What is an Innovation Ecosystem?

By Deborah J. Jackson

National Science Foundation, Arlington, VA

The analogy with biological ecosystems

One expects there to be a conceptual analogy between an innovation ecosystem and the biological ecosystems observed in nature. The biological ecosystem is a system that includes all living organisms (biotic factors) in an area as well as its physical environments (abiotic factors) functioning together as a unit. It is characterized by one or more equilibrium states, where a relatively stable set of conditions exist to maintain a population or nutrient exchange at desirable levels. The ecosystem has certain functional characteristics that specifically regulate change or maintain the stability of a desired equilibrium state.

In the biological system, the *equilibrium* state is described by modeling the energy dynamics of the ecosystem operations?[1] In this context, the energy is simply the way the predator-prey relationship and the plants transfer energy; calories are burned consuming prey, thereby transferring the energy of the prey to the predator and as plants die and decompose, their energy is transferred to the soil where it is taken up again by other plants. Because the energy dynamics are a complex function, an ecosystem can only be considered as a whole, not piecemeal, as every part of the ecosystem has a functional effect on another.

In summary, a biological ecosystem is a complex set of relationships among the living resources, habitats, and residents of an area, whose functional goal is to maintain an equilibrium sustaining state.

---

[1] http://www.sustainablescale.org/ConceptualFramework/UnderstandingScale/BasicConcepts/EcosystemFunctionsServices.aspx

In contrast, an innovation ecosystem models the economic rather than the energy dynamics of the complex relationships that are formed between *actors* or *entities* whose functional goal is to enable technology development and innovation. In this context, the actors would include the material resources (funds, equipment, facilities, etc.) and the human capital (students, faculty, staff, industry researchers, industry representatives, etc.) that make up the institutional entities participating in the ecosystem (e.g. the universities, colleges of engineering, business schools, business firms, venture capitalists (VC), industry-university research institutes, federal or industrial supported Centers of Excellence, and state and/or local economic development and business assistance organizations, funding agencies, policy makers, etc.). The innovation ecosystem comprises two distinct, but largely separated economies, the research economy, which is driven by fundamental research, and the commercial economy, which is driven by the marketplace. By design, the two economies are weakly coupled because the resources invested in the research economy must be derived from the commercial sector. This definition includes government research and development (R&D) investments which are ultimately derived from tax revenues. In order to foster the serendipitous investigations that are essential to innovative discovery, it is also important that the incentives driving the research economy be decoupled from the financial incentives driving the commercial economy.

Why do we care about developing the innovation ecosystem?

The two ways to increase economic output within an economy are to (i) increase the number of inputs in the productive process, or (ii) think of new ways to get more output from the same number of inputs. The latter is the essence of what is broadly meant by Schumpeter's concept of innovation[2], which is defined as "the introduction of new or significantly improved products (goods or services), processes, organizational methods, and marketing methods in internal business practices or the marketplace". Innovation is believed to be the fundamental source of significant wealth generation within an economy. This belief is

[2]Schumpeter saw innovation as the critical dimension of economic change.
http://en.wikipedia.org/wiki/Joseph_Schumpeter

foundation of the current administration's strategy for the economic recovery[3] and undergirds the National Science Foundation's efforts to nourish the nation's innovation ecosystem[4]. In particular, because high-tech industries offer higher growth potential, the best way to spur job creation and economic growth is by facilitating more efficient translation of budding innovations from the research economy into the commercial sector. Given today's economic downturn, with its high unemployment rates and low tax revenues, federal, state, and local government entities are now actively seeking new ways to grow their economies by creating jobs. The higher growth rate for high-tech industries, in particular, offers a strong incentive for government entities to actively develop and nurture innovation ecosystems that leverage fundamental technology research within academe, and industry.

An important feature of an innovation ecosystem is that the resources available to the research economy are coupled to the resources generated by the commercial economy, usually as some fraction of the profits in the commercial economy. Another feature is that entities within the ecosystem are either geographically localized or strategically linked to focus on developing a specific technology. Silicon Valley is the best known example of a geographically localized ecosystem. Two high profile examples of attempts to seed the development of strategically linked ecosystems are the Department of Energy's Innovation Ecosystem Development Initiative[5] which is focused on speeding up the adoption of *energy* innovations and the European Innovation Initiative's Digital Ecosystem technologies[6] that focuses on developing business systems based on information and communications technology. These national and international level strategic initiatives are just two examples; clearly innovation ecosystems can be structured around almost any subject matter. On a smaller scale, the Engineering Research Centers (ERC) program[7] at the National Science Foundation systematically funds potentially transformative

[3] Executive Office of the President (2009). A strategy for American Innovation: Driving towards Sustainable Growth and Quality Jobs http://whitehouse.gov/assets/documents/SEPT_20_Innovation Whitepaper FINAL.pdf.
[4] The Role of the National Science Foundation in the Innovation Ecosystem; http://www.nsf.gov/eng/iip/innovation.pdf
[5] http://www.topgovernmentgrants.com/grants_gov_display.php?program=DE-FOA-0000356
[6] http://www.digital-ecosystems.org/
[7] http://www.erc-assoc.org/

engineering systems and then fosters the development of innovation ecosystems centered on the engineered system's technologies. This program, which originated more than 25 years ago within the NSF's Engineering Directorate, has been very effective at initiating and maturing ecosystems that are stable enough for the ERCs to continue operating after the initial NSF funding terminates after 10 years. Currently, 82% of the graduated ERCs continue to embody the primary characteristics of an ERC (i.e. the integration of research, education, and industry as an organizing principle and the maintenance of an engineered systems focus). [8]

An innovation ecosystem is said to be thriving and healthy when the resources invested in the research economy (either through private, government, or direct business investment) are subsequently replenished by innovation induced profit increases in the commercial economy. At that point, the two economies (research and commercial) exist in balanced equilibrium and the innovation ecosystem is deemed to be healthy. This is expressed by the following equation,

$$P = P_0(I_{R\&D}) + \Delta P = P_0(1 - a) + \Delta P \ , \qquad (1)$$

where P_0 is defined as the initial profit before the investments in fundamental research are made, P is defined as profits corrected for investment, $P_0(I_{R\&D}) = P_0(1 - \alpha)$, $I_{R\&D} = \alpha P_0$, is defined as the commercial economy's research investment in the research economy, and ΔP is the innovation induced growth in the economy. Thus a small amount of the profit, $I_{R\&D}$, is reinvested in order to finance fundamental research. The result is a feedback loop, known as the virtuous cycle, which is depicted in Figure 1.

[8] James E. Williams, Jr. and Courtland S. Lewis, *Post Graduation Status of National Science Foundation Engineering Research Centers: Report of a Survey of Graduated ERCs,* Prepared for the National Science Foundation by SciTech Communications LLC, January 2010.

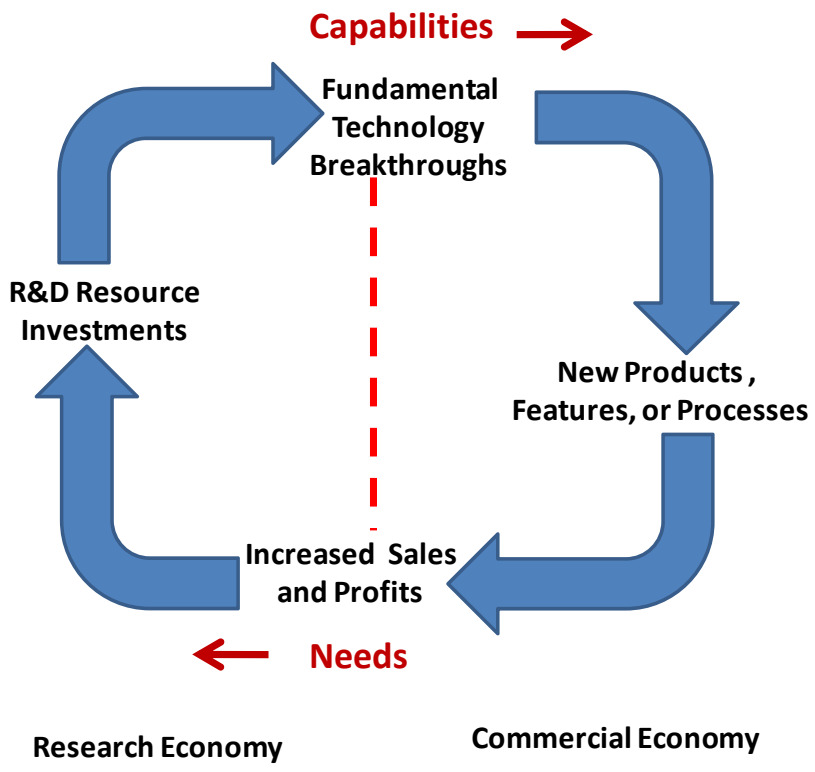

Figure 1. Virtuous cycle depicting how R&D resource investments are replenished through increased profits in the commercial economy in a thriving innovation ecosystem.

When the innovation induced growth in profits exceeds the initial R&D investment, instead of being balanced, the innovation ecosystem is said to be growing. Clearly the goal of most of today's government entities that fund innovation is to put their economies into a growth phase with increasing taxable earnings:

$$P > P_0(I_{R\&D}) + \Delta P = P_0(1-\alpha) + \Delta P \ . \qquad (2)$$

Innovation spectrum

The challenge to creating growth in an innovation ecosystem is figuring out how to turn the breakthroughs of R&D efforts into products that lead to profits. Achieving this goal is complicated by the fact that the two economies operate on different reward systems, thereby making it challenging to link

discoveries derived from fundamental research with innovative products that can translate into profits in the market place.

Another challenge is the scarcity of implementation resources, $I_{TD\&D}$, for technology demonstration and development. In Figure 2, the innovation spectrum shows the distribution of resources invested in activities aimed at discovery, technology demonstration, technology development, and commercialization. At the far left of the spectrum (i.e. where academic research is concentrated), there is a heavy concentration of government investment in fundamental research; while to the far right of the spectrum (i.e. in the commercial marketplace) there is a much higher level of industry investment in direct product development. This gap in resources for technology demonstration and development (TD&D) is colloquially known as the *Valley of Death*. The actors engaged in moving innovations from discovery through commercialization are academia, small businesses, the investor community, and commercial industry. For these actors, it is within this *valley* that many potential innovations die for lack of the resources to develop them to a stage where industry or the investor community can recognize their commercial potential and assess the risk associated with bringing them to market.

One might naively assume that the most effective way of helping the ecosystem to thrive is by substantially increasing TD&D resources available in the *Valley of Death*. Though this may successfully move more innovations into the commercial sphere, it doesn't guarantee a thriving innovation ecosystem because the assumption fails to account for resource limitations and other uncertainties that could limit growth and profits in the marketplace. To properly account for these uncertainties, a better understanding of the difficult-to-model economic dynamics within the ecosystem is needed. However, when the system is required to satisfy the constraints of the virtuous cycle, a simple resource projection of the model reveals that the effect of increasing the TD&D investments further reduces the ecosystem's aggregated profits, thereby requiring a larger innovation induced profit, ΔP, to complete the virtuous cycle as in equation 3,

$$P \geq \{P_0(1-\alpha) - I_{TD\&D}\} + \Delta P\,. \qquad (3)$$

To make things worse, 99.9% of the TD&D enterprises presented to investors fail[9], which means that the magnitude of the losses from the failed TD&D investments, $I_{TD\&D}$, in equation 3 can be significant.

The high loss rate can be mitigated by teaming with professionals experienced in translating technologies across the gap such as successful entrepreneurs, angel investors, or venture capitalists. But even with the extensive resources and thorough due diligence practices of venture capitalists, only one out of every 10 of venture capitalist investments are considered to be commercial successes[10]. The reason that venture capitalists cannot guarantee the success of the innovation enterprises they select is because there are many uncontrollable factors in the marketplace that cause enterprises to fail. Common reasons[11] for failure are misjudging the marketplace, government created roadblocks in approval (FDA, FCC, FAA, etc.), no market for the product; stronger competition than expected; technologies that do not work as expected; bad management decisions; bad luck; the required funding outgrowing possible financial rewards; unexpected government changes to laws or regulations, etc.

[9] Jeffry A. Timmons, Andrew Zacharakis, and Stephen Spinelli, *Business Plans that Work*, McGraw Hill Companies, 2004, p. 17

[10] http://ezinearticles.com/?Improve-Venture-Capital-Returns-With-IP-Portfolio-Management&id=1420039

[11] http://www.questia.com/googleScholar.qst?docId=5001285456

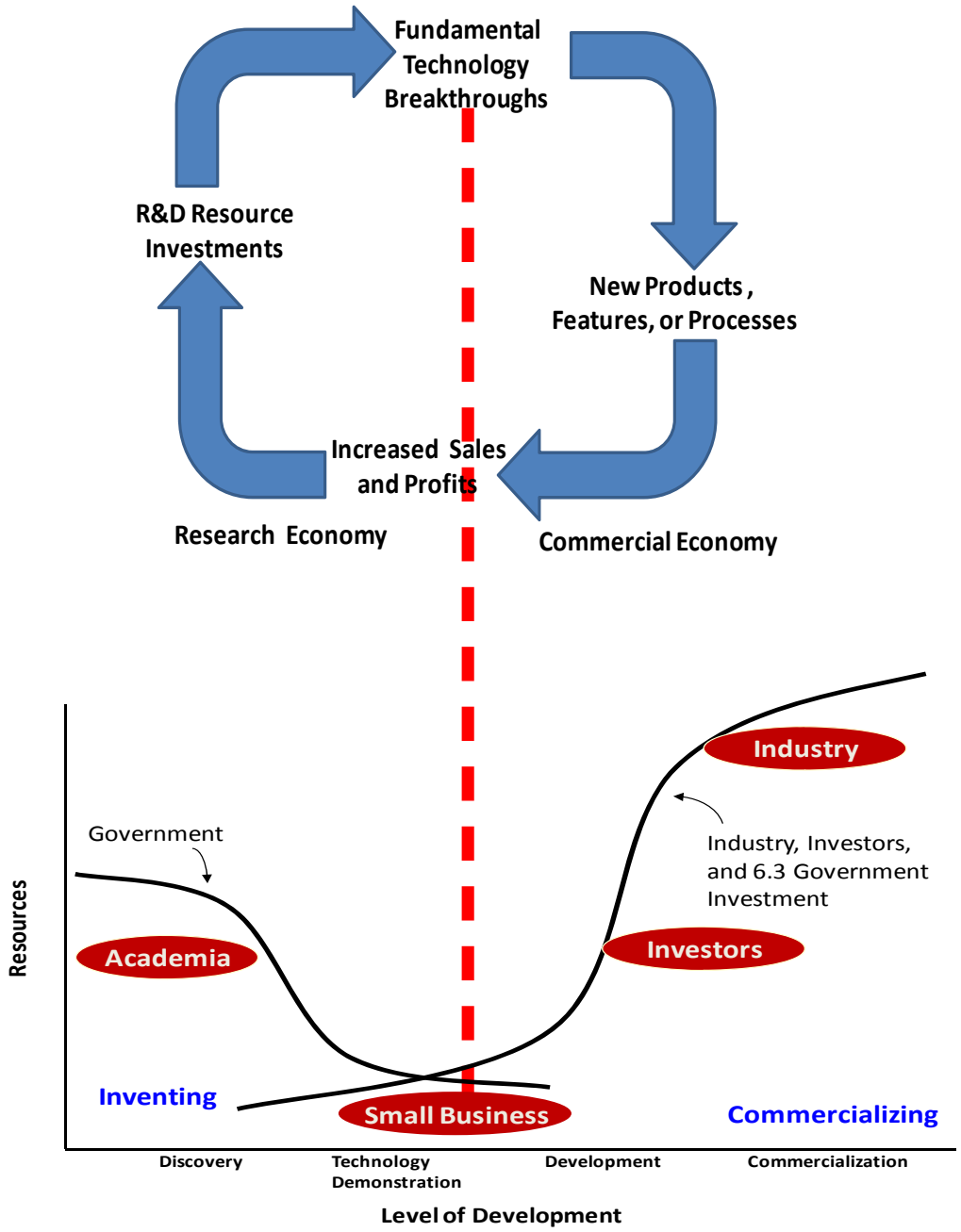

Figure 2. This figure links the innovation Spectrum to the two economies in the virtuous cycle; thereby illustrating the projection, along the different development stages, of the available resources within an ecosystem for discovery, technology development, and commercialization

Statistically, 50% of the venture capitalists investment portfolios fail outright, 30% are marginal in that they don't fail, but also don't experience growth, 10% grow at a rate of about twenty percent a year, and

10% grow fast enough to provide returns in excess of 1000%. Venture capitalists only classify an investment enterprise as successful if its return on investment (ROI) exceeds a factor of 10. The reason venture capitalists require a minimum ten-fold ROI is to ensure that they can recover their investments on the other nine investments that "fail". Like the venture capitalists, the innovation ecosystem must experience enough earnings growth to recover all investments in the TD&D to be considered healthy and thriving.

The high risk to investors leads to several important conclusions about healthy conditions that define innovation ecosystems. First, the increased productivity from successful enterprises must be profitable enough to compensate for the monetary investment in fundamental research *and* for the aggregated investment in both the successful and the failed TD&D ventures. Because there is a high probability most enterprises launched in the ecosystem will fail, a healthy ecosystem should also be structured to handle failures in a way that encourages terminating losing investments early in order to facilitate more efficient utilization of ecosystem resources. Ideally, the ecosystem is structured to efficiently recover and recycle any resources (including human capital) that are released upon the failure of individual enterprises. Because resources within the ecosystem are limited, the dynamics of success and failure within the *Valley of Death* represents an important mechanism for regulating the consumption of the ecosystem's resources.

Nurturing the culture of the innovation ecosystem

In the context of nurturing the culture of the innovation ecosystem, successful enterprises are considered to be those that are self-sustaining. Given that standard, the above statistics on venture capitalists success rates suggests that at least 50% of the venture capitalist investments in a technology arena become viable enough to contribute to the ecosystem's culture by helping to create jobs, helping to shape the competitive environment, and through participation in the ecosystem's ideation and innovation dialogs. Besides assembling the actors who will contribute to the innovation ecosystem, a healthy ecosystem also provides a mechanism for building relationships and other intangibles between the actors and entities. It

is the development of these relationships that help facilitate deals when the need arises. In addition, finding ways to quickly identify and root-out failing ventures while simultaneously accelerating the passage of winning ventures through the *Valley of Death* facilitates the efficiency and sustainability of the innovation economy.

Turning *Valley of Death* into a Challenge Basin

What are some of the intangible ways of enhancing the odds that emerging technology innovations will successfully bridge the *Valley of Death*? There is no set recipe for developing relationships within an ecosystem because it depends on the specifics of the technology, the cultures of the ecosystem entities, and the personalities of the players. The best way to describe how to approach the development of these relationships is to start by viewing the "*valley*" in a metaphorical sense (see Figure 3). In this context, the intangible relationships of the innovation ecosystem comprise everything one does to the infrastructure to effectively move the research side of the *valley* wall further to the right; or to move the commercial side of the *valley* wall further to the left thereby improving the odds of an innovative venture successfully spans the *Valley of Death*. For example, training a cadre of champions to shepherd ventures toward commercial success represents a technology push that effectively moves the valley wall to the right.

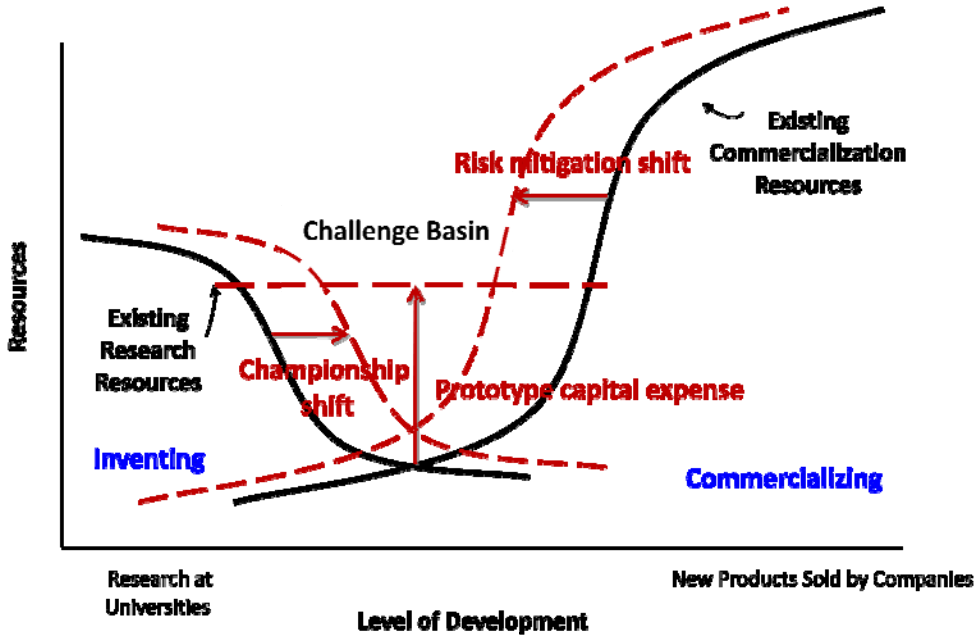

Figure 3. The innovation ecosystem consists of the actors, entities, and intangibles. The intangibles are the complex relationships that effectively move the valley walls inward and the valley floor upward in order to replace the deep walled Valley of Death with the gentle slope of a challenge basin.

Ideally, healthy ecosystems that have made such human capital investments also find ways to keep their champions engaged and circulating within the innovation ecosystem by providing a means of subsistence or other incentives for them to elect to stay within the ecosystem. For example, ecosystems benefit from the by actively engaging the marginal and moderate growth enterprises that are considered to be failures by venture capitalist standards because they don't produce large enough profits. In contrast, within the innovation ecosystem, these enterprises bring value because (i) they have sustainable cash flows that don't impact the to they can serve as habitats for champions between enterprise ventures. It is a common wisdom in the circles of investors that the experience of failure is just as valuable on the resumes of champions as the experience of success. Indeed, some have argued that the experience of failure is more valuable, because it teaches the champions when best to cut their losses. Thus even failed enterprises bring valuable lessons and experience into the culture of the ecosystem.

An effective strategy for moving the commercial side of the *valley* wall further to the left would be to find ways of lowering the perceived risk for investors. For example, ecosystems that find ways to translate knowledge of discoveries developed in the research community into a context that is relevant to the industry investors reduce the perceived risk for the investor so that he/she might be inclined to invest in the technology at an earlier stage. Another approach would be for the researchers to find ways to establish regular brainstorming dialogs with members of the investor communities about nascent technology and it potential capabilities thereby leveraging the industry and investor community's first-hand knowledge of the market sectors and the unfilled needs that a nascent technology might potentially address.

Beyond the intangibles, there are infrastructure investments that are designed to benefit the innovation ecosystem as a whole which can reduce the negative impact of failures on the virtuous cycle's feedback loop. For example, putting in place rapid prototyping infrastructure is beneficial to the innovation ecosystem because it (i) lowers the entry costs for start-ups to engage in innovation and (ii) it raises the success rate by increasing the number of attempts at translating the *Valley of Death*. It is the type of investment that government entities may be more willing to make because it spreads their risk among a larger number of ventures, thereby increasing the chances that they will have invested in an enterprise generates more revenue and creates jobs. The best examples of this are the Semiconductor Research Corporation (SRC) for integrated electronics [12] and the ERC proof of concept testbeds. The Engineering Research Center for Structured Organic Particulate Systems (C-SOPS), for example, recently established a continuous tablet manufacturing prototype testbed facility[13,14] for the benefit the pharmaceutical industry. Other infrastructure investments might involve creating institutional positions and career pathways that allow champions and other actors involved in the innovation process to reside within the ecosystem between ventures (for example, innovation post docs, professors of practice, etc), thus creating a ready manpower pool which is available for launching innovation enterprises.

In summary, fundamental research is a necessary ingredient for the development of transformational innovations that have potential for delivering significant economic growth. Ecosystems that reduce their profits in order to invest in fundamental research begin to thrive when enough innovation induced profits are generated to replenish the initial investment. Harkening back to the biological ecosystem, a close analogy exists between the biological "nutrient exchange" processes that regulate the biological equilibrium and the "innovation cocktail" (i.e. fundamental knowledge, intellectual property, implementation know-how, marketplace knowledge, creative ideas, management savvy, human

[12] Semiconductor Research Corporation—http://www.src.org/
[13] http://showcase.erc-assoc.org/accomplishments/2010/2010-CSOPS1-D-pharmaprocess_DL-CLedit.html
[14] http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0951845

resources, infrastructure resources, and financial resources) that regulate the equilibrium of the virtuous cycle.