Institutional Analysis of Nanotechnology Innovation Network, Phoenix, AZ, USA
Executive Summary

Part 1: Static Analysis
1.0 Collective action
The case of nanotechnology innovation in Phoenix, Arizona, USA is an addition to the original Common-Pool Resource (CPR) database. This CPR report was entered in 2013 by Michael Bernstein at Arizona State University. The nanotechnology innovation network of Metropolitan Phoenix ranks among the top thirty across US cities focused on nanotechnology development. The present case examines the structure of the innovation network, consisting of approximately 400 diverse organizations, between 2011 and 2012. The commons dilemma revolves around managing future risks and benefits from nanotechnology development; the resource is a heterogenous mix of natural and human-made infrastructures.

Background on Nanotechnology
Nanotechnology refers to materials and chemicals engineered and manufactured at the scale of 10^{-9} meters. More than 800 nanotechnology products already exist commercially, serving as preservatives, sealants, or water-proofing agents, or providing structural reinforcement, scratch-resistance.[1] The present work re-frames the nanotechnology innovation process as a collective action situation[2] involving a heterogeneous community of resource users, a heterogenous resource, a several federal government public infrastructure providers, and a suite of public infrastructures.

1.1 The Commons Dilemma/Collective action dilemma
The collective action dilemma is one of innovators self-organizing to minimize the risks and maximize the benefits of nanotechnology development. I posit that the present case reflects a dilemma related to 1) the under provision of infrastructure necessary to minimize the potential risks of nanotechnology development, and 2) the over appropriation of present benefits that accrue to nanotechnology developers. A mismatch exists in which public funds are provisioned (for nanotechnology research) but benefits accrue to select individuals and firms (technology transfer and commercialization). I focus a my attention on the collective action dilemma related to allocation of such funding.

1.2 Biophysical Context (IAD)
Nanotechnology applications developed in Metropolitan Phoenix include, "personalized medicine, renewable energy solutions, semi-conductors and electronics, automobile enhancements, aerospace and defense, and water filtration" (Foley and Wiek, 2013).

As a resource, nanotechnology is variable and dynamic. Nanotechnologies are developed from a combination of infrastructures—ores, precious metals, gasses, water, solar, and fossil energy make

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[1] National Nanotechnology Initiative (ND) *Benefits and Applications.* Available at http://nano.gov/you/nanotechnology-benefits. Accessed on 2 December 2013.

[2] This analysis stretches the institutional analysis framework to a non-traditional application, following in the tracks of other work expanding the "commons paradigm" on topics ranging from genetic resource (Hess and Ostrom 2006) to intellectual property and the internet (Bollier, 2005).

up the natural infrastructure; vast amounts of soft-human infrastructure (knowledge, technical expertise, skills, etc.) are also required, along with hard, human-made infrastructure (sterile research facilities, complicated machinery, etc.). Further, manipulation, appropriation, and use of the resource also requires inputs of human hard and soft infrastructure such as university laboratories and equipment, researchers, federal research funding, venture capital etc. (Foley and Wiek, 2013).

One of the main inputs driving nanotechnology development is money: it is expensive to provision and appropriate the above combinations of infrastructure. Cumulative U.S. federal investments alone, since fiscal year 2001, total some $20 billion (NSTC, 2013). This investment does not include the billions of additional dollars going to transportation, information and communication, and satellite infrastructures that already enable nanotechnology research and development.

Due to the heterogeneous nature of the nanotechnology resource, the provision and appropriation of funding (required to accumulate sufficient infrastructure) seems the most promising attribute of the biophysical system to influence. Focusing on funding has the potential to shift the dilemma from a complex commons case of interacting public, private, and common-pool goods to a collective action dilemma involving the allocation of financial resources for greatest social gain (howsoever defined).

1.3 Attributes of the Community (IAD)

The Metropolitan Phoenix nanotechnology innovation network involves approximately 400 organizations. In total, some nine actor groups are represented in Phoenix, including government funders and regulators, academia, businesses, insurance firms, the media, and non-governmental organizations. Key participants in the Metropolitan Phoenix nanotechnology innovation network specifically are academia, industry, and government. At the city level, government controls zoning and construction requirements that affect the location of technology incubators (scope rule) (Foley and Wiek, 2013). Industry controls the "distribution, manufacturing, and marketing of products" as well as "the creation of product standards and reliability measurements" (Foley and Wiek, 2013), meaning that, baring federal regulatory oversight, the resource users involved in the Phoenix system are also, to a certain extent, public infrastructure providers themselves. Universities act as major research hubs (securing government funding) and providers of technology licenses; for example Arizona State University researchers, graduate, and undergraduate students involved in a variety of nanotechnology research endeavors (Foley and Wiek, 2013).

Collaboration across nanotechnology sectors (e.g., semi-conductor and water purification) is stymied by competition for research funding (Foley and Wiek, 2013). Federal public infrastructure providers provision technical guidance, research and development funding, and conservation and safety regulations. Across the Metropolitan Phoenix innovation network commercialization (monetary gain) and operationalization (military application) are the dominant goals, often coming at the expense of wider social benefit or environmental integrity (Foley and Wiek, 2013).

Levels of trust in the community vary along domains of nanotechnology specialization, making cross-sector collaboration a challenge. In addition, competition for scarce research and development funding seems to favor individualistic, non-cooperative behavior by businesses or research groups. The presence of some information-sharing networks however, is promising for the potential of future collaboration. At present, seemingly low levels of trust and competitive barriers to cooperation indicate low ability to solve a collective-action dilemma related to allocation of financial resources for greatest social gain.

1.4 Rules in Use (IAD)

Public infrastructure, monitoring, and enforcement

Although no new pieces of federal legislation speak directly to nanotechnology (Kimbrell, 2009), a variety of soft-public infrastructures are relevant. The Bayh-Dole Act[3] stipulates that patents from federally financed research may be transferred from the federal government to individuals, research groups, and business university technology. Allowances for technology transfer may be part of what makes nanotechnology research commercially viable (information and payoff rules). The absence of a feedback (for example a revised scope rule) linking technology transfer to applications with high potential social gain may perpetuate the mismatch in which public funds are provisioned for general research but benefits accrue to small groups of individuals or firms.

The U.S. Environmental Protection Agency (EPA) regulates nanoscale materials under the Toxic Substances Control Act (TSCA), as well as the clean water, clean air, and safe drinking water acts.[4] The EPA's statutory responsibility is monitored by nonprofit groups; disputes are resolved through the judicial branch of the U.S. government, as recently demonstrated by a 9th U.S. Circuit court of appeal ruling, "that the EPA didn't follow its own rules for determining" the safety of a pesticide continuing nano-silver material nano-silver.[5]

The U.S. Department of Health and Human regulates nanoscale materials through the Food and Drug Administration (FDA). The FDA requires pre-market review of "new drugs, new animal drugs, biologics, food additives" (USFDA, 2012) (scope rule). Consumer products and pharmaceuticals containing nanotechnologies thus fall under FDA regulation. For products that do not require review, the FDA recommends complying with voluntary consultations, as companies maintain liability for the goods they create (USFDA, 2012). At the state level, Arizona[6] has opted not to regulate nanotechnology until such action is required by federal authorities (Foley and Wiek, 2013).

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[3] For more information, please see this helpful Wikipedia entry on the Bayh-Dole Act of 1980, available at: http://en.wikipedia.org/wiki/Bayh%E2%80%93Dole_Act. Update 11/18/2013 at 06:28. Accessed on 25 November 2013.

[4] US EPA (2007) Nanotechnology White Paper. United States Environmental Protection Agency Science Policy Council. Washington, DC. Available at: http://www.epa.gov/osa/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf. Accessed in 26 November 2013 p. 78

[5] National Resource Defense Council (November 2013) Court Ruling in NRDC's Favor Should Limit Pesticide Nanosilver in Textiles. Available at: http://www.nrdc.org/media/2013/131107.asp Accessed on 22 November 2013

[6] Brewer, J. (2011) EO 2011-05: state regulatory rule making review and moratorium to promote job creation and retention. Available at: http://azmemory.azlibrary.gov/cdm/ref/collection/execorders/id/709. Accessed on 26 November 2013.

While the coverage of nanotechnology by conservation acts already "on the books" is promising, the novel nature of nanotechnology contamination detection and remediation especially challenging; in addition, knowledge of toxic effects and human health impacts are minimally understood, marking some need for special treatment of nanotechnology (Maynard et al., 2011). The seeming lack of revision to rules governing nanotechnology innovation is troubling when viewed in context of the larger collective action dilemma of how to minimize the risks and maximize the benefits of nanotechnology development.

1.5 Summary

Nanotechnology Innovation in Metropolitan Phoenix operates successfully without a common-pool resource dilemma. Success of the community, as measured by continued industrial operations and economic profitability, seems related to the presence of strong private property rights, and low regulatory burden. Several factors decrease the network's capacity for collective action, including competitive pressures from scarce funding and a lack of cross-sector dialogue/ High infrastructure costs prohibiting market entry, and a lack of environmental health and safety regulations further hamper the capacity of the network for collective action. Despite current economic success, there seems to be a collective action dilemma around minimizing the risks and maximizing the benefits of nanotechnology development.

	Clear boundaries & memberships	congruent rules	collective-choice arenas	monitoring	graduated sanctions	conflict-resolution mechanisms	recognized rights to organize	Institutional performance
Original Case, 2011-'13	heterogenous resource poorly defined; profit well-defined	congruence low; appropriators profit, risk externalized	arena's exclusive; appropriators have privileged access	moderate; material challenges present novel monitoring issue	present through existing national regulatory and legal systems	present through existing national legal systems	high; current approach to nanotechnology regulation is self-organizing	robust semi-commons/ semi-private arrangement

Table 1: Evaluation of the current nanotechnology innovation network against IAD principles (Ostrom, 1990)

Part II. Robustness

2.0 Robustness Summary

In sum, a the high modularity of the innovation network, the low connectivity across modules, a robust-control for profit, and a low diversity of 'definitions of success' make the system robust to an economic performance (manage dynamic uncertainty for profit). Such robust nanotechnology profit-protocols are reinforced by a larger, conservative (high resistance to change) capitalist system. Endogenous robustness of nanotechnology for profit, however, increases inequality of the larger economic system and externalize environmental risk, making the system vulnerable to exogenous factors such as economic collapse, environmental collapse, and pubic opposition.

Bibliography

***indicates included in the CPR database bibliography

Bollier, D. (2005) Growth of the Commons Paradigm In Hess, C. and Ostrom, E. (Eds) Understanding Knowledge As a Commons : From Theory to Practice. MIT Press: Cambridge, MA. 382 pp.

***Foley and Wiek (2013) Patterns of nanotechnology innovation and governance within a metropolitan area. *Technology in Society*, 35(4):233-247

Hess, C. and Ostrom, E. (2006), A framework for analysing the microbiological commons. International Social Science Journal, 58: 335–349. doi: 10.1111/j.1468-2451.2006.00622.x

***Kimbrell, G. (2009). Governance of nanotechnology and nanomaterials: principles, regulation, and renegotiating the social contract. *Journal Of Law, Medicine & Ethics*, 37(4), 706-723.

Maynard, A., Bowman, D., & Hodge, G. (2011). The problem of regulating sophisticated materials. Nature Materials, 10(8), 554-557.

NSTC. (2013). *Supplement to the President's Budget for Fiscal Year 2014: The National Nanotechnology Initiative*. National Science and Technology Council.

Ostrom, E. (2010). Polycentric systems for coping with collective action and global environmental change. Global Environmental Change, 20(4), 550-557.

***Renn, O., & Roco, M. C. (2006). Nanotechnology and the need for risk governance. Journal of Nanoparticle Research, 8(2).

U.S. Food and Drug Administration (2012) FDA's Approach to Regulation of Nanotechnology Products. U.S. Department of Health and Human Services. Page Update: 04/20/2012. Accessed on 11/22/2013. Available at: http://www.fda.gov/ScienceResearch/SpecialTopics/Nanotechnology/ucm301114.htm

U.S. Environmental Protection Agency. (2011) Control of Nanoscale Materials under the Toxic Substances Control Act. Page Update 4/29/2011. Accessed on 11/22/2013. Available at: http://www.epa.gov/oppt/nano/