclear realm—that spans state processes and apparently technical program outcomes is Sonja Schmid's *Producing Power*, which shows how two very powerful rival state ministries within the Soviet state "not only *reflected* the … centralized state bureaucracy … [b]ut actively *defined* technical features of the [nuclear] reactors ultimately chosen for mass implementation"—including the reactor design at Chernobyl (my emphases)."[5] Another exemplar is Målfrid Braut-Hegghammer's forthcoming *Unclear Physics*, which focuses not on powerful entrenched state bureaucracies but on the separate and distinct failures of nuclear weapons programs in two personalistic autocracies, Iraq and Libya. In each state, the demands from the dictators Saddam Hussein and Muammar al-Gaddafi respectively led fearful scientists and bureaucrats to make unrealistic assessments of timelines and the rate of progress, causing each program to fail in its own way.[6]

Work on both very large and small scales is not for the faint of heart. But work as successful as *Barriers to Bioweapons* and other work in STS—whether explicitly comparative or not—serve as powerful models for future comparative work in the field.[7]

Ben Ouagrham-Gormley's use of the intriguing concept of "knowledge reservoirs" (27-36) draws especially from work by the scholar of organizational behavior Linda Argote and her colleagues. Organizational behavior is the intellectually richer business school version of political science's organization theory. Readers of the following reviews who are not steeped in the abstractions of the organizational behavior literature will likely better understand the power of the concept "knowledge reservoirs" by starting with Ben Ouagrham-Gormley's insights.

Ben Ouagrham-Gormley writes:

> Written documents—be they blueprints, protocols, scientific publications, or other scientific data—are the main reservoirs of explicit knowledge, as they can be easily transferred and stored for long periods of time. Written documents, however contain only knowledge that can be codified…. Experimental protocols are a second form of explicit data [and] usually reach another lab through the transfer of a lab researcher

[4] See also the work of Ben Ouagrham-Gormley's closest collaborator Kathleen M. Vogel, *Phantom Menace or Looming Danger? A New Framework for Assessing Bioweapons Threats* (Baltimore: Johns Hopkins University Press, 2013); and see their citations to their joint work.

[5] Sonia D. Schmid, *Producing Power: The Pre-Chernobyl History of the Soviet Nuclear Industry* (Cambridge: MIT Press, 2015), 65.

[6] Målfrid Braut-Hegghammer, *Unclear Physics: Why Iraq and Libya Failed to Build Nuclear Weapons* (Cornell University Press, 2016).

[7] An earlier exemplar is Gabrielle Hecht's *The Radiance of France: Nuclear Power and National Identity after World War II* (Cambridge, Mass.: MIT Press, 1998).

> who can demonstrate how to use them. Users also typically modify common protocols…. Such modifications are rarely documented…. These written documents are all incomplete reservoirs of knowledge [and] require extensive interpretation, user modifications, and adaptations (27).

By contrast, the scholars of organizational behavior Linda Argote and Paul Ingram—from whom Ben Ouagrham-Gormley draws—define six dyadic networks, composed of members, tasks, and tools, where organizational knowledge is embedded. They begin with "member-member network[--]the organization's social network," and so on, concluding with the single triadic network, the "member-task-tool network [that] specifies which members perform which tasks with which tools…Organizational performance improves with increases in both the internal compatibility of the networks and their external compatibility with other networks (153) ….In order for knowledge transfer to be successful, the reservoirs or subnetworks that are moved must fit or be compatible with the new context …. [T]he most problematic knowledge conduits are the subnetworks involving people and not the people in them per se (159).[8]

Despite its abstraction, there is a great deal to be learned from this literature on knowledge reservoirs, and also on knowledge transfer and knowledge loss. Ben Ouagrham-Gormley has drawn on and made these ideas her own, much to the reward of readers of *Barriers to Bioweapons*.

Ben Ouagrham-Gormley is fully aware of the new and remarkable ability of biologists and bio-engineers in "biotech" and the new field of synthetic biology to intervene in, manipulate, and create genetic material. Indeed, she wrote her book in the context of two major sets of discoveries and inventions that have deeply changed the field of biology. The first is a process largely developed in the early to mid-1980s that enabled scientists to "amplify," that is, make great quantities of, genetic material through a process called PCR (Polymerase Chain Reaction).[9] This was almost certainly the single most important tool in what is broadly termed biotechnology, but it is not the only one.

The second development is synthetic biology, a set of disciplines and series of processes incorporating and building on biotechnology. Synthetic biology can be broadly dated to the beginning of this century and is the "convergence of advances in chemistry, biology, computer science, and engineering."[10] Synthetic biology *automates* construction of DNA, is in the process of *standardizing* biological "components," and is developing

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[8] Linda Argote and Paul Ingram, "Knowledge Transfer: A Basis for Competitive Advantage in Firms," *Organizational Behavior and Human Decision Processes* 82:1 (May 2000), 150-169, at 153. See also the Linda Argote and Eric Darr, "Repositories of Knowledge in Franchise Organizations: Individual, Structural, and Technological," in Giovanni Dosi, Richard R. Nelson, and Sidney G. Winter, eds., *The Nature and Dynamics of Organizational Capabilities,* rev. ed. (New York: Oxford University Press, 2001), 51-68.

[9] See Paul Rabinow, *Making PCR: A Story of Biotechnology* (Chicago: University of Chicago Press, 1996). One of the key figures, Kerry Mullis, was awarded the Nobel Prize in chemistry in 1993.

[10] "Convergence … and engineering," and also learning resources: see the website of the Synthetic Biology Engineering Research Center, https://www.synberc.com.

more abstract languages that have greater scope and ease of use. The latter can be thought of moving from the computer world of machine language of 1s and 0s to the many programs computer users work with now.[11]

As *Barriers to Bioweapons* was nearing completion, in June 2012, a third breakthrough was published in *Science* that has opened up a "new frontier of genome engineering."[12] At its simplest, this is a "group of molecules that can edit DNA."[13] 'Cut and paste' editing was already being done, but not with this ease of use. The breakthrough enables a remarkable manipulation of genetic material with a precision and speed not before possible.

This new tool has a name only a scientist could love, CRISPR-Cas9. The acronym, pulled apart, tells the story. CRISPR stands for "clustered regularly interspaced short palindromic repeats."

Think of the twisted ladder of the double helix of DNA. The "steps" of the ladder are the matched pairs of four nitrogen "bases": adenine (A), thymine (T), guanine (G), and cystosine (C), in which an A on one side of the ladder is always joined to a T on the other, and a G on one side is always joined by a C. CRISPR is a highly regular order found at some locations on the ladder. To take a notional example, going up one side of the ladder, one might see the DNA palindrome ACCCT TCCCA. (Directly across on the other side of the ladder would be the matched pair TGGGA AGGGT.)

Between the DNA palindromes are long stretches of DNA sequences that for many years seemed to be in no obvious order, with no obvious function. It turns out, however, that what looked unordered contained pieces of previously encountered viruses; they had been filed as references should they attack again.

Cas9 (**C**rispr-**as**sociated proteins) are enzymes that function like a knife.

When a virus appears that matches the DNA of a filed virus, CRISPR-Cas9 locates it, and Cas9 very efficiently cuts it out, thus providing immunity. Moreover, it turns out that this ability to recognize and manipulate is not limited to viruses, but applies to any DNA sequence chosen. The discovery has been lauded, and the technology is being quickly adapted. In November 2014, Jennifer Doudna and Emmanuelle Charpentier were awarded the 2015 Breakthrough Prize in life sciences. Sponsored by Silicon Valley

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[11] The definition is drawn from Stanford bioengineering professor Drew Endy, "Defining Synthetic Biology" https://www.youtube.com/watch?v=XIuh7KDRzLk.

[12] Jennifer A. Doudna and Emmanuelle Charpentier, "The new frontier of genome engineering with CRISPR-Cas9," *Science* 346:6213 (28 November 2014), 1077; this is a review of the field by the two senior scientists who in 2012 discovered the CRISPR-Cas9 technology. I am grateful to Megan J. Palmer for bringing the issue to my attention.

[13] A "group of molecules that can edit": Carl Zimmer, "Breakthrough DNA Editor Born of Bacteria," *Quanta* (6 February 2015). See also the very accessible and excellent science journalism of Amy Maxmen, "The Genesis Engine," *Wired* (August 2015); also see Sarah Zhang, "Everything You Need to Know About CRISPR, the New Tool that Edits DNA," *Gizmodo* (6 May 2015). For further explications of CRISPR-Cas9, and the human side of the story, which includes a fierce rivalry with another team, see Jennifer Kahn, "CRISPR QUANDRY," *New York Times Magazine* (9 November 2015), and Michael Specter, "Gene Hackers," *New Yorker* (16 November 2015): 52-62.

technology billionaires, the prize awarded each scholar $3 million. A year later, CRISPR was awarded *Science*'s "2015 Breakthrough of the Year" award (for which it had been runner-up twice before).[14]

Ben Ouagrham-Gormley does not take up this breakthrough, but at the end of *Barriers to Bioweapons*, she does discuss scientists' new capabilities to synthesize viruses and genes (160-167). Will her claims about the difficulties of transferring tacit knowledge, "the skills and laboratory practices [that] remain essential elements of successful outcomes," (164) still hold for this revolutionary new method—and the consequences of it?

Fortunately, *Barriers to Bioweapons* provides us with the questions to be asked and answered: what quality of management, equipment, institutional paths to learning, and explicit and tacit knowledge will be required to use CRISPR-Cas9 and similar new tools being developed? And what qualities and knowledge will not be required? Precisely when and under what circumstances does tacit knowledge come into play? CRISPR-Cas9 is a very powerful tool, but what are the error rates when deployed, and what determines those rates? Understanding error and consequence is all the more critical with the greater ability to edit genes. Scientists are interested in editing human cells, and one group has already worked on modifying human embryos.[15] What will error mean here?

And, more broadly, how should this tool, and others, be used ethically? How should ethical behaviour be coded in professional standards and government regulations? There is, as yet, not a robust system of governance.[16] Who will write the rules? How should they be enforced? What restrictions should be put on modification of the human genome? What should be allowed?

Explicitly in the wake of CRISPR-Cas9, the National Academies of Science and Medicine have undertaken the Human Gene-Editing Initiative to "examine the scientific underpinnings and clinical, ethical, legal, and social implications of human gene editing" in order "to inform decision making related to [these] advances." Toward the end of 2016, the committee will make "recommendations for the responsible use of human gene-editing research."[17] Recommendations, however, are not the same as actually establishing a sound system of governance. For those who want and need to understand the range and subtlety of these issues, *Barriers to Bioweapons* should be required reading.

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[14] Zimmer, "Breakthrough DNA Editor," *Quanta*; John Travis, "Making the cut: CRISPR-genome-editing technology shows its power," *Science* 350:6267 (18 December 2015): 1456-1457.

[15] David Cyranoski and Sara Reardon, "Embryo editing sparks epic debate," *Nature* 520 (30 April, 2015): 593-594. On a wider range of ethical issues, see Specter, "Gene Hackers," *New Yorker*.

[16] Megan J. Palmer, Francis Fukuyama, and David A. Relman, "A more systematic approach to biological risk," *Science* 350:6267 (18 December 2015): 1471-1473. The article provides an excellent overview of current fractured oversight and provides broad recommendations based on other regulatory institutions.

[17] The National Academies of Sciences, Engineering, and Medicine, "Human Gene-Editing Initiative," http://nationalacademies.org/gene-editing.

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Philip Egert is a Ph.D. candidate in the Department of Science and Technology in Society at Virginia Tech's Northern Virginia campus. He has over 30 years of experience with weapon systems design, production, and policy as both a private consultant and defense contractor. His current research interests include the social construction of large-scale technological systems and their failures, and the security/justice balance in national dual-use biotechnology policies. His related dissertation research focuses on the global political, economic, cultural, and knowledge fields of struggle in the recent H5N1 virus publishing controversies.

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Alexander H. Montgomery is department chair and associate professor of Political Science at Reed College. He has a B.A. in Physics from the University of Chicago, an M.A. in Energy and Resources from the University of California, Berkeley, and an M.A. in Sociology and a Ph.D. in Political Science from Stanford University. He has published articles on theorizing and dismantling proliferation networks; the perils of predicting proliferation, intelligence, and security studies; and on the effects of social networks of international organizations on power, interstate conflict, and economic sanctions. Most recently, he has been a Residential Fellow at the Woodrow Wilson International Center for Scholars; prior to that he was a Council on Foreign Relations International Affairs Fellow in Nuclear Security with a placement in the US Office of the Secretary of Defense (Policy) working for the Deputy Assistant Secretary of Defense for Countering Weapons of Mass Destruction, where his portfolio included writing a new Department of Defense Strategy for Countering Weapons of Mass Destruction. His current book project is on knowledge transfer, nuclear weapons, and counterproliferation policy.

Alex Spelling completed a B.A. in Modern History at the University of East Anglia in 2000 and received an M.A. in Modern History from the University of Nottingham in 2003. He was awarded his Ph.D. in History from Nottingham in 2008 for a study of the Anglo-American relationship during the Nixon Administration. Through to 2013 he was a Teaching Fellow in American History, specialising in 20th Century Foreign Policy, particularly the Cold War, at the Universities of Southampton and Aberdeen. He is currently a Research Fellow in STS on an AHRC-funded project *Understanding Biological Disarmament: The Historical Context of the Origins of the Biological Weapons Convention*. Dr. Spelling's research interests lie in Cold War History from a transatlantic perspective, with special reference to the U.S.-UK relationship and arms control issues relating to chemical and biological weapons (CBW).

Review by Philip R. Egert, Department of Science, Technology, and Society, Virginia Tech

While writing this review, I had the timely diversion of attending the National Science Advisory Board for Biosecurity (NSABB) meeting to hear the presentations and discussions on the board's preliminary risk and benefit assessments for "gain-of-function studies of concern" – or research with the potential to generate pathogens with enhanced pathogenicity, transmissibility, and the ability to evade public health control measures.[1] The meeting was part of a deliberative policy-making process set in motion in late 2014 when the U.S. government took the unprecedented step of pausing all gain-of-function research on influenza (primarily the Highly Pathogenic Avian Influenza A virus, subtypes H5N1 and H7N9), Middle East Respiratory Syndrome, and Severe Acute Respiratory Syndrome viruses until a new government policy on gain-of-function research could be developed. While the meeting lacked the hysterics of potential bioterrorist fears that influenced the initial 2011/2012 NSABB meetings and set the opening pages for Sonia Ben Ouagrham-Gormley's book, the new risk benefit assessments presented by the NSABB generally relied on their earlier previously flawed assumptions and materials-based, technological deterministic models. In fact, the weakness in these models was admitted in the board's working paper: "estimating [biosecurity] risk by understanding consequences without their likelihood is challenging."[2] Nonetheless, American policy makers press forward in trying to construct regulations to limit the risks of malevolent development and use of biological materials based on an incomplete understanding of the expertise and organizational barriers to weaponizing biological materials.

Against this expert policy-making backdrop and during an era when virtually every biological public crisis, from the Ebola outbreaks in West Africa to E Coli outbreaks at the Chipotle chain of restaurants, are framed on social media by conspiracists as potential bioterrorist actions, Ben Ouagrham-Gormley convincingly challenges the prevailing assumptions of policy experts and conspiracy theorists alike. Based on over a decade of research, including two years of field work in Kazakhstan studying the former Soviet Union's bioweapons programs, her research shows "how difficult, protracted, and expensive bioweapons efforts have been…with outcomes rarely achieved by what the magnitude of investment might have suggested" (x). And while she notes that this is good news for those concerned with the possible proliferation of biological weapons, the bad news is that failure to understand or recognize the 'key determinants' of bioweapons can create the unanticipated consequences of actually creating new opportunities for proliferation. Ben Ouagrham-Gormley is not the first to address this issue, but certainly is one of the few to authoritatively offer a counter narrative to deterministic bioterrorism expert and policy hawks.

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[1] See the NSABB's meeting website for the agenda and links to the meeting's presentations and working papers, accessed 10 January 2016, http://osp.od.nih.gov/office-biotechnology-activities/event/2016-01-07-130000-2016-01-08-220000/national-science-advisory-board-biosecurity-nsabb-meeting.

[2] NSABB Working Group, *Working Paper Prepared by the NSABB Working Group on Evaluating the Risks and Benefits of Gain-of-Function Studies to Formulate Policy Recommendations*, 23 December 2015, accessed 28 December 2015, http://osp.od.nih.gov/sites/default/files/NSABB%20WG%20Working%20Paper%20on%20Gain-of-Function%20Studies%2012-23-2015.pdf.

Kathleen Vogel recently explored the relationship of social constructions to the acquisition and transfer of bioweapons knowledge and the relationship of tacit knowledge to bioweapons development.[3] Whereas Vogel highlights the 'technological frame' that privileges technical factors without considerations of the social dimensions surrounding those technical factors, Ben Ouagrham-Gormley complements Vogel's analysis with an exploration of the endogenous and exogenous variables that determine the progress, timelines, and success or failure of bioweapons programs. Similarly, James Revill and Catherine Jefferson recently explored the marginalization of tacit knowledge in its relationship to the Biological Weapons Convention (BWC).[4] They note that failure to understand the enormous sociotechnical difficulties in development of biological weapons results in distorted perceptions of the threat posed by dual-use biotechnologies with a resultant flawed approach to policies designed to prevent proliferation of biological weapons. Similarly, Ben Ouagrham-Gormley complements Revill and Jefferson's research with an expansion of the relationship between tacit knowledge at the expert and non-expert level and its position within the larger bioweapons organizations at both a temporal and spatial level.

What separates Ben Ouagrham-Gormley's work from these and other similar works is the breadth of disciplines that she draws from to frame her five empirical case studies (the large state-sponsored U.S. and former Soviet Union bioweapons programs, and the smaller covert programs of Iraq, South Africa, and Aum Shinrikyo). Not unexpectedly, her background in economics, organizational theory, and weapons of mass destruction (WMD) nonproliferation studies is woven throughout, but she also adroitly draws from the rich science and technology studies (STS) corpus on the nature of knowledge.[5] This interdisciplinary richness provides the foundation for the book's three fundamental questions: "What is bioweapons knowledge? How can it be acquired and transferred? What facilitates or impedes bioweapons developments?" (ix). To answer these questions, Ben Ouagrham-Gormley begins with a brief review of the recent H5N1 publishing controversies about whether or not potential bioterrorists could replicate a virus with pandemic implications just by reading two articles in the journals *Nature* and *Science*. The biosecurity and pathogen weaponization questions raised by the H5N1 controversies lay the groundwork for the first of three interrelated misconceptions or assumptions about the perceived threats of bioweapons that Ouagrham-Gormley convincingly debunks.

Expanding the earlier work of Christian Enemark, Jeffrey Cavanaugh, and especially Allison Macfarlane, the former Chairman of the U.S. Nuclear Regulatory Commission, Ben Ouagrham-Gormley offers that biological weapons should not be equated with nuclear weapons because the barriers to entry are vastly different.[6] This argument is critical because one of the prevailing nonproliferation and counterproliferation

[3] Kathleen M. Vogel, *Phantom Menace or Looming Danger? A New Framework for Assessing Bioweapons Threats* (Baltimore: Johns Hopkins University Press, 2013).

[4] James Revill and Catherine Jefferson, "Tacit Knowledge and the Biological Weapons Regime," *Science and Public Policy* 41 (2014): 597-610.

[5] For a comprehensive STS literature review on the relationship of knowledge production to security, see Kathleen Vogel et al. "Chapter 36. Securing Knowledge: Science, Technology, and Security," in *The Handbook of Science and Technology Studies*, eds. Ulrike Felte, Clark Miller, Rayvon Fouche, and Laurel Smith (Cambridge: MIT Press, forthcoming).

[6] See, for example, Christian Enemark, "Biological Attacks and the Non-State Actor: A Threat Assessment," *Intelligence & National Security* 21:6 (2006): 911-930; Christian Enemark, "Farewell to WMD: The Language and

policy arguments is based on the mistaken assumption that biological weapons development does not face the steep organizational and financial barriers that nuclear weapons do, and therefore they are easy and cheap to produce. This "front-end/material-based nuclear model produces a distorted and even apocalyptic picture of the threat" (4) and results in technological deterministic arguments such as the one most recently given by biosecurity expert and former U.S. Department of Homeland Security Under Secretary Daniel Gerstein, "democratization of biotechnology means that the world is literally *one* [emphasis added] rogue microbiologist away from a potentially devastating biological attack." [7]

Ben Ouagrham-Gormley persuasively argues that these apocalyptic narratives are not only patently false; they are more importantly deleterious to meaningful nonproliferation policy development, writing that "unlike nuclear weapons, which rely on materials with physically predictable properties, bioweapons are based on living organisms or by-products of living organisms, which evolve, are prone to developing new properties, and are sensitive to environmental and handling uncertainties" (5-6). And, it is precisely the unpredictability of biological organisms, from the initial acquisition of a capricious volatile microorganism to its controlled scale-up into a weapon capable of effective delivery, that places far greater emphasis on the organizationally integrated systems-level knowledge necessary for biological weaponization than in the development of nuclear weapons. There is not a single example of legitimate scientific biological research or intended programs of biological weaponization, by either a state or nonstate terrorist group, which places the world on a technological trajectory of "one rogue microbiologist" being able to launch a devastating biological attack.

The second assumption and misconception that Ben Ouagrham-Gormley takes on is the fallacy of universal, free-flowing knowledge. Returning to one of the initial arguments in the H5N1 controversies, she characterizes this fallacy as the idea that "knowledge spreads easily, and written documents, such as scientific publications, weapons designs, or scientific protocols, constitute complete representations of a technological artifact, thus allowing the replication of past work, even by untrained individuals" (8). Debunking this misconception is one of the book's core strengths and unique contributions to the literature on bioweapons. To do so, Ben Ouagrham-Gormley reaches across a rich body of literature and research in economics, cognitive science, knowledge management, STS, and even philosophy to explore the critical role of tacit knowledge in scientific endeavors and large-scale technological systems development programs, such as bioweapons development.

Framing her arguments on the work of STS scholar Harry Collins, Ben Ouagrham-Gormley offers that there are two categories of tacit knowledge that are important to understand when looking at the reproducibility of past research: "the first category includes forms of tacit knowledge that could conceivably be made explicit or

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Science of Mass Destruction," *Contemporary Security Policy,* 32:2 (2011), 382-400; Jeffrey M. Cavanaugh, "From the 'Red Juggernaut' to Iraq WMD: Threat Inflation and How it Succeeds in the United States," *Political Science Quarterly* 122:4 (2007/2008): 555-584; and Alison Macfarlane, "All Weapons of Mass Destruction Are Not Equal," *MIT Center for International Studies Audit of the Conventional Wisdom* 5:8 (2004): 1-5, accessed 4 January 2016, http://web.mit.edu/cis/pdf/Audit_6_05_Macfarlane.pdf.

[7] Daniel M. Gerstein, "We're Not Prepared for a Biological Attack: The U.S. Needs to Show Leadership and Initiative at the Biological Review Convention Eighth Review Conference," *U.S. News & World Report*, 23 December 2015, accessed 5 January 2016, http://www.usnews.com/opinion/blogs/world-report/articles/2015-12-23/the-us-needs-to-exercise-leadership-at-the-biological-weapons-convention.

verbalized but require direct contact between people for their identification and transfer.[8] The second category includes types of tacit knowledge that cannot be or are not made explicit either because they rest on deeply unconscious mechanisms or because they are too complex to be effectively translated into words. Their transfer also requires direct interaction between individuals and, more importantly, a long-term collaborative engagement" (19). For the purposes of understanding the barriers to bioweapons development, the role of tacit knowledge means that it is, "…in fact local, person specific, private, and noncumulative" (36). Ben Ouagrham-Gormley cites numerous examples in both her empirical studies as well as in other related instances of the way the tacit production of knowledge has played out in the laboratory. For example, one of the H5N1 studies referred to earlier took 10 years to prepare the experiment, followed by four years of actual research; a long-term process built on the cumulative individual and communal tacit knowledge resident in a large co-located team of scientists, postdoc researchers, laboratory technicians, and other supporting expertise that was impossible to capture in the controversial eight-page article in the journal, *Science*.[9] Other examples include the significant large-scale delays, repeated failures, and costs incurred when the U.S. and the Soviet Union tried to transfer bioweapons development and production between locations, facilities, teams, and individuals. Or, on a much smaller scale, the same failed results occurred due to the loss of tacit knowledge when the terrorist group Aum Shinrikyo had to move its operations from Tokyo to Mount Fuji for security concerns.

Third, Ben Ouagrham-Gormley takes on the fallacy of treating technology as a black box and obscuring the role that knowledge acquisition and use plays in the development of bioweapons, and, more importantly, creating an obfuscation that leaves a large gap in nonproliferation policy. This misconception is based on the two important albeit faulty premises: "new technologies and equipment are black boxes…which can be used by any user, irrespective of their technical skills; and technology developments result in the gradual deskilling of technology and scientific work. Therefore, machines and their accompanying instructions become the embodiment of human knowledge, captured, and codified for easier use by less experienced individuals" (11). While this misconception may initially appear to be more obtuse, if not merely academic, when compared to the previous two, it in fact goes straight to the heart of Ben Ouagrham-Gormley's ultimate argument. That is, erroneous assumptions about the barriers to bioweapons development are not just debatable academic fodder, they have real world nonproliferation policy implications. Reliance on the myth of linear technological determinism produces faulty assessments of a bioweapons program's developmental timeline, chances for success, and tends to greatly overstate the threat. As the U.S. learned with disastrous consequences in Iraq, all bioweapons programs are not equally successful within similar time frames. Equal access to biomaterials, scientific documents, and technological equipment do not produce equal results. Moreover, a myopic policy projection based on the singular role of these materials in a threat assessment not only obscures the role of knowledge but also produces counterproductive nonproliferation policy in attempts to control only the material component of bioweapons development.

[8] See Harry M. Collins, "The TEA Set: Tacit Knowledge and Scientific Networks," *Science Studies* 4:2 (1974): 165-185; Harry M. Collins, "Tacit Knowledge, Trust, and the Q of Sapphire," *Social Studies of Science*, 31:1 (2001): 71-85; Harry M. Collins, *Tacit and Explicit Knowledge* (Chicago: University of Chicago Press, 2010); and Harry Collins, "Three Dimensions of Expertise," *Phenomenology and the Cognitive Sciences* 12:2 (2013): 253-273.

[9] See Sander Herfst et al., "Airborne Transmission of Influenza A/H5N1 Virus between Ferrets," *Science* 336 (2012): 1534-1541.

Obviously, Ben Ouagrham-Gormley felt it was important to initially tackle these three materials-based misconceptions about bioweapons programs because they are so pervasive in today's hyperventilated terrorism-obsessed policy and public discourse. And, while extremely useful in offering a counter narrative, they are not the book's true value, which in fact lies in the new analytical framework Ben Ouagrham-Gormley proposes for more meaningfully assessing "the progress, timelines, and outcomes of state and terrorist bioweapons programs" (12) so that effective nonproliferation and counterproliferation policies can be developed to prevent future threats. Having established the importance and role of knowledge in bioweapons programs, Ben Ouagrham-Gormley offers a substantive argument for her empirically driven framework. Her framework is based on two sets of factors that affect the development and use of knowledge in bioweapons programs: endogenous variables that come from within the program and exogenous variables that come from the outside.

Endogenous variables include, "a bioweapons program's structural and work organization, its management style, and the social context within which knowledge is created" (13). And, because bioweapons programs do not exist in a vacuum, their timelines and outcomes are also based on external, or exogenous variables. Ben Ouagrham-Gormley identifies five such variables that shaped the bioweapons programs in her empirical case studies: the amount of available foreign technical assistance, the timing and absorptive capacity of this technical assistance, the priority political or group leaders devote to a program, the program's economic circumstances, and in many cases, the actual geographical locations of the programs. As she states, "[m]ost important to a program's timeline and outcome is the way in which states or terrorist groups integrate these two sets of variables: social, organizational, and managerial factors that influence knowledge acquisition and scientific work from within; and exogenous variables that influence achievements from the outside" (13-14). Theoretically, a program should be successful if it can manage to effectively balance both sets of variables, but as Ben Ouagrham-Gormley shows neither the U.S. nor the Soviet Union could successfully manage these variables to produce the desired outcome, especially when contrasted against the time and resources invested in them. And, the other three smaller bioweapons programs, operating under even far greater limitations, never really came close.

Composed in three parts, the middle section of Ben Ouagrham-Gormley's book (chapters 4-6) provides strong empirical support for her framework. She presents chapter-length analyses of the U.S. and former Soviet Union's bioweapons programs, respectively, and an intriguing third chapter which combines three smaller case studies of the Iraqi, South African, and Aum Shinrikyo bioweapon programs. A possible interesting addition to this chapter to illustrate the known opposite end of the scale from the Soviet program might have been the primitive salmonella bioweapon program in Oregon by followers of the religious cult leader Bhagwan Shree Rajneesh. That said, Ben Ouagrham-Gormley provides a rich highly granular account of each of these five bioweapons programs. She has made good use of the published historical record on each of her five empirical studies and supplemented that literature with extensive personal interviews and unpublished archival research, especially in the former Soviet Union, to provide a unique insight into the programs. In doing so, Ben Ouagrham-Gormley provides a compelling argument for the way the endogenous and exogenous variables combined to shape the outcomes of each of the programs.

Ben Ouagrham-Gormley's analysis of the U.S. program effectively supports her primary conclusion that access to expertise and facilities cannot be used as the only variable when assessing the possibility of a new state-sponsored bioweapons program. After almost three decades of effort, while the U.S. was able to constitute a complete bioweapons research, production, and testing capability, it was unable to produce a bioweapon that fit military doctrine or needs. Of course, one could argue there was a disconnect between the

U.S. program and its military doctrine from the very beginning, but that is a subject beyond the scope of Ben Ouagrham-Gormley's analysis. Likewise, with even greater resources in terms of funding, expertise, and facilities, the Soviet program was not able to achieve its desired outcomes. And, because the Soviet program continued after the BWC went into effect, it suffered from the additional constraints of having to operate in a covert manner. As Ben Ouagrham-Gormley quite correctly notes, "the Soviet case illustrates oft-ignored consequences of covertness. Maintenance of a covert program not only dramatically raises the financial cost of an illicit program but also negatively affects scientific results" (121). She uses this point as a segue to exploring the importance of the BWC which, by definition, if not necessity, drove the Iraqi and South African programs underground. Lacking both the time and resources of the U.S. and Soviet programs, combined with the increased burdens of operating covertly, both programs failed due to characteristics which are common to all covert programs: participants who had been selected for loyalty to the cause instead of scientific or technically relevant credentials, flawed research and managerial decisions that were driven by fear and violence, suboptimal organizational structures that were caused by the need to avoid detection, and program instantiations that were based on, at best, ignorant, and, at worst, delusional political leadership. Last, Ben Ouagrham-Gormley shows how these causes of failure were actually magnified in Aum's bioweapons program because it lacked the state support that at least gave the Iraqi and South African programs an illusory representation of progress. Ben Ouagrham-Gormley closes her Aum study with a fascinating speculation by the group's leader Shoko Asahara that U.S. narratives on the relative technological ease of developing bioweapons were in fact a misinformation ploy "designed to mislead terrorist groups into pursuing such weapons" (143).

Ben Ouagrham-Gormley uses Asahara's speculation as a way of introducing the perils of misinformed nonproliferation and counterproliferation policies with an equally interesting quotation from al-Qaeda's deputy head Ayman Al Zawahiri on how that terrorist organization considered developing bioweapons precisely because "the enemy drew our attention to them by repeatedly expressing concerns that they can be produced simply with easily available materials" (145). Clearly the current technology-based narratives about the ease of bioweapons development and readily available agents, which Ben Ouagrham-Gormley traces back to the 2008 WMD Commission's *World at Risk*, are lacking in dissuasive authority. The need to alter this narrative to focus on the knowledge barriers and their key determinates is the first of four policy recommendations in the closing chapter. Her second recommendation focuses on the need for more robust U.S. support for expansion of the BWC to include a formal verification mechanism. Recognizing that any inspection regime is not a panacea, Ben Ouagrham-Gormley argues that it could at least delay or disrupt bad actors' intentions – which, as she shows, can often be enough to effectively derail a bioweapons program, especially when applied in the early knowledge-accumulation stage. Closely related to the need for better inspections are also better assessment frameworks. As Ben Ouagrham-Gormley notes, the U.S. has a dismal track record of accurately assessing past bioweapons programs, since the assessments are exclusively materials-based and do not account for the type and level of knowledge necessary to successfully work with the materials. She suggests that even a "sketchy picture…of what constitutes the hinges of a program – knowledge, organization, and integration" (156) will produce better results than past assessments. Last, and closely related to her first recommendation, is a recommendation for policy makers to move beyond the myth of the so-called biotechnology revolution speeding the spread of expertise and facilitating bioweapons development. Citing both the Cooperative Threat Reduction Program and the H5N1 controversies[10] as

[10] Ironically, the H5N1 publishing controversies broke out in the middle of an ongoing reproducibility crisis in the life sciences that Ben Ouagrham-Gormley does not address in her book, but additionally bolsters her claims of published research being a poor material predictor of research reproducibility. See, for example, John Ioannidis, "Why

examples, Ben Ouagrham-Gormley argues that access to technologies and other materials cannot be used as predictors of success in scientific replication, particularly bioweapons work. "[S]uccess…still depends on the cumulative and cooperative work of teams of scientists, who acquire specific skills over a lengthy period of time, and who work within local organizational and managerial contexts" (165).

I close this review with a brief comment on what I earlier referred to as this book's real value: Ben Ouagrham-Gormley's assessment framework that is built around a set of interdependent exogenous and endogenous variables. While I heartily endorse the need and application of such a framework and fully support the logic underlying its formulation, in application to a non-state terrorist organization it suffers from *presuming others would act as we would*. While the framework is suitable for analyzing state-sponsored programs through the historical lens of the modern nation state, even for mercurial rogue states such as North Korea, it lacks two important additional variables when applied to today's large non-state terrorist organizations, such as al-Qaeda, Boko Haram, or Islamic State in Iraq and Syria (al-Sham) (ISIS). The first is a simple exogenous infrastructure variable: access to an undetectable continuous source of clean electric power over a multi-year period of time. Lacking this resource, bioweaponering is simply physically impossible. The second is a more complex endogenous variable that gets to the motivations and intentions of terrorist organizations, and more specifically the multi-variable tradeoffs they continuously make in terms of time, timing, resources, and priorities. For example, to use the very real and admittedly extreme apocryphal example of ISIS control of the Iraq Mosul Dam in 2014: why take on the immense challenges of covertly developing even a crude bioweapon that ultimately may or may not work at some undesignated date in the distant future, when instead you can blow up a dam on a specific date for a couple thousand dollars' worth of explosives, immediately post video of the explosion on social media for recruiting purposes, and drown half a million people within a few days. In other words, today's terrorist organizations make "low tech/high concept" tradeoffs about potential weapons and their effects, that modern states do not, which need to be accounted for in a bioweapons assessment framework.

This comment should not be construed as a criticism, but rather as a suggestion for additional consideration to an otherwise insightful and cogent examination of a subject that is too frequently discussed in unapproachable technical terms or cloaked in political hubris. Ben Ouagrham-Gormley has done the field of bioweapon nonproliferation and counterproliferation studies a tremendous service with the clarity and objective thoughtfulness of her arguments. She closes the book with a suggestion that a knowledge-based framework could also be useful in supporting the nonproliferation efforts and related threat assessments of other forms of WMDs and missile delivery systems. I would expand that suggestion to offer that her interdisciplinary-based arguments extend beyond weapon systems, and can provide a useful new framework for analyzing the success and failures of many civilian large-scale scientific and technological systems

Most Published Research Findings Are False," *PLoS Medicine* 2 (2005)" 0696-0701; Glenn Begley and Lee Ellis, "Drug Development: Raise Standards for Preclinical Cancer Research," *Nature* 483 (2012)" 531-533; Meredith Waldman, "NIH Mulls Rules for Validating Key Results," *Nature* 500 (2013)" 14-16; and Sonia Ben Ouagrham-Gormley and Shannon Fye, "Restricted Science," *Frontiers in Public Health* 2 (2014): 158-160.

Review by Jacques E. C. Hymans, University of Southern California

Sonia Ben Ouagrham-Gormley's *Barriers to Bioweapons* is a major step forward for the literature on the proliferation of weapons of mass destruction. It should have a big impact on both scholarship and policy.

The book's first contribution to the proliferation literature is simply its topic: the inner workings of biological weapons programs. The overwhelming majority of scholarship on proliferation has focused on nuclear weapons. Nuclear weapons certainly pose big dangers, but many people fear that bioweapons will be the *next* big danger. Are their fears really justified? What specific threats are likely to arise? How much time do we have to forestall them? Unfortunately, most of the short reading list on these questions is written by people channeling their inner Michael Crichton. By contrast, *Barriers to Bioweapons* stands out for its detailed and sober depiction of the real world of bioweapons R&D.

The book's second contribution is its strong riposte to the rampant fears that millennial terrorist groups or crazy state leaders will soon be in a position to spread incurable diseases rapidly across the population of the U.S. or other hated enemies. It turns out that modern bioweapons are at least as difficult to produce as nuclear weapons. In some respects they are more difficult to produce, as their basis in fragile living things makes them incompatible with standard military approaches to weaponization and stockpiling. Even the highly professional U.S. bioweapons program ran into considerable trouble in the face of these technical challenges.

The book's third contribution is its application of the general literature on the organizational and management challenges of scientific research and development projects to the specific case of bioweapons R&D. Ben Ouagrham-Gormley concludes that the most important 'barriers to bioweapons' are not international inspectors, U.S. cruise missiles, or Mossad assassins. Instead, they are essentially the same barriers that confront all 'big science' projects: the difficulties of building cooperative teams of highly trained scientific and technical workers and giving them operational autonomy, ample material resources, and clearly defined collective goals—all in complete secrecy. No wonder the oft-repeated predictions of biological Armageddon since 9/11 have failed to materialize.

Ben Ouagrham-Gormley also explicitly links her findings on the difficulties of achieving bioweapons proliferation with the recent findings by myself, Alexander Montgomery and other scholars on the difficulties of achieving nuclear weapons proliferation.[1] The convergence of these two strands of the international security literature should greatly reinforce the field's confidence in the findings of both. The fundamental point is that the proliferation of weapons of mass destruction (WMD) is very hard to achieve and usually slow going. The rogue states and terrorist groups that most want WMD today are also the least likely to succeed in producing such weapons, because they routinely abuse the norms of scientific professionalism. Moreover, the

[1] Jacques E. C. Hymans, *Achieving Nuclear Ambitions: Scientists, Politicians, and Proliferation* (Cambridge University Press, 2012); Alexander Montgomery, "Stop Helping Me: When Nuclear Assistance Impedes Nuclear Programs," in Adam Stulberg and Matt Fuhrmann (eds.), *Nuclear Renaissance and International Security* (Stanford University Press, 2013), 177-202; Robert E. Kelley, "The Iraqi and South African Nuclear Weapon Programs: The Importance of Management," *Security Dialogue* 27:1 (1996): 27-38.

nightmare of a lone wolf terrorist producing genuine WMD in his basement workshop is a complete Hollywood fantasy. Therefore, there is no cause for panic.

Barriers to Bioweapons has its shortcomings. First, the book does not precisely define its dependent variable. In other words, at what point can it be said that a state or terrorist group has succeeded in producing bioweapons? We never get a straight answer to this question. Perhaps we are expected to rely on the legal definition of biological weapons offered by the Biological Weapons Convention (BWC), but that definition is almost a post-modern parody. The BWC's Article I prohibits the development, production, stockpiling, acquisition or retention of any of the following: (1) microbial or other biological agents, or toxins whatever their origin or method of production, of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes; (2) weapons, equipment, or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict.[2]

It is amazing that the formal legal definition of a biological weapon explicitly hinges on whether the possessor's lawyers can figure out some other excuse for having it. Maybe such definitional ambiguity is unavoidable in light of the dual-use nature of many biological materials. But even if there are inherent problems in defining the overall concept, Ben Ouagrham-Gormley could have laid out a rough-and-ready operational definition of 'success' in bioweapons R&D, akin to the nuclear proliferation field's traditional metric of the date of a country's first explosive nuclear test.[3] A clearer operationalization of the book's dependent variable would have allowed for better cross-national empirical measurement and theory-testing.

The acute problem with the book's vagueness about its dependent variable is that we are left unable to gauge the extent to which the hypothesized barriers to bioweapons development can truly be counted on to block the acquisition of any such weapons. Indeed, worryingly, the book's case studies of the U.S. and Soviet programs imply that weapons of mass death are actually easier to produce than mere battlefield bioweapons, because in the former case there is no need for precise targeting, immediate and predictable consequences, and protection of friendly troops. For example, the 1979 anthrax leak from the Soviet Union's Sverdlovsk facility might have killed tens of thousands if the wind had been blowing toward town instead of away from it. But Ben Ouagrham-Gormley does not seem to consider that anthrax emission to be an anthrax weapon, because she later states that the Soviets only started large-scale testing of "the anthrax weapon…by the late 1980s" (97). The fact that the Soviets continued to flounder in their quest to produce proper battlefield 'weapons' for many years *after* their program had already almost killed tens of thousands of their own citizens is not very reassuring.

These points about the Soviet case also highlight some shortcomings of the book on the independent variable side of the ledger. Ben Ouagrham-Gormley explains the Soviet bioweapons effort's many dead ends and frustrations over the years as consequences of a program structure that was "the complete opposite of what is

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[2] For the complete text of the BWC, see http://www.state.gov/t/isn/bw/c48738.htm

[3] The field's reliance on the first nuclear test as the basic metric of nuclear weapon stateness has been criticized in recent years, but even an imperfect yardstick is better than none. See Jacques E. C. Hymans, "When Does a State become a 'Nuclear Weapon State'? An Exercise in Measurement Validation," *The Nonproliferation Review* 17:1 (March 2010): 161-180, and Jacques E. C. Hymans and Matthew S. Gratias, "Iran and the Nuclear Threshold: Where is the Line?" *The Nonproliferation Review* 20:1 (March 2013): 13-38.

required to use knowledge efficiently" (99). But if that is true, then how did the Soviets end up accomplishing anything at all? The book does not give this question the attention it deserves. It only briefly suggests that what progress the Soviets did make was largely due to the country's long prior history of research in relevant scientific disciplines, which gave them a head start and greater "absorptive capacity." The book further argues that the bioweapons programs of Iraq, South Africa, and the Japanese terrorist group Aum Shinrikyo were utter failures because they "selected organizational and managerial models similar to those of the Soviet Union" (123) while also lacking its favorable scientific legacies.[4] Ben Ouagrham-Gormley's hypothesis on this point is plausible, but it begs the question of how the mismanaged Soviet bioweapons program was able to harness the country's rich scientific legacies.

A relevant comparative data point here is that the Iraqi program also started out with a reasonably strong scientific base, but the professional scientist carriers of that knowledge were soon weeded out because the regime wanted firm Ba'athist Party loyalists (125). The Iraqi comparison suggests that overall—and despite the ideological excesses and purges of the of the Lysenkoist movement in Soviet biology during the Joseph Stalin period—the Soviet program actually enjoyed relatively greater autonomy, and that its greater autonomy explains its relatively higher scientific quality and goal attainment. Such a conclusion, however, would be in tension with the book's claim that the two countries shared the same basic organizational and management model.

One possible way to resolve the tension would be to reconsider the consequences of the Soviet program's enormous size and dizzying fragmentation, which Ben Ouagrham-Gormley sees as major barriers to R&D progress (see, for example, 99-102). One could hypothesize instead that those structural factors of the Soviet program actually facilitated the program's R&D progress. The logic here is that the great size and fragmentation of the Soviet program allowed its scientists and engineers to avoid being completely manhandled by Moscow, whereas the participants in the smaller Iraqi program had nowhere to hide from Saddam Hussein and his inner circle. Many of the details provided in the book's case studies support this alternative hypothesis. However, another possibility is that Ben Ouagrham-Gormley simply goes too far in equating the Soviets' approach to project management with that of the Iraqi Ba'athists and the Aum Shinrikyo cultists. Here we have another example of how the book could have benefited from a more systematic and cross-nationally valid measurement of its core variables.

The shortcomings of *Barriers to Bioweapons* are reflective of a literature that is still in its infancy. They can be overcome. Indeed, thanks to Ben Ouagrham-Gormley's demolition of the myth of 'easy' bioweapons development, the stage is now set for rapid further progress in our understanding of this important international security issue.

[4] It should be noted that the book's interpretation of the South African program as a failure is open to question. Actually the program did succeed in its primary assigned task of developing assassination weapons that were extensively used by death squads linked to the apartheid regime. Ben Ouagrham-Gormley may be right to claim (134) that the program as structured would not have been able to achieve grander goals. But if the program had been given grander goals, it would not have been structured as it was.

Review by Alexander H. Montgomery, Reed College

Professor Sonia Ben Ouagrham-Gormley's book, *Barriers to Bioweapons: The Challenges of Expertise and Organization for Weapons Developmen*t, succeeds in fulfilling its many promises. It successfully connects together the multiple disciplines that constitute the study of weapons of mass destruction (WMD), while remaining accessible and thorough. It contributes to literature in political science, economics, security studies, public policy, and international relations, among others. In particular, the book ably spans multiple disparate fields, employing (thankfully) readable versions of frequently-obtuse theories in the social studies of science to demonstrate that the proliferation of biological weapons is much more difficult and therefore less likely than expected by most academics and policymakers. Furthermore, her conclusion applies the lessons of her book to new areas, including the dissuasion of new offensive biological weapons programs and the myth that dual-use biological research inevitably will lead to proliferation. Overall, the book significantly advances social-science research in WMD.

The book centers, perhaps unsurprisingly given the title, around the proliferation of biological weapons, with a focus on the interplay between tacit knowledge, organizational structure, and scientific management. As the author astutely points out, most policymakers and academics who work on biological weapons take the scientific processes surrounding the creation of knowledge for granted: materials and equipment are thought by scholars, with the notable exception of Kathleen Vogel, to be the only important chokepoints for aspiring weapons programs.[1] Ben Ouagrham-Gormley's work demonstrates conclusively that it is, rather, the production and transfer of knowledge that are the most difficult elements of biological programs, although she does not substantially differentiate between the *creation* of knowledge and the longer-term *maintenance* of it. By this I mean that it is entirely possible to have an organizational environment that allows individuals to successfully create knowledge (and weapons) but not to pass it on to future generations. This is not the book's focus—which is the overall success or failure of the program—but it is worth noting that these processes may differ significantly even if the organizational environments required (her focus) may be similar. *Barriers to Bioweapons* nonetheless shows a thorough comprehension of the multiple literature surrounding scientific knowledge (from business-school case studies through anthropological ethnographies). It translates these often-inaccessible texts into a set of variables that constitute important factors that limit or enable scientific knowledge-production processes. These include creating, identifying, and maintaining knowledge reservoirs in individuals, groups, or organizational structures; shaping organizational structures to promote frequent cross-pollination of ideas in person through mobility or proximity to create cognitive consensus; engineering systems to coordinate and integrate efforts while maintaining low barriers between organizational units; and managing the external environment.

I read an earlier draft of this book's manuscript, and so I have a perhaps unique perspective on the evolution of this book project. Previous drafts conceptualized a role that is perhaps oddly absent here*:* 'transactional engineers,' who facilitate interactions across organizations and institutionalizes knowledge. Although I normally despise neologisms, I found this one to be a very useful way of describing the role that a number of scientists have played in successful WMD programs. Los Alamos National Laboratory director Robert Oppenheimer, for example, was less a great scientist than he was a fantastic manager, keeping bureaucratic structures to a minimum while promoting transactions and integration across disparate parts of the U.S.

[1] Kathleen M. Vogel, *Phantom Menace or Looming Danger?: A New Framework for Assessing Bioweapons Threats*. Baltimore: Johns Hopkins University Press, 2013.

nuclear weapons program. Interestingly, in the final version of the book it is not Oppenheimer but Manhattan Project director Leslie Groves who is in the spotlight as one of Thomas Hughes' heterogenous engineers, "an individual who manages and sustains the alliances that will provide support for a long-term technological project" (51), with the other role of Ben Ouagrham-Gormley's missing transactional engineers being played instead by individuals who move around in the weapons complex and develop personal directories of knowledge, or "transactive memory" (40). While I agree with the characterization of Groves as managing the external environment with Oppenheimer in the lead role of internally managing the project itself, this is a potential missed opportunity for theoretical innovation since the term transactional engineer decently articulates the structural position of the internal manager who institutionalizes the processes by which transactive memory is created and sustained.

Theoretically innovative or not, the empirical chapters are very well-done; although the Soviet bioweapons program is somewhat well understood, the American one has comparatively been neglected (although see Frank Smith III's book on biodefense),[2] and consequently both of the author's main case studies not only effectively demonstrate her theoretical propositions but also expand our understanding of these programs with new research based on direct interviews with the participants. Her *International Security* article had already significantly moved the field forward while incorporating original research,[3] and I am glad to see this additional material come to light. The inclusion of additional case studies (Iraq, Aum Shinrikyo, South Africa) significantly bolster Ben Ouagrham-Gormley's overall argument and very effectively demonstrate the relevance of her work for both policy and research.

I do have a few minor quibbles with the text, primarily with the organization rather than the quality of the work. Providing a wider set of criteria for the 'success' or 'failure' of a program would be useful; although the author points out that both the U.S. and Soviet cases fell well short of the ideal posed by the nuclear case (i.e., creating a large number of useful variants and creating a wide variety of effective delivery systems), exactly which elements came together to create the particular degree of success or failure is not always immediately apparent. Also, because the U.S. and Soviet chapters are separate rather than combined, the comparison is more difficult to draw between the two than it could potentially be. Her theoretical framework specifies a number of endogenous (structural and work organization, management style, and the social context) and exogenous (external assistance, which is affected by the absorptive capacity of the recipient country as well as the endogenous variables; the priority political or group leaders devote to a program; and a program's economic circumstances) variables. I had hoped that the final manuscript might include a table that compared all of the cases along these variables that might in turn yield insights; this is unfortunately not the case. This may be for good reason, since there are complex interactions between these variables that surpass simplistic Boolean logics; nonetheless, it would be worth having such a table if only to be able to start thinking about necessary and sufficient conditions for success in different aspects of each program or the set of interactions (positive or negative) observed between these different variables.

[2] Frank L. Smith III, *American Biodefense: How Dangerous Ideas about Biological Weapons Shape National Security* (Ithaca: Cornell University Press, 2014).

[3] Sonia Ben Ouagrham-Gormley, "Barriers to Bioweapons: Intangible Obstacles to Proliferation." *International Security* 36:4 (2012): 80–114.

These are truly minor objections, however, when compared with the overall impact of this book. I often judge books based on how frequently I refer to the footnotes in order to track down sources for good ideas. Based on that metric, *Barriers to Bioweapons* is superb—I now have a lengthy list of additional sources that I need to track down for my own work. Rarely do I find a new book that significantly expands my knowledge of literature that I'd previously thought I'd more-or-less exhausted. In particular, her argument about the difficulty that untrained terrorists will have in replicating controversial experiments such as the H5N1 virus is a welcome counter to most of the literature and common wisdom, which massively overinflate biological threats. Similarly, Ben Ouagrham-Gormley's arguments regarding the Soviet experience of attempting to genetically engineer pathogens with novel characteristics are at least somewhat of a relief given the typical hysteria over the possibility of using newly black-boxed technologies to resurrect old pathogens or create new ones.

Nonetheless, I have a few nits to pick here as well. The first is with respect to U.S. counterproliferation policy. While in the past this policy has focused primarily on 'the stuff' (technology and materials), in more recent policy documents expertise has achieved equal footing, both in terms of concerns about the movement of experts and in terms of maintaining counter-WMD expertise.[4] The second is that the author's astute analysis of the Soviet Union's massive bioweapons program somewhat undermines the idea that genetic engineering is unlikely to produce novel weapons; the laundry list of problems that the entire complex faced throughout its existence makes me wonder how it ever produced anything useful at all. As such, it doesn't present a good test of the proposition that genetic engineering won't be useful for creating novel bioweapons.

Finally, Ben Ouagrham-Gormley's points on dissuasion in her last chapter bring to mind a plausible counter-argument. She argues that there are significant barriers to bioweapons development that, if better messaged, might dissuade potential proliferators. The flipside, however, is that if bioweapons are so difficult, perhaps we are better off not trying to convince proliferators that they are not worth their time, but rather letting them waste their efforts trying to produce weapons that will not work rather than focusing on more efficient methods. I am reminded of the U.S. acquiescence to the export license of lasers to Iran in the late 1970s under the Shah. Although the United States knew that Iran was investigating laser enrichment of uranium, it allowed it in any case since U.S. officials had concluded that the technology was unworkable.[5] Moreover, the pursuit of such weapons provides for excellent indicators and warnings of intent. Perhaps, in the end, we should allow these actors to tilt at these windmills of mass destruction.

[4] United States Department of Defense, "Department of Defense Strategy for Countering Weapons of Mass Destruction", 2014, Office of the Deputy Assistant Secretary of Defense for Countering Weapons of Mass Destruction. http://archive.defense.gov/Releases/Release.aspx?ReleaseID=16804

[5] Alexander H. Montgomery, "Stop Helping Me: When Nuclear Assistance Impedes Nuclear Programs." In *The Nuclear Renaissance and International Security*, edited by Adam N. Stulberg and Matthew Fuhrmann (Stanford: Stanford University Press, 2014), 177-202.

Review by Alex Spelling, Science and Technology Studies, University College London

With *Barriers to Bioweapons,* Sonia Ben Ouagrham-Gormley has written a concise and very interesting account of the great scientific and organizational challenges which characterised past state-led and terrorist bioweapons programmes; and why such history needs to be properly disseminated when assessing contemporary proliferation issues. Combining a number of theoretical approaches with empirical evidence, the author goes on to demonstrate how such multifaceted knowledge, organisational, and managerial issues were reflected in the difficulties encountered in delivering fully realised biological weapons (BW) capabilities during the twentieth century. Calling on a wide range of sources, particularly interviews with former scientists from the U.S. and Soviet programmes, the book is aimed primarily at those who are familiar with chemical and biological weapons (CBW), arms control, and counter-proliferation issues. It is an excellent read nonetheless for broader audiences, with the chapters providing a clear, engaging account of this often complex area. Indeed much of the detail actually concerns the organisational realities of scientific research and development programmes rather than BW science or military-strategic objectives. It complements much of the contemporary work done in this field by the likes of Kathleen Vogel, James Revill, Catherine Jefferson, Filippa Lentzos and Claire Marris[1].

One of the starting points for the book is the continued assertion by prominent politicians, such as then Secretary of State, Hilary Clinton in 2011 (17), and security commentators that terrorists could acquire biological weapons. Supposedly technological advancements have now rapidly reduced what once might have been insurmountable barriers. These claims unsurprisingly have been made regularly since 9/11 with Al Qaeda's global emergence and the anthrax letter attacks in the U.S. Indeed, when computer files seized from that terrorist organization revealed its wishes and attempts to develop bioweapons the die appeared to have been cast. If the Aum Shinrikyo cult in Japan (which also form part of the book's BW case studies) could actually deploy chemical nerve agents as in the 1995 Tokyo subway attack, then was not the sky the limit for other terrorist groups, especially if they had assistance from state powers? Such rhetoric was regularly deployed leading up to the Iraq invasion in 2003. The U.S. meanwhile has spent tens of billions of dollars on domestic counter measures against a potentially deadly terrorist-biological attack – which the author convincingly argues is highly unlikely in the forms often suggested (4-8).

Ben Ouagrham-Gormley highlights three misconceptions that she believes are at the heart of this "…faulty assessment of the bioweapons threat" (3) and why 'a great disconnect' exists between public perceptions and actual reality. First, that without the same material barrier to acquisition that nuclear weapons present (highly enriched uranium or plutonium as a minimum) they are cheap and easy to produce. Second, that any biological knowledge is applicable to bioweapons development and that bioweapons expertise is easily acquired. Third, that new technologies and discoveries will erase the technical barriers to bioweapons development, allowing untrained individuals to achieve successful results. A new analytical model, the author argues, is needed to explain the differences and distinctions between the various historical case studies. Subsequently Ben Ouagrham-Gormley differentiates factors that have an effect within programmes

[1] Kathleen Vogel, *Phantom Menace or Looming Danger,* John Hopkins University Press, 2012; James Revill and Catherine Jefferson, *Tacit knowledge and the biological weapons regime,* Science and Public Policy, 41:5 (2014): 597-610; Filippa Lentzos, Catherine Jefferson & Claire Marris, "The myths (and realities) of synthetic bioweapons", *The Bulletin of Atomic Scientists*, published online 18 September 2014; Catherine Jefferson, Filippa Lentzos & Claire Marris "Synthetic biology and biosecurity: Challenging the 'myths'", *Frontiers in Public Health* 2 (2014), 115.

(endogenous) and those from outside (exogenous). By studying the variables of bioweapons proliferation, she argues that policymakers and analysts can design new non-proliferation and counter-proliferation policies.

Building on the nuclear comparison Ben Ouagrham-Gormley cites numerous historical examples, highlighting the many similarities of that difficulties that states faced in bringing nuclear weapons programmes to fruition. However, it is perhaps the disparity in the size and cost of nuclear and biological programmes that mark the key difference. This forms part of the book's main, pervasive argument: that acquiring certain biological agents is neither prohibitively expensive nor difficult– rather the principal difficulty lies in the developmental phase of 'weaponising' such agents and finding suitable delivery systems; in fact the gap is huge. Yet this is not just based upon the technical challenges involved: it is intrinsically linked to an array of scientific, intellectual, training, collaborative, and managerial cultures, which are themselves often directly related to the culture and politics of the states in which they are based.

Competing levels of authority and access to resources within the byzantine Soviet system, for instance, including rivalry between different service branches and individuals, including scientists, hampered and prolonged successful outcomes in the covert BW programme which went into high gear after 1972. The physical size of the country and decision to construct facilities with great distances between them also played a part. Similarly, endemic suspicion leading to arrests, sackings and sometimes worse proved to be poor facilitators to 'progress'; for example, results were often falsified (99-121). Likewise corruption, nepotism, and the threat of violence all have hindering effects. The latter features, also characterised by a lack of expertise, undermined the Iraqi and South African programmes. Another overarching constraint is provided by prohibitive legislation. Ben Ouagrham-Gormley effectively demonstrates that the need to maintain secrecy after the 1972 Biological Weapons Convention (BWC) in the Soviet and Iraqi programmes, although operating on much different scales, equally hindered progress (122-131). This serves as a powerful reminder of the importance of prohibition and its effectiveness, even when lacking verification and compliance procedures as the BWC does. Research and development conducted under such strict secrecy to avoid possible detection multiplied many of the existing challenges already faced. As such, maintaining and strengthening such prohibitions should continue to be a priority of the international community.

Throughout seven thematic chapters, including one apiece on the U.S. and Soviet programmes, Ben Ouagrham-Gormley makes clear the large number of variables that effect BW development; sometimes this is irrespective of funding – the Soviet Union, for example, directed a comparative fortune towards it in the 1970s and 1980s. Whilst an array of highly virulent agents was produced, given the timescale and complexity of the research and development, the end results fell short of expectations (5, 99-108). An interesting contrast emerges, however: even in countries where there are great advantages in academic and commercial freedom, negating the correct organizational structures and/or not prioritising BW research – as arguably was the case during the life of the American programme – produced equally frustrating results. Once again, issues of bureaucratic, professional and inter-service rivalries surfaced, as did competition versus collaboration in terms of individual and institutional achievements (80-90). Alternatively, in terms of achieving success, experience points to concentrated locations, where scientists, technicians, managers etc. can freely exchange ideas and even socialise together and where competition is replaced with collaboration. An application of the systems-analysis approach, married to intellectual freedom and informality, would appear to bear fruitful results (71-80).

Yet obstacles remain. One of the biggest factors, and germane to those who study nuclear proliferation, concerns the concept of explicit versus tacit knowledge (18-22). Here Ben Ouagrham-Gormley dismisses what she sees as the fallacy of technology as a black box (11). Written instructions, formulas, processes etc. are often redundant without the practical, minutely specialized experience that is borne through trial and error. Moreover these are skills which can often only be replicated through direct instruction from those with the requisite experience. Knowledge is context dependent and explicit data needs to be teamed with other tacit skills to acquire meaning. Ben Ouagrham-Gormley is keen to reiterate the central point that specialized bioweapons knowledge is not easily acquired – and even once acquired – requires a whole host of supporting factors to be put into use. Furthermore, scientists trained in one biological specialization cannot easily transfer their expertise into other areas, such as between virology and biochemistry. Added to this is the fragility of BW agents, meaning there are often minute, practice-driven variables that equal the difference between success and failure. It was in part such mismatched organization that caused delays for the Soviet programme and considerable difficulties for the Iraqi. Aum Shinrikyo, as mentioned earlier, came away empty handed despite concerted attempts and resources devoted to developing a range of BW agents; its ambitions far exceeded its capabilities (138-42).

In the contemporary world therefore, the publishing of papers which contain biological agent processes and the advent of new technology, not least as the biotech revolution continues to grow, does not simply herald potential gateways for rogue states, terrorist groups, or individuals to develop BW. Tacit knowledge, special skills, professional networks, laboratory conditions and such are not just vital to the process, they *are* the process. Equally, when such skills and facilities are disrupted, dismantled or undergo other changes, tacit-knowledge drift is often the first consequence. An example from the U.S. nuclear sector in the early 2000s is instructive in this regard. Post-Cold War retirements and shifting strategic emphases saw a diminution of specialist skills, causing problems (and escalating costs) when the government tried to replicate the production of a foam material for coating Trident missile warheads (30-32). However that significant 'barriers to bioweapons' exist does not mean a future free of potential BW proliferation.

Assessing current policies by way of a conclusion, the author argues that preventing access to the troika of resources is but one form of deterrent. Rather, if the international community targeted knowledge and factors that affect use, an end to proliferation altogether could be achieved (145-52). She formulates a number of suggestions, based in part on past and contemporary examples. These include disrupting organisations through the possibility of inspections or police operations, which can cause severe operational setbacks; or more clandestine measures like sowing uncertainty and disloyalty among employees. At the other end of the spectrum, more constructive measures can be employed such as effective management of brain-drain prevention programmes where clusters of researchers are re-employed. In such cases not simply repackaging exploitable structures and creating new proliferation potential requires close oversight.

Such suggestions, however, inevitably carry many ambiguities and both implementation and measurement would likely be very difficult – issues which are recognised but could be more fully addressed by the author in the closing stages. Likewise a brief assessment of the on-going work of the BWC review conferences to manage new developments and how the contracting parties might be able to utilise some of the policies discussed here could have been included. In this context what might be learned from the experiences of the Organisation for the Prevention of Chemical Warfare (OPCW) or the International Atomic Energy Agency (IAEA)? The narrative that the U.S. and Soviet programmes did not make significant gains could also be challenged depending on the methodology adopted. Reference wise, a separate bibliography would be helpful as a guide to wider and specialist reading. *Barriers to Bioweapons* is nevertheless a valuable addition to the literature on BW and a timely reminder of the need to exercise caution rather than hyperbole when assessing potential future proliferation threats. At the same time it offers many pertinent assessments on the complexities of advanced weapons programmes and why investment or ideology is no determinant of success.

Author's Response by Sonia Ben Ouagrham-Gormley, George Mason University

Let me start by thanking Thomas Maddux and Diane Labrosse for organizing this roundtable on my book. I am also deeply grateful to the four reviewers for their thoughtful and laudatory comments. It is comforting to see that they all appreciate the value of the new analytical framework that I propose for evaluating the bioweapons proliferation threat, which is too often viewed in overly simplistic terms. Bioweapons have the unique characteristic of being based on living microorganisms, which creates challenges that do not exist in other weapons fields. At the same time, developing bioweapons is a scientific and technical endeavor that shares many characteristics with other scientific and technical projects, military and civilian alike. The nature of such projects thus requires an interdisciplinary analysis of their progress and chances of success. These projects also happen in specific social, economic, political, cultural, and organizational contexts, which affect a project's timeline and outcome, notwithstanding the importance of the resources they benefit from. I am happy to see that the reviewers have noted the importance of this multi-faceted approach to producing more accurate threat profiles. The reviewers also raise interesting questions, which I will attempt to respond to in the following sections.

I agree with Philip Egert's concluding comment that the interdisciplinary-based argument of my book could also be used to analyze civilian scientific and technological projects. I am in the process of applying this framework to new civilian and biodefense scientific undertakings, and I am hoping that this research will reveal additional variables that may not exist in the weapons field. Egert also raises an interesting question about identifying other variables that might affect terrorist bioweapons programs more so than they affect states. My book analyzes the bioweapons program of only one terrorist group—Japan's Aum Shinrikyo—which, by virtue of its organization, resources, and its stable environment, operated more like a state than most terrorist groups. Current terrorist groups, such as the Islamic State of Iraq and Syria (ISIS), do not benefit from the same resources and tranquility, so it is only logical to assume that they may be affected by variables not analyzed in the book, particularly when these groups operate in a war context, and/or are constantly on the run. Egert suggests that these groups may be affected by insufficient power supply, which would compromise bioweapons developments. I agree. That said, power shortages were common in the Soviet context, so this feature may not be unique to terrorist groups. Nevertheless, it is a line of inquiry worth pursuing; it may reveal variables unique to terrorist circumstances, or it may show that terrorist groups are more sensitive than states to some variables identified in my book, or it may even show, as Egert points out, that the effort/rewards ratio may be skewed toward low-tech/tested conventional methods, and therefore terrorist groups should not even bother considering bioweapons. All of these outcomes would be useful from the policy standpoint.

Both Egert and Alex Spelling underline the importance of the Biological Weapons Convention (BWC) as a nonproliferation and program disruption tool, two virtues often insufficiently or not at all recognized, because of the treaty's lack of a verification mechanism. Yet, even without a verification mechanism, the BWC has had the effect of driving underground all bioweapons programs that subsisted or were created after its signature. Most analysts will view this as a negative feature: a clandestine program is more difficult to detect. That is true, but covertness in the bioweapons field, as shown in my book, has deleterious effects regarding knowledge creation and transfer; it pushes a program towards suboptimal organizational and managerial models, and it can promote bad science, all of which will compromise a program's progress and outcome. The power of the BWC could be used more effectively if the disruptive effects of a verification mechanism were recognized by member states and acted upon. Many analysts believe that it is unlikely that BWC member states will establish a verification process, but I do not think this is out of the question. This bears on a question Spelling poses: How does the current BWC process manage new technological developments and how can member states use some of the policies proposed in my book?

The review of technological developments can be improved by acknowledging the importance of tacit skills in the life sciences. Already, the concept of tacit knowledge has been discussed within the BWC. Indeed, the U.S. delegation submitted a paper devoted to the issue of tacit knowledge during the BWC meeting of State Parties in August 2015, which I am proud to say quotes my research along with Kathleen Vogel's.[1] The paper encourages state parties to develop a common understanding of tacit knowledge in order to assess future threats, particularly as they relate to new scientific and technological developments. If state parties do seize on the U.S. proposal, they will be able to evaluate the threat potential of new technologies more accurately than by just making lists of potentially worrisome technologies, as is the case today.

It is worth noting that during the same meeting of State Parties, the Swiss delegation suggested creating a science and technical committee responsible for reviewing technological developments. This is a good idea. However, it is important that the committee's composition not be limited to technical experts as proposed in the Swiss document. It should also include experts in the social studies of science, and practitioners of the technology being analyzed. These two categories of experts are more likely to probe the context of and skills required to use new technologies to better assess their threat potential. To wit, important details about the H5N1 experiment emerged during a World Health Organization meeting gathering flu virus practitioners, not during the National Science Advisory Board for Biosecurity's (NSABB) initial review of the experiment. This new data ultimately prompted the NSABB to reverse its original decision to halt publication.

Spelling also asks whether anything can be learned from the International Atomic Energy Agency (IAEA) and the Organization for the Prohibition of Chemical Weapons (OPCW). These are two excellent organizations, which have successfully supported the implementation of the Nuclear Nonproliferation Treaty and the Chemical Weapons Convention, respectively. The OPCW is probably a better model for the BWC simply because of the dual-use nature of chemicals: they can be used extensively in a variety of civilian sectors, which requires regular site visits by OPCW inspectors. Routine visits under a BWC verification regime, should one be developed, would help keep proliferators on their toes. The OPCW is sometimes criticized for focusing more on former weapons facilities to the detriment of civilian facilities. A BWC implementation organization could learn from this oversight and focus equally on civilian and biodefense related facilities. I noted Spelling's comment on the difficulty of implementing and measuring the efficiency of the policies I propose. But is not that the case for all nonproliferation policies?

I am glad Alexander Montgomery highlights the elements that are missing from my book, because all of them have a simple answer: space. The draft book was too long and the editor requested cuts. So I had to make difficult decisions. I deleted the concept of 'transactional engineer' from the book for two reasons: First, I agree with Montgomery that this is an important concept, and I wanted to emphasize it by writing an article

[1] United States of America, "Tacit Knowledge: The Concept and its Implications for Biological Weapons Proliferation," Meeting of State Parties to the BWC, July 30, 2015, http://www.unog.ch/80256EDD006B8954/(httpAssets)/9664084534E4927FC1257E9700436621/$file/BWC_MSP_2015_MX_WP6.pdf ; Kathleen Vogel, "Framing Biosecurity: An Alternative to the Biotech Revolution Model?" *Science and Public Policy* 35:1 (2008): 45-54.

focusing on the concept, while also using other material deleted from the book. I hope this article will be published soon.

Second, when debating what part of the management chapter should be deleted, I wanted to make sure that all of the levels of management required for successful weapons development were included in the book. From that point of view it was important to keep the concept of heterogeneous engineer (for example, Leslie Groves in the Manhattan Project) because it plays a unique role in a program's management chain, namely a link between political/military decision-makers and the scientific staff. By keeping decision-makers informed of a program's progress and aware of what the scientific staff can and cannot do, the heterogeneous engineer contributes to the political, financial, and programmatic stability of a program. The U.S. bioweapons program did not have a heterogeneous engineer, and thus no one to remedy the insufficient financial and political support for the program, which fostered stop-and-go projects. This role is often neglected in the literature, because of the prevailing belief that once decision-makers support a program they will provide the requisite political and financial backing. History shows otherwise: even a priority program like the Manhattan Project had to justify and compete with other projects for financial and material support. The transactional engineer, on the other hand, operates within a program and links together different program parts to make them work efficiently towards its ultimate goal. I thought that the concept of system engineer that I discuss in the book, albeit different from the transactional engineer, emphasized effectively the importance of in-program coordination, and therefore removing details about transactional engineer did not damage the argument too much. I look forward to this issue being remedied by my aforementioned separate treatment of the role of the transactional engineer.

I also noted Montgomery's comment about the possible distinction to be made between the organizational variables that promote knowledge creation and those that foster knowledge transfer to future generations. This is a question that requires further thinking and I will reserve my response for future treatment. The idea of creating a comparative table is a good suggestion, but as Montgomery notes, the interactions between variables are so complex that there is a risk of oversimplifying the argument.

Finally, I will disagree with Montgomery on the point he makes about bio-dissuasion: if bioweapons are so difficult to produce why not allow malevolent actors to waste their resources on what seems to be an unachievable goal? For one, bioweapons are banned, and turning a blind eye to state- or non-state actors' bioweapons efforts would be equivalent to promoting bioweapons development, which would contradict current U.S. nonproliferation policy. Second, for such a strategy to work, you need to be sure that the technology is unachievable, and possess a robust assessment of the enemy's capabilities. Bioweapons are not unfeasible; the U.S. and the Soviet Union produced them. But they are very difficult to produce, and their development requires a certain social, political, organizational, and cultural environment to succeed. So doing nothing to prevent a state or non-state actor from developing them redounds to giving them the space to create the proper environment, notably the continuity and stability of work that is needed for success. What's more, U.S. intelligence possesses a decidedly weak record of accurately estimating bioweapons threats. And, as indicated in my book, this strategy was used in the past and failed miserably: what is unachievable in one context may be achievable in another. Let us not tempt the devil.

Jacques Hymans's comment on the necessity to define more precisely what constitutes a biological weapon and success in bioweapons Research and Development—i.e., at what point does a state or group acquire a bioweapons status—is at once easy to respond to and very complicated. The easy answer is that page 2, footnote 4, in chapter 1 provides the following definition of a bioweapon, which I concede should have appeared in the text instead of in a footnote: "*By 'effective working weapon,' I mean one that when delivered can produce mass casualty effects, not simply highly localized contamination*." In other words, a country or group achieves bioweapons status when they have not only designed one or several lethal agents, successfully carried them through the development, testing, and production process, but also designed a delivery mechanism that disseminates the agent without destroying it, and consequently can produce mass casualty effects. The book elaborates extensively on these various stages, and I believe that it demonstrates clearly that based on this definition, the U.S. and the Soviet Union, which not only designed several types of biological bombs but also tested them in test chambers and in the open, achieved bioweapons status (notwithstanding the military's dissatisfaction with these weapons). On the other hand, Iraq, which did not produce a working weapon, and South Africa and Aum Shinrikyo, which failed at various stages of the process before reaching the weaponization phase, did not achieve such a status. I might note here that the 1979 inadvertent anthrax release in Sverdlovsk was an accident, not a case of weapons use, as Hymans seems to suggest. Even though the anthrax was lethal, it was still under development and its production process was completed only in Stepnogorsk in the early 1980s. In other words, an agent alone is not a weapon: it needs to be processed, produced, weaponized, and tested for dissemination and behavior analysis to qualify as a weapon. Similarly the Rajneeshee salmonella attack, which Egert suggests might have been addressed in my book, was not included for the simple reason that the Rajneeshees did not really develop a bioweapon as defined in my book. Theirs was not a mass-casualty weapon, but a crudely disseminated toxic agent, meant for localized contamination.[2]

The more complicated answer is that defining precisely at what point a state or group acquires a bioweapons capability will always be a guessing game because of the dual-use nature of biology. In the biological field, there is no equivalent to the nuclear 'fuel cycle,' and establishing clearly at what point scientific and technical work moves to the dark side is impossible due to the fact that virtually all aspects of a bioweapon—biological agents, facilities, laboratory equipment, laboratory material such as reagents, and to a certain extent design, development, and production processes, as well as some dissemination mechanisms (aerosol)—can have legitimate scientific and pharmaceutical purposes. Several attempts were made over the years to draw a demarcation line between civilian and bioweapons-related work, but none of them resulted in a satisfactory clarification. The truth is that biological weapons are not amenable to the type of thought model used for nuclear weapons, where clear boundaries and milestones in development are indicative of an actor's progress, and as a consequence, of the imminence of the threat. Biological weapons developments must be viewed as a process where the key challenge is to keep fragile microorganisms alive while transforming them to acquire the requisite lethal properties, and maintaining these properties during dissemination of the agent. Therefore, looking at bioweapons developments through the prism of individual development stages or isolated material can only produce a distorted picture of an actor's progress and chances of success.

I will disagree with Hymans on one important point: My book in no way implies that nuclear weapons are easier to produce than biological weapons. Chapter 1 makes it clear that they are different, and present different challenges. I also note in my book that except for a handful of analysts—including Hymans and Montgomery—the current literature tends to downplay the challenges of producing a nuclear weapon.

[2] For details see: W. Seth Carus, "The Rajneeshees (1984)," in Jonathan B. Tucker (ed.), *Toxic Terror: Assessing Terrorist Use of Chemical and Biological Weapons*, (MIT Press, 2000)

As for the achievements of the Soviet and Iraqi programs, I welcome Hymans's challenge to my argument. This will give me the opportunity to address the issue of how to measure the achievements of the Soviet program, which Montgomery and Spelling have also raised.

Hymans's alternative theory that the Soviet program made headways while the Iraqi program failure was primarily due to the level of autonomy they enjoyed is mistaken. The Soviet program did develop a variety of weapons based on classical agents and made important scientific discoveries, some of which were used in the civilian and medical sectors. But what accounts for the fact that by the 1960s the achievements of the Soviet program were similar to those of the American program, in spite of it having a 20-year head start? Second, why did the last 20 years of the program, conducted illegally after the signature of the BWC, fail to produce weapons based on genetically engineered agents in spite of the vast expansion of the program's infrastructure and the enormous human, material, and financial resources poured in the program during its last two decades?

These puzzling questions can be answered by analyzing the interactions of the endogenous and exogenous variables I propose in my book: The constant intrusion of political figures and political organizations—Soviet leader Joseph Stalin and his scientific protégé Trofim Lysenko and later the KGB, Communist Party, and trade unions—the organizational structure of the program, the fragmentation of scientific projects and teams, the secrecy, the management style, the lack of coordinating mechanisms at the program and facility levels, and the deficiencies of the economic system all conspired to create discontinuity and instability at the scientific level, thus preventing the program from using the resources and expertise available for maximum output, and thus creating the conditions for bad science.

The program's achievements are due not solely to the country's prior history, as Hymans states, but to the ability of some facility directors and some political figures to transcend the negative effects of these variables to harness prior knowhow, create new knowledge, and make progress. Still, the fragmentation of the program did not allow achievements made by innovative facilities to spread across the program. In other words, the program wasted enormous resources.

Therefore, it would be a mistake to focus solely on one variable: interactions between scientists and political authorities to conclude that it is the main cause of success (Soviet program) or failure (Iraqi program). As noted earlier, Soviet scientists were far from being autonomous. The Stalin/Lysenko era resulted in the elimination of a large cadre of competent scientists. Later, central authorities continued to interfere in scientific issues through their representatives— the KGB, the Communist Party, and Trade Unions—which were present in all facilities.[3] The Iraqi program failed not only because of frequently violent political interference, but also because of the lack of expertise of its personnel, the discontinuity of the program, the reigning secrecy, and poor organizational structure.

Furthermore, the South African case contradicts the idea that when left alone scientists do good work. South Africa's program enjoyed complete freedom from political and military authorities. This freedom was used by

[3] Trade unions in the Soviet system were political organizations meant to represent the interests of the state, not to defend workers' interests.

its director, Wouter Basson, to cripple the program's resources for personal gain, not to advance the program's objectives.

So a program's success or failure is the result of the combined effect of endogenous and exogenous variables, which, when taken together, have a greater impact on a program than the sum of their individual positive or negative values.

Thanks again to all of the reviewers for their time and thought-provoking comments, and to H-Diplo's editors for organizing this round-table.