The Political Economy of Controversial Technologies

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2012 AAEA Annual Meeting, Seattle, Washington, August 12-14, 2012

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1. Introduction

The adoption and diffusion of new technologies is an important element of economic growth. However, new technologies may have environmental and public health, as well as economic, ramifications that lead to demand for public oversight and regulation, and such interventions significantly impact the adoption and use of the technology itself. The literature on adoption (Sunding and Zilberman, 2001) emphasizes that adoption rates vary by location, due to biophysical and to socioeconomic conditions. In particular, differences in regulatory policies may be a major reason for differences in adoption by country. Agricultural biotechnology is one clear example where differences between regulations in US, Canada, Brazil, and Argentina, on the one hand, versus the European Union and most of the countries in Africa and Asia, on the other hand, contribute to major differences in adoption rates (NRC 2010). Another controversial technology is food irradiation. Some European countries constrained the use of food irradiation, while others, like the Netherlands, Belgium, and France, routinely irradiate many food products. The formation of such regulatory policies is often a part of the introduction of new technologies. Breakthroughs are followed by intense policy debates between conflicting assessments of merits and risks, leading to the introduction of a new regulatory framework.

Most political-economic models reduce to a “politician” or “regulator” that weighs the interests of various groups within the economy, i.e., groups that have managed to solve the collective action problem and are well enough informed with respect to their likely costs or benefit arising from the regulations in question (Becker, 1983; Grossman and Helpman, 2001; Peltzman, 1976; Zusman, 1976). These weights reflect the relative influence each of the groups over the politician. The groups engage in actions to influence the regulator—for instance, by making political contributions, making endorsements, or simply casting votes—and thereby affect policy outcomes in ways that cause them as a group to gain in terms of economic welfare or economic rents. In fact, Posner (1974)’s capture theory can be considered a special case in which one group has full weight and all other groups have zero weight in influencing the regulator.

Whereas the traditional political-economic framework with multiple interest groups (Grossman and Helpman, 2001) provides some useful insights, it is still too simple to capture some of the key phenomena shaping the political economy of regulation of controversial technologies, particularly in terms of actual versus perceived consumer welfare, the effect of risk perceptions in the formation of expectations about future welfare, and interactions amongst the different groups within society, including the roles of environmental activist organizations and the media.

This paper introduces a model of regulatory decisions within a dynamic political-economy framework, in contrast to the political economy literature in which static models are used to analyze the introduction of regulations of new technologies (Rausser, Swinnen, and Zusman 2011). As in standard models, the regulator considers the interests of different stakeholder groups across society, weighing those interests by the degree of political influence of each such group. However, in this paper, the regulation of a controversial new technology is developed in a multi-period, multi-country game. In the first period, the technology is introduced. Public debate ensues as the innovating infant industry and environmentalists provide public information about the new technology resulting in the controversy over this technology. In the course of the public debate we allow for the generation or destruction of '*goodwill*' toward the new technology. Goodwill is defined as an aggregation or index of imperfectly formed expectations over the future net social benefits of the technology, including economic surpluses from consumption and production, as well as public good and externality impacts on welfare, such as environmental and health impacts. Thus, goodwill is a summary of public perceptions, or following its namesake in finance, the value of the technology above and beyond immediately appropriable returns based upon its reputation. Goodwill is represented as a stock variable updated each period based on information about the technology provided by different stakeholder groups as well as actual performance of the technology. Goodwill influences the considerations of consumers and other stakeholder groups regarding how much regulation they prefer over the new technology. Decisions are made by the regulator in each period and each country considering each of the relevant stakeholders' current preferences and domestic political weight through a typical political-economic process. The net policy outcome in each period and in each country thus reflects the net welfare impacts percieved by each of the stakeholder groups.

More specifically, we consider the following groups: the innovators who produce the output product based upon or using the new technology (e.g. in the case of GMOs, the biotech companies), the incumbents (companies who produce a substitute output product based upon or utilizing a competing incumbent technology, e.g. agchemical companies), the consumers of the product, and environmentalists. Following the political economy literature, the welfare of each group is measured by net economic surplus, expanded to include perceived future net benefits or risks informed by the level of 'goodwill'. We develop a formal modeling the dynamics of goodwill, where stakeholder groups are allowed to influence perceptions of the new technology. Consumers may not be well informed about the technology and may be quite influenced by 'goodwill'. The framework takes into account ongoing accumulation of information about the new technology and resulting changes in 'goodwill'. Key parameters in the process include the reliability of different sources of information as well as the political weights of different interest groups, which may differ across countries and thus result in different outcomes even in countries with otherwise identical initial conditions.

Results of our analysis suggest that when the gains of individual consumers from the new technology are relatively small, a deficit of goodwill towards that technology due to negative information provided by groups that are considered as highly reliable may lead consumers to support tough regulations. Given the large weight of consumers, this can be enough to tip the political economic calculations of the regulator. Similarly, the net losses of the incumbent producers and their relative large political weight can lead to tougher regulation of the new technology. We can use the analysis to explain some of the differences between regulation of genetically modified crops and food irradiation in the US and Europe, and we discuss implications for major developing country markets.

2. Model

There are two products, an incumbent product that is produced using the prevailing or incumbent technology, Q^I, and a substitute product, produced using an innovative but less familiar new entrant technology, Q^E. Consumers are understood to derive utility both from direct consumption of products and from their perception of the products' effects on the common good. Let $u_C(Q^I, Q^E)$ denote consumers' utility derived from consumption of either of these products. Consumers also derive utility from regulation and its implications for the environment and health (Hamilton et al. [2003]). Let goodwill (GW^E) be a measure of public perceptions of the social benefits or risks associated with producing and consuming the new product (Q^E), such that that a larger GW a public perception of a more benign effect on the environment or public health from that technology.[1] However, GW also affects consumer utility indirectly. For simplicity, we assume separability between private consumption and the (perceived) common benefits or risks to the environment. This simple additive structure nests consumer's willingness to pay (WTP) for the products within a more general model of preferences for regulation. That is, consumer preference for regulation is

$$U = u_c(Q^E, Q^I, GW) + u_e(GW). \tag{1}$$

Consider an incumbent industry that, in period *t*, produces and markets the good $Q^I(t)$ whose characteristics are well known (see footnote 1). In addition, assume an infant industry that produces and markets the good $Q^E(t)$ which is a substitute for $Q^I(t)$ but whose environmental and health impacts are not yet well known. Without loss of generality, assume each industry is composed of only one firm, namely, an incumbent firm and an entrant firm.

The incumbent firm faces a downward sloping demand curve for its product, where the price of the product demanded at time t, $P^I(t)$, is a decreasing function of the quantity demanded at time t, $Q^I(t)$ and the quantity demanded at time t of the substitute product, $Q^E(t)$: $P^I(t) = P^I\big(Q^I(t), Q^E(t)\big)$, where $\frac{\partial P^I}{\partial Q^I} < 0$ and $\frac{\partial P^I}{\partial Q^E} < 0$. The elasticity of current-period demand is defined as $\epsilon_{Q^I,P^I} = -\frac{\partial Q^I}{\partial P^I}\frac{P^I}{Q^I}$ and, by assumption, $1 < \epsilon_{Q^I,P^I} < \infty$. Let $C_Q^I(Q^I)$ denote total production cost for the incumbent firm, where $\partial C_Q^I/\partial Q^I > 0$. The firm's profits are π^I, such that

$$\pi^I = P^I Q^I - C_Q^I(Q^I) \tag{2}$$

For the entrant firm, let $C_Q^E(Q^E, X)$ denote total production cost, where the variable X, X∈[0,1], measures the extent to which production of Q^E is restricted and therefore creates additional regulatory compliance costs relative to the incumbent product. Let us alos assume $\partial C_Q^E/\partial Q^E > 0$ and $\partial C_Q^E/\partial X > 0$, $\partial^2 C_Q^E/\partial {Q^E}^2 > 0$, $\partial^2 C_Q^E/\partial X^2 > 0$, and $\partial^2 C_Q^E/\partial X \partial Q^E > 0$.

The entrant firm also faces a downward sloping demand curve. $P^E(t)$, the price of the product demanded at time t, is a decreasing function of quantity at time t, $Q^E(t)$, a decreasing function of the quantity of the incumbent product at time t, $Q^E(t)$, and an increasing function of the stock of GW prevailing at time t, $GW(t)$. Accordingly, $P^E(t) = P^E\big(Q^E(t), Q^I(t), GW(t)\big)$, where $\frac{\partial P^E}{\partial Q^E} < 0$, $\frac{\partial P^E}{\partial Q^I} < 0$, and $\frac{\partial P^E}{\partial GW} > 0$. The elasticity of

[1] Our concept of goodwill does apply to the technology used to produce both products (i.e. there is a GW^I and a GW^E). For example, there is a certain level of goodwill regarding use of chemical pesticides to control crop pests and a level of goodwill regarding use of transgenic insect resistant crops to control crop pests. However, for simplicity, we will assume that GW^I, while not necessarily better than GW^E in any absolute sense, has developed over a much longer time horizon, is more informed by actual experience, and is thus stable and not easily influenced within the time periods considered in this model. In short, it is no longer a controversial technology. We will therefore omit goodwill of the incumbent technology from consideration, and GW will henceforth be assumed to apply only to the new technology (i.e. GW = GW^E)

current period demand is defined as $\epsilon_{Q^E,P^E} = -\frac{\partial Q^E}{\partial P^E}\frac{P^E}{Q^E}$ and by assumption $1 < \epsilon_{Q^E,P^E} < \infty$.

Either firm can seek to directly influence the public debate. It supplies the public with information, A^I or A^E. For the entrant firm, for example, the cost of supplying this information is $C_A^E(A^E)$, where $\partial C_A^E/\partial A^E > 0$, and thus the firm's profits are π^E:

$$\pi^E = P^E Q^E - C_Q^E(Q^E, X) - C_A^E(A^E). \tag{3}$$

In addition, we have environmentalist groups. Assume that the environmentalists care about the environment's health; however, also assume that they primarily derive utility from actively affecting public debate and being perceived (i.e. by donors) to be doing so, and denote this benefit B.[2] As defined, the public's perception of damage to the environment, among other things, is measured by the stock of GW, and thus changes in the public's perceptions are measured by the change in this stock, i.e., $\bullet\, GW$.

The environmentalists try to affect such change by engaging in the public debate and supplying information A^N to affect the stock of goodwill GW and even the regulatory barriers to production, X, of using the new technology. Put differently, the environmentalists maximize their benefit $B^N(A^N)$, where $\partial B^N/\partial A^N > 0$ and $\partial^2 B^N/\partial A^{N^2} < 0$, while accounting for the cost of supplying information $C_A^N(A^N)$, where $\partial C_A^N/\partial A^N > 0$ and $\partial^2 C_A^N/\partial A^{N^2} > 0$. The environmentalists chooses A^N so as to maximize

$$N = B^N(A^N) - C_A^N(A^N). \tag{4}$$

We adapt one of the main conventions of the political economy literature and assume the regulator or government maximizes a weighted sum of various stakeholders' current period *perceived* surpluses by choosing the variable X, which measures the extent to which production of the new technology Q^E is restricted, where $X \in [0,1]$ such that $X = 0$ implies production of Q^E is banned while $X = 1$ suggest no restrictions. The regulator maximizes

$$G = U + \gamma^E \pi^E + \gamma^I \pi^I + \gamma^N N, \tag{5}$$

where $\gamma^I, \gamma^E, \gamma^N > 0$ are the weights placed on the incumbent firm, the entrant firm, and the environmentalist groups, respectively. Because of the dynamic effects of the formation of perception, we model a dynamic decision process whereby the regulator maximizes the objective function [Eq. (5)] over time.

The regulator cares about the *perceived* net economic welfare of consumption and the environment. Thus, various stakeholders may affect the regulatory outcome by influencing the common goodwill GW, and uninformed groups' common perception of the new technology. Consumers may not be well informed about the technology, and may feed off the information

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[2] It stands to reason that donations to such non-profit groups are often more a function of what donors think they are doing than they are a function of actual environmental impacts that result from their activities, something which is, even in the best of circumstances, difficult to monitor and evaluate. It also stands to reason that environmentalist groups that are not perceived as having much of a public impact will not continue as environmentalist groups for very long.

supplied during the public debate.

Key parameters in the process include the reliability of different sources of information, as well as the political weights of different interest groups, which may differ across countries and thus result in different outcomes even in countries with otherwise identical initial conditions. The information supplied by each group has a reliability factor, which is a function of the exogenous flow of information relative to that supplied by the various groups. For instance, European attitudes toward genetically modified crops and food has been shaped by a variety of factors, including the experience of a major food safety crisis (mad cow disease), the lack of confidence in food regulators, widespread media coverage of the issue, and activism by politically influential environmental, consumer and anti-globalization groups. These factors resulted in low reliability of the European regulatory body and citizens lack of trust in the regulatory process. This will result in flow of information having a small effect on the stock of goodwill.

Assume factors exogenous to our model supply information in period t, $I(t)$, and let $g(I(t))$ denote the information multiplier of the generation of GW by these factors, where $\partial g/\partial I > 0$. Let $h^i(A^i, I)$ denote the information multiplier of the generation of GW by stakeholder $i \in \{E, N\}$, where $\partial h^i/\partial A^i > 0$. We introduce reliability into the information multipliers and assume that the information multiplier places more weight, on information supplied by stakeholder i, the closer it is to $I(t)$; that is,

$$\frac{\partial}{\partial I}\left(\frac{\partial h^i}{\partial A^i}\right) = \begin{cases} > 0 & if \quad A^i > I \\ < 0 & if \quad A^i < I \\ = 0 & otherwise \end{cases}$$

The stock variable is generated by the emerging industry (A^E), the environmentalists (A^N), and nature (I), according to the following equation of motion:

$$\dot{GW} \equiv \frac{dGW}{dt} = \left[g(I(t)) + h^E(A^E(t), I(t)) + h^N(A^N(t), I(t))\right](1 - GW(t)) - \psi GW(t). \quad (6)$$

The parameter ψ is the constant rate of GW decay as a result of forgetfulness. The index $(1 - GW)$ measures the remaining potential of the firm's GW and in the equation of motion it implies decreasing returns to investment in the stock of GW. That is, the infant firm ability to enhance the demand for its products is limited. Note that (6) implies that the maximum amount of GW is normalized to 1, and $0 \leq GW(t) < 1$, since, as GW approaches 1, $\dot{GW}$ becomes negative and GW declines. Thus, $GW(t)$ is the proportion of maximum goodwill utilized by the infant firm to enhance the demand for its product.

3. The timing of the game

The analysis begins with the introduction of a new technology, whose environmental implications are not fully known. This technology is developed by a firm, and is used to produce a good Q^E that is a close but not perfect substitute of an existing product Q^I. Public intervention is justified based on the unknown environmental and health implications of the new technology. The political economic process leading to regulation of Q^E consists of several steps over time (see Fig. 1).

[Figure 1. The timing of the game–period t]

We begin with the entrant firm that introduces the new but contentious technology. Following the launch of the new technology, public debate ensues as different groups (the entrant, incumbent, and environmentalists) disseminate information about the technology. The public debate affects the perceptions of members of various groups because by impacting the common stock of goodwill (GW); a stock variable updated each period based on new information provided by different parties (including, potentially, parties that are exogenous to the model). For example, information from activists, industry, and academic scientists affects consumers' perception of their own welfare, such as possible health risks or health benefits, even though the actual level of risk continues to be unknown or uncertain.

The policy maker's objective is to maximize a weighted sum of the perceived wellbeing of the various groups overtime. What arises is a situation in which each of the various groups seeks during the public debate to shape the perceptions in a direction that generally serves its own interest (Babinard and Josling, 2001; Herring 2008). Groups that stand to lose welfare from lax regulation will, for instance, seek to provide bad news regarding the safety of the products. Those who stand to gain will provide good news (i.e., the entrant). Other stakeholders weigh the evidence, filtered through the degree of trust and confidence they have in the group providing the evidence, to form a common stock of perceptions or reputation of the technology, i.e., GW. The GW affects various groups' perceived benefit and cost from production and consumption of Q^E. These benefits and costs enter the regulator's objective function, which chooses X. Once the regulatory instrument is set, producers and consumers interact and surpluses are formed.

The policy maker maximizes the following inter-temporal objective function at time $t = 0$ at which time the technology is introduced,

$$\mathcal{L}(0) = \max \int_0^\infty e^{-rt}\, [U + \gamma^E \pi^E + \gamma^I \pi^I + \gamma^N N] dt$$

$$s.t. \ \ \cdot GW = \left[g\big(I(t)\big) + h^E\big(A^E(t), I(t)\big) + h^E\big(A^N(t), I(t)\big)\right]\big(1 - GW(t)\big) - \psi GW(t); \quad (7)$$

$$Q^{I*} = \ Q^I \arg\ \max \ \ \left\{\pi^I = P^I Q^I - C_Q^I(Q^I)\right\} (8)$$

$$\{Q^{E*}, A^{E*}\} = \ \{Q^E, A^E\} \arg\ \max \ \ \left\{\pi^E = P^E Q^E - C_Q^E(Q^E, X) - C_A^E(A^E)\right\} (9)$$

$$A^{N*} = \ A^N \arg\ \max \ \ \{N = B^N(A^N) - C_A^N(A^N)\}$$

$$GW(0) = GW_0, \ \ 1 \le -X \le 0, \text{ and } -Q^I, -Q^E, -A^E, -A^N \le 0. \quad (10)$$

We adopt the plausible assumption of $\le \psi$, i.e., r, now standing for the alternative cost of aggregate consumption in terms of enhanced investment in the stock of GW, is smaller than the decay rate of GW, ψ.

4. The optimization problem: A two-step solution

We solve the optimization problem in two steps. First, the static solution to the incumbent, entrant, and environmentalists' maximization problem is derived. These maximization problems are done over a convex domain and the objective function is strictly concave for the two firms but strictly convex for the environmentalists (Appendix ??? – think this is true but need to confirm). The first order conditions of these optimization problems suggest that

$$\frac{\partial \pi^I}{\partial Q^I} = 0 \Leftrightarrow \frac{P^I - C_Q^I}{P^I} = -\frac{1}{\eta_{P,Q}^I}$$
$$\frac{\partial \pi^E}{\partial Q^E} = 0 \Leftrightarrow \frac{P^E - C_Q^E}{P^E} = -\frac{1}{\eta_{P,Q}^E}$$
$$\frac{\partial \pi^E}{\partial A^E} = 0 \Leftrightarrow \frac{\partial P^E}{\partial \cdot GW}\frac{\partial h^E}{\partial A^E}(1 - GW) = \frac{\partial C_A^E}{\partial A^E}$$
$$\frac{\partial \pi^E}{\partial A^E} = 0 \Leftrightarrow \frac{\partial B^N}{\partial A^N} = \frac{\partial C_A^N}{\partial A^N}.$$

Using these conditions, we derive the following four arguments:

$$\{Q^{I*}(GW, X), Q^{E*}(GW, X), A^{E*}(GW, X), A^{N*}(GW, X)\}.$$

Note that the arguments are a function of GW and X–the two variables that maximize the inter-temporal objective function [Eq. (10)]. The optimal value of these two variables is determined at the second step, when we solve Eq. (10). That is, when the regulator solves the following problem:

$$\mathcal{L}(0) = \max \int_0^\infty e^{-rt}\,[U + \gamma^E \pi^{E*} + \gamma^I \pi^{I*} + \gamma^N N^*]dt$$
$$s.t. \ \cdot GW = \left[g\big(I(t)\big) + h^E\big(A^E(t), I(t)\big) + h^E\big(A^N(t), I(t)\big)\right]\big(1 - GW(t)\big) - \psi GW(t);$$
$$GW(0) = GW_0, \ \ 1 \le -X \le 0, \ \text{and} \ -Q^I, -Q^E, -A^E, -A^N \le 0. \tag{11}$$

where

$$\pi^{I*} = P^{I*} \cdot Q^{I*}(GW, X) - C_Q^I(Q^{I*}(GW, X))$$
$$\pi^{E*} = P^{E*} \cdot Q^{E*}(GW, X) - C_Q^E(Q^{E*}(GW, X), X) - C_A^E(A^{E*}(GW, X))$$
$$N^* = B(A^{N*}(GW, X)) + C_A^N(A^{N*}(GW, X))$$

and where

$$P^{I*} = P^{I*}(Q^{I*}(GW, X), Q^{E*}(GW, X)),$$
$$P^{E*} = P^{E*}(Q^{I*}(GW, X), Q^{E*}(GW, X), GW).$$

Let $\mathcal{H}(t)$ designate the Hamiltonian formulated from $\mathcal{L}(0)$; that is,

$$\mathcal{H}(t) = U + \gamma^E \pi^{E*} + \gamma^I \pi^{I*} + \gamma^N N^* +$$
$$+\lambda\left[\left[g\big(I(t)\big) + h^E\big(A^E(t), I(t)\big) + h^E\big(A^N(t), I(t)\big)\right]\big(1 - GW(t)\big) - \psi GW(t)\right]$$
$$+\mu_0(t)X(t) + \mu_1(t)X(t).$$

Let λ denote the current value costate variable, and $\mu_0(t)$ and $\mu_1(t)$ are the Kunn-Tucker multipliers associated with the two inequalities; namely, $0 \leq X$ and $X \leq 1$, respectively.

Two conditions then follow:

1) $\frac{\partial \mathcal{H}}{\partial X} = \frac{\partial G}{\partial GW} + \lambda\left(\frac{\partial h^E}{\partial A^{E*}}\frac{\partial A^{E*}}{\partial X} + \frac{\partial h^N}{\partial A^{N*}}\frac{\partial A^{N*}}{\partial X}\right)(1 - GW) + \Delta\mu = 0,$ where $\Delta\mu = \mu_0 - \mu_1$, $\mu_0, \mu_1 \geq 0,$ and $\mu_0 X = 0$ and $\mu_1 X = 0$.

2) $\dot{\lambda} = r\lambda - \frac{\partial \mathcal{H}}{\partial GW} = \lambda\big(r + \psi + g(I) + h^E(A^E, I) + h^N(A^N, I)\big) - \frac{\partial G}{\partial GW}$, where

$$\frac{\partial G}{\partial GW} = \frac{\partial U}{\partial GW} + \gamma^I \frac{\partial \pi^I}{\partial GW} + \gamma^E \frac{\partial \pi^E}{\partial GW} + \gamma^N \frac{\partial N}{\partial GW}$$

$$\frac{\partial U}{\partial GW} = \left(\frac{\partial u_C}{\partial Q^{I*}}\frac{dQ^{I*}}{dGW} + \frac{\partial u_C}{\partial Q^{E*}}\frac{dQ^{E*}}{dGW}\right) - \frac{du_e}{dGW}$$

$$\frac{\partial \pi^I}{\partial GW} = \left(\frac{\partial P^I}{\partial GW} + \frac{\partial P^I}{\partial Q^{I*}}\frac{dQ^{I*}}{dGW}\right)Q^{I*} + \frac{dQ^{I*}}{dGW}P^I - \frac{\partial C_Q^I}{\partial Q^{I*}}\frac{dQ^{I*}}{dGW}$$

$$\frac{\partial \pi^E}{\partial GW} = \left(\frac{\partial P^E}{\partial GW} + \frac{\partial P^E}{\partial Q^{E*}}\frac{dQ^{E*}}{dGW}\right)Q^{E*} + \frac{dQ^{E*}}{dGW}P^E - \frac{\partial C_Q^E}{\partial Q^{E*}}\frac{dQ^{E*}}{dGW} - \frac{\partial C_A^E}{\partial A^{E*}}\frac{dA^{E*}}{dGW}$$

$$\frac{\partial N}{\partial GW} = \left(\frac{\partial B^{N^{N*}}}{\partial A} - \frac{\partial C_A^N}{\partial A^{N*}}\right)\frac{dA^{N*}}{dGW}.$$

1. The model's internal and corner solutions

We derive the necessary conditions for any one of these three types of the model's solutions: a corner solution, an internal solution or a null solution.

There is always a maximum that satisfies the necessary conditions, i.e., there is always either an internal solution or a corner one. The null solution $X(t) = GW(t) = 0$ is always a local optimum and if costs are higher than benefits it is also the global optimum. In what follows, we characterize solutions with positive-valued variables.

Condition (1), i.e., $\frac{\partial \mathcal{H}}{\partial X} = 0$, suggests that

$$\frac{\partial H}{\partial X}=\left(\frac{\partial U}{\partial X}+\gamma^{E}\frac{\partial \pi^{E}}{\partial X}+\gamma^{I}\frac{\partial \pi^{I}}{\partial X}+\gamma^{N}\frac{\partial N}{\partial X}+\lambda\frac{\partial\cdot GW}{\partial X}\right)+\underbrace{\mu_0}_{\Delta\mu}-\mu_1=0$$

where

$$\frac{\partial U}{\partial X}=\left(\frac{\partial u_C}{\partial Q^{I*}}\frac{dQ^{I*}}{dX}+\frac{\partial u_C}{\partial Q^{E*}}\frac{dQ^{E*}}{dX}-\frac{\partial u_e}{\partial Q^{E*}}\frac{dQ^{E*}}{dX}\right)$$

$$\frac{\partial \pi^{I}}{\partial X}=\left(\frac{\partial P^{I}}{\partial X}+\frac{\partial P^{I}}{\partial Q^{I*}}\frac{dQ^{I*}}{dX}\right)Q^{I*}+\frac{dQ^{I*}}{dX}P^{I}-\frac{\partial C_Q^{I}}{\partial Q^{I*}}\frac{dQ^{I*}}{dX}$$

$$\frac{\partial \pi^{E}}{\partial X}=\left(\frac{\partial P^{E}}{\partial X}+\frac{\partial P^{E}}{\partial Q^{E*}}\frac{dQ^{E*}}{dX}\right)Q^{E*}+\frac{dQ^{E*}}{dX}P^{E}-\left(\frac{\partial C_Q^{E}}{\partial Q^{E*}}\frac{dQ^{E*}}{dX}+\frac{\partial C_Q^{E}}{\partial X}\right)-\frac{\partial C_A^{E}}{\partial A^{E*}}\frac{dA^{E*}}{dX}$$

$$\frac{\partial N}{\partial X}=-\frac{dB^{N}}{dX}-\frac{\partial C_A^{N}}{\partial A^{N*}}\frac{dA^{N*}}{dX}$$

$$\frac{\partial\cdot GW}{\partial X}=\left[\frac{\partial h^{E}}{\partial A^{E*}}\frac{dA^{E*}}{dX}+\frac{\partial h^{N}}{\partial A^{N*}}\frac{dA^{N*}}{dX}\right]\left(1-GW(t)\right)$$

and thus

$$\begin{pmatrix} P^{I}\frac{dQ^{I*}}{dX}+P^{E}\frac{dQ^{E*}}{dX}-\frac{du_e}{dX}+\gamma^{I}\left(MR_X^{I}-\frac{dC_Q^{I}}{dX}\right) \\ +\gamma^{E}\left(MR_X^{E}-\frac{dC_Q^{E}}{dX}-\frac{\partial C_A^{E}}{\partial A^{E*}}\frac{dA^{E*}}{dX}\right)+\gamma^{N}\left(\frac{\partial B^{N}}{\partial A^{N*}}-\frac{\partial C_A^{N}}{\partial A^{N*}}\right)\frac{dA^{N*}}{dX} \\ +\lambda\left(\frac{\partial h^{E}}{\partial A^{E*}}\frac{dA^{E*}}{dX}+\frac{\partial h^{N}}{\partial A^{N*}}\frac{dA^{N*}}{dX}\right)(1-GW) \end{pmatrix}\le or > 0$$

$\Rightarrow$

$$\frac{\left(P^{I}\frac{dQ^{I*}}{dX}(1+\gamma^{I})+P^{E}\frac{dQ^{E*}}{dX}(1+\gamma^{E})+\gamma^{I}MR_X^{I}+\gamma^{E}MR_X^{E}\right)-\left(\frac{du_e}{dX}+\gamma^{I}\frac{dC_Q^{I}}{dX}+\gamma^{E}\left(\frac{dC_Q^{E}}{dX}+\frac{\partial C_A^{E}}{\partial A^{E*}}\frac{dA^{E*}}{dX}\right)+\gamma^{N}\left(\frac{\partial B^{N}}{\partial A^{N*}}-\frac{\partial C_A^{N}}{\partial A^{N*}}\right)\frac{dA^{N*}}{dX}\right)}{\left(\frac{\partial h^{E}}{\partial A^{E*}}\frac{dA^{E*}}{dX}+\frac{\partial h^{N}}{\partial A^{N*}}\frac{dA^{N*}}{dX}\right)(1-GW)}$$

$$=\frac{WMSW_X\overbrace{weighted\ marginal\ benefit\ of\ X-weighted\ marginal\ cost\ of\ X}}{MIE_X\underbrace{marginal\ information\ effect\ of\ X}}\le or > -\lambda$$

$\Rightarrow$

$$\frac{WMSW_X}{MIE_X}\le \text{or} > -\lambda$$

Proposition 1. When the solutions have positive-valued variables, three equilibriums may emerge.

1. An interior solution: $0<X<1$ and $\frac{WMSW_X}{MIE_X}=\lambda$;
2. Corner solution I: $X=1$ and $\frac{WMSW_X}{MIE_X}>\lambda$; and
3. Corner solution II: $X=0$ and $\frac{WMSW_X}{MIE_X}<\lambda$.

Condition (2) suggest that along the optimal path,

$$\cdot \lambda = r\lambda - \left(\frac{\partial U}{\partial GW} + \gamma^E \frac{\partial \pi^E}{\partial GW} + \gamma^I \frac{\partial \pi^I}{\partial GW} + \gamma^N \frac{\partial N}{\partial GW} + \lambda \frac{\partial \cdot GW}{\partial GW}\right)$$

$$= \Bigg(r + g(I) + h^E(A^{E*}, I) + h^N(A^{N*}, I) + \psi - \text{marginal information effect of GW } (MIE_{GW}) \underbrace{\left(\frac{dh^I}{dGW} + \frac{dh}{dG}\right.}$$

$$-\text{weighted marginal social welfare of GW } (WMSW_{GW}) \underbrace{\left(\frac{\partial U}{\partial GW} + \gamma^E \frac{\partial \pi^E}{\partial GW} + \gamma^I \frac{\partial \pi^I}{\partial GW} + \gamma^N \frac{\partial N}{\partial GW}\right)}$$

$$\Rightarrow$$

$$\frac{\cdot \lambda + WMSW_{GW}}{\lambda} = r + g(I) + h^E(A^{E*}, I) + h^N(A^{N*}, I) + \psi - MIE_{GW}$$

1. The steady state

At the steady state, $\cdot GW = 0$ and thus

$$GW = \frac{g(I) + h^E(A^{E*}, I) + h^N(A^{N*}, I)}{g(I) + h^E(A^{E*}, I) + h^N(A^{N*}, I) + \psi} < 1.$$

Furthermore, $\cdot \lambda = 0$ and thus

$$\lambda = \frac{\frac{\partial G}{\partial GW}}{\left(r + \psi + g(I) + h^E(A^E, I) + h^N(A^N, I)\right)}.$$

2. Sufficient conditions for a global optimum

If the Lagrangian is strictly concave, then the optimal solution $\{X^*(t), GW^*(t)\}$ is a unique global optimum.

That is, if

$$H(.) \leq H(.) + \frac{\partial H}{\partial X}(X - X^*) + \frac{\partial H}{\partial GW}(GW - GW^*)$$

$$\Rightarrow$$

$$0 \leq \left(\left(\frac{\partial U}{\partial X} + \gamma^M \frac{\partial \pi^M}{\partial X} + \gamma^I \frac{\partial \pi^I}{\partial X} + \gamma^N \frac{\partial N}{\partial X} + \lambda \frac{\partial \dot{GW}}{\partial X}\right) + \Delta\mu\right)(X - X^*) +$$

$$\left(\frac{\partial U}{\partial GW} + \gamma^M \frac{\partial \pi^M}{\partial GW} + \gamma^I \frac{\partial \pi^I}{\partial GW} + \gamma^N \frac{\partial N}{\partial GW} + \lambda \frac{\partial \dot{GW}}{\partial GW}\right)(GW - GW^*)$$

then our solution is unique.

5. Conclusions

There are several key conclusions that emerge from this model.

First, the level of regulation can diverge from that which is optimal for the environment to the extent that perceptions of risk diverge from objective risk.

Second, it is likely to be in the interest of incumbents that the new technology be heavily regulated if not banned (corner solution), to prolong the profitability of the incumbent technology.

Third, when the gains of individual consumers from the new technology are relatively small, a deficit of goodwill towards that technology due to negative information provided by groups that are considered as highly reliable may lead consumers to support tough regulations. Given the large weight of consumers, this can be enough to tip the political economic calculations of the regulator.