Modeling Risk in Complex Bioeconomies

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Economic theories—and their applied variants in business practice—are almost entirely grounded in abstract concepts (e.g., supply, demand, labor, capital) that divorce market phenomena from the specific social, political, and technological contexts within which they occur. Social scientists have studied the processes and practices by which actors make market abstractions, noting that they do so simultaneously, across epistemic, performativity, and materiality dimensions (e.g., Cronon 1991; Steinberg 1994; Sunder Rajan 2006; Mackenzie 2008; Busch 2013). Yet, as recent concerns about sustainability highlight, even the simplest of markets, such as commodity markets, can never fully be isolated from the complex webs that link key aspects of these markets to diverse social, ecological, technological, and geophysical systems. How much worse, then, complex market phenomena—that cut across biology, society, economy, engineering, and ecology—such as those envisioned in novel synthetic bioeconomies?

Bioeconomies have a lengthy historical record that testifies to the problem of market abstraction. Agriculture has fed large populations for thousands of years; yet, great famine has also persisted as a systemic feature of the political economy of agricultural markets (Sen 1981). For the vast majority of agricultural history, slavery and indentured servitude were common. Today's agricultural system has perhaps escaped famine and slavery (although hunger and malnutrition persist at high levels, globally, as do mistreated farm workers), at the expense of massive resource inputs that have contributed to land degradation, disruptions of carbon and nitrogen cycles (and associated impacts, such as climate change, deforestation, ocean acidification, and ocean dead zones), widespread pollution from agrochemicals, the construction of massive water systems (with their own disruptive effects), and the rise of monocultures that are highly vulnerable to increasingly pesticide-resistant diseases and demand constant innovation in order to fend off rapid declines in yield and productivity. Likewise, today, agro-food systems have hugely distorted human nutritional patterns, especially around the overconsumption of sugars, contributing to rapid increases in the United States in childhood obesity, diabetes, and other diseases.

Other modern bioeconomies have also had their share of problems. Blood manufacturing systems, crucial to the practice of surgery and emergency medicine, as well as treatments for hemophilia and other diseases of the blood, have experienced numerous episodes of disease transmission, including hepatitis C and AIDS (Dubin and Francis 2013). Hospitals and feedlots have combined to produce super-resistant microbes that cannot be treated by any known anti-bacterial medicines. Interwoven food and transportation markets combine with migratory bird ecologies to annually generate and spread deadly infectious diseases among people, pigs, and avians. Other market interactions generate sporadic but seemingly inevitable outbreaks of food-borne pathogens—e.g., periodic outbreaks of Ebola from bushmeat markets and *e. coli* infections in hamburger. Recently, complex interactions between food and fuel markets contributed to price spikes for staple foods in poor communities around the globe. These risks are compounded when we go beyond considerations of health and biophysical harm to include consideration of social and economic risk, power, identity, justice, and ethics.

The risks associated with complex bioeconomies arise both because: (1) markets transform complex relationships among social, technological, biological, organizational, economic, and ecological systems, and (2) existing forms of knowledge have a great deal of difficulty in capturing the complexities of cross-system dynamics. While synthetic bioeconomies are hardly unique, they complicate concerns about risks for several reasons. First, they create novel forms of life whose biological properties are not fully known or predictable when integrated into complex biological and ecological systems. Second, they unsettle taken-for-granted social, political, and cultural assumptions around which (sometimes only modestly) stable social orders have been established. Third, they create new demands for biological production (e.g., biofuels) that may stress already overwrought relationships among social, technological, and biological systems. Fourth, they potentially disrupt (sometimes only modestly) stable markets that provide critical services (e.g., food and health) to large populations. Peoples' lives, livelihoods, identities, relationships, institutions, and communities are bound up with biomarkets—to transform such markets is inevitably to transform society.

To develop a capacity to address these concerns in an anticipatory fashion—as opposed to simply reacting to surprises that occur—requires a capacity to model complex bioeconomic transformations that straddles biological (including medical and ecological), economic, engineering, and sociological disciplines. By model, I mean significantly more than computational modeling. While some risks may occur as a result of dynamics that are fully quantifiable, others may not. Social practices, meaning and identity formation, ethical norms, and organizational and institutional dynamics are frequently critical elements in the rise and propagation of risks. Often risks arise as a result of social practices, or of social responses to new possibilities or events, as the recent outbreak of Ebola virus in W. Africa is revealing. Just as significantly, these challenges demand analyses that extend across supply chains and over the full lifecycle of synthetic bio-products, and they demand a capacity to model both functioning systems/markets and the ways in which systems/market transformations come into being and take shape, sociologically.

Accomplishing these goals will require unprecedented interdisciplinary collaboration. It will require new forms of synthesis in systems modeling that provide meaningful insights across social, organizational, technological, biological, ecological, and economic models built on radically different epistemologies. It will also require greater transparency in the early phases of synthetic bio-product and bioeconomy formation than is common in current intellectual property regimes or innovation policies. It will require a robust capacity to anticipate the social dynamics of new bio-capabilities and to monitor evolving social dynamics to compare real-world developments to modeled and anticipated expectations. Finally, it will require new forms of inquiry and organization to feed the insights of these types of knowledge into practices of responsible innovation within the synthetic biology industry.

Due to the relatively early stage of synthetic biology research and development, NSF has the opportunity to invest in the research necessary to develop tools and methods for critically and comprehensively assessing risk in emerging synthetic bioeconomies, but only if they begin now. Work under programs such as the now ended Biocomplexity program, the just beginning Resilient Interdependent Infrastructures Processes and Systems program, and the long-running Coupled Natural-Human Systems program could potentially serve as a model for such an initiative, but each is structured in ways that limit inquiry so as to prevent the development of the kinds of tools and expertise necessary. In particular, new initiatives should find strategies for studying complex multi-system dynamics that blend what can be measured quantitatively and modeled computationally with research strategies that examine social, institutional, and other dynamics that cannot. Absent such an effort, synthetic biology will, without warning, as history suggests of all previous bioeconomies, generate new risks that surprise us and create destruction and havoc.