Welfare Impacts of Cross-Country Spillovers in Agricultural Research

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Abstract

The welfare implications of intellectual property protection (IPP) for private sector agricultural research are analyzed, focusing on the realistic cases in which countries provide different IPP levels, technology spills over across countries, and the public sector is involved in research. A model is developed to determine who benefits from, and who should pay for, the associated research. The paper contains some interesting results on the implications of a harmonization of IPP policies through multilateral agreements or via technology that allows research firms to prevent the copying of plants and animals that express traits that have emerged from their research.

Keywords: biotechnology, GURTs, intellectual property, research spillover, welfare analysis.

JEL Classification: F13, L11, O31, O34, Q16, Q17.

WELFARE IMPACTS OF CROSS-COUNTRY SPILLOVERS IN AGRICULTURAL RESEARCH

Advances in private sector plant and animal genetics often have applicability outside the country where the research was conducted. Historically, firms that conducted successful research and development (R&D) have captured some of the international benefits by charging a premium for the resulting seedstock. For example, rents associated with improved performance of hybrid breeds and varieties can be captured by charging a premium price for these seeds, and this premium can be maintained for many generations by controlling access to the purebred parental lines. This premium pricing solution has had less relevance in breeds and varieties where the commercial traits are passed on in retained seeds and in the offspring of commercial farm animals. Until relatively recently, the only way to capture any benefits associated with these breeds and varieties has been to charge a premium for the first generation knowing that the producer will replicate this improvement in future generations.

Governments have attempted to stimulate private sector agricultural R&D by providing legal protection for intellectual property in both domestic and international markets. However, the ability of countries to impose intellectual property rights on farmers in other countries has not been universally accepted (WG-FAO 2001). In some instances, the private sector has been willing to conduct R&D even when little intellectual property protection (IPP) was afforded in one or two major markets. For example, work on Roundup Ready soybeans progressed despite the relative lack of IPP for this technology in some major soybean growing countries (i.e., Brazil and Argentina), because legal IPP was available in the U.S. domestic market.

In the present article we focus on the welfare implications of legal IPP in agriculture when the associated R&D has commercial application in more than one country. Agricultural markets tend to be unique in that the customer is a farmer who sells the resulting crop or livestock product into competitive domestic and international markets. The farmer further may have the option of using unimproved genetics, or possibly the newly developed technology from crops and animals grown in previous years. The present study develops a model that allows policy makers and those who design domestic and international mechanisms to protect intellectual property to determine who benefits from, and who should pay for, the associated R&D.

Recent developments have generated public interest in this topic. First, there has been a large reduction in public research capacity in developing countries due in large part to a decline in international funding for this research. This suggests that these countries will rely more and more on research spillovers from more developed countries to remain competitive. Second, the recent development of genetic use restriction technologies (GURTs), popularly known as the "terminator gene," can be viewed as an extreme form of IPP, and this technology has received criticism from some less developed countries. Third, the development of Roundup Ready soybean seed by Monsanto introduced a new form of IPP in the U.S. marketplace. To access this technology, U.S. soybean producers must pay a technology fee of about $7.50 per 50-pound bag of Roundup Ready planting seed and must agree not to keep the harvested beans for future planting or for re-selling to other farmers (Schnepf 2003). The disparity in the application of this technology fee has become controversial because U.S. producers feel that they are paying for research that helps their foreign competitors (American Soybean Association 2003). Finally, cross-country protection of intellectual property rights in agriculture continues to stimulate discussion and controversy at international bodies such as the World Trade Organization via the 1994 Agreement on Trade-Related Aspects of Intellectual Property Rights (WTO 1994).

Related Research

The framework developed for the present study is based on a model by Lence *et al.* (2005), which in turn is based on studies by Loury (1979), Lee and Wilde (1980), Dixit (1988), and Srinivasan and Thirtle (2002). The single-country model by Lence *et al*. (2005) is nested within the model proposed here and their results can be replicated within the present model by restricting the number of countries to one and by eliminating the public sector.

Related work includes Moschini and Lapan (1997), but they do not consider the incentive structure for R&D firms, the welfare impacts that occur after the expiration of the innovator's patent, the uncertainties associated with R&D, spillovers, or the public sector. Other recent relevant studies are Alston and Venner (2002) and Tongeren and Eaton (2002), who incorporate the incentives for the R&D firms but do not include spillovers, the market for the crop, the welfare of those who produce the crop, or the public sector.

Spillovers in the context of IPP and North-South trade are addressed by Žigić (1998, 2000). Among other important differences with our model, Žigić equates the intensity of spillovers to the strength of IPP and focuses on economy-wide spillovers rather than the agricultural research spillovers that are our main interest. Swanson and Goeschl (2000) and Goeschl and Swanson (2002) point out that GURTs are a way for innovators to protect their intellectual property, and they recognize that this will enhance R&D. They also attempt to quantify the potential impact of GURTs on crop yields in developing countries by extrapolating the experience with hybrid seeds. Harhoff, Régibeau, and Rockett (2001) discuss GURTs as a means by which innovators can exert market power and conclude that GURTs may be beneficial because they improve market performance.

The structure of our model requires simultaneous equilibrium in three markets in each country. The seedstock industry must in equilibrium conduct an amount of R&D that can be justified by the expected earnings from that research, and each seedstock industry participant must respond to incentives and to competition from other companies in an optimal way. The market for seeds and breeding stock must also be in equilibrium, and the farmers who purchase the improved product should do so only if the premium charged is less than the additional profits they can expect. Finally, the domestic and international markets for the final product must be in equilibrium, and changes in costs and farm productivity must eventually impact market prices. We parameterize the model and simulate the impact of changes in these three factors on consumer, producer, and R&D industry welfare in both countries.

The model is designed so that, to the extent possible, the inputs required for calibration are readily available. To the best of our knowledge, the main difficulty regarding data requirements for the proposed model concerns the parameterization of the R&D hazard rate, as little empirical research has been performed on this topic. However, this limitation is overcome by means of sensitivity analysis using alternative parameterizations. Importantly, the proposed model is helpful not only because it can be used to perform empirical analysis when properly calibrated but also because it allows potential users to conceptualize the various critical issues involved in the evaluation and determination of "optimal" IPP systems for agriculture. We begin with the private sector model and extend it to include a public sector that also conducts research.

A Multi-Country Model of Private Investment in Agricultural R&D

The strength of the IPP regime is embedded in a parameter $\mu_{q,IPP} \equiv \mu_{q,right} + \mu_{cost} \geq 0$, which measures the maximum markup over the marginal cost of producing x_1 (c_1) that the developer of an improved farm input would be allowed to charge for it in country q.[1] The legal IPP level $\mu_{q,right} \geq 0$ is increasing with the extent up to which the developer is granted IPP rights on the innovation in country q, and with the level of enforcement of such IPP rights in q. Parameter $\mu_{cost} \geq 0$, on the other hand, reflects the markup advantage enjoyed by the innovator over its competitors arising from the costs of transferring or copying the output-enhancing innovation.

At time 0, R&D firms invest resources to compete in a race to develop x_1, a more productive version of an existing farm input (e.g., seed, or breed) x_0. A successful outcome (x_1) of the development process is random and the R&D competition ends at time t, when x_1 is first obtained. The first developer of x_1 is granted legal IPP for T periods, so the successful innovator could legally charge a price $w_{q,1} = (1 + \mu_{q,right} + \mu_{cost})\, c_1$ over the interval $[t, t + T]$ if it found it optimal to do so and firms in the industry had no other source of market power. The legal IPP level is reduced to zero once the IPP rights expire at time $t + T$, (i.e., $\mu_{q,right} = 0$), so the innovator's maximum allowable markup falls to its cost advantage μ_{cost} only.

The previous discussion highlights the need to address the various components affecting the R&D investment decision at time 0. Such components include the derived demand for the improved farm input x_1—which in turn involves the end-demand for farm output, the innovator's pricing decision $w_{q,1}$, the nature of the R&D process, and the determination of equilibrium in the R&D market at time 0. Each of these components is the object of the following subsections.

Farm Production

Let $f_q(x_{q0}, z_q)$ and $g_q(x_{q1}, z_q)$ denote the production functions of country q under x_{q0} and x_{q1}, respectively, where z_q is a vector of other variable inputs. Assuming for concreteness that x_1 is a Hicks-neutral improvement in x_0, the R&D improvement is represented by $g_q(x_{q1}, z_q) = (1 + \alpha_q)$ $f_q(x_{q1}, z_q)$, with improvement factor $\alpha_q \geq -1$ and function $f_q(\cdot)$ assumed to satisfy standard regularity conditions. The improvement factor α_q will typically differ across countries and may even be negative for some countries. However, $\alpha_{q=j} > 0$ if the new input was specifically developed to enhance output in country j. In this instance, $s_{q\neq j} \equiv \alpha_{q\neq j}/\alpha_{q=j}$ provides a measure of the new technology "spillover" to country $q \neq j$. For example, $s_{q\neq j} < 0$ means that the new technology designed for country j actually reduces output if employed in country $q \neq j$. At the other extreme, $s_{q\neq j} > 1$ indicates that, even though the new technology was designed for country j, it leads to an even greater improvement on the production function of country $q \neq j$.

Given prices p_q^S, w_{q0}, w_{q1}, and r associated with farm output y and farm inputs x_0, x_1, and z, respectively, country q's farm profit functions dual to the "traditional" and "new" technologies are (1) and (2), respectively:

(1) $$\pi_{q0}(p_q^S, w_{q0}, r_q) \equiv max_{x_{q0}, z_q}[p_q^S\ f_q(x_{q0}, z_q) - w_{q0}\, x_{q0} - r_q\, z_q],$$

(2) $$\pi_{q1}(p_q^S, w_{\backslash q1}, r_q) \equiv max_{x_{q1}, z_q}[p_q^S\ g_q(x_{q1}, z_q) - w_{q1}\, x_{q1} - r_q\, z_q].$$

If farmers can choose either technology, the unrestricted farmers' profit function is (3):

(3) $$\pi_q(p_q^S, w_{q0}, w_{q1}, r_q) \equiv max[\pi_{q0}(p_q^S, w_{q0}, r_q), \pi_{q1}(p_q^S, w_{q1}, r_q)].$$

Profit functions (1) through (3) are used below to analyze equilibrium in the output and input markets. Farmers are assumed to behave as perfect competitors in all markets. In other words, the model assumes that individual farmers do not internalize the effects of their own actions on the markets, either for the final crop or for either type of input.

Equilibrium in the Market for Farm Output

Using Hotelling's lemma, country q's farm supply $y_q^* \equiv y_q(p_q^S, w_{q0}, w_{q1}, r_q)$ is given by (4):

$$(4)\qquad y_q^* = \begin{cases} \partial\pi_{q0}(p_q^S, w_{q0}, r_q)/\partial p_q^S \text{ if } \pi_{q0}(p_q^S, w_{q0}, r_q) > \pi_{q1}(p_q^S, w_{q1}, r_q), \\ \partial\pi_{q1}(p_q^S, w_{q1}, r_q)/\partial p_q^S \text{ if } \pi_{q0}(p_q^S, w_{q0}, r_q) < \pi_{q1}(p_q^S, w_{q1}, r_q), \\ \text{and a convex combination of } \partial\pi_{q0}(\cdot)/\partial p_q^S \text{ and } \partial\pi_{q1}(\cdot)/\partial p_q^S \text{ otherwise.} \end{cases}$$

Supply function (4) is increasing in p_q^S as long as $\pi_{q0}(p_q^S, w_{q0}, r_q)$ and $\pi_{q1}(p_q^S, w_{q1}, r_q)$ are increasing and convex in p_q^S.

Conditional on input prices $\underline{w}_0 \equiv [w_{10}, \ldots, w_{Q0}]$, $\underline{w}_1 \equiv [w_{11}, \ldots, w_{Q1}]$, $\underline{r} \equiv [r_1, \ldots, r_Q]$, equilibrium in the world market for farm output requires consumer and producer prices to equate aggregate crop consumption with aggregate crop output:

$$(5)\qquad \sum_{q=1}^{Q} D_q(p_q^D{}^*) = \sum_{q=1}^{Q} y_q(p_q^S{}^*, w_{q0}, w_{q1}, r_q),$$

where $D_q(\cdot)$ denotes the Marshallian demand function for the crop in country q, and p_q^D is the consumer price for the crop in country q. In addition, equilibrium consumer and producer prices for the crop and "net exports" must also satisfy condition (6) for all countries q and j to rule out arbitrage opportunities:

$$(6)\qquad p_j^D{}^* - p_q^S{}^* - \xi_{qj} \le 0,\ \upsilon_{qj} \ge 0,\ (p_j^D{}^* - p_q^S{}^* - \zeta_{qj})\ \upsilon_{qj} = 0.$$

In (6), ξ_{qj} represents the wedge between the consumer price in country q and the producer price in country j, and υ_{qj} is the crop consumption in country q supplied by crop producers in country j. The term ξ_{qj} captures not only transportation costs but also other frictions such as import tariffs. Further, $\xi_{qq} > (<) \, 0$ represents a tax (subsidy) on domestic consumption met by domestic producers. Conditions (5) and (6) define the vectors of equilibrium consumer and producer prices for farm output $\underline{p}^{D}* \equiv [\, p_1^D *, \ldots, \, p_Q^D *]$ and $\underline{p}^{S}* \equiv [\, p_1^S *, \ldots, \, p_Q^S *]$, respectively, where $p_q^D * \equiv p_q^D(\underline{w}_0, \underline{w}_1, \underline{r}, \underline{\xi})$, $p_q^S * \equiv p_q^S(\underline{w}_0, \underline{w}_1, \underline{r}, \underline{\xi})$, $\underline{\xi} \equiv [\underline{\xi}_{1\cdot}, \ldots, \underline{\xi}_{Q\cdot}]$, and $\underline{\xi}_{q\cdot} \equiv [\xi_{q1}, \ldots, \xi_{qQ}]$.

The Innovation Supplier's Pricing Decision and Input Market Equilibrium

Application of Hotelling's lemma yields country q's derived demands for standard farm input $x_{q0}* = x_{q0}(\, p_q^S, w_{q0}, w_{q1}, r_q)$ and improved farm input $x_{q1}* = x_{q1}(\, p_q^S, w_{q0}, w_{q1}, r_q)$:

$$x_{q0}* = \begin{cases} -\partial \pi_{q0}(p_q^S, w_{q0}, r_q) / \partial w_{q0} \text{ if } \pi_{q0}(p_q^S, w_{q0}, r_q) > \pi_{q1}(p_q^S, w_{q1}, r_q), \\ 0 \text{ if } \pi_{q0}(p_q^S, w_{q0}, r_q) < \pi_{q1}(p_q^S, w_{q1}, r_q), \\ \text{and a convex combination of } 0 \text{ and } -\partial \pi_{q0}(p_q^S, w_{q0}, r_q) / \partial w_{q0} \text{ otherwise.} \end{cases} \tag{7}$$

$$x_{q1}* = \begin{cases} -\partial \pi_{q1}(p_q^S, w_{q1}, r_q) / \partial w_{q0} \text{ if } \pi_{q0}(p_q^S, w_{q0}, r_q) < \pi_{q1}(p_q^S, w_{q1}, r_q), \\ 0 \text{ if } \pi_{q0}(p_q^S, w_{q0}, r_q) > \pi_{q1}(p_q^S, w_{q1}, r_q), \\ \text{and a convex combination of } 0 \text{ and } -\partial \pi_{q1}(p_q^S, w_{q1}, r_q) / \partial w_{q1} \text{ otherwise.} \end{cases} \tag{8}$$

It is clear from (5) through (8) that the prices of farm inputs x_0 and x_1 determine crop output and consumption, as well as input usage. This implies that simultaneous equilibrium in the crop and input markets requires the specification of the technology used to produce inputs x_0 and x_1, as well as the competitive behavior of the suppliers of such inputs.

In the interest of space, attention will be restricted to scenarios where the x industry is perfectly competitive except for the market power conferred by the legal IPP and the innovator's cost advantage.[2] Also for simplicity, it will be assumed that x_0 is produced at constant marginal cost c_0, and that x_1 is produced by the innovator at constant marginal cost c_1.[3] Under perfect competition and constant marginal costs c_0, the price of the standard farm input x_0 is $w_{q0} = c_0$ for all countries q. Hence, if the innovator behaved as a monopoly in each country q, it would set $w_{q1} = w_{q1}^m(c_0, c_1, \underline{r}, \underline{\xi})$ to maximize profits. That is:

$$(9) \qquad \underline{w}_1^m = argmax_{\underline{w}_1} \{\sum_{q=1}^{Q} (w_q - c_1)\, x_{q1}[\, p_q^S(\, c_0, \underline{w}_1, \underline{r}, \underline{\xi}), c_0, w_{q1}, r_q]\}.$$

Embedded in (9) is the pricing constraint imposed by the competition from the traditional input being supplied at price c_0. Expression (9) also assumes that potential arbitrageurs are not allowed to trade the new input across countries to take advantage of price differentials.

In contestable markets (Baumol, Panzar, and Willig 1982), however, the optimal prices charged by the innovator for the improved farm input will be (10) instead of (9):

$$(10) \qquad \underline{w}_1{}^* = argmax_{\underline{w}_1} \{\sum_{q=1}^{Q} (w_{q1} - c_1)\, x_{q1}[\, p_q^S(\, c_0, \underline{w}_1, \underline{r}, \underline{\xi}), c_0, w_{q1}, r_q]\}.$$

$$\text{subject to:} \qquad w_{q1} \leq (1 + \mu_{q,IPP})\, c_1,\ q = 1, \ldots, Q.$$

In (10), $\mu_{q,IPP} \equiv \mu_{q,right} + \mu_{cost}$ is the innovator's effective IPP level in country q. According to (10), the extent to which the innovator appropriates the rents from the improved input in country q depends on the extra marginal cost incurred by potential competitors to produce x_1 ($\mu_{q,IPP}$). This extra cost arises from two sources, namely, competitors' technological disadvantage (μ_{cost}) and legal liability ($\mu_{q,right}$). For example, in the instance of a seed innovation, μ_{cost} would represent the additional costs (in units of c_1) associated with transferring the trait without access to the original parent lines.[4] This cost would obviously be greater for hybrid lines than for open pollinated varieties. Further, if the seed innovation has a utility patent, the legal liability cost ($\mu_{q,right}$) faced by those violating the patent would be determined by the probability of being sued and found guilty, and by the penalty imposed on them if convicted.

In summary, given production costs c_0 and c_1, the innovator's degree of market power $\underline{\mu}_{IPP} = [\mu_{1,IPP}, \ldots, \mu_{Q,IPP}]$, and the values of exogenous variables ($\underline{r}$ and $\underline{\zeta}$), (10) yields the innovator's optimal prices for input x_1 across countries $\underline{w}_1{}^*$. In turn, $\underline{w}_1{}^*$ determines equilibrium consumer ($\underline{p}^{D}{}^*$) and producer ($\underline{p}^{S}{}^*$) prices for the crop from (5) and (6), total farm output $y^* = \Sigma_q y_q{}^*$ from (4), and the amount of the new input bought by farmers $x_1{}^* = \Sigma_q x_{q1}{}^*$ from (8).

A Firm's Decision to Invest in R&D

If the improved input x_1 is first obtained at time t and the innovator is granted an effective level of IPP rights $\mu_{q,right}$ through the next T periods, the innovator's IPP levels will be $\mu_{q,IPP} = \mu_{q,right} + \mu_{cost}$ over the interval $(t, t + T)$ and $\mu_{q,IPP} = \mu_{cost}$ afterward. Hence, at time t the present value of the rents extracted by the successful innovator are given by (11):

$$(11)\quad v(c_0, c_1, \underline{r}, \underline{\xi}, \underline{\mu}_{right}, \mu_{cost}, T, i) = \int_t^{t+T} \sum_{q=1}^{Q} \{[w_{q1}(\cdot) - c_1]\, x_{q1}(\cdot)\}\,|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}\ exp(-\,i\ \tau)\, d\tau$$

$$+ \int_{t+T}^{\infty} \sum_{q=1}^{Q} \{[w_{q1}(\cdot) - c_1]\, x_{q1}(\cdot)\}\,|_{\mu_{q,IPP}=\mu_{cost}}\ exp(-\,i\ \tau)\, d\tau,$$

$$= i^{-1}\,[1 - exp(-\,i\ T)] \sum_{q=1}^{Q} \{[w_{q1}(\cdot) - c_1]\, x_{q1}(\cdot)\}\,|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}$$

$$+ i^{-1}\, exp(-\,i\ T) \sum_{q=1}^{Q} \{[w_{q1}(\cdot) - c_1]\, x_{q1}(\cdot)\}\,|_{\mu_{q,IPP}=\mu_{cost}}\ ,$$

where i is the continuously-compounded interest rate per unit of time and τ is a variable of integration. The terms $\Sigma_q\{[w_{q1}(\cdot) - c_1]\ x_{q1}(\cdot)\}$ represent the rents per unit of time accruing to the innovating firm. The present value of each period's rents is obtained by discounting them at the appropriate discount rate i by means of $exp(-\ i\ \tau)$. Finally, the present value of the discounted rents over the entire period is obtained by integrating with respect to time.

R&D firms must decide whether to attempt to develop x_1 and obtain the associated IPP before x_1 exists. Here, such a decision is represented by means of the standard model of R&D competition advanced by Loury (1979) and Lee and Wilde (1980). This model postulates that there are N identical R&D firms. To participate in the competition to develop the improved farm input x_1, firm n must make a lump-sum R&D investment (e.g., physical capital) k_n and then incur a recurrent cost (e.g., labor) l_n. R&D sunk cost k_n and recurrent cost l_n jointly determine the firm's hazard rate $h_n = h(k_n, l_n)$, where $h(\cdot)$ is concave, twice continuously differentiable, strictly increasing, and satisfies $h(0, 0) = lim_{k\to\infty} h_1(\cdot) = lim_{l\to\infty} h_2(\cdot) = 0$. The firm's hazard rate h_n is the conditional probability that it will succeed in developing the improved x_1 in the next small unit of time, given that no firm has succeeded so far. Individual firms' hazard rates are thus functions of the respective lump-sum investments and recurrent costs, but are independent of the length of time elapsed since the R&D competition started.[5]

The aggregate hazard rate for the R&D industry (H) is obtained by adding up the individual hazard rates:

$$(12) \qquad H = \sum_{n=1}^{N} h(k_n, l_n).$$

Given that H is the hazard rate for the R&D industry, the probability that no firm has won the race by time t is $exp(-H\,t)$. Further, if no firm has won the race, the probability that firm n (who invested k_n at the starting time 0) will win the R&D race in the next infinitesimally small interval $(t + dt)$ is $h_n\,dt$. Hence, the unconditional probability that such a firm wins the R&D race over the interval $(t, t + dt)$ is $exp(-H\,t)\,h_n\,dt$, and the present value of the expected rents associated with such a victory equals $v(\cdot)\,exp(-i\,t)\,exp(-H\,t)\,h_n\,dt$. As of time 0, the present value of the expected rents to firm n from winning the R&D race is the sum of the latter expression over all future infinitesimal time intervals. That is:

$$(13) \qquad \int_0^\infty v(\cdot)\ exp(-i\ \tau)\ exp(-H\ \tau)\ h_n\ d\tau = v(\cdot)\ h_n/(i + H).$$

In addition to the lump-sum k_n invested at time 0, R&D firm n will incur the recurrent cost l_n until the race is over. The expected present value of the recurrent costs is (14):

$$(14) \qquad \int_0^\infty \left[\int_0^{\tau_1} l_n\ exp(-i\,\tau_0)\,d\tau_0 \right] exp(-H\ \tau_1)\ H\ d\tau_1 = \int_0^\infty \frac{l_n\,[1 - exp(-i\,\tau_1)]}{i}\ exp(-H\ \tau_1)\ H\ d\tau_1,$$

$$= l_n/(i + H).$$

The inner integral on the left-hand side of (14) represents the present value of the recurrent costs if the race finished at time τ_1, whereas the term $[exp(-H\ \tau_1)\ H\ d\tau_1]$ denotes the probability of such an event. The outer integral accounts for the fact that the race may finish at any time after the lump-sum investment is made.

With expected returns and expected recurrent costs given by (13) and (14), respectively, firm n's expected profits from investing k_n at time 0 to participate in the R&D race are:

(15) $$V(k_n, l_n, H_{(-n)}; \cdot) = v(\cdot)\ h(k_n, l_n)/[i + h(k_n, l_n) + H_{(-n)}] - k_n - l_n/[i + h(k_n, l_n) + H_{(-n)}],$$

where $H_{(-n)} \equiv \Sigma_{j\neq n}\ h(k_j, l_j)$. The decision problem for expected-profit-maximizing R&D firm n consists of choosing k_n^* and l_n^* so as to maximize $V(k_n, l_n, H_{(-n)}; \cdot)$, given the hazard rate $H_{(-n)}$ for the rest of the industry. Optimal values $k_n^* = k^*(H_{(-n)};\cdot)$ and $l_n^* = l^*(H_{(-n)};\cdot)$ are obtained from the first-order necessary conditions for the maximization of (15).

Equilibrium in the R&D Market

Optimal lump-sum investment and recurrent costs for each of the R&D entrants are obtained as indicated in the preceding subsection. Because firms are identical, equilibrium in the R&D industry is postulated to be the symmetric Nash equilibrium. That is, the equilibrium optimal capital and labor levels for each of the N R&D firms must satisfy conditions (16) and (17):

(16) $$k^e = k^*[(N-1)\ h(k^e, l^e);\cdot],$$

(17) $$l^e = l^*[(N-1)\ h(k^e, l^e);\cdot].$$

Therefore, the equilibrium aggregate lump-sum investment and recurrent costs are given by $K^e = N\ k^e$ and $L^e = N\ l^e$, respectively. Further, from (12), (16) and (17), the equilibrium aggregate hazard rate for the R&D industry is:

(18) $$H^e = N\ h(k^e, l^e).$$

The equilibrium industry hazard rate H^e represents the equilibrium probability that the innovation will occur in the next unit of time. Alternatively, quantity $1/H^e$ is the equilibrium average time that it takes to obtain the innovation. Given K^e, L^e, and H^e, the present value of the aggregate total expected R&D costs in equilibrium is $K^e + L^e/(i + H^e)$.

Welfare Analysis

Let $\pi_{q0}^{e}(\cdot)$, $\pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}$, and $\pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}}$ denote farmers' equilibrium profits in country q before the innovation, after the innovation but under IPP rights, and after expiration of IPP rights, respectively. Then, if the innovation occurred at time τ_1, the change in country q's producer surplus per unit of time would be zero up to time τ_1, $[\pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}} - \pi_{q0}^{e}(\cdot)]$ from time τ_1 until time $\tau_1 + T$, and $[\pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}} - \pi_{q0}^{e}(\cdot)]$ afterward. Discounting such changes up to time zero and adding them up yields the present value of the change in producer surplus if the innovation happened at time τ_1, which is the term within curly brackets in (19):

$$(19)\qquad \Delta PS_q = \int_0^{\infty} \Big\{ \int_{\tau_1}^{\tau_1+T} [\pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}} - \pi_{q0}^{e}(\cdot)]\ exp(-\,i\ \tau_0)\, d\tau_0$$

$$+ \int_{\tau_1+T}^{\infty} [\pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}} - \pi_{q0}^{e}(\cdot)]\, exp(-i\,\tau_0)\, d\tau_0 \Big\}\ exp(-\,H^e\ \tau_1)\ H^e\, d\tau_1,$$

$$= \frac{H^e}{i\,(i+H^e)}\ \{\pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}\ [1 - exp(-\,i\ T)]$$

$$+\ \pi_{q}^{e}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}}\ exp(-\,i\ T) - \pi_{q0}^{e}(\cdot)\}\,.$$

The present value of the *expected* change in country q's producer surplus due to the introduction of the improved input x_1 (ΔPS_q) is computed as in (19) because $[exp(-\,H^e\ \tau_1)\ H^e]$ is the probability of the innovation occurring during the interval $(\tau_1,\ \tau_1 + d\tau_1)$.

The *expected* change in country q's consumer surplus due to the innovation (ΔCS_q) can be measured in a similar way. That is, define $p_{q0}^{De}(\cdot)$, $p_{q}^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}$, and $p_{q}^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}}$

as country q's equilibrium consumer prices for the crop before the innovation, after the innovation but under IPP rights, and after expiration of IPP rights, respectively. Then, if the innovation occurred at time τ_1, the change in consumer surplus per unit of time would be zero until time τ_1, $\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\, d\zeta$ from time τ_1 until time $\tau_1 + T$, and

$\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\, d\zeta$ after time $\tau_1 + T$. Discounting and adding up such values yields the change in consumer surplus if the innovation occurred at time τ_1, shown as the term within curly brackets in (20):

$$(20)\qquad \Delta CS_q = \int_0^{\infty}\left\{\int_{\tau_1}^{\tau_1+T}\left[\sum_{q=1}^{Q}\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\, d\zeta\right] exp(-\, i\ \tau_0)\, d\tau_0\right.$$

$$\left. + \int_{\tau_1+T}^{\infty}\left[\sum_{q=1}^{Q}\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\, d\zeta\right] exp(-i\, \tau_0) d\tau_0\right\} exp(-\, H^e\ \tau_1)\, H^e\, d\tau_1,$$

$$= \frac{H^e}{i\,(i + H^e)}\ \{[1 - exp(-\, i\ T)]\ \sum_{q-1}^{Q}\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{q,right}+\mu_{cost}}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\, d\zeta$$

$$+ exp(-\, i\ T)\ \sum_{q=1}^{Q}\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=\mu_{cost}}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\, d\zeta\ \}.$$

Expression (20) takes into account the probabilities associated with the innovation taking place at different times in the future.

Still another welfare measure is the equilibrium aggregate present value of *expected* profits for the R&D industry (*RDS*). This can be computed from (21):

$$(21)\qquad RDS = N\ V(k^e, l^e, (N - 1)\ h(k^e, l^e);\ \cdot].$$

That is, *RDS* is calculated by aggregating (15) across the *N* R&D firms.

Public Investment in Agricultural R&D

The R&D model discussed so far has ignored the importance of public sector R&D, implicitly considering private sector R&D as separable and additive to public R&D. However, there are reasons to be cautious about this assumption. The public sector is often seen as a viable substitute for private sector research, and domestic governments and international organizations often fund public sector research on yield improvements. In particular, the Consultative Group on International Agricultural Research (CGIAR) supports fifteen centers located throughout the world with a mission to foster agricultural growth through the provision of public goods (see *http://www.cgiar.org/who/index.html*).

The question as to whether private research substitutes for, or complements public research has been controversial. For example, Wright and Pardey (2006) have shown that the bulk of public sector work on transgenic crops in developing countries involve traits developed in the U.S. They also report on a survey of stakeholders with interest in plant breeding in developing countries indicating that U.S. patents adversely affected their research. Graff *et al.* (2004) report that inefficiencies in accessing intellectual property (e.g., legal costs and uncertain ownership rights) appear to be hindering public sector research on some horticultural crops, an argument that can easily be extended to orphan crops in developing countries. Another problem that has received attention is the possible reduction in the public sector's "freedom to operate" due to existing patents on the research tools themselves (see, e.g., Binenbaum *et al*. 2003).

The interaction between private and public sector R&D is important because, as pointed out by Evenson and Gollin (2003), many historically important genetic improvement projects in the developing world were based on productive plant types developed in the North and then bred for location-specific traits in the South. The literature discussed above suggests that private sector IPP when improperly designed can hamper valuable public sector R&D, and in this case the additional value created by stronger private sector IPP will be offset by reduced effectiveness of public sector research.

The model introduced in the previous section can be modified to incorporate public R&D investment. However, such an exercise requires the specification not only of the public sector's R&D technology but also the public sector's objective function. Here, we assume that the public sector's technology is identical to the one used by the private sector, thus implying that public R&D directly competes with private R&D. As per the public sector's objective function, it is assumed that the public sector is exogenously mandated to use a proportion B of the total labor and capital used by the private sector in R&D, and (if successful in its R&D endeavor) to sell the innovation x_1 at marginal cost.

There are other ways of specifying the interaction between the public and private sectors, but these involve strategic interactions that would needlessly complicate the model. The way we have approached the issue is to assume that the public sector conducts R&D based on the same criteria as the private sector. For example, both sectors will focus more on economically important crops that are specific to economically important growing areas. This assumption sets up the public sector as a substitute for the private sector. We do not explore the situation where the public sector is a complement to the private one, as would be the case where the former does basic research and the latter applies such research. This complementary research relationship does not appear to be controversial.

To incorporate the public sector, the equations presented in the previous section that require modifications are re-specified below using the same numbers as before, but with an apostrophe. So for example, the expected profits to firm n from investing the lump-sum k_n at time 0 in the presence of public R&D is represented by equation (15') instead of (15):

$$(15') \quad V(k_n, l_n, K_{(-n)}, L_{(-n)}, H_{(-n)}; \cdot) = v(\cdot)\, h(k_n, l_n)/[i + h(k_n, l_n) + H_{(-n)} + h_B] - k_n - l_n/[i + h(k_n, l_n) + H_{(-n)} + h_B],$$

where $K_{(-n)} \equiv \Sigma_{j\neq n}\, k_j$, $L_{(-n)} \equiv \Sigma_{j\neq n}\, l_j$, $H_{(-n)} \equiv \Sigma_{j\neq n}\, h(k_j, l_j)$, and $h_B \equiv h[B\,(k_n + K_{(-n)}), B\,(l_n + L_{(-n)})]$ is the public sector's hazard rate.

Optimal values $k_n^* = k^*(K_{(-n)}, L_{(-n)}, H_{(-n)};\cdot)$ and $l_n^* = l^*(K_{(-n)}, L_{(-n)}, H_{(-n)};\cdot)$ are obtained from the first-order necessary conditions for the maximization of (15'). In equilibrium, the optimal lump-sum investment and recurrent costs for each individual firm are given by (16') and (17'), respectively, whereas the aggregate hazard rate is given by (18'):

(16') $k^e = k^*[(N-1)\, k^e, (N-1)\, l^e, (N-1)\, h(k^e, l^e);\cdot]$,

(17') $l^e = l^*[(N-1)\, k^e, (N-1)\, l^e, (N-1)\, h(k^e, l^e);\cdot]$,

(18') $H^e = N\, h(k^e, l^e) + h(B\, N\, k^e, B\, N\, l^e)$.

Therefore, equilibrium aggregate lump-sum investment and recurrent costs can be calculated as $K^e = (1 + B)\, N\, k^e$ and $L^e = (1 + B)\, N\, l^e$, respectively.

The introduction of public-sector R&D affects the welfare analysis both directly and indirectly. The indirect impact stems from the changes in equilibrium lump-sum investments, recurrent costs, and aggregate hazard rate induced by the public-sector R&D, as given by (16') through (18') instead of (16) through (18), respectively. In essence, the public sector's indirect effect is due to the change in the expected time until innovation.

In contrast, the public sector's direct impact arises from the zero-markup marginal-cost pricing of x_1 when the public sector is the successful innovator. To see this, note that the unconditional expected change in country q's producer and consumer surpluses can be expressed as (19') and (20'), respectively:

(19') $$\Delta PS_q = \frac{Nh(k^e, l^e)}{H^e}\, \Delta PS_q(\cdot)|_{Success=Priv} + \frac{h(BNk^e, BNl^e)}{H^e}\, \Delta PS_q(\cdot)|_{Success=Pub},$$

(20') $$\Delta CS_q = \frac{Nh(k^e, l^e)}{H^e}\, \Delta CS_q(\cdot)|_{Success=Priv} + \frac{h(BNk^e, BNl^e)}{H^e}\, \Delta CS_q(\cdot)|_{Success=Pub}.$$

The terms $\Delta PS_q(\cdot)|_{Success=Priv}$ and $\Delta PS_q(\cdot)|_{Success=Pub}$ ($\Delta CS_q(\cdot)|_{Success=Priv}$ and $\Delta CS_q(\cdot)|_{Success=Pub}$) are the expected changes in country q's producer (consumer) surpluses conditional on the successful innovator being respectively a private firm and the public sector, whereas the terms $N\, h(k^e, l^e)/H^e$

and $h(B\,N\,k^e, B\,N\,l^e)/H^e$ are the corresponding probabilities. The expressions for $\Delta PS_q(\cdot)|_{Success=Priv}$ and $\Delta CS_q(\cdot)|_{Success=Priv}$ are like (19) and (20), respectively, except for the aggregate hazard rate being given by (18') instead of (18). In contrast, the public sector's marginal cost pricing of x_1 means that $\Delta PS_q(\cdot)|_{Success=Pub}$ and $\Delta CS_q(\cdot)|_{Success=Pub}$ must be computed as (22) and (23), respectively:

$$(22)\qquad \Delta PS_q(\cdot)|_{Success=Pub} = \int_0^{\infty}\{\int_{\tau_1}^{\infty} [\pi_q^e(\cdot)|_{\mu_{q,IPP}=0} - \pi_{q0}^e(\cdot)]\, exp(-i\,\tau_0)\,d\tau_0\ \}\ exp(-H^e\ \tau_1)\,H^e\,d\tau_1,$$

$$= \frac{H^e}{i\,(i+H^e)}\ [\pi_q^e(\cdot)|_{\mu_{q,IPP}=0} - \pi_{q0}^e(\cdot)],$$

$$(23)\qquad \Delta CS_q(\cdot)|_{Success=Pub} = \int_0^{\infty}\left\{\int_{\tau_1}^{\infty}\left[\sum_{q=1}^{Q}\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=0}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\,d\zeta\right] exp(-i\,\tau_0)\,d\tau_0\right\}\ e(-H^e\ \tau_1)\,H^e\,d\tau_1,$$

$$= \frac{H^e}{i\,(i+H^e)}\ \sum_{q=1}^{Q}\int_{p_q^{De}(\cdot)|_{\mu_{q,IPP}=0}}^{p_{q0}^{De}(\cdot)} D_q(\zeta)\,d\zeta\ ,$$

where the equilibrium aggregate hazard rate is defined by (18').

To calculate expected changes in societal welfare, the introduction of public-sector R&D requires consideration of the expected change in the surplus of the public R&D sector. Under the stated assumptions, the latter surplus consists simply of the (negative of the) sum of the public-sector's lump-sum investment and the present value of the public sector's recurrent costs until the innovation is obtained. In equilibrium, the public R&D sector's expected change in surplus is calculated as:

$$(24)\qquad PUS = -\,B\,N\,[k^e + l^e/(i + H^e)],$$

where k^e, l^e, and H^e are given by (16'), (17'), and (18'), respectively.

Simulation Specification and Parameterization

We resort to simulations to analyze the implications of technological spillovers and public research on equilibrium welfare and R&D. The simulations require specifying functional forms for each country's crop production and demand, and for the hazard rates of the individual R&D firms. Crop production functions under the traditional input are postulated to exhibit constant elasticity of substitution between inputs and decreasing returns to scale (so as to yield upward-sloping crop supply curves):

$$(25) \qquad f_q(x_{q0}, z_q) = F_q \; \{[\, a_{qx}^{1/\sigma_q} \;\; x_{q0}^{(\sigma_q-1)/\sigma_q} \; + \; z_q^{(\sigma_q-1)/\sigma_q} \,]^{\sigma_q/(\sigma_q-1)}\}^{\eta_q/(1+\eta_q)},$$

where $F_q > 0$ is a scaling parameter, $\sigma_q \geq 0$ is the elasticity of substitution between inputs x_{q0} and z_q, and $\eta_q > 0$ is the constant elasticity of crop supply. Parameter $a_{qx} > 0$ determines the share of total costs due to input x_{q0}, as the cost share equals $a_{qx}\; w_{q0}^{1-\sigma_q} /(a_{qx}\; w_{q0}^{1-\sigma_q} \; + \; r_q^{1-\sigma_q})$.

The farm profit function associated with (25) is:

$$(26) \qquad \pi_{q0}(p_q, w_{q0}, r_q) \equiv \eta_q^{\eta_q} \;(1 + \eta_q)^{-(1+\eta_q)} \; F_q^{1+\eta_q} \;\; p_q^{1+\eta_q} \;\; (a_{qx}\; w_{q0}^{1-\sigma_q} \; + \; r_q^{1-\sigma_q})^{-\eta_q/(1-\sigma_q)}.$$

Technology and profits under the improved input ($g_q(x_{q1}, z_q)$ and $\pi_{q1}(p_q, w_{q1}, r_q)$, respectively) are straightforward to obtain from (25) and (26) by noting that $g_q(x_{q1}, z_q) = (1 + \alpha_q)\, f_q(x_{q1}, z_q)$. Crop demand is assumed to be isoelastic for each country, so that $D_q(p_q) = D_q \;\; p_q^{-\varepsilon_q}$, where $D_q > 0$ is a scaling parameter and $\varepsilon_q > 0$ is country q elasticity of demand for the crop. Finally, the hazard rate function of each individual R&D firm is represented by the decreasing returns to scale Cobb-Douglas technology $h(k, l) = A \;\; k^{\kappa_K} \;\; l^{\kappa_L}$, where A is a scaling parameter, and $\kappa_K > 0$ and $\kappa_L > 0$ are constants such that $\kappa_K + \kappa_L < 1$.

Given the postulated functional forms, simulating the model for Q countries entails specifying values for 2 Q demand parameters (ε_q and D_q), 6 Q supply parameters and exogenous variables (η_q, σ_q, a_{qx}, F_q, α_q, r_q), Q legal IPP parameters ($\mu_{q,right}$), and Q^2 transaction cost parameters (ζ_{qj}). In addition, values must also be specified for the length of time during which

IPP rights are enforced (T), the interest rate (i), the competitive disadvantage cost (μ_{cost}), the cost of producing old seed (c_0) and new seed (c_1), the productivity of labor and capital in the R&D process (κ_L and κ_K), the number of R&D firms (N), and the relative size of the public R&D sector (B). Therefore, to simplify matters, we restrict attention to simulations involving just Q = 2 countries with frictionless crop transactions ($\zeta_{qj} = 0$) and identical parameters except for improvement factors (α_q) and legal IPP parameters ($\mu_{q,right}$). "Home" denotes the country for which the new input is developed and "Rest-of-the World" (ROW) denotes the country receiving the technological spillover. Because of the frictionless transactions, in equilibrium consumer prices equal producer prices for the crop.

The parameterizations we use are based on those in Lence *et al.* (2005). The conclusions reached hold for a wide range of parameter values. For the purpose of reporting results, the benchmark scenario with no public R&D (i.e., $B = 0$) was parameterized with $\eta = 1.5$, $\varepsilon = 0.5$, $\sigma = 0.3$, cost share = 10 percent, T = 20 years, i = 10 percent per year, $\mu_{cost} = 0$, $\kappa_K = \kappa_L = 0.4$, N = 5 firms. Other parameters of the model are normalized to unity; these are the price of other inputs (r), and the cost of producing old seed (c_0) and new seed (c_1). Simulations were conducted by fixing the home country's improvement factor at α_{Home} = 10 percent and allowing for spillover levels from the home country to ROW ($s_{ROW} \equiv \alpha_{ROW}/\alpha_{Home}$) to vary between $s_{ROW} = 0$ (i.e., no spillover) and $s_{ROW} = 1$ (i.e., full spillover). To explore the effects of legal IPP, simulations were performed for a large range of feasible legal IPP values in the home country ($\mu_{Home,right}$), and ROW was assumed to either have no legal IPP (i.e., $\mu_{ROW,right} = 0$) or to have the same level of legal IPP as the domestic country ($\mu_{ROW,right} = \mu_{Home,right}$) (i.e., the latter scenario represents harmonized legal IPP). The effect of public R&D was examined by running simulations with B ranging from 0 to 1 (note that $B = 1$ means that public lump-sum investment and recurrent costs in R&D are equal to the aggregate of the analogous private R&D expenditures).[6]

In the reported simulations, the home country and ROW were assumed to have identical market shares in crop production and consumption.[7] Comprehensive sensitivity analyses of alternative parameterizations were performed, in particular regarding market shares and elasticities. The results were qualitatively very similar to those that are shown in the figures below, apart from some obvious differences in scaling.

Results and Discussion

The main results from the simulations are summarized pictorially in figures 1 through 18, which report expected welfare changes for a range of spillovers and legal IPP levels in the home country. Panels A and B of figures 1 through 14 show respectively results for the scenarios without and with public R&D (i.e., $B = 0$ and $B = 1$).

Figures 1-8, 13, 15, and 16 correspond to the base scenario with no legal IPP in ROW, whereas figures 9-12, 14, 17, and 18 represent the base scenario under harmonization (i.e., where the legal IPP in ROW is the same as in the home country). These two alternative scenarios are discussed next.

No Legal IPP in ROW

Figure 1.A shows the present value of the expected change in consumer surplus in the home country, under a range of legal IPP levels in the home country and spillover coefficients from the home country to ROW. The graph shows that home consumers always benefit from strictly positive appropriability ($\mu_{Home,IPP} > 0$). When there is no spillover ($s_{ROW} = 0$), the change in welfare of the home consumers increases with additional appropriability up to a value of about $\mu_{Home,IPP} = 1.4$. This increase in consumer welfare occurs because increased legal IPP encourages R&D, and R&D reduces the crop price as the new technology enhances the output of farmers in the home country. The reduction in consumer welfare change after this maximum point occurs because the owner of the new technology captures more and more of the benefits associated with it, leaving less room for a reduction in crop prices. However, at even higher legal IPP levels ($\mu_{Home,IPP} \geq 2.1$), rent extraction by the owner of the new technology is restricted by the possibility of home farmers reverting to the old technology. Hence, the welfare increase of home consumers reaches a plateau.

As the spillover level is increased from $s_{ROW} = 0$ to $s_{ROW} = 1$, the level of appropriability that maximizes the change in consumer welfare increases as well. The logic behind this result is that full spillover allows ROW farmers to take full advantage of the new technology, but the absence of any legal IPP in ROW means that the owner of the technology cannot capture any benefit from its use by ROW farmers. In this situation, the leakage of rents associated with the spillover reduces the ability of R&D firms to capture the benefits associated with the new technology from all of those who use it. This means that less R&D is done than is optimal from the consumers' standpoint. This rent leakage can be partly offset by increasing the legal IPP level in the home country.

Consumer welfare in the home country increases monotonically with the level of spillover. Consumers gain from additional crop output and when R&D conducted in the home country leads to additional output from ROW, consumers benefit regardless of their location. The welfare response surface of ROW consumers is not shown because it is identical to the one shown for the home country. This is true because consumers in the home country and ROW are assumed to have the same share of world consumption (50 percent share for each country) in the baseline scenario, and all consumers are assumed to face the same prices regardless of where they live. In general, consumer welfare is greatest whenever spillover is highest and for appropriability $\mu_{ROW,IPP} \geq 2$. From the consumers' perspective, a large amount of spillover increases the case for high legal IPP in the home country. This is true because higher appropriability in the home country encourages R&D, and this enhances not only the production capability of home farmers but also that of farmers in ROW. As ROW has no legal IPP, ROW farmers do not have to pay any rents to the innovator. In turn, this allows ROW farmers to offer their output to all consumers at a lower price.

Figure 2.A shows the R&D industry's welfare surface. This surface is from the same set of simulations used to generate the consumer surface described above, and again the shape of this surface is insensitive to alternative parameterizations. Starting with a spillover of $s_{ROW} = 0$, the welfare of R&D firms increases in the home country's level of appropriability, but this

response flattens when the level of legal IPP exceeds $\mu_{Home,IPP} = 2.1$. This flattening occurs because farmers in the home country always have the choice of reverting to the unimproved breed or variety, and this option limits the monopoly pricing power of the successful R&D firm. The welfare of the R&D industry falls as spillover grows. By assumption, the successful R&D firm cannot capture any rent from ROW producers. Spillovers allow ROW farmers to capture market share from home producers, because home farmers must pay a premium for the improved seed that is not charged in ROW. As this change in the competitiveness of home farmers decreases the relative size of their crop, it reduces the ability of R&D firms to capture rents from them.

In other simulations that are not reported here, the degree to which the welfare of R&D firms falls with respect to the spillover coefficient increases as the elasticity of supply increases, and as demand becomes more inelastic. However, the degree to which the welfare of R&D firms falls with respect to the spillover is not monotonic in the output share of ROW; the fall is largest when ROW's baseline output share is 50 percent.

Figure 3.A shows the welfare change surface for producers in the home country under the same parameters as the consumer and R&D surpluses described above. Starting with a spillover of $s_{ROW} = 0$, we see that producers in the home country benefit slightly from increased legal IPP up to the point $\mu_{Home,IPP} = 1.3$. This increase in producer welfare is surprising because we assume an inelastic demand ($\varepsilon = 0.5$). One would normally expect producers to lose from outward shifts in the supply curve when demand is inelastic. The result comes about because appropriability increases R&D that enhances the technology available to farmers in the home country, but has no direct impact on the technology available to ROW producers. Therefore, such R&D allows farmers in the home country to capture market share from producers in ROW. However, when we introduce even small amounts of spillovers (e.g., $s_{ROW} \geq 0.2$), the positive link between legal IPP and the welfare of producers in the home country is broken. Producers in the home country are generally worse off when appropriability is high and spillovers are greatest. The welfare

change surface of ROW producers (see figure 4.A) looks like a mirror image of the welfare change surface for producers in the home country.

Figures 5.A and 6.A show the changes in producer welfare with a much higher demand elasticity ($\varepsilon = 1.5$), and all other parameters at the levels used for figures 3.A and 4.A. These results are very similar to those shown in figure 3.A and 4.A, respectively, despite the large change in the demand elasticity. This result suggests that under a wide range of parameters, producers in the home country lose from legal IPP when spillover is positive.

Figure 7.A shows the change in total surplus for the home country under the same set of parameters as used in figures 1.A through 3.A. Total welfare in the home country increases with the legal IPP level up to a point, and eventually flattens out as R&D firms are allowed to capture rents. Total welfare in the home country achieves its maximum when appropriability equals $\mu_{Home,IPP} = 1.6$ and spillover is $s_{ROW} = 0$. However, the total welfare of the home country is relatively insensitive to the level of spillover. This is true because losses to home farmers and R&D firms caused by large spillovers are offset by gains to home consumers. The socially optimal level of legal IPP in the home country is slightly larger as the level of spillover increases.

The aggregate welfare change surface for producers, consumers and R&D firms in both countries are depicted in figure 8.A. World welfare rises monotonically with spillovers. Further, except for small spillovers ($s_{ROW} \leq 0.3$), world welfare also rises monotonically with the level of appropriability in the home country up to the point where the ability of R&D firms to capture the benefits of the research is limited by the ability of the home farmers to revert to the unimproved technology.

The results presented above suggest that as spillovers increase, the welfare of both producers and R&D firms in the country with strong legal IPP falls. This clearly acts as a disincentive for producers to support stronger IPP and encourages both R&D firms and producers to work to reduce spillovers. This is unfortunate because world welfare increases with spillovers and it also increases in legal IPP up to a point. An obvious question is whether harmonizing legal IPP levels across countries yields a more desirable outcome. Harmonization might occur via multilateral agreement or by usage of GURTs.

It is important to note, however, that the present analysis implicitly assumes that spillovers are independent of IPP in the two countries. This may not be the case, especially in ROW. As Zilberman *et al*. (2004) show, lower IPP may lead to less effort to introduce traits of various local varieties, thus reducing the gain from the new technology. This may be interpreted as a reduction of the spillover, suggesting that only some areas of the spillover-IPP space are realistic and thus provide useful information.

Harmonized Legal IPP

When we conduct welfare comparisons under harmonized legal IPP, the R&D industry benefits from both spillovers *and* appropriability under all parametric assumptions. This result makes sense. R&D firms benefit when they are allowed to collect rents in both countries, and the rents they obtain from ROW producers depends on the relevance of the research (i.e., the spillover) to them. Under harmonized IPP the R&D firms have a much greater incentive to conduct research relevant to ROW producers and, as a result, world welfare and ROW welfare under harmonized IPP are greater than when ROW does not provide legal IPP.

Figures 9.A and 10.A show producer surplus in the home country under inelastic and elastic demand, respectively. Unlike the scenario without legal IPP in ROW, home producers now benefit from both legal IPP *and* spillovers (up to a point that depends on the demand elasticity). The welfare maximizing outcome for home producers occurs when legal IPP is $\mu_{Home,IPP} = 1$ and spillover equals $s_{ROW} = 0.5$ for the inelastic demand case. For the scenario with elastic demand (not shown), maximum home producer surplus is achieved for $\mu_{Home,IPP} = 1.4$ and $s_{ROW} = 0.7$.

Producer surplus in ROW for inelastic and elastic demand is depicted in figures 11.A and 12.A, respectively. These graphs are crucially different from the ones corresponding to no IPP in ROW, in that ROW producer surplus does not increase monotonically with spillovers. Indeed, ROW producer surplus is *minimized* at the same legal IPP and spillover levels at which home producer surplus is maximized.

The producer surplus results under harmonization are counterintuitive. Figures 9.A and 10.A suggest that home producers would sometimes favor research that is of some relevance to ROW producers over research that has no spillovers at all. Analogously, figures 11.A and 12.A indicate that ROW producers would sometimes prefer R&D that does not spillover to them rather than R&D that can be of some use to them. The answer to this puzzle is that if neither the legal IPP level nor spillover is too high, the successful R&D firm is able to extract all potential rents from ROW producers, but it cannot do the same with the farmers in the home country. At these levels of appropriability and spillover, the new input has a positive impact on ROW output technology, but this impact is smaller than the new input's effect on the home country output technology. The R&D firm is able to charge ROW farmers a price that leaves them indifferent between the old and the new input, but it cannot do the same with the home country farmers (because the legal IPP is not strong enough to allow it). Since expected rents to R&D from ROW increase with spillovers and because these rents provide incentives to invest in R&D, the resulting R&D can be expected to end up benefiting farmers in the home country at the expense of ROW producers when spillovers are in an appropriate range, as home producers gain market share at the expense of ROW farmers.

Comparison of producer surpluses in the home country and ROW shows that, regardless of the level of legal IPP, farmers in both countries experience the same level of welfare when there is full spillover ($s_{ROW} = 1$). This is to be expected, as the research is of equal relevance to producers in both countries, and producers in both countries pay an identical amount for it.

Obsolescence of the Innovative Input

In real-world situations, the "effective" length of protection enjoyed by the developer of x_1 in country q is likely to be eroded or eliminated altogether by the introduction of an even more productive new input x_2 with $\alpha_{q2} > \alpha_q$.[8] This suggests that the sensitivity of cross-country welfare calculations to the effective duration of protection needs to be assessed. To this end, the basic model can be generalized to allow input x_1 to become obsolete $T_{q,obsol}$ years after its introduction. This can be achieved by setting the effective length of protection in country q as $T_q \equiv min(T_{q,obsol}, T_{right})$, where T_{right} denotes the life of the patent. This implies that the developer of input x_1 is able to extract monopoly rents for the entire life of the patent if the latter expires before x_1 becomes obsolete ($T_{right} \leq T_{q,obsol}$). Otherwise ($T_{q,obsol} < T_{right}$), the innovator only enjoys monopoly rents over the period $[t, t + T_{q,obsol}]$, and receives no rents thereafter.

The discussion above implies that, if time until obsolescence is taken as exogenous, policy-makers can enhance innovators' incentives by increasing the length of the patent only up to the point where $T_{right} = T_{q,obsol}$. Beyond that point, increasing T_{right} has no effect and the only means to affect the incentives to innovate is through the IPP appropriability level μ_{IPP}.

To explore the quantitative and redistributional effects of time until obsolescence, the original scenarios were re-estimated using the same length of patent life as before ($T_{right} = 20$ years), but letting the innovation become obsolete considerably before the expiration of the patent ($T_{q,obsol} = 6$ years). Early obsolescence has two main effects that are illustrated by means of figures 13.A and 14.A. Figure 13.A (14.A) depicts the change in the present value of the home country consumer (producer) surplus under no legal IPP (harmonized IPP) in ROW and is analogous to figure 1.A (9.A). The first effect consists of a *ceteris paribus* significant reduction in the magnitude of the changes in welfare, clearly illustrated by the smaller scale of the vertical axis in figures 13.A and 14.A relative to figures 1.A and 9.A, respectively. The second effect is to render the changes in welfare more monotonic in the IPP level. For example, in figure 1.A without spillovers increasing the level of IPP beyond a certain level translates into reduced consumer welfare, but no such reduction is observed in figure 13.A. The explanation for both effects is that, for any given level of IPP, early obsolescence prevents the successful innovator from extracting as much rents as it would otherwise. Importantly, figure 14.A shows that the non-monotonicity of the change in home-country producer surplus with respect to spillovers is robust to obsolescence.

Gradual Adoption of the Improved Variety

Another aspect that may be deemed unrealistic about the advocated model is that it assumes that the innovation is adopted immediately, whereas in the real world it typically takes some time for innovations to diffuse. Slower rates of adoption by potential users reduce the innovator's rents, providing smaller incentives to perform R&D. Therefore, other things equal, the longer it takes for an innovation to diffuse, the greater the potential relevance of the IPP level.

Denoting by $\vartheta_{q\tau} \in [0, 1]$ the proportion of farmers in country q willing to adopt the innovation τ periods after the latter is introduced, the impact of gradual adoption was assessed by conducting simulations with $\vartheta_{Home,\tau} = \vartheta_{ROW,\tau} = 0$ for $\tau \in [0, 0.5)$, $\vartheta_{Home,\tau} = \vartheta_{ROW,\tau} = 1/6$ for $\tau \in [0.5, 1.5)$, $\vartheta_{Home,\tau} = \vartheta_{ROW,\tau} = 1/2$ for $\tau \in [1.5, 2.5)$, $\vartheta_{Home,\tau} = \vartheta_{ROW,\tau} = 5/6$ for $\tau \in [2.5, 3.5)$, and $\vartheta_{Home,\tau} = \vartheta_{ROW,\tau} = 1$ for $\tau \geq 3.5$.[9] To save space, graphs for the simulations with gradual adoption are omitted, as they are almost undistinguishable from the plots corresponding to immediate adoption except for the scale of the welfare changes. Compared to immediate adoption, gradual adoption reduced the absolute magnitudes of the welfare changes by around 30 percent to 40 percent.

Importance of Spillovers for Policy

The results presented above suggest that if the level of spillover is a choice made by the R&D companies, then low IPP in developing counties will result in fewer high-spillover innovations. However, if the degree of spillover is random and large, as appears to have been the case for hybrid crops, Iowa dent corn and transgenic crops, then producers in ROW benefit from weak IPP in their country and strong IPP in the home country, as do consumers in ROW (figure 1.A). This result may explain why some countries are reticent to impose strong IPP. World welfare is enhanced by strong ROW IPP in both the deterministic spillover and random spillover cases, which motivates the international focus on harmonization. Further, in the case of random spillovers it may even justify compensation to ROW countries to encourage them to adopt stronger IPP.

Results with a Public Sector

Figures 1.B through 14.B show that the shape of the welfare surfaces with a public sector spending as much on R&D as the private sector is similar to those for the private sector alone. Two major results from these simulations. First, the public sector essentially dilutes the market power of the private sector and this eliminates the area of the charts where increased IPP causes reduced consumer and societal welfare. Second, the welfare level is influenced by the existence of the public sector. Specifically, the amount of consumer surplus is typically 12 percent greater with a public sector (without taking into account the tax burden created by the public sector expenditures in R&D). The presence of public sector research reduces the amount of private sector research, so that aggregate R&D is approximately the same on both scenarios. However, because (if successful) the public sector sells the innovation at marginal cost and without markup, consumers gain as more producers adopt and as these producers pass along lower input costs to consumers. Expected profits of the R&D sector fall by approximately 50 percent, as one might expect given that half of the aggregate R&D activities are performed by the public sector. Producer surplus is almost identical under both the private and the public/private scenarios. With the same amount of aggregate research being performed, the expected impact on the producer comes via the lower cost of seed from the public sector. But in equilibrium, producers pass most of this lower cost on to consumers. World surplus is very similar under the private sector when compared to the public/private sector scenario, as gains by consumers are offset by reduced profits to the private R&D sector and the taxes levied to support public R&D (see Figures 15 through 18).

Summary and Conclusions

The provision of intellectual property rights in agriculture has gained increased attention as governments have attempted to stimulate private sector research and because the recent (as yet to be commercialized) development of GURTs makes it possible for the private R&D sector to protect farmers from growing future generations of the improved variety. The welfare implications of increased protection of intellectual property in agriculture are different from those in the rest of the economy because the customer for the improved product is a farmer who uses the technology to produce a final product that is then sold into competitive markets. A key contribution of the model presented here has been the acknowledgement that in many instances the technology used in agriculture is subject to spillovers. For example, improvements to the genetic composition of plants and animals developed in one country are often captured to some extent by producers in other countries. This fact has some important implications for welfare analysis and for policy prescriptions on where the burden of paying for the research should lie. We have paid particular attention to the realistic case where some countries provide legal protection for intellectual property, while other countries do not offer such protection. The model is designed to replicate the incentive structures and institutions that exist in the seed sector and we focus only on results that are robust across changes in key parameters. We have also worked with several different formulations of the model presented here and again we focus only on those results that were robust across model formulations. However, we acknowledge that, as with any formalized model, one should carefully evaluate the degree to which the model accurately reflects the real word before using the results to evaluate policies.

In general, world welfare rises as the amount of research spillover increases, and it increases up to an optimal point in the level of intellectual property protection (IPP) offered in countries that develop the new technologies. This optimal level of protection also increases as spillovers increase because spillovers magnify the benefits of research. In all of the cases we examined, the relationship between world welfare and the level of appropriability flattens at high levels of appropriability.

Producers and consumers in countries with no legal IPP generally benefit from legal IPP in other countries so long as some reasonable level of spillover exists. Producers in countries with strong IPP almost always lose when spillovers exist, whereas consumers in the country protecting intellectual property always gain from the existence of spillovers. Whether the latter gains are large enough to offset the former losses as spillovers increase depends on the relative magnitudes of the sectors producing and consuming the crop in the country with high legal IPP. When the crop production sector is of similar or greater size than the crop consumption sector (i.e., when the country is an exporter of the crop), producer losses tend to exceed consumer gains as spillovers increase.

Producers and R&D companies in countries with strong IPP lose from research that is of relevance to producers in other countries. If producers and R&D firms respond to this incentive and avoid research that might spill over, then world welfare falls. One solution is to harmonize legal IPP across countries via agreements or via GURTs. This provides R&D firms with a strong incentive to conduct high spillover research and it gives producers in research-oriented countries an incentive to support IPP even if this sometimes spills over into other countries.

When we add a public sector that conducts similar research to the private sector, consumers benefit (ignoring taxes paid to support the public sector) and seed companies lose. The net impact on total surplus is very small. However, the study focuses on the case where the public sector competes with the private sector. Therefore, such conclusions need not apply to scenarios where public research is complementary to private R&D, as when the public sector performs basic research or does research on orphan crops. The latter are two examples of the many potentially fruitful extensions of the model presented here.

Notes

1. Note that the definition of $\mu_{q,IPP}$, $\mu_{q,right}$, and μ_{cost} here is different from the definition of the parameters designed with similar notation in Lence *et al*. (2005). As it will become clear later, the former parameters are obtained by rescaling the latter parameters by the marginal cost of producing x_1 (c_1). That is, Lence *et al*.'s μ_{IPP}, μ_{right}, and μ_{cost} are measured in dollars per unit of x_1, whereas $\mu_{q,IPP}$, $\mu_{q,right}$, and μ_{cost} here are measured in units of marginal cost c_1.

2. Allowing for market power unrelated to IPP in the x industry may significantly affect the results of the model. To illustrate this point, consider the extreme case where the x industry consists of a monopoly. Unlike the case of perfect competition, the monopoly scenario will result in R&D investment even if there is no legal IPP or cost advantage, provided the new input x_1 allows the monopoly to obtain greater profits than supplying the old input x_0. Indeed, conferring legal IPP in such a situation will not exert any impact whatsoever on the (monopoly) incentives to innovate. In the real world, the R&D industry may have market power for reasons other than IPP. However, to focus on the virtues and vices of granting monopoly power targeted at promoting innovation, we restrict attention here to the case of perfect competition. The reason for this is that non-IPP market power can be conceptually distinguished from the IPP market power and it can be legally challenged (e.g., by antitrust laws).

3. To make the problem interesting, it is also assumed that c_1 and c_0 are such that the improved farm input x_1 represents a Pareto improvement over the standard farm input x_0 (i.e., that $\Omega(x_1) > \Omega(x_0)$, where $\Omega(x_1)$ denotes the welfare to society resulting from the use of x_1 only, and $\Omega(x_0)$ is defined in an analogous manner). This requires that the marginal cost of producing x_1 not be "too large" relative to the marginal cost of producing x_0. The condition that $c_1 \leq [1 + max(\alpha_q)]\, c_0$ ensures that x_1 is a Pareto improvement over x_0, but it is more restrictive than necessary.

4. Note that μ_{cost} is the same across countries. This assumption is adopted to focus on the impact of differential levels of property rights ($\mu_{q,right}$) across countries and can be justified if, for example, the costs of trading x_1 in the absence of legal restrictions were negligible.

5. For analytical and numerical tractability, the hazard rate is assumed to be independent of state variables. Otherwise, the hazard rate and the recurrent R&D costs would vary with time. Such an assumption is unrealistic in that the probability of a real-world firm developing a new variety at any point in time is likely to depend on its own (and possibly the industry's) previous research activity. However, it does not invalidate our main conclusions because the study focuses on a static *ex ante* analysis, rather than on the evolution of the hazard rate and the recurrent R&D costs. For the present purposes, the main impact of the hazard rate is through the expected time until discovery, whereas the hazard rate's evolution effect is only of second order of significance. In other words, the results from our model would be very similar to the results from a model with time-varying hazard rates calibrated to have the same expected time until discovery.

6. As pointed out in footnote 14 of Lence *et al*. (2005), changing $(1 + B) N$ exerts a "scale" effect and a "competition" effect. Following their reasoning, attention is restricted to the competition effect by setting $A = [(1+B)N]^{\kappa_K + \kappa_L - 1}$, which may be interpreted as normalizing the aggregate amount of "fixed" input at unity. To see this, let the hazard rate have constant returns to scale by having $A = \phi^{1-\kappa_K-\kappa_L}$, where ϕ is a <u>fixed input</u>. Hence, the aggregate hazard rate is $H = (1 + B) N h(k, l) = \Phi^{1-\kappa_K-\kappa_L} \; K^{\kappa_K} \; L^{\kappa_L}$, where $\Phi \equiv (1 + B) N \phi$, $K \equiv (1 + B) N k$, and $L \equiv (1 + B) N l$ are the aggregate amounts of fixed input, lump-sum investment, and recurrent costs, respectively. The advocated normalization consists of setting $\Phi = 1$, so that $\phi = 1/[(1 + B) N]$ and $A = [(1+B)N]^{\kappa_K + \kappa_L - 1}$. The profits of the private R&D sector are therefore the returns to their corresponding share of the fixed factor $N \phi = 1/(1 + B)$.

7. Different output (consumption) market shares can be simulated by varying F_{Home} and F_{ROW} (D_{Home} and D_{ROW}). Scaling factors are normalized so that $F_{Home} + F_{ROW} = 1 = D_{Home} + D_{ROW}$. Hence, for example, a 30 percent output (consumption) market share for ROW is obtained by setting $F_{ROW} = 0.3$.

8. An anonymous reviewer informed us that PVP data from EU countries suggests that only 40-60 percent of PVP certificates survive for more than five years, less than 30 percent survive for more than 10 years, and less than 3 percent survive for the full term of legal IPP protection.

9. The postulated $\vartheta_{q\tau}$ values imply that, for example, one year after the innovation, 16.7 percent of producers in both the home country and ROW adopt x_1 if it is more profitable for them do so than using x_0, whereas the remaining 83.3 percent of producers are unwilling to adopt the innovation and keep using x_0.

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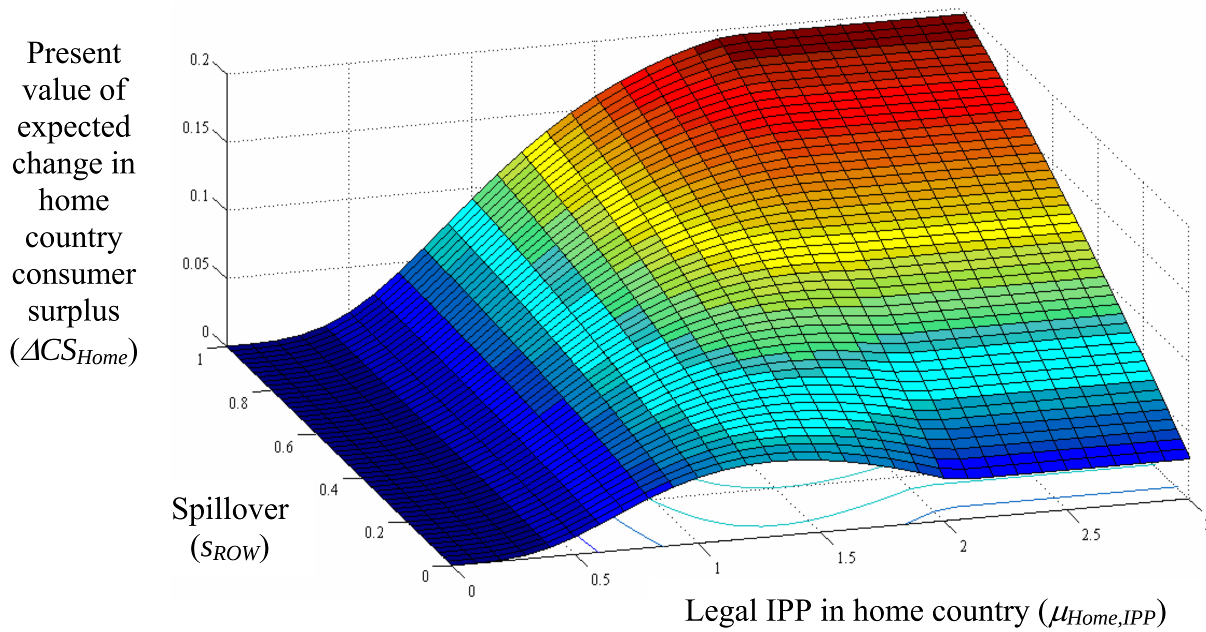
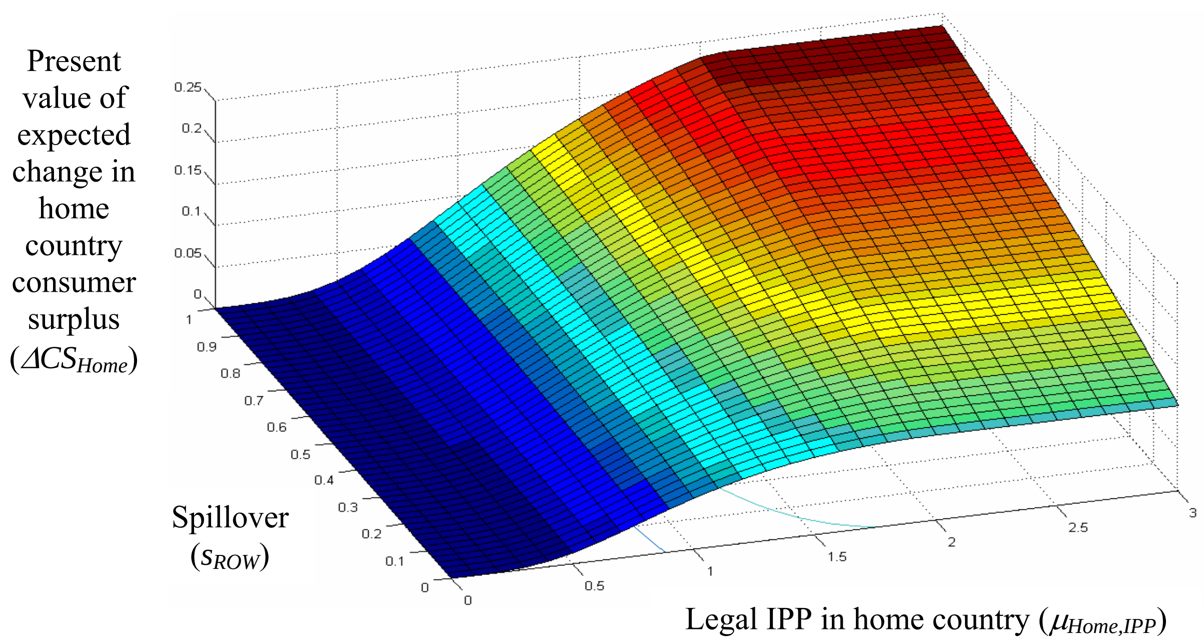
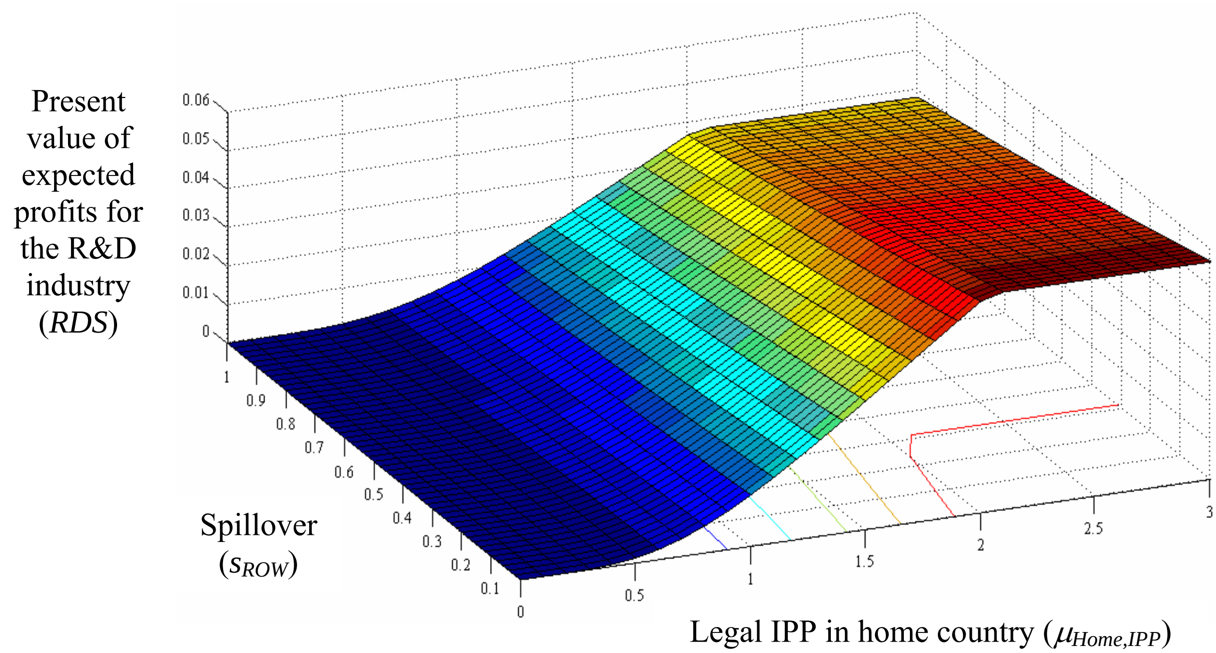


A. Without public R&D (B = 0)



B. With public R&D (B = 1)

Figure 1. Present value of expected change in home country consumer surplus (ΔCS_{Home}) for inelastic demand (ε = 0.5), in the absence of legal IPP in ROW



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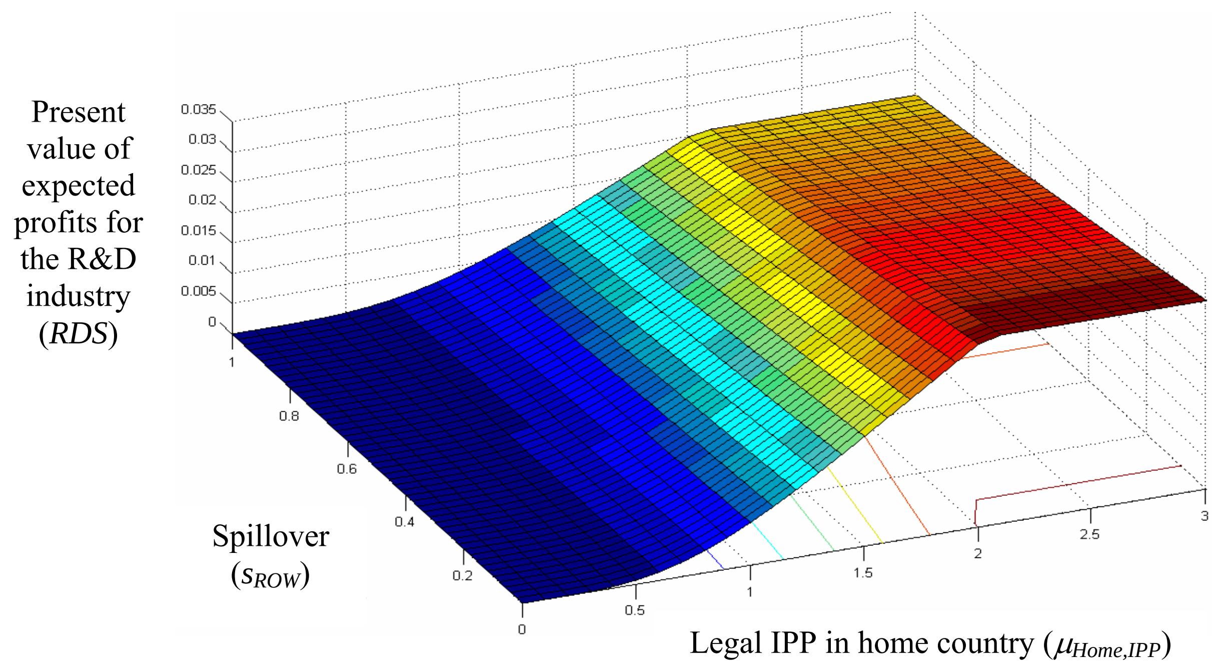
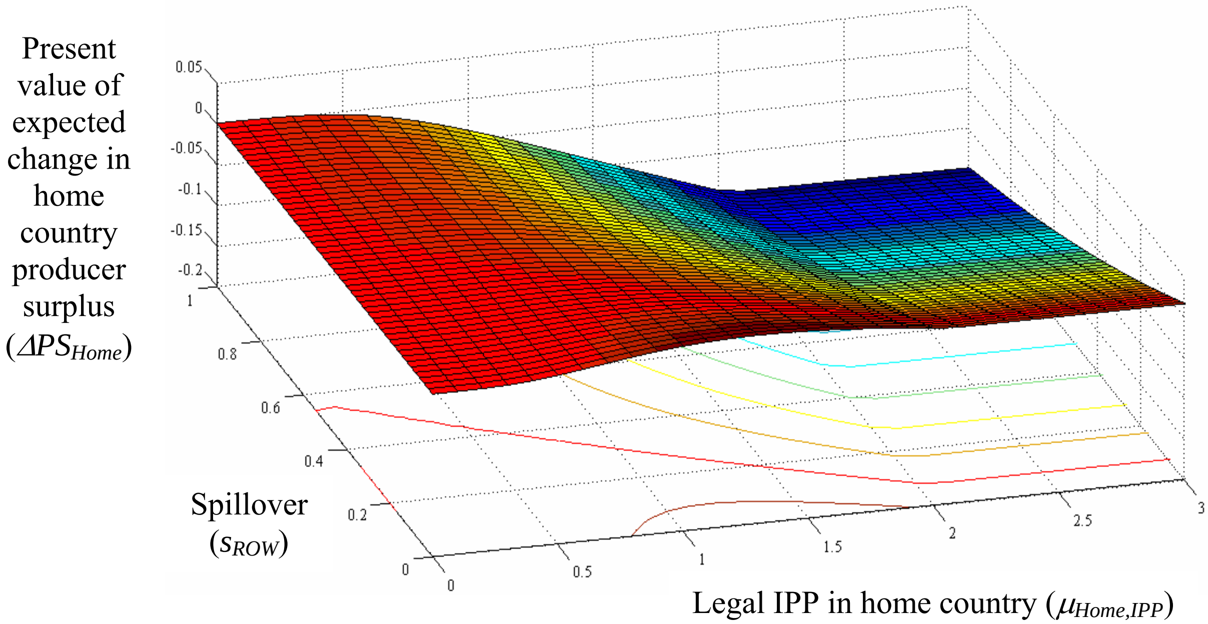


B. With public R&D (*B* = 1)

Figure 2. Present value of expected profits for the R&D industry (*RDS*) for inelastic demand (ε = 0.5), in the absence of legal IPP in ROW



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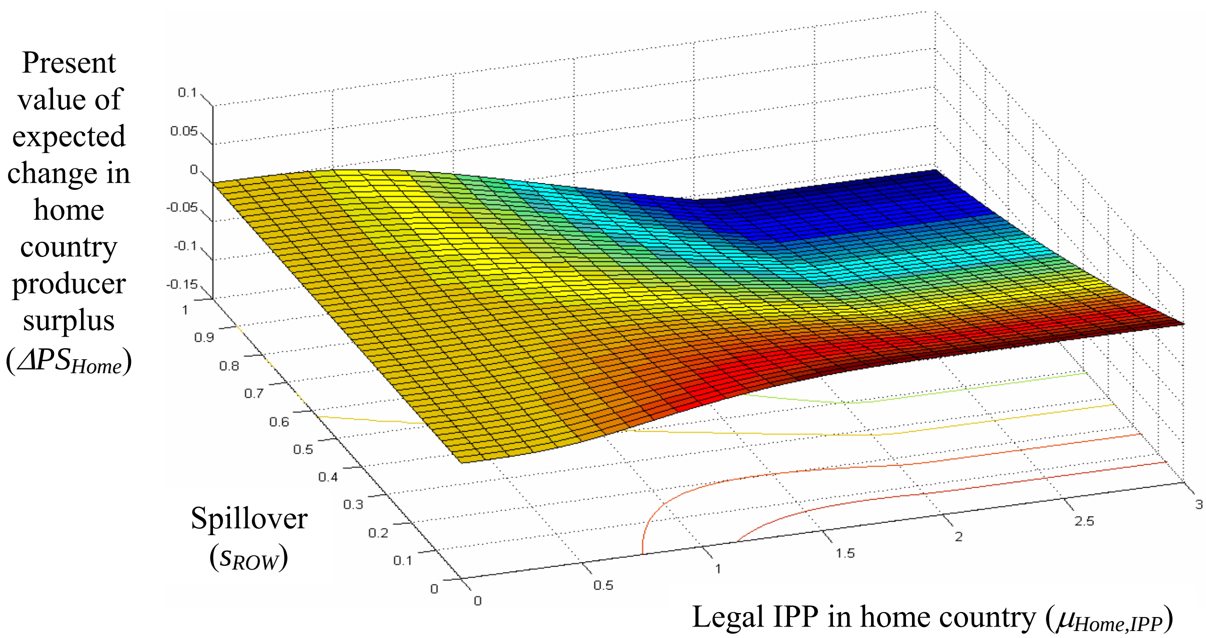

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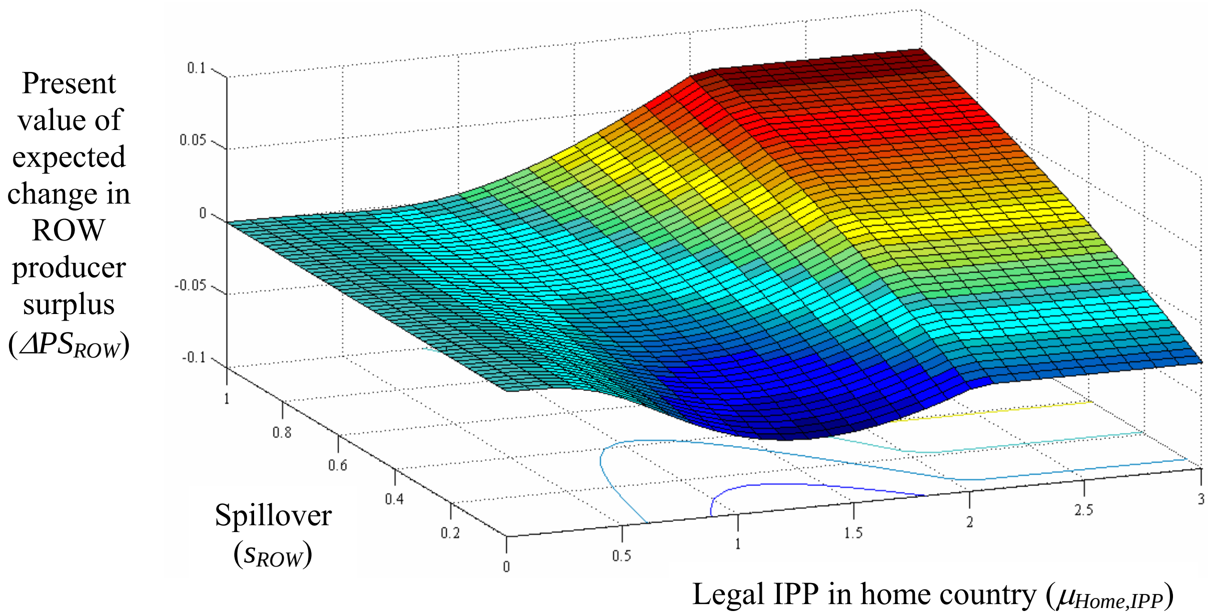
Figure 3. Present value of expected change in home country producer surplus (ΔPS_{Home}) for inelastic demand ($\varepsilon = 0.5$), in the absence of legal IPP in ROW



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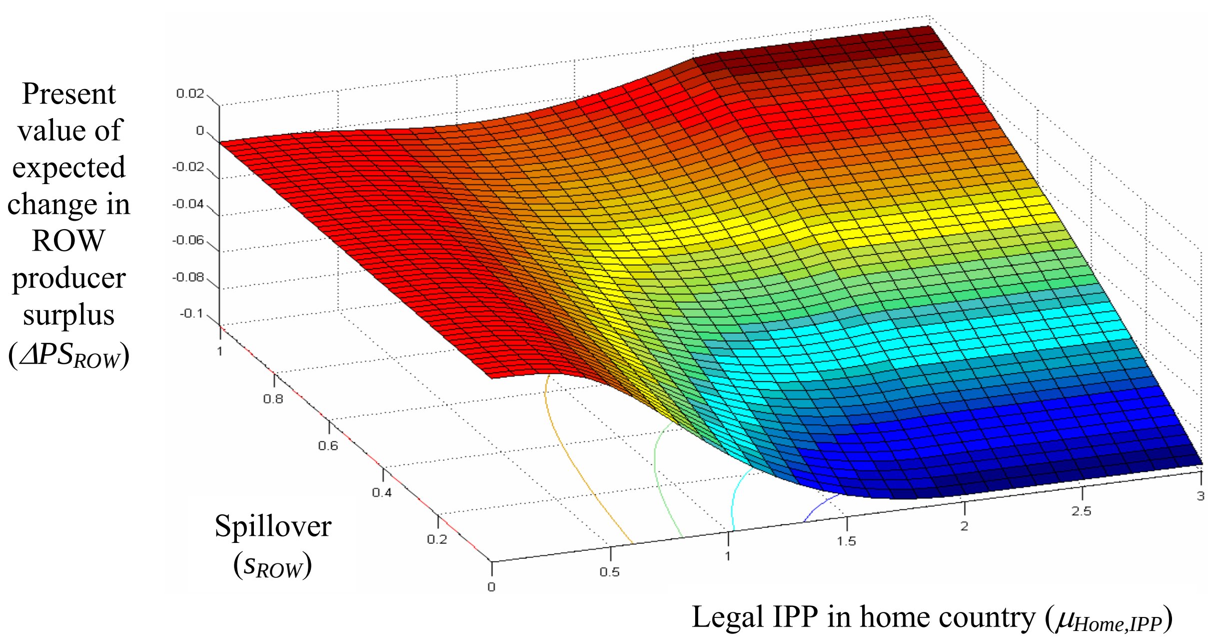

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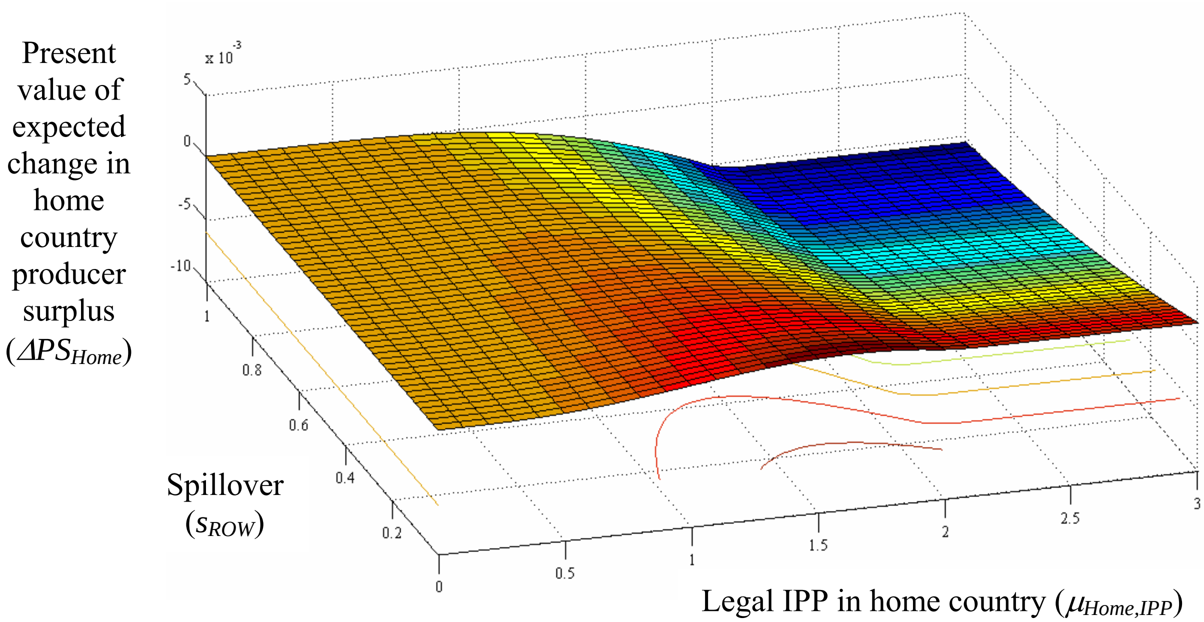
Figure 4. Present value of expected change in ROW producer surplus (ΔPS_{ROW}) for inelastic demand (ε = 0.5), in the absence of legal IPP in ROW



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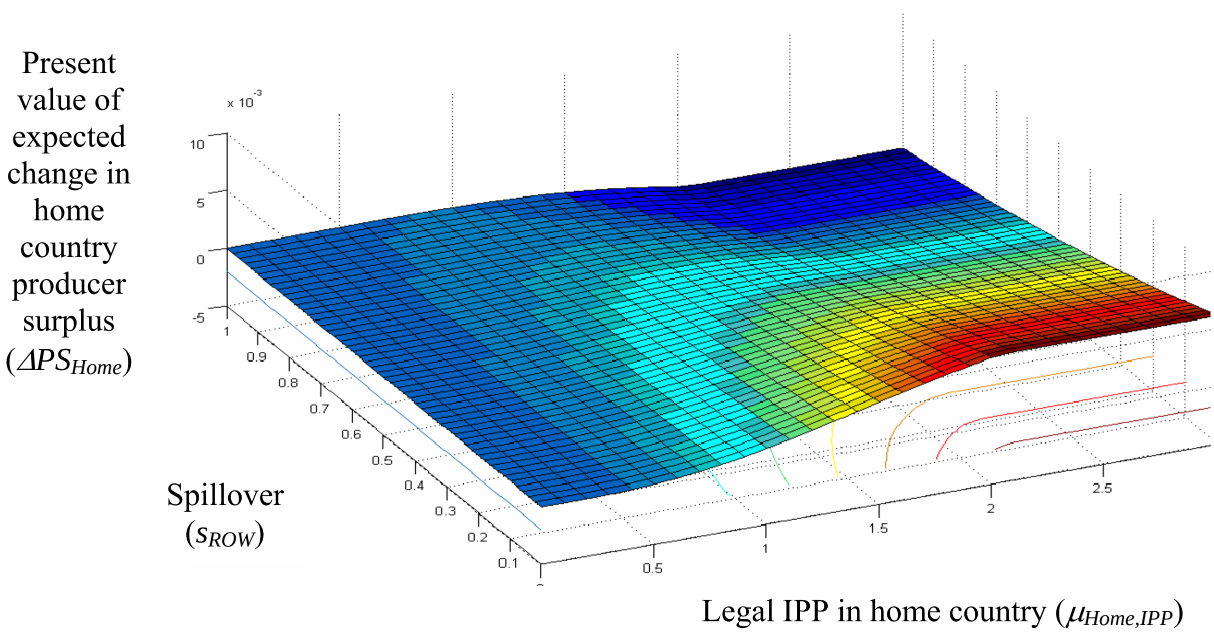
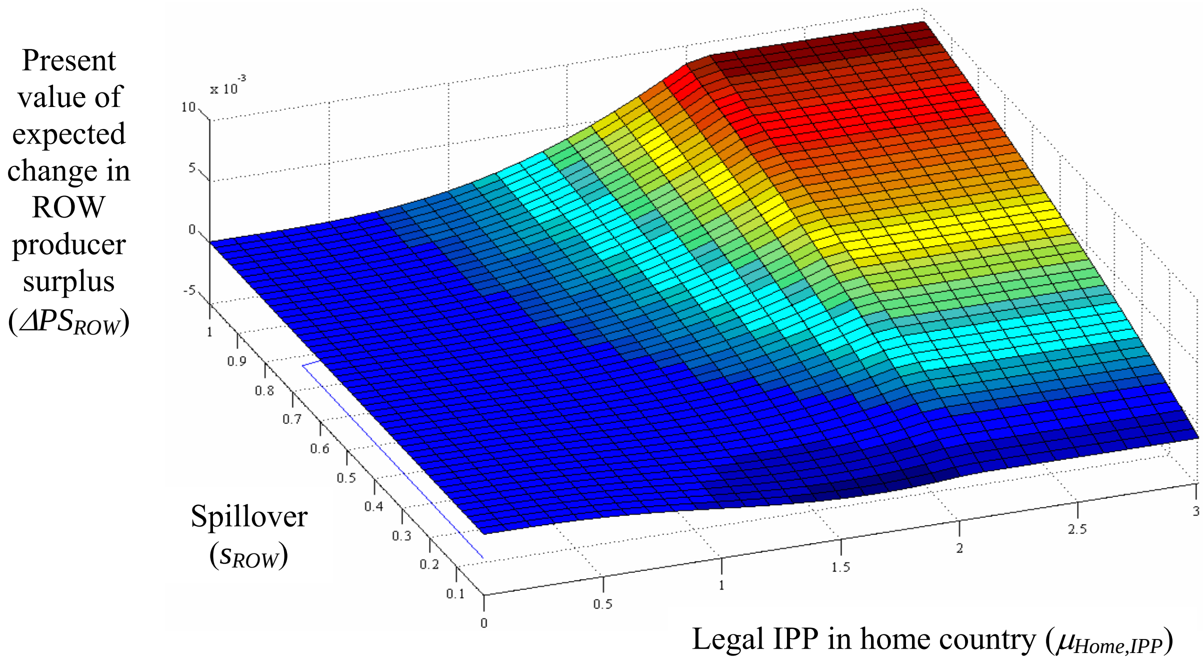


B. With public R&D (*B* = 1)

Figure 5. Present value of expected change in home country producer surplus (ΔPS_{Home}) for elastic demand (ε = 1.5), in the absence of legal IPP in ROW



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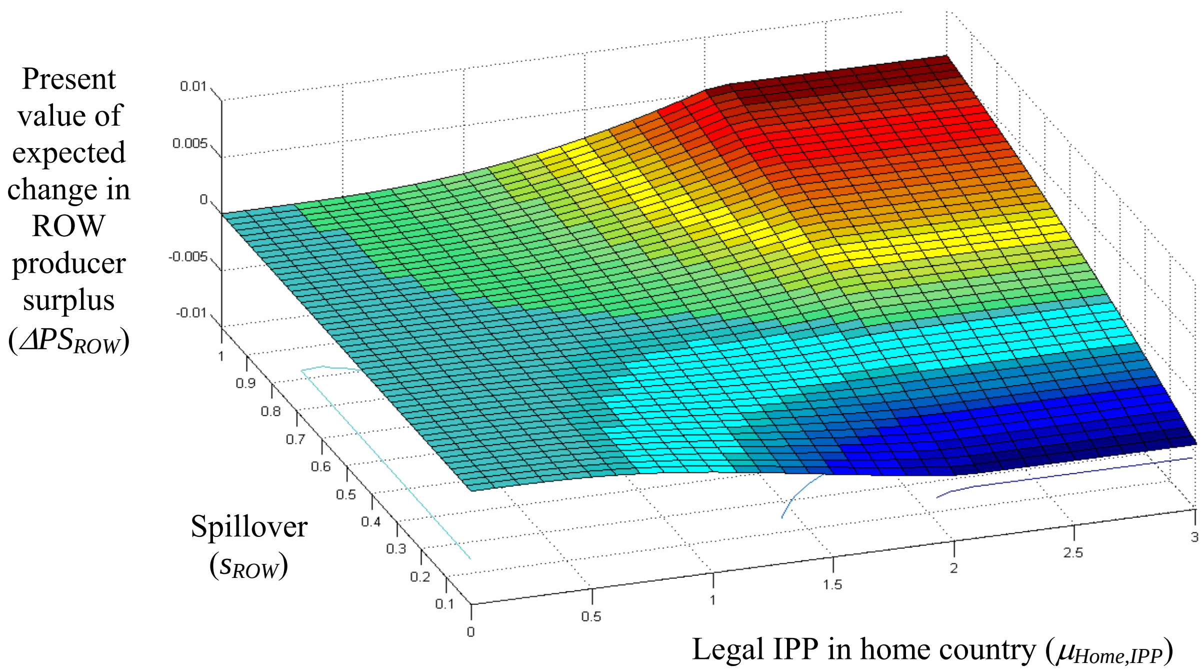
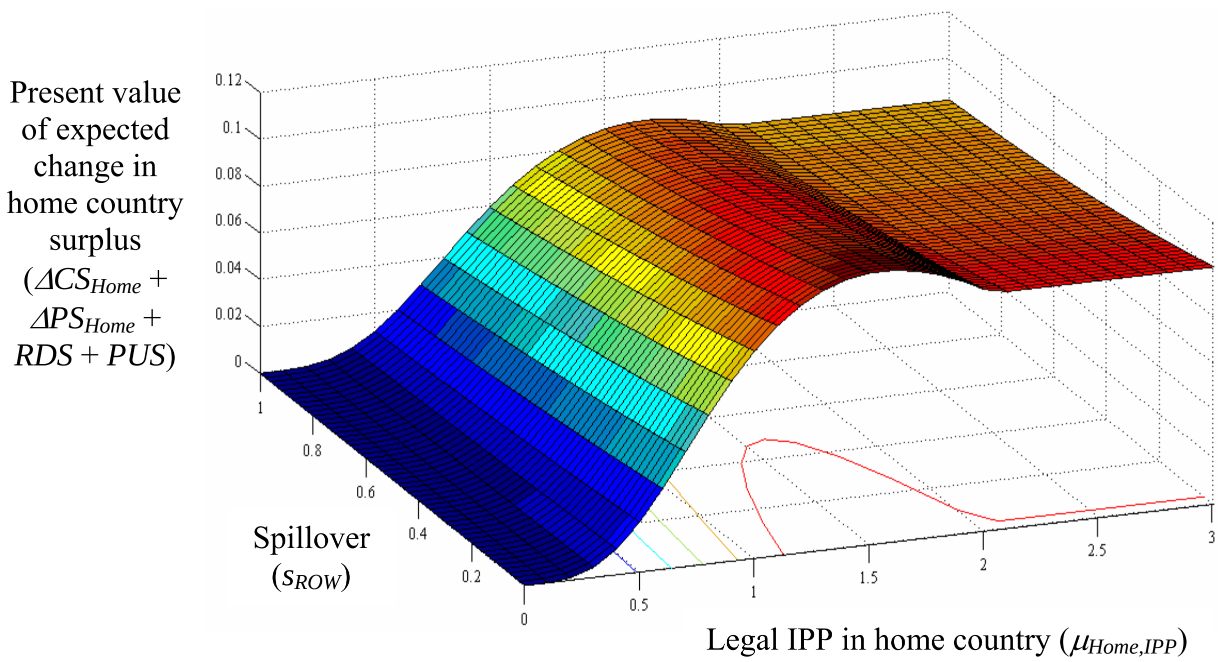


B. With public R&D (*B* = 1)

Figure 6. Present value of expected change in ROW producer surplus (ΔPS_{ROW}) for elastic demand (ε = 1.5), in the absence of legal IPP in ROW



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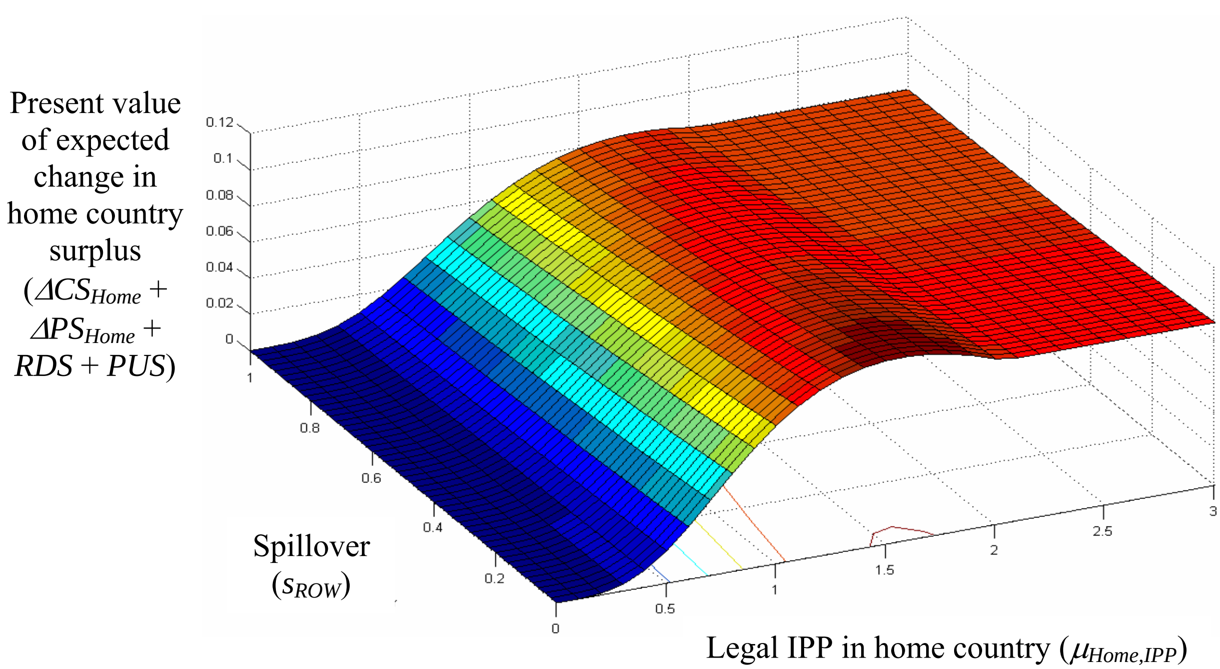
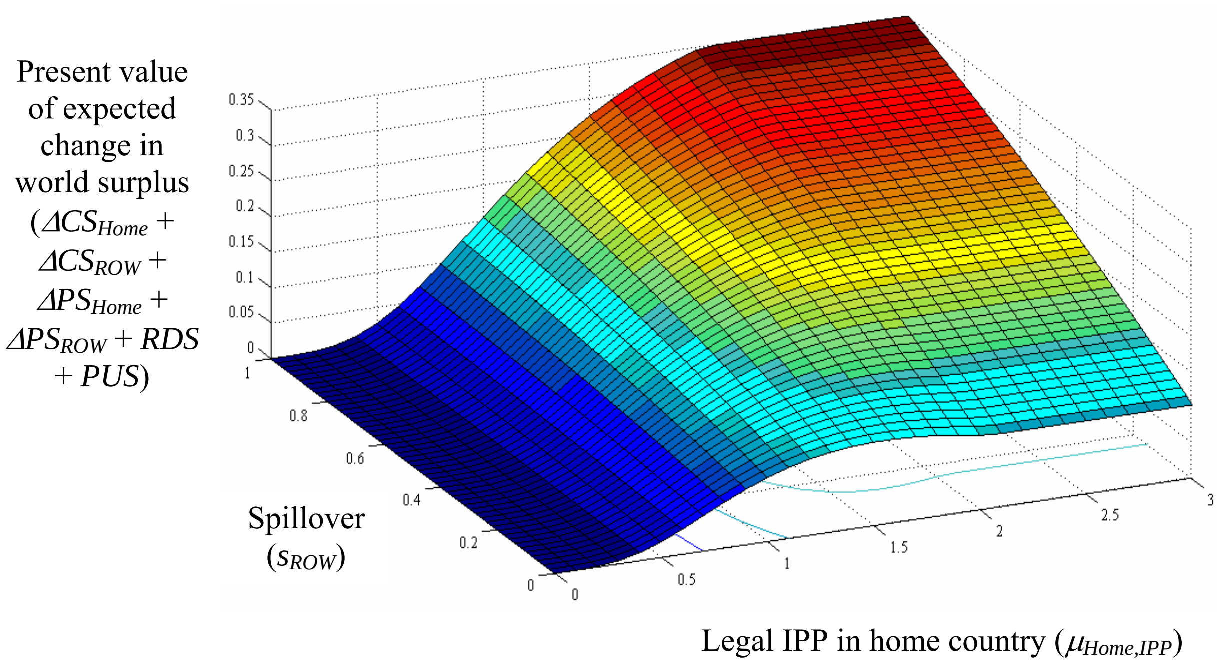


B. With public R&D (*B* = 1)

Figure 7. Present value of expected change in home country surplus (ΔCS_{Home} + ΔPS_{Home} + RDS + PUS) for inelastic demand (ε = 0.5), in the absence of legal IPP in ROW



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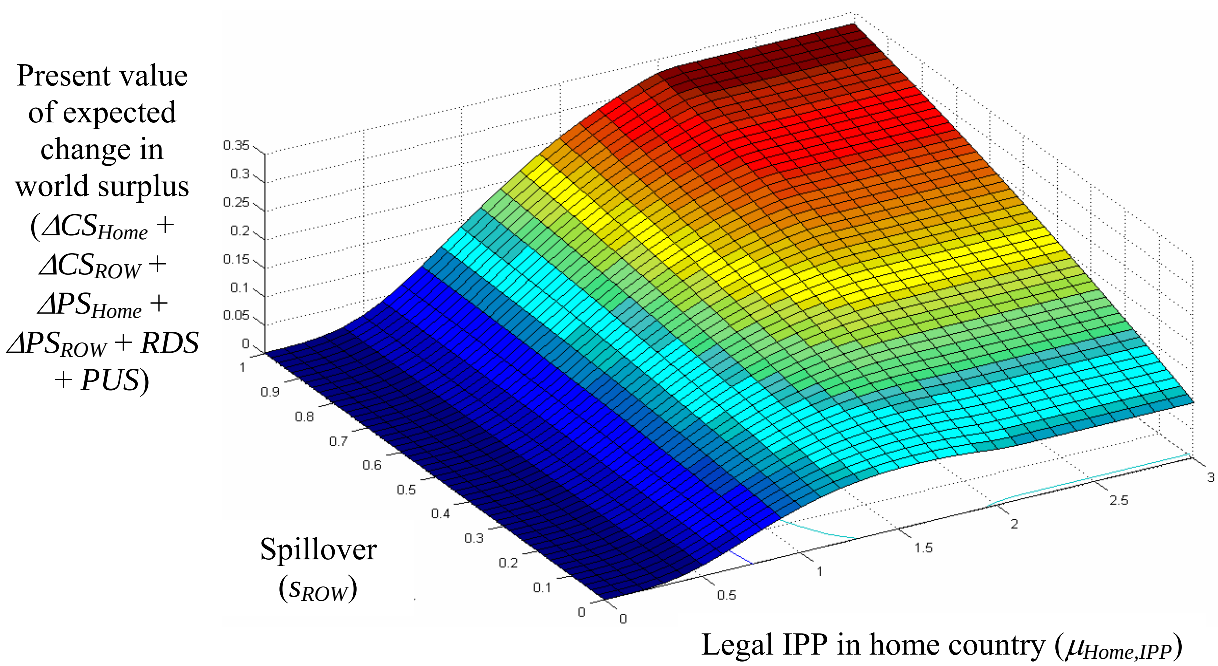
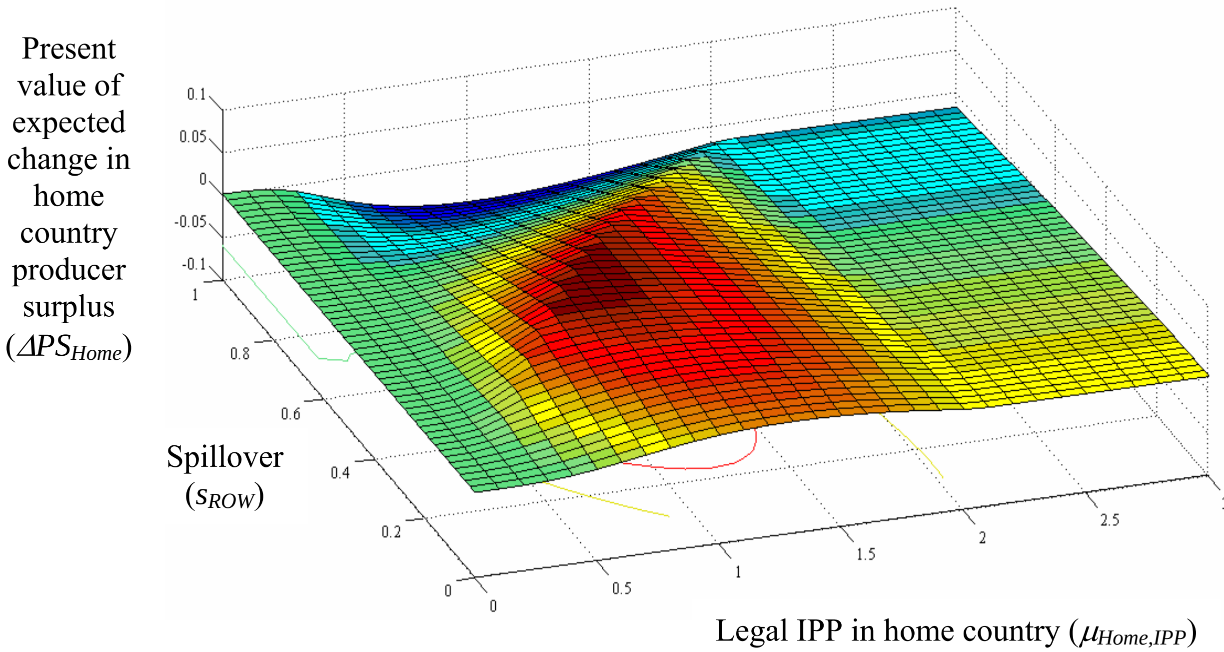
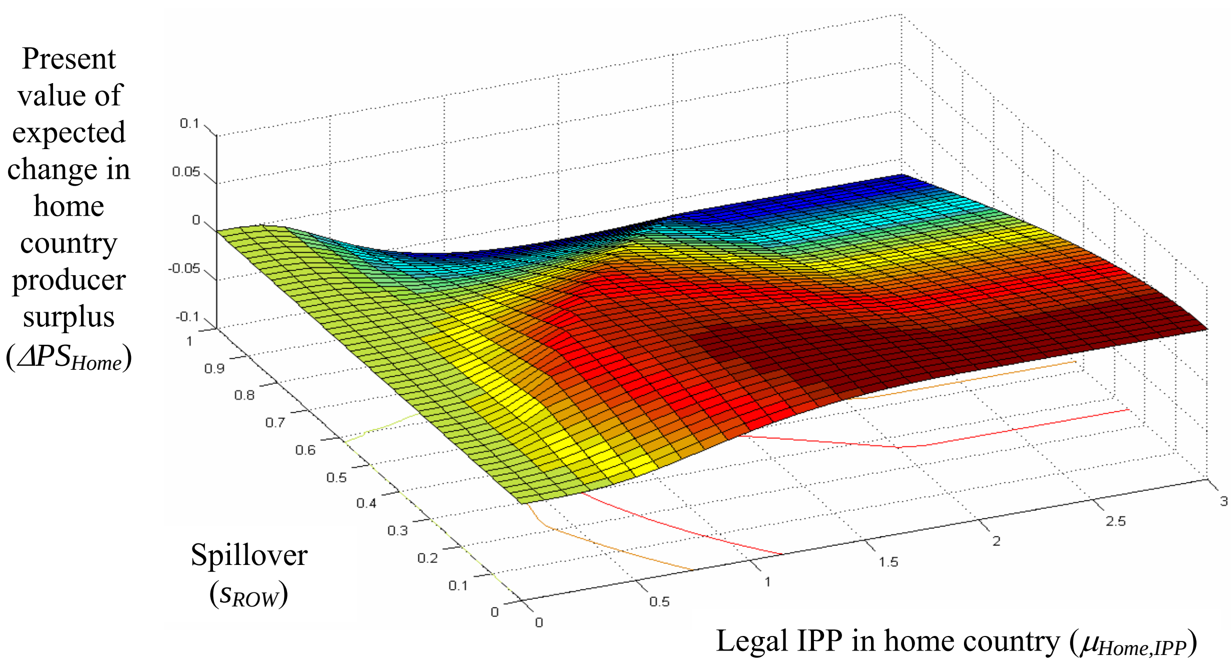


B. With public R&D (*B* = 1)

Figure 8. Present value of expected change in world surplus (ΔCS_{Home} + ΔCS_{ROW} + ΔPS_{Home} + ΔPS_{ROW} + RDS + PUS) for inelastic demand (ε = 0.5), in the absence of legal IPP in ROW

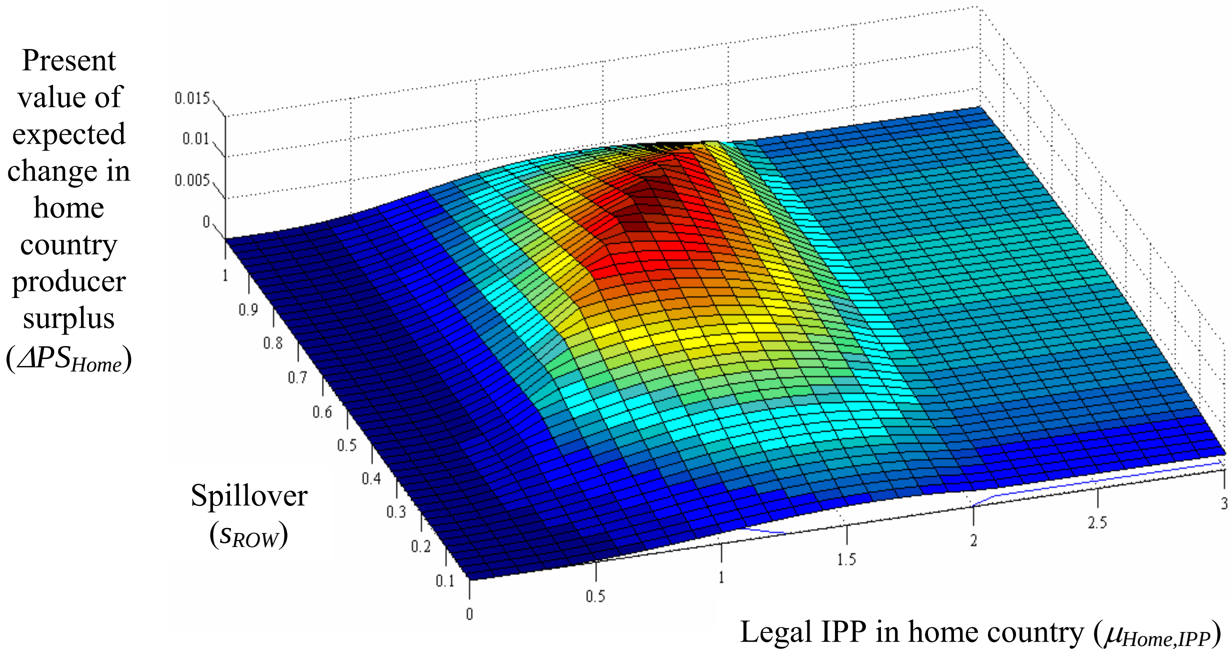


A. Without public R&D (B = 0)

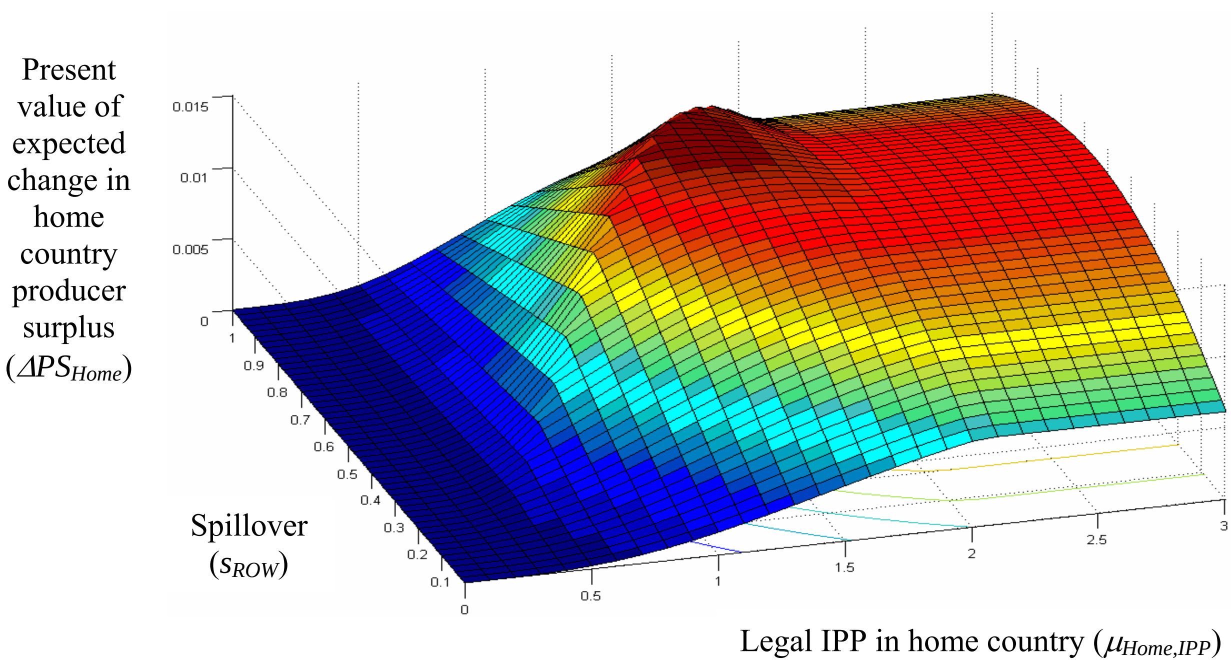


B. With public R&D (B = 1)

Figure 9. Present value of expected change in home country producer surplus (ΔPS_{Home}) for inelastic demand (ε = 0.5), under harmonized legal IPP

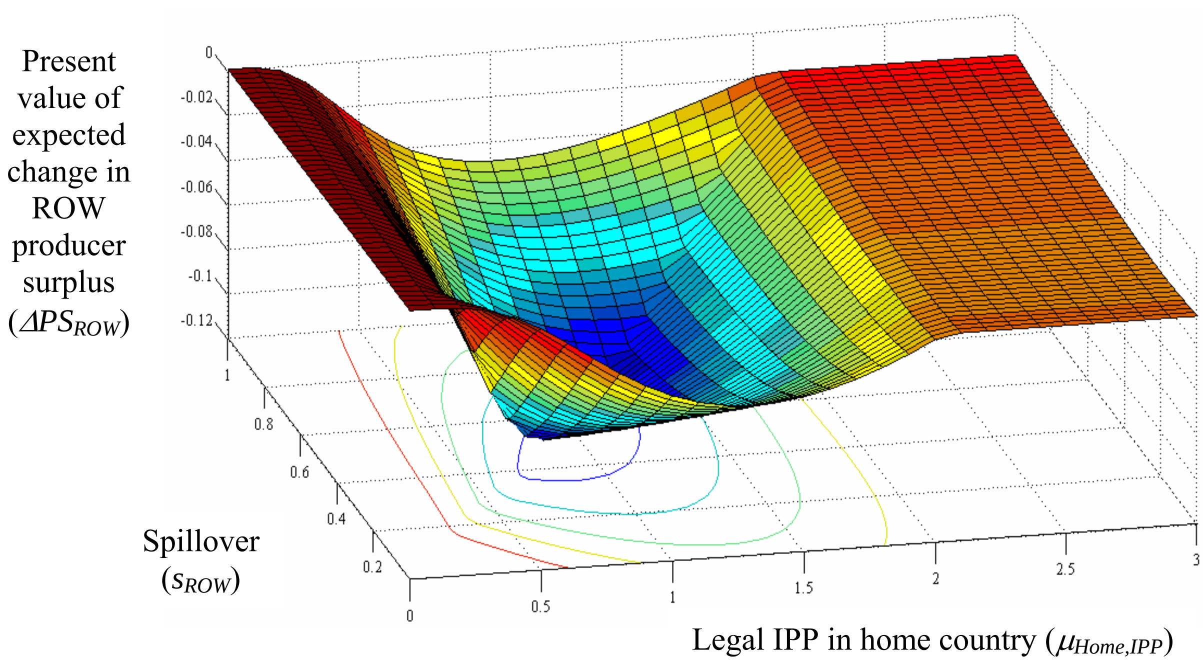


A. Without public R&D (B = 0)

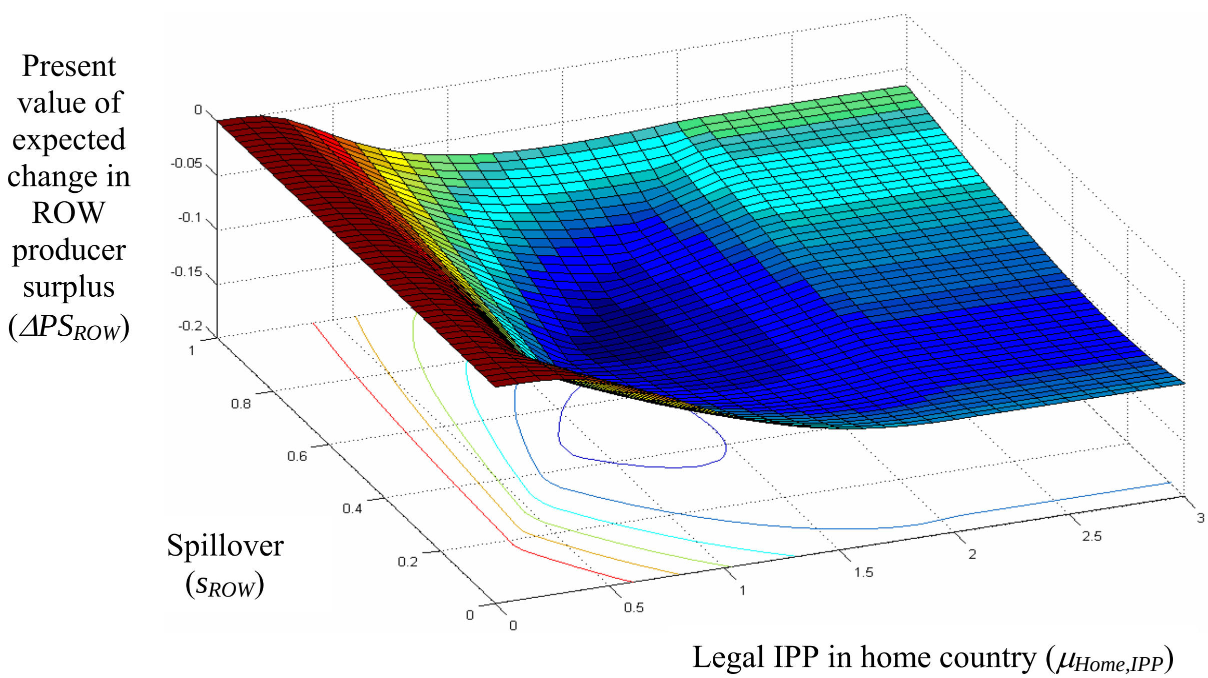


B. With public R&D (B = 1)

Figure 10. Present value of expected change in home country producer surplus (ΔPS_{Home}) for elastic demand (ε = 1.5), under harmonized legal IPP

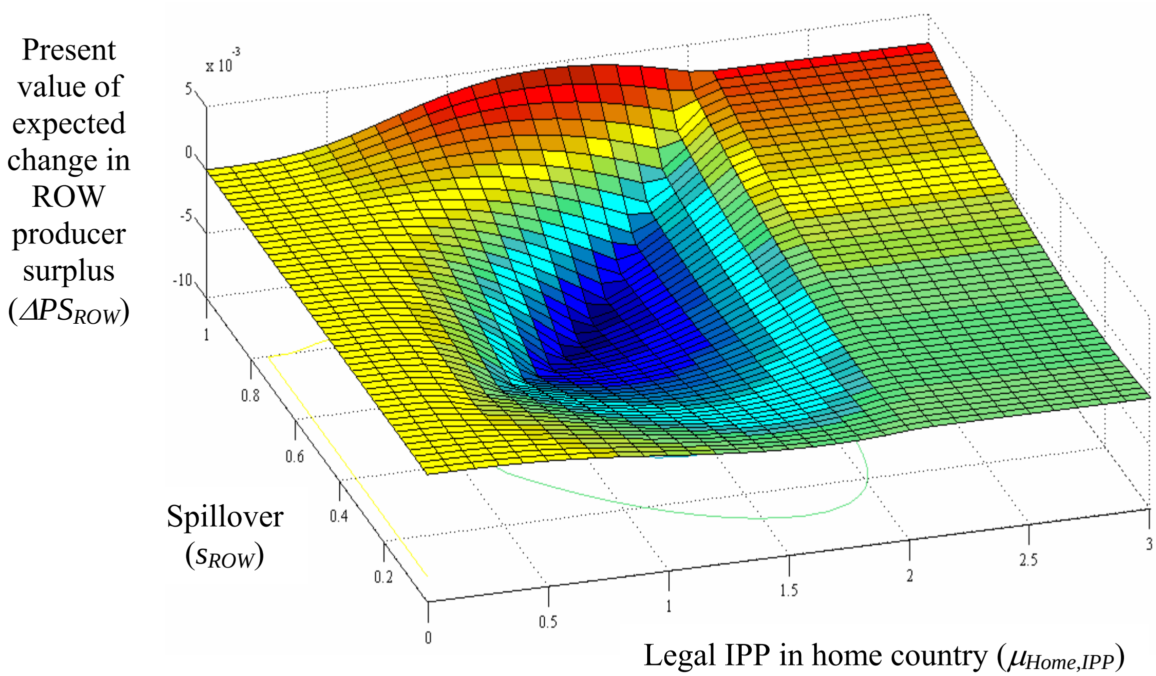


A. Without public R&D (B = 0)

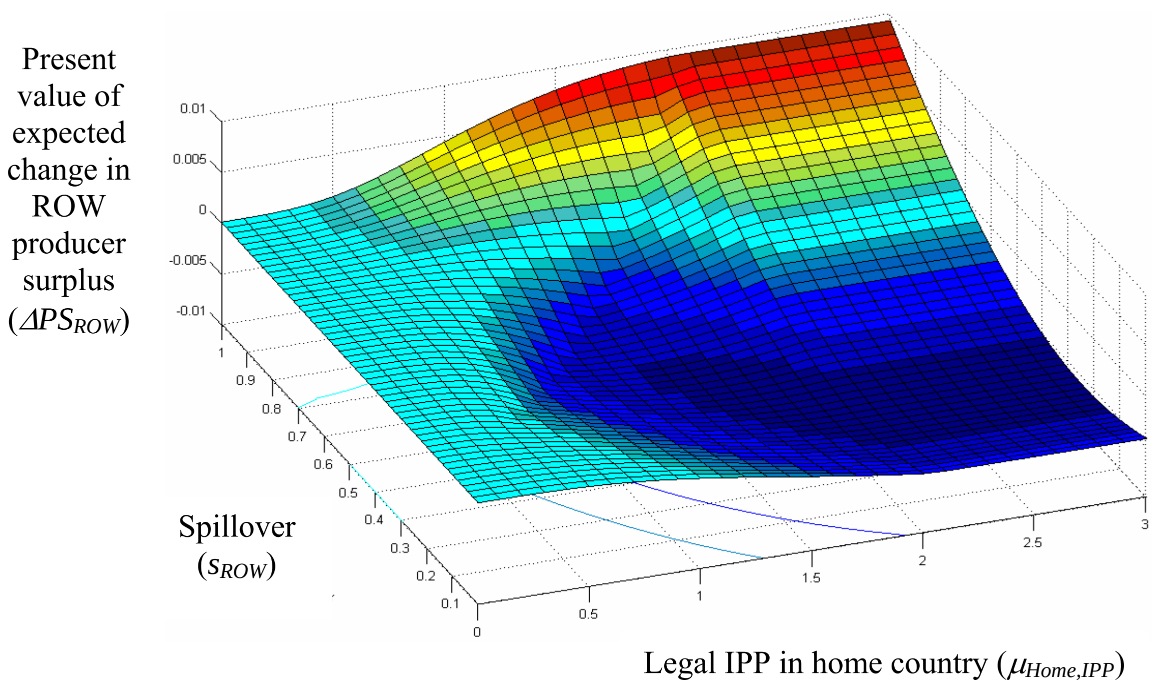


B. With public R&D (B = 1)

Figure 11. Present value of expected change in ROW producer surplus (ΔPS_{ROW}) for inelastic demand (ε = 0.5), under harmonized legal IPP

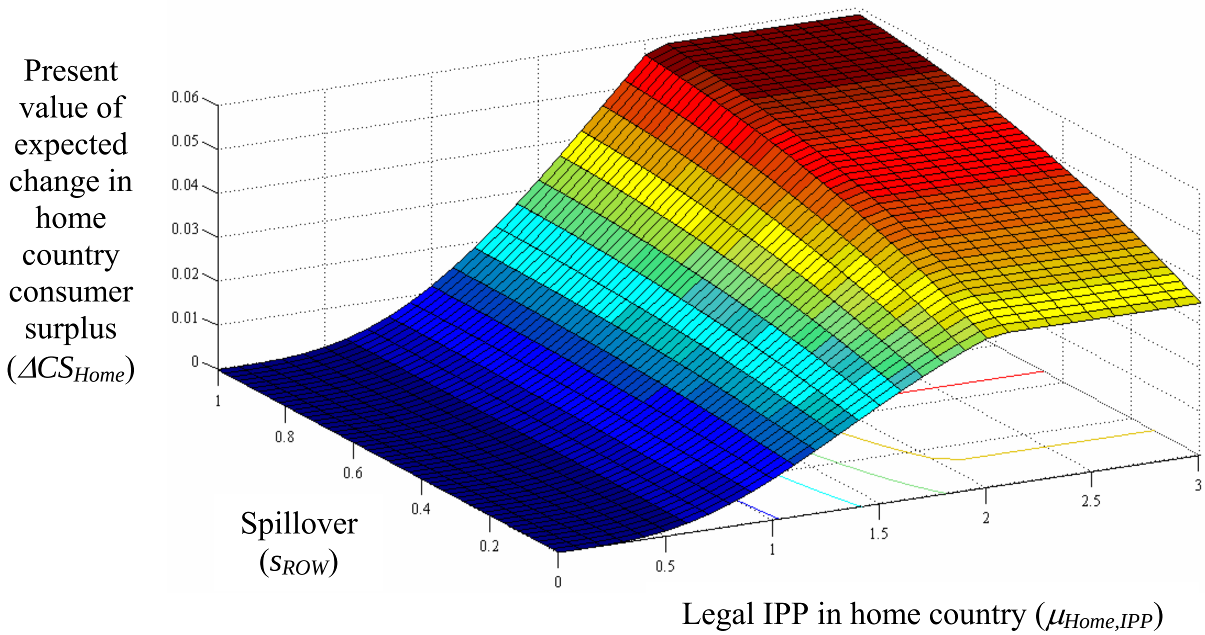


A. Without public R&D (B = 0)

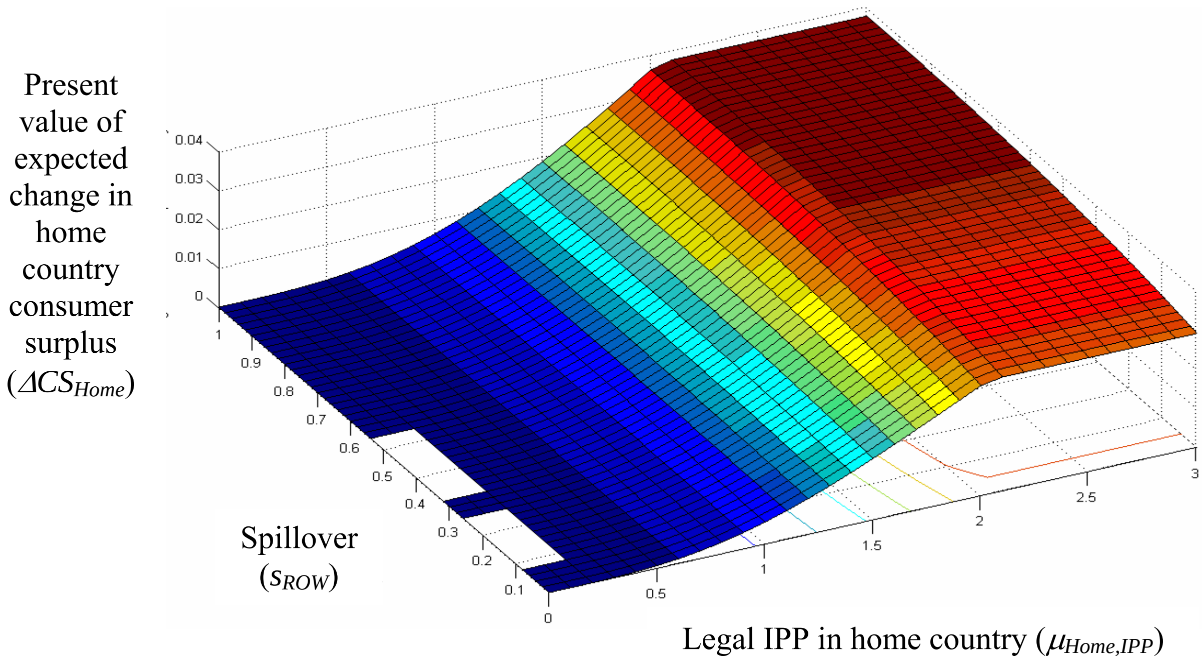


B. With public R&D (B = 1)

Figure 12. Present value of expected change in ROW producer surplus (ΔPS_{ROW}) for elastic demand (ε = 1.5), under harmonized legal IPP

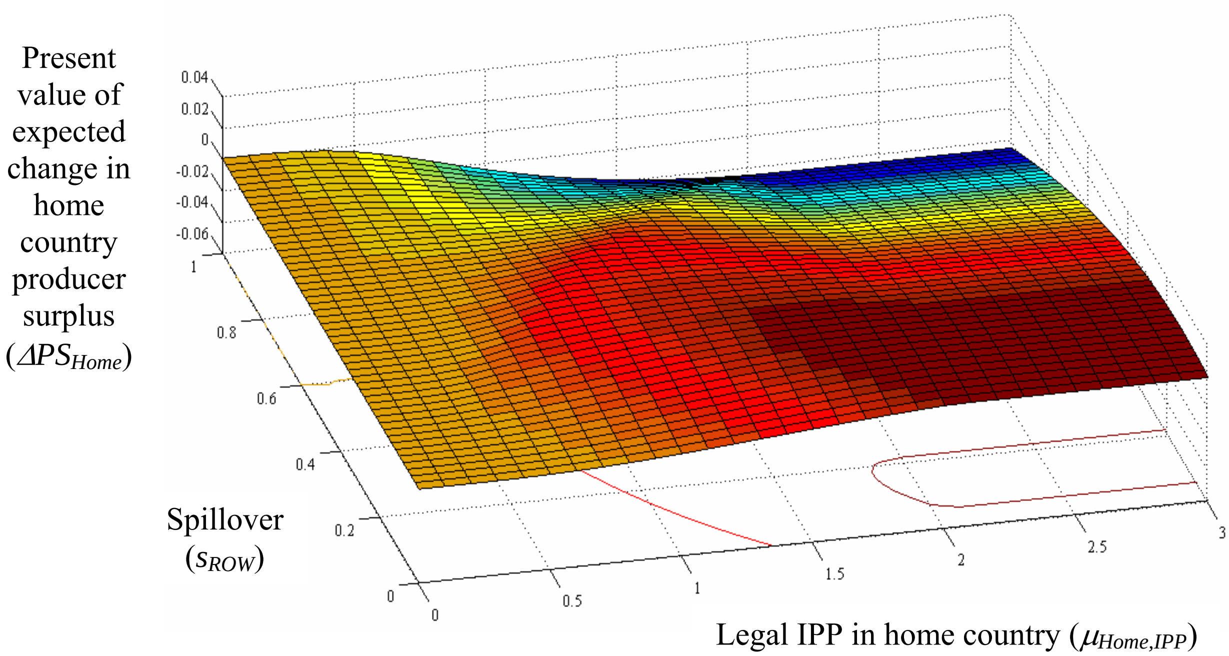


A. Without public R&D (B = 0)

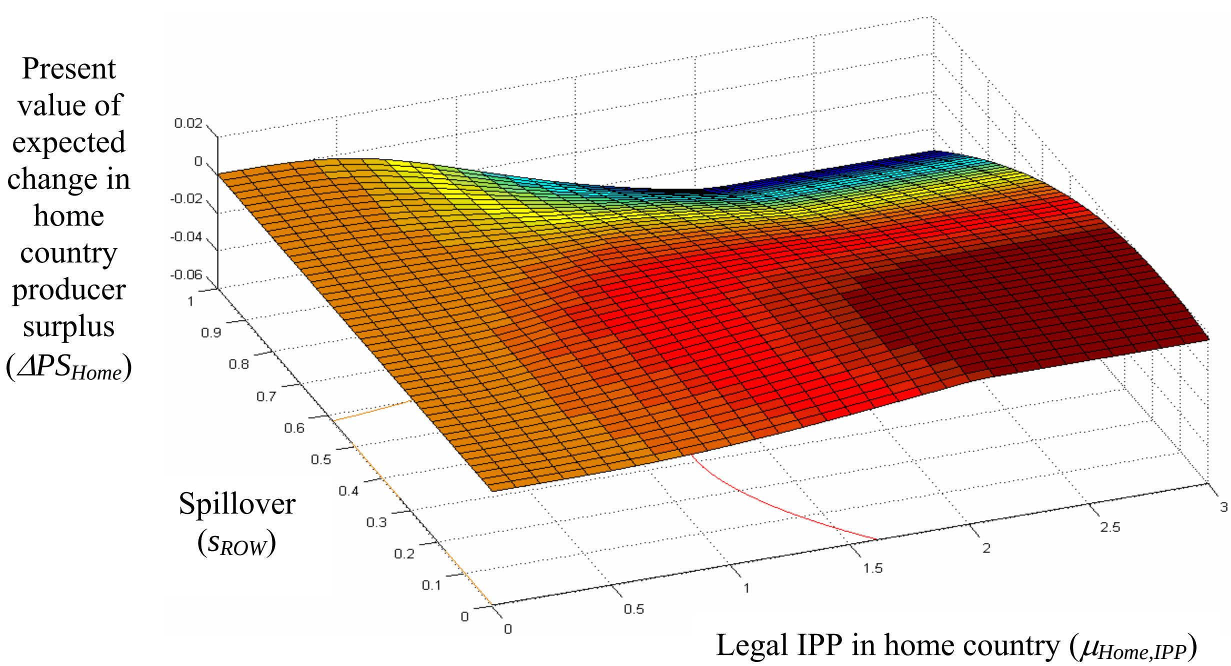


B. With public R&D (B = 1)

Figure 13. Present value of expected change in home country consumer surplus (ΔCS_{Home}) for inelastic demand (ε = 0.5) and $T_{q,obsol}$ = 6 years, in the absence of legal IPP in ROW



A. Without public R&D (B = 0)



B. With public R&D (B = 1)

Figure 14. Present value of expected change in home country producer surplus (ΔPS_{Home}) for inelastic demand (ε = 0.5) and $T_{q,obsol}$ = 6 years, under harmonized legal IPP

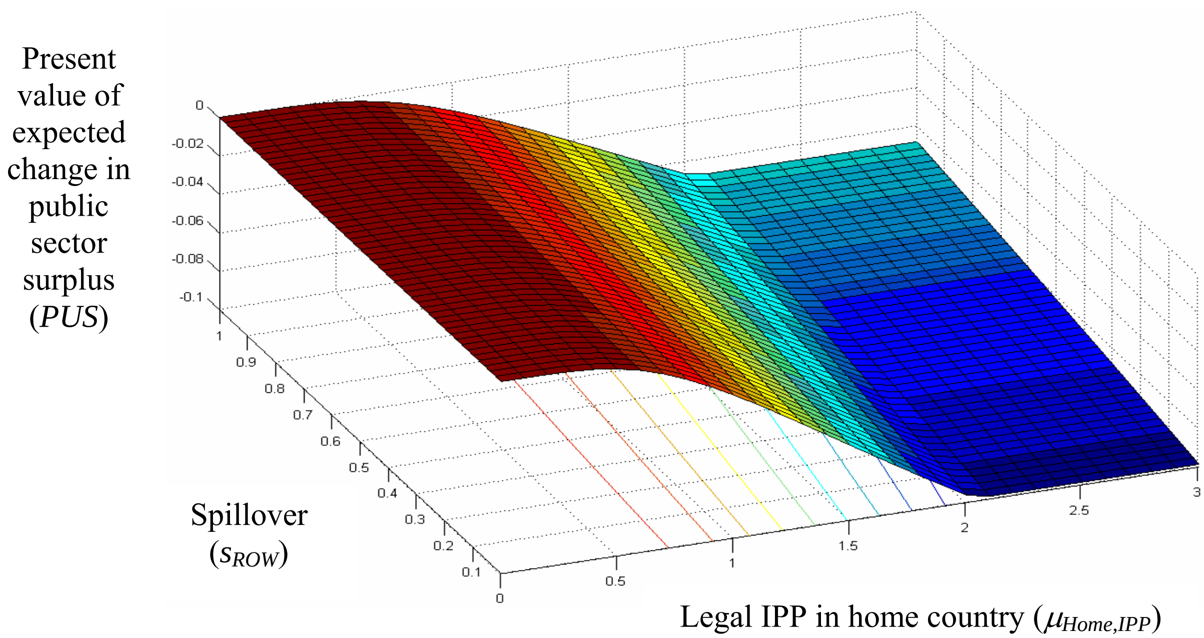


Figure 15. Present value of expected change in public sector surplus (*PUS*) for *B* = 1, inelastic demand (ε = 0.5), in the absence of legal IPP in ROW

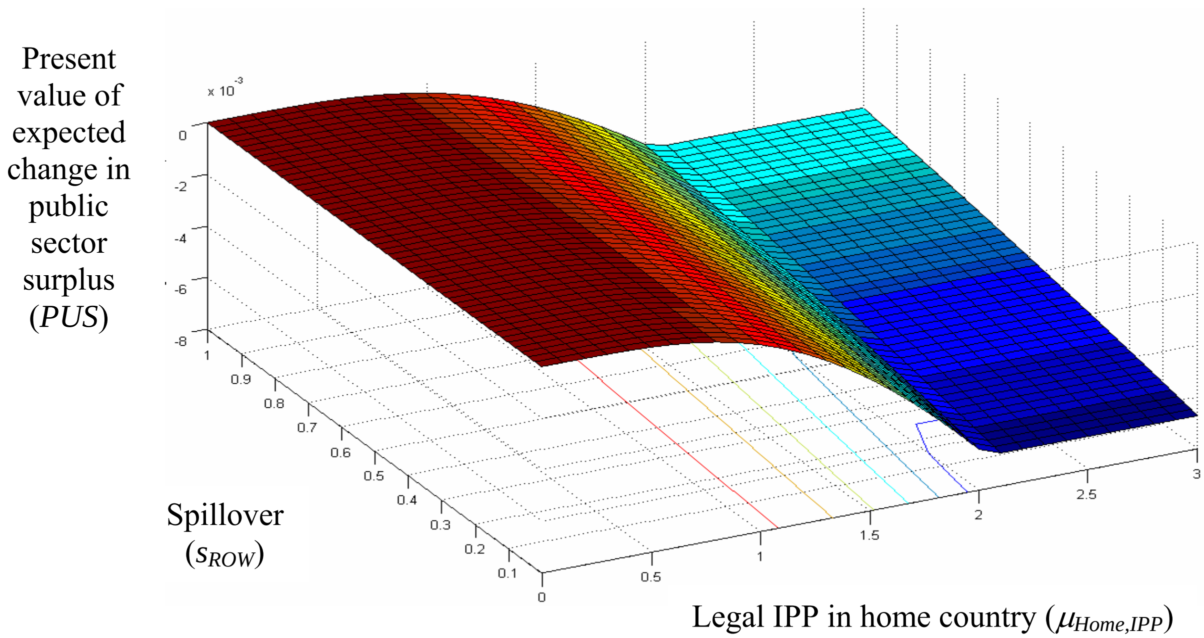


Figure 16. Present value of expected change in public sector surplus (*PUS*) for *B* = 1, elastic demand (ε = 1.5), in the absence of legal IPP in ROW

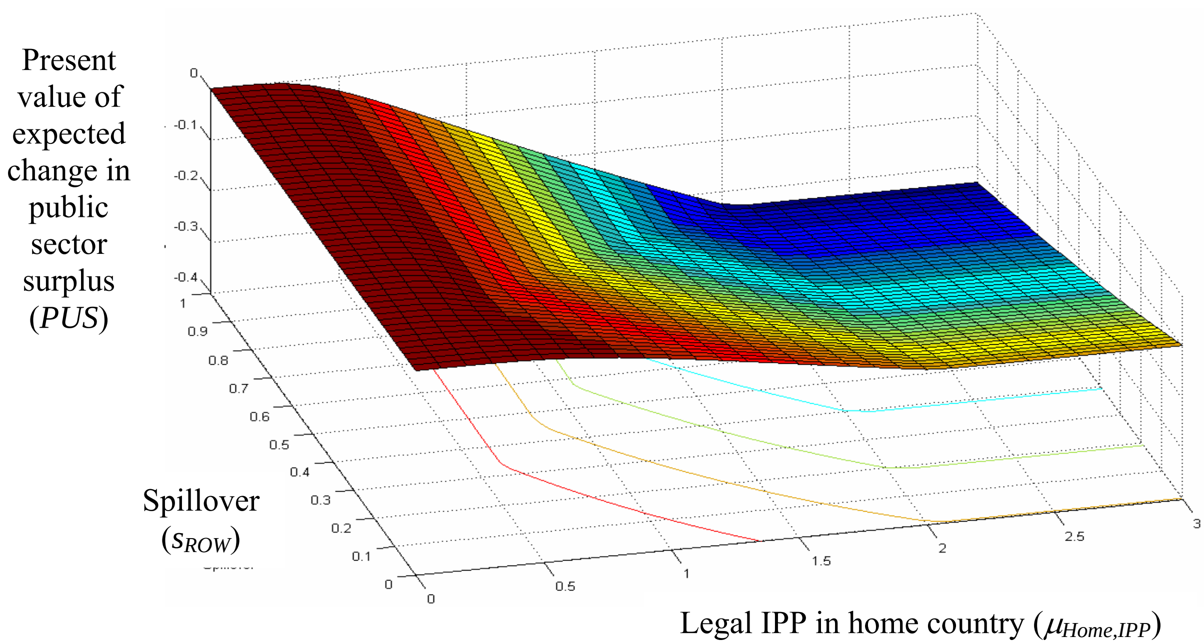


Figure 17. Present value of expected change in public sector surplus (*PUS*) for *B* = 1, inelastic demand (ε = 0.5), under harmonized legal IPP

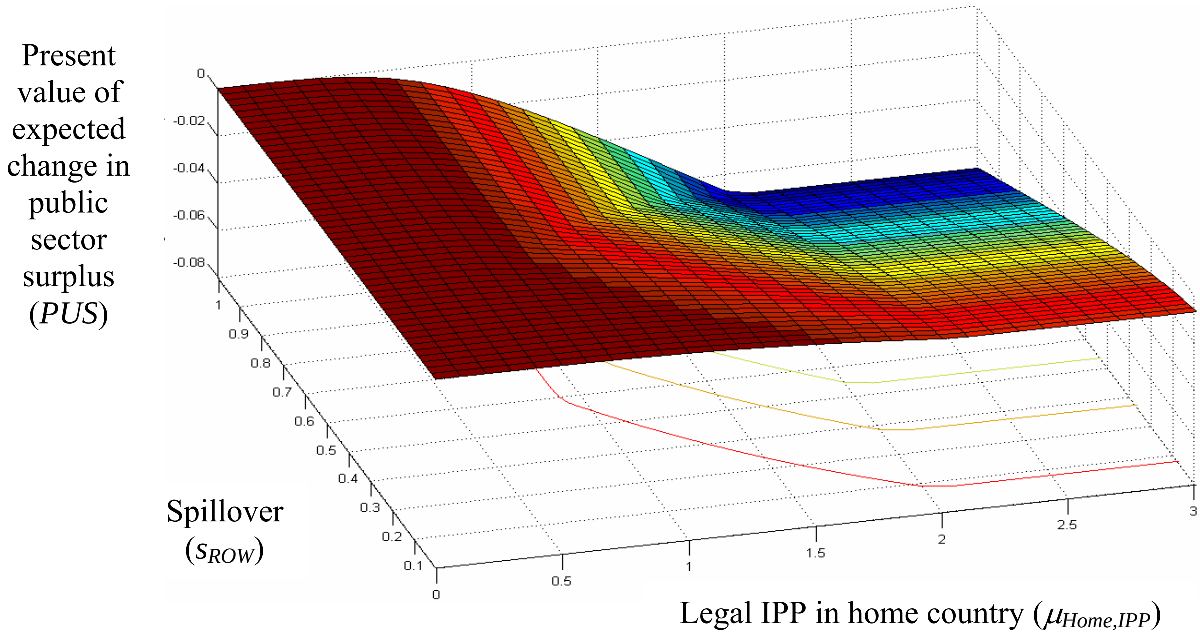


Figure 18. Present value of expected change in public sector surplus (*PUS*) for *B* = 1, elastic demand (ε = 1.5), under harmonized legal IPP