# Designing the Interface: Promoting Innovation

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*We identify and characterize the policy interfaces between the layers of economic agents: the individual, the firm and the government level. Innovation is modeled with a production function which captures the physical tradeoffs among the inputs. The inputs include the usual capital, labor and materials, but also less common inputs: knowledge, infrastructure and motivation. Policies to promote (or inhibit!) innovation can be gleaned from the interfaces between the layers. The theoretical model draws from economic innovation literature in macro, micro, development and economic history. The proposed framework is useful in both descriptive and prescriptive ways.*

## INTRODUCTION

The objective of this study is to identify and characterize the policy interfaces between economic agent "layers": between the individual and the firm, and between the firm and the government/economy.

The "output" of innovation, is modeled as a production function which captures the physical tradeoffs among the inputs. The inputs include the usual capital, labor and materials, but also less common inputs: knowledge, infrastructure and motivation. The inputs take on different context at each of the different economic agents. Policies to promote (or inhibit!) innovation can be gleaned from the interfaces between the layers.

The theoretical model draws from economic innovation literature in macro, micro, development and economic history. The proposed framework is useful in both descriptive and prescriptive ways. Examples are provided to illustrate the use and usefulness of the approach. We first describe the framework then discuss the policy implications at each level.

## CONTRIBUTION

This is not an attempt to model the <u>impact</u> of innovation.[1] Here, we will assume that it is desirable, for some reason, to produce innovation and that it would be helpful to better understand that process and the policy tools that can influence it.

The purpose of this work is to identify and characterize the policy interfaces which influence amount of innovation. We start with a model of the <u>production</u> of innovation. We fully acknowledge that great innovations could occur spontaneously[2] or serendipitously but this is not an attempt to describe those cases. The process of production involves science, engineering, resources, and time. It also proceeds "on purpose".

In many ways, the production of innovation is not unlike production of any good or service. However, it is precisely those ways that it is unlike other types of production that make it more interesting and more useful to single out for study. Innovation has some aspects of a public good and has the potential for spillover effects into other firms and other industries. Some choices are highly-strategic and game-like due to patents and due to "priority", the benefits of being first. The process often has more in common with evolution than with a series of optimal choices. The production of innovation, at all levels, takes on different characteristics near the frontier of knowledge.

As is true in many areas of economics, the micro-foundations at one level are apparent in the next level, but the whole is different than (just) the sum of the parts. Firms are comprised of individuals, and when they are combined as firms, they have different goals and characteristics than individuals on their own. The interfaces between these levels are the focus of this study.

- Interface ISF (Individual Seeks Firm) is where the individual considers producing an innovation as a member of a firm.
- Interface FHI (Firm Hires Individuals), is where the firm considers hiring an individual for the purpose of producing an innovation.
- Interface FPG (Firm Part of Government project) is where the firm considers producing an innovation as part of a government project. This can be officially part of the project because the Government is providing some funding or a mandate, or unofficially because the Firm accepts the Government's bully-pulpit message.
- Interface GCF (Government Contracts with Firm) is where the government considers contracting (officially or via its influence on the firm) with a firm for the purpose of producing an innovation.

The interfaces between the layers, that is, between individuals and firms, and between firms and governments, provide the opportunities for policies that stimulate or inhibit the production of innovation.

## RECONCILE DIFFERENT APPROACHES TO INNOVATION

Before describing the model and the interfaces, it is helpful to consider the various approaches to innovation. Each approach, particularly the non-neo-classical approaches, provides insights which improve the innovation production model. Innovation (Z) has been studied at the macro economy level, the firm level and personal level because innovation provides benefits at each of these levels. Innovation results in economic growth, so economies (governments) want it. Innovation results in firm growth, so companies want it. Innovation is a creative outlet that often also results in increased income/fame, so individuals want it.

Although we recognize that it is possible that innovation is not always a "good", typically more innovation is better. If more is better, how can the production of innovation be encouraged and rewarded? Should the focus of the economics of innovation be on the individual, on the firm or on the national economy? Researchers differ in their approach and focus, but these options are not independent. Theoretic approaches have included the usual growth model approach (Romer, 1990), an evolutionary approach (Nelson & Winter, 1982), and a 'learning approach' (Ludvall, Johnson, Andersen, & Dalum, 2002). Baumol (2010) described micro-foundations of the entrepreneur as it contributes to economic welfare. Most of these have focused on the *impact* resulting from innovation. Herein we focus on the production of innovation itself. We provide a framework that treats each layer separately and yet the layers are interconnected in a useful manner.

Ultimately an individual is involved with any innovation that is brought into the market place, but situations differ to the extent that individuals can bring together the resources needed to produce the innovation. In the spirit of Coase (1992), it makes economic sense for a firm to bring an innovation to the market place if a firm can acquire the resources needed for the innovation at lower cost than can any one individual. The cost savings may be, for example, the result of lower transactions costs or because the risk is distributed over more agents. Likewise firms may be involved in bringing an innovation to market, but an isolated innovation does not provide growth in an economy.

Individuals, firms and economies (or governments responsible for economies) typically have different goals, and this might lead to different outcomes. They also have different opportunities. Different goals and opportunities provide the occasion for a variety of policy actions.

We first describe the framework and then discuss the different policy options.

## INNOVATION PRODUCTION FUNCTION (Z)

We propose that the innovation "production" function is a function of the usual labor (L), capital (K), and land/resource (N), but also of the accessible knowledge Base (λB), infrastructure (S), and motivation (V).

$$Z = f(L, K, N, \lambda B, S, V) \tag{1}$$

A production function is intended to describe the nature of the physical tradeoffs among various ways to accomplish similar amounts of output, here, the output of innovation.

Innovation output (Z) is a placeholder for a quantity of new products or services, improvements and cost reductions. That is, we are interested in the production of what Schumpeter (1947, p. 150) called the "creative response". Output which is 1) "Understood after *ex post*, but it can practically never be understood ex *ante",* 2) results in a fundamental change in social and economic situations that could not have resulted without it and 3) where frequency of occurrence is related to the quality of people, the relative quality of people and individual decisions, actions and patterns of behavior.

At the risk of splitting hairs, we will restrict an innovation to be more than just a new scientific observation. That is, as used here, Z is not the production of science, but rather the production of a good or service that has economic value. In casual parlance, we are talking about the D, not the R, in R&D.

Like our more conventional production functions, *more* of this output is generally more desirable than *less* of it and diminishing returns set in if some inputs are fixed and one of the other inputs is increased. Analogously to the production of goods and services, the individual's, firm's or government's target level of innovation is selected well before production is maximized. The production function describes the nature of the *physical relationships* among the inputs; how inputs can be combined to produce a particular amount of output. The relationships are not necessarily deterministic, but it is also not "magic" or pure "art"; the relationships include engineering and scientific relationships.

Some of the inputs to the innovation production function have similar definitions to those in a more conventional production function, but clarity of definition and examples for the production of innovation are useful to the policy discussion that follows. The discussion below is relevant to all levels. Equations (2)-(8) show that adding more of the input increases the output of innovation, but (when at least one other input is fixed); diminishing returns do eventually set in. Unless specified, some of each input is required if innovation is to occur.

### Labor (L)

Labor is a measure of effort by an individual or group of individuals, typically measured in time. Labor does not become part of the output, but labor is an essential input; nothing is produced if no labor is used. In other words, innovation is a human-based activity. Labor used in the production in innovation cannot be used in other ways.

$$Z(L=0) = 0; \ \partial \mathbf{Z} / \partial \mathbf{L} > \mathbf{0} \text{ and } \partial \mathbf{Z} / \partial \mathbf{L}^2 < \mathbf{0} \tag{2}$$

### Capital (K)

Capital is the set of tools used to produce the output. This includes human capital "tools" acquired on the job or via formal education. Capital does not become part of the output and can usually be used to produce many different types of output. That is, it can be put to different uses. Capital includes buildings, laboratories, microscopes, hammers (but not nails), rules for accounting, a method for distilling liquid, how to determine if the cantaloupes are ready to pick, as well as the health of the worker (Schultz T. W., 1980), ability to observe carefully, lateral thinking (de Bono, 1970) and TRIZ (Mann, 2001).

Capital is an essential input; nothing is produced if capital is not used. Capital typically depreciates. Human capital is lost when the human stops working. A unit of Capital is worth more right now at time[3] "t" than it will be worth in the future at time "t+1". Since it is difficult to sum up these different types of items, typically capital is listed as monetary cost of acquiring the capital.

$$Z(K=0) = 0,\ \partial \mathbf{Z} / \partial \mathbf{K} > \mathbf{0} \text{ and } \partial \mathbf{Z} / \partial \mathbf{K}^2 < \mathbf{0} \tag{3}$$

$$\text{If } K(t)=y, \text{ then } K(t+1)=y\delta, \text{ where } \delta \text{ is a depreciation factor.} \tag{4}$$

**Material/ Land (N)**

Analogous to the more conventional production relationship, Material or Land includes inputs that become part of the innovation or are consumed in the production of the innovation. The production of innovation may use natural resources or intermediate products as varied as pencil lead, electricity, plastic, chemicals or magnetic force. If the innovation is not a product, but a service or an improved process, then it is possible that very little or no Land is used in the production of the innovation.

$$Z(N=0) >= 0,\ \partial \mathbf{Z} / \partial \mathbf{N} > \mathbf{0} \text{ and } \partial \mathbf{Z} / \partial \mathbf{N}^2 < \mathbf{0} \tag{5}$$

**Knowledge Base (B)**

Knowledge base is often lumped with capital through human capital, but as pointed out by Moykr (2002) and others, there is a difference between the propositional knowledge of the way things work (e.g., mathematics, scientific theories, geography, history) and the practical prescriptive knowledge that functions more like a tool (e.g., instructions for using the Pythagorean Theory to find the distance between 2 locations). That is, it is useful to distinguish between the stock of knowledge (here, B) and the practical use of that knowledge (here, included in K). Both of these are different from the flow of new knowledge which is $\Delta B$. Since some of our policy options make use of these differences, we separate them here. Additional discussion is included later in this paper.

The stock of knowledge may exist, but it must also be accessible to the Labor inputs used in the production function. We use $\lambda$ to capture how "tightly" (Mokyr, 2002) the knowledge is held. Tightness can be increased through, for example, by education, by assembling a team of individuals who know different parts of this knowledge, and by improved Internet access.

The innovation production function is meaningless in the range near where B=0. (How does one deliberately innovate when one knows nothing?) We expect more innovation the larger the stock of knowledge, but it is unclear how the rate of change in innovation is affected by larger stocks of knowledge. The ambiguity is likely to result from the use of knowledge base at the different layers. An individual can only make limited use of an ever-growing stock of knowledge. A firm may be able to make better use of a larger stock of knowledge by assembling a team. But it takes an economy, perhaps even the world economy, to make use of the entire stock of knowledge.

The important characteristic of knowledge base is that part of this base may have characteristics of a public good (Arrow (1962), Stephan (1996)). Some use of knowledge in the production of innovation may be both non-rivalrous and non-exclusive. In fact, as others (Mokyr, 2002) have pointed out, the knowledge becomes more useful when more people know it; that is, the "tightness" of the knowledge matters. It is often the interaction between knowledge base and other inputs that results in an innovation.

General knowledge may be both non-rivalrous and non-exclusive, but often one of these characteristics is missing. That is, the relevant knowledge base may have characteristics more aligned with contribution goods (Kealey & Ricketts, 2014), club goods or common pool goods. Contribution good characteristics are relevant when the spillover effects (Audretsch & Stephan, 1999) benefit those participating. Club good characteristics are relevant when knowledge used for innovation may be specific to the industry or firm and well understood within but not outside the industry. Common pool characteristics, with their 'tragedy of the commons' problems, are relevant when the knowledge is widely understood and applied in many innovations.

It is not assumed that knowledge is under produced. Markets may under-produce certain types of knowledge but positive spillover, and non-market responses such as priority (Stephan, 1996), may more than offset the deficiency without government intervention (Davidson & Potts, 2016). Nelson and Winters (1982) discuss the relationship between the knowledge base spillover and the resulting innovations in a dozen different industries.

$$Z\ (B=0) = \text{undefined},\ \partial \mathbf{Z} / \partial \mathbf{B} > \mathbf{0},\ \partial \mathbf{Z} / \partial \boldsymbol{\lambda} > \mathbf{0} \text{ and } \partial \mathbf{Z} / \partial \mathbf{B}^2 <=> \mathbf{0} \qquad (6)$$

**Infrastructure (S)**

Infrastructure includes the set of capabilities and institutions that are not included in the other inputs to the innovation production function, but which facilitate the *combination* of inputs. This would include a system of money, laws, property rights, communication systems, transportation systems, and existing products; that is, "institutional development and the structure of payoffs these provided (Baumol, 2010, p. 150). It includes the ability for inputs to flow to their most useful use. For example, infrastructure could include the development of factors that lead to what Florida (2014) calls the creative class. A lack of infrastructure can delay or prevent innovation. As Rosenberg (1982) explained, the interdependence of innovations means that the relevant set of "existing products" includes substitutes, complements, and inputs of the innovation produced. For example, it only makes sense to produce an "app" for displaying traffic data if there is a device (e.g., iPhone) on which to run it and roads on which the traffic would occur.

The positive impact of infrastructure is partially offset by its negative impact. Taxes and regulations imposed by governments can restrict or prevent innovation from occurring. Law suits and rent seeking can threaten (Baumol, 2010, p. 170) the production of innovations. These negative impacts of infrastructure are represented by T.

$$Z(S=0) >= 0,\ \partial \mathbf{Z} / \partial \mathbf{S} > \mathbf{0},\ \partial \mathbf{Z} / \partial \mathbf{T} < \mathbf{0} \text{ and } \partial \mathbf{Z} / \partial \mathbf{S}^2 < \mathbf{0} \qquad (7)$$

**Motivation (V)**

A conventional production function does not typically include motivation; rather, motivation is lumped within the goal or objective that the economic agent is pursuing. However motivation or entrepreneurial spirit is an important input to the production of innovation. It can be considered separately from, for example, a goal of profit-seeking or utility maximizing. (Surely each of us can identify people who have a lofty or ambitious goal and all the "tools" for success, but still no motivation to follow through with the actions necessary to achieve the goal.)

The distinction is more important for work like the production of innovation which involves considerable thinking; that is, where it is costly to observe "shirking". Motivation captures items such as the incentive-enhancing preferences (Bowles, Gintis, & Osborne, 2001), the ability to deal with disequilibria (Schultz T. W., 1975), the desire to win the patent race (Kamien and Schwartz (1975), Reinganum (1981)) and the attraction to puzzle solving and priority (Stephan, 1996). That is, the production of an innovation requires certain types of motivation as input.

Some might prefer to model this as a highly specialized type of human capital. However, the sources for acquiring more of this input are of a different nature than other types of human capital. If no motivation is present, then no intentional production occurs.

$$Z\ (V=0) = 0,\ \partial \mathbf{Z} / \partial \mathbf{V} > \mathbf{0} \text{ and } \partial \mathbf{Z} / \partial \mathbf{V}^2 < \mathbf{0} \qquad (8)$$

**Selection of Inputs**

The use of inputs used in the production of innovation is in competition with their use in the production of existing goods and services. That is, there is an opportunity cost of using L, K, N, S, V, and to a limited extent B, to produce innovations. The unique nature of the Motivation required for the production of innovation may mean that its opportunity cost is low or zero.

$$P_L > 0, P_K > 0, P_N > 0, P_S > 0, P_V >= 0, P_B >= 0 \quad (9)$$

## FRAMEWORK IN LAYERS

The specific details of the input depend on the layer at which the innovation is considered: individual, firm or economy.

**Layer Characteristics**

Each layer builds upon the previous layer(s). The layers are tied to each other through many of the inputs. Firms must align incentives of hired individuals with those of the firm. The usual way is a set of incentives including compensation and recognition. Governments must align the incentives of firms (and indirectly individuals) with those of the government.[4] Typically incentives are in the form of contracts with private firms, taxes/subsidies, and bully pulpit. Most of the firms for which the government hopes to align incentives with its "innovation policy" really have no direct connection to the government. Although the government's problem is similar to the principle-agent problem, it is different enough that we have labeled this the "leader-follower" problem.

**Individual**

Goal for the individual is utility maximization subject to a (time and money) budget constraint. Utility may be increased by the ability to purchase more of those goods and services that are desired, that is, the motivation for innovating may be to make more income, but other types of utility are particularly relevant for innovation. Innovations have been produced for the innovator's convenience (for example, to automate a boring task), to solve a puzzle or in support of a "cause" (cure cancer, save the planet). We assume that individuals are risk averse or risk neutral which may provide link to the firm-level; risk adverse individuals may prefer to produce their innovation within a firm rather than on their own.

It might be helpful to think of the individual layer as firms of size=1. That it, the individual's production function has a maximum of 1 unit of Labor. However, the micro-foundations of the individual's choices become important at other layers, so this remains its own layer.

The individual innovator uses both physical capital and acquired human capital, where human capital includes education, training and health (Schultz T. W., 1980). This capital is used within a personal infrastructure that enhances or retards the production of innovation. This infrastructure includes incentive-enhancing preferences (Bowles, Gintis, & Osborne, 2001) including greater orientation toward the future over the present, sense of personal efficacy, a low dis-utility of work; stick-to-it-ness (Stephan, 1996), and the ability to handle disequilibrium (Schultz T. W., 1975).

The knowledge required by the individual producing innovation includes the scientific, engineering and behavioral information driving the physical relationships involved in the innovation, but also a framework for understanding new information. For example, with a working understanding of the periodic table of elements and how two elements react together, we can readily predict reactions of similar elements.

Note that this knowledge extends to frameworks beyond the specific information relevant to the innovation, for example, the individual's world view and self-image. Seemingly unrelated knowledge from another problem domain may be utilized by an individual producing innovation. For incremental changes, depth of knowledge may be important, but for truly radical innovations, breath of knowledge over many different spheres of information may be important (Mann, 2001).

**Firm**

The firm's objective for pursuing the production of innovation include: to generate a larger stream of future profits, to protect its existing monopolistic position or to replace the current market leader, or to address a strategic concern of its owners. That is, pursuing innovation may have strategic as well as economic goals. The usual objective of the firm, "profit maximization subject to the constraints of the production function," does not capture all the goals. Even though, production of innovative ideas and products within a firm is largely the same as producing some other good or service, one important difference may be the significance of time. Since investment in research and development (R&D) must be made now and the profits (or strategic benefits) only realized at some point in the future, the profit maximization must be considered over (a long) period of time. Like the individual innovator, firms that are producing innovation typically have an orientation toward the future over the present (Bowles, Gintis, & Osborne, 2001).

Strategic goals provide an objective for innovation, particularly for larger, established firms. Leading firms may seek to maintain their lead. Lagging firms may seek to leap to the front or simply be in the position to quickly imitate the leader. Innovative output may also help a firm navigate public relations issues, for example, emphasizing its attention to issues like the environment.

The firm has options not available to individuals in the production of innovation. Firms can acquire knowledge by assembling a team of diverse individuals.[5] Compared to individuals, firms have better access to financial resources that better shift resources across time and better mitigate against risk. Teams of individuals at a firm may also produce a synergy such that the output of the team is greater than the sum of the individual contributions. The firm facilitates this through its infrastructure of organization, "corporate" identity, networks, and sense of practical business that enables its innovators to "orbit the hairball" without being tangled up in the hairball (Mackenzie, 1998).

"Business and industry's rationale [to pursue R&D] relates to the desire to innovate." (Stephan, 1996, p. 1212) It hires individuals for the purpose of producing the innovation; that is, the demand for labor for innovation is a derived demand and that demand is sensitive to the swings in the perceived present value of the activity. The nature of the production of innovation is that it is costly to monitor the work. In many types of production, the firm can avoid shirking by setting an incentive scheme of compensation and recognition to align the workers' goals with the firm's goals. To produce innovation, the incentive scheme must typically move beyond financial compensation and offer recognition, cool toys (e.g., laboratories, accelerators, wind tunnels, etc.), insulation against financial issues and the opportunity to work with like-minded peers (Stephan, 1996).

**Government/ Country/ Economy**

Practically speaking, those in-charge of the government/ country/ economy, want to stay in-charge. This translates to winning the next election or preventing overthrow. Constituents with jobs and experiencing the benefits of economic growth are less likely to vote unfavorably or march in the streets. Jobs and economic growth are often linked to innovation; consequently governments tend to be interested in promoting innovation. The government's objective with promoting innovation is often closely links to national goals like national defense, the desire to win the "Scientific Olympics" (Johnson, 1972), and the perceived need to subsidize the production of public good knowledge ("basic science"). (Davison & Spong (2010), Nelson (1995)) It may also seek a new way to address the problems it faces.

At this layer, the labor force involved in the actual production of innovation in some particular sector or region is the relevant labor for the innovation production function. This labor may be directly hired by the government or be hired by firms. However additional labor is implicitly involved in providing the infrastructure, and consuming the innovations or the celebration of the success of the innovation.

The concept of capital for innovation is more general as well. At this layer, "capital" represents the flow of money over time that is used to purchase the physical capital; both savings and investment. It also includes the investment in increasing the "quality" of the work force through spending on infrastructure to provide education and improvements of population health (Schultz T. W., 1980).

Knowledge at this layer includes preservation of history, culture, science, and language, and the "tightness" with which this knowledge is held (Mokyr, 2005). It also includes collective knowledge and its depositories and access points: museums, encyclopedias, libraries, Internet, and national parks.

Infrastructure is critical but often overlooked at this layer. It includes the transportation, communication, financial and legal systems. This is not to suggest that the government should be or could be responsible for providing these, but they often are, for reasons separate from the production of innovation.

## INTERFACES

The interfaces between these levels provide the opportunities for policies that increase innovation. Policies that increase the benefits or decrease the costs on the interface will result in additional innovation. Policies that improve the signaling between agents can reduce transactions costs.

### Interfaces: Individuals and Firms

The arrangements between individuals and firms for the purpose of producing innovation are similar to those for other types of employment, but with recognition of the entrepreneurial nature of the relationship.

#### *ISF (Individual Seeks Firm) Interface*

An individual seeks out a firm to produce innovations which are not likely to be achieved without resources beyond those available to the individual. As part of a firm, the individual benefits from reduced risk, from potentially larger capital acquisition, and from the interaction with other people who are also pursuing the innovation (and the human capital and understanding of the knowledge base of those other people). The individual may also be able to pursue projects which are of a different scale (e.g., space exploration, nuclear weapons, cancer cures, green energy, sport cars) than can typically be handled by an individual. Part of the reduction in risk may be from not having to be concerned about how to fund the production of innovation. However this is not without cost. The primary cost is loss of control – of the objective, of the project, of the resources, and loss of the high profits/rewards from the development of a successful innovation. To be 'in the game' of innovation production, the individual must acquire relevant human capital and access to the knowledge base, and must be able to signal skill/capabilities to the firm.

#### *FHI (Firm Hires Individuals) Interface*

A firm hires innovative individuals to produce innovations within the firm. Without innovative individuals, the firm is not able to be innovative. If a firm strives to be innovative, it hires individuals to add to its human capital and to its readily accessible knowledge base.

The cost to the firm is the incentive scheme that must be used to attract the individuals it requires, and the financial resources needed. The incentive scheme includes salary, but may also include bonuses, relinquishing (some) control over capital budgets or project directions, and other amenities (e.g., parking spots, prestigious titles, awards, conference travel, release time, stock options, opportunities to publish, etc.). Financial resources can include retained earnings and investors. The firm can provide all the funding for the innovative activity or it can provide support for administering outside funding (such as from a grant). The firm must signal that it is pursuing interesting projects and has financial solvency commensurate with the task.

### Interfaces: Firms and Governments

The arrangements between firms and governments for the purpose of producing innovation are different from other types of arrangements governments might make with private firms (e.g., providing road construction, school lunches, or low rent housing). It involves a higher level of persuasion and usually less control.

*FPG (Firm Part of Government Project) Interface*

A firm seeks to be part of the production of innovation directed by a government agency or non-profit organization primarily because of the nature of the projects, strategic association with other firms, special infrastructure (e.g., special transportation and communication systems), and availability of vital resources for the project (e.g., uranium, giant lasers, pathogens, water, archives, stationary orbits), but project funding is also key. A firm becomes part of a government project either directly by contract or by grant or indirectly by association. The funding model is connected to the amount of control it relinquishes over the project direction, capital budget and project timeline. An additional cost could be that the project (and its funding) is political and subject to the swings in the political cycle. To become part of the project, a firm must typically signal its ability to meet project timelines and that it has resources (e.g., human capital, knowledge base) that are particularly valuable on the project.

*GCF (Government Contracts with Firm) Interface*

A government or organization will contract with innovative firms to produce innovations for the government or for the people or place over which the government has jurisdiction. The contract may be explicit or implicit. Implicit contracts include privately funded projects which address a government's or organization's publically stated cause (e.g., pollute less, emphasize STEM[6], increase literacy, conserve water, re-build infrastructure, win the war, prevent birth defects). Without innovative firms, the government is not able to be innovative and typically does not have the expertise to adequately triage among competing innovation projects—both from an economic point of view and from a scientific/engineering point of view. If a government strives to be innovative, it can make explicit arrangements with firms in order to bring human capital, physical capital, and its readily accessible knowledge base to the government's project. The cost of contracting with firms for innovation production is the fees or grants paid, the additional infrastructure provided, and the opportunity cost of backing the wrong idea.

A government seeking to be innovative can also make implicit arrangements with firms. Through its use of the "bully pulpit", it can rally firms and individuals to its agenda. The benefits of this approach include reduced risk of selecting the "wrong" project, little out-of-coffer money, and potential for a wider set of new innovations. The cost of implicit association is the (almost total) lack of control of the innovative production and cajoling firms to innovate in directions advocated by the government may be a bit like pushing on a string. There is also potential for too many resources to be devoted to the innovation of a particular project (Stephan, 1996).

The government or organization signals its intentions primarily through well-established channels for bids and grants or through public announcements. It might also be necessary to signal likelihood of persistence of the objective and/or funding source.

## SUMMARY

We identified and characterized the policy interfaces between the layers of economic agents: the individual level, the firm level and the government/economy level. Innovation was modeled as a production function with the usual capital, labor and materials, as well as inputs of knowledge base, infrastructure and motivation. The theoretical model draws from economic innovation literature in macro, micro, development and economic history. The goals, benefits and costs were explored at the interface between individuals and firms, and between firms and governments.

## ENDNOTES

1. Most economic studies focus on the impact of innovation on an objective “X”, where X is “growth”, “development”, “education”, “industrial sectors”, “prestige”, etc. That is, we expect, $\partial \mathbf{X} / \partial \mathbf{Z} > 0$ where Z is the amount of innovation and X is the economic agent’s objective. We also acknowledge that when at least one factor is fixed, eventually, diminishing returns set in so $\partial \mathbf{X} / \partial \mathbf{Z}^2 < 0$
2. The process involved with spontaneous innovations might best be described as “discovery” rather than “production”.
3. Time is not explicitly listed as a determinant of the innovation production function because time does not contribute to the output of innovation. However, time is implicitly part of the function and the choices made in a previous time period have an impact on the choices available to the decision maker in a subsequent time period.
4. For a representative government, it might be assumed that the government’s goals flow forth form the people who elected them, but even if we assume this, there could be a large portion of the firms and individuals that did not share the viewpoint of those elected. It would be desirable to align their actions with the new viewpoint.
5. Here diversity is not a legal definition regarding race, age, etc., but rather a description of the different viewpoints and frameworks that different individuals bring to an innovation team.
6. Science, Technology, Engineering and Math

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