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Monopolistic pricing power for transgenic crops when technology adopters face irreversible benefits and costs

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Pricing of biotechnology innovation under a patent grant is reconsidered in a model with uncertain returns and irreversible costs and benefits. Past results on restricted monopoly pricing in the presence of competing technologies showed that pricing power is reduced. The timing of adoption of an innovation is delayed and the pricing power of the restricted monopolist is further reduced when uncertainty and irreversibility is considered. The presence of irreversible benefits results in increased willingness-to-pay for the innovation, accelerating adoption, and increasing the innovator's restricted monopolist pricing power. Using Monte-Carlo simulation, the quantitative effects were approximated by a linear function through the hyper-plane.

I. INTRODUCTION

When innovations in agriculture biotechnology offer enhanced returns to users, and where use can be restricted through intellectual property rights (IPR) such as patents, a return to the innovation can be claimed and used to finance RandD. The feasibility of this approach to financing RandD depends on the IPR establishing monopolistic pricing power for the technology developer. Under perfect monopoly, the innovator will price the technology where marginal costs equal marginal revenue. This type of model has been applied to the welfare analysis of agriculture biotechnology (e.g. see Falck-Zapeda *et al*., 2000 or Demont *et al*., 2002). Weaver and Kim (2002) reconsidered pricing power under a monopoly that is restricted by the presence of alternative technologies, showing that this implies a threshold price that restricts the range of pricing under the monopoly grant of a patent. The threshold price is shown to be defined by the characteristics of the alternative technology, as well as by their farm specific implications that define its value. This implies optimal pricing under restricted monopoly is not uniform, but instead would be a contract-based pricing scheme where price is nonlinear in the incentives of the patented and the alternative technology. Weaver and Wesseler (2003) (WandW) have extended the model by considering *ex-ante* uncertainty and irreversibility of the technology adopter and the implications for monopolistic pricing.

Within this contribution the model of WandW is further elaborated and the relevance of irreversible costs and

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benefits for exercising pricing power are stressed. This is done by using Monte-Carlo simulation and a linear approximation of the results. The contribution unfolds as follows, first, WandW's model is briefly reviewed. Based on this framework the study evaluates pricing and adoption implications of the evolution of incentives, irreversible costs and benefits, as well as of the returns to the innovation by using Monte-Carlo simulation.

II. FRAMEWORK FOR TRANSGENIC INNOVATION PRICING

To briefly summarize the WandW framework, suppose the innovator is also the supplier of the seed. The private returns to a seed-based innovation follow directly from revenue from the sale of the seed. The price the supplier of the seed can charge will depend on alternative choices of the technology adopter. Choice of technology results in a value function indicating the maximum value per land area unit for each crop, which is farm specific. Following this, the *relative willingness-to-pay* of farmer j for technology i for crop c versus the second best alternative is defined as:

$$\omega_{jc}^{i} \equiv V_{jc}^{i} - V_{jc'}^{i'} > 0 \quad \forall\, [i, c] \neq [i', c'],\ c \in C,\ i \in I \tag{1}$$

where the value functions are continuous in their incentive vectors including, variable and quasi-fixed input factors, output quantities and input and output prices. Equation 1 can be viewed as a measure of the monopoly pricing power and implies that power is restricted by the presence of alternative technologies and crops.

This deterministic theory is extended to incorporate the case where costs and benefits associated with the technology may be both irreversible and uncertain. Two salient features of transgenic seed involve irreversibility and uncertainty (Morel *et al*., 2003; Wesseler, 2003). First, transgenic seed innovations include an array of changes in production practices involving both changes in the efficient levels of variable inputs, as well as changes in quasi-fixed inputs and possible irreversible external changes. Thus, implementation of the technology selection involves investments that can be assumed to be irreversible. With respect to irreversible external effects of the adoption decision, consider the case of herbicide tolerant soybeans. In this case, changes in field practices, pesticide use and pest management practices can be expected, see Carpenter (2001) and Carpentier and Weaver (1997). These changes follow from irreversible investments in know-how, management practices, and related equipment. Both benefits and costs may incorporate private, or internal, changes such as farm operator health and public, or external, components such as impacts on soil structure and ecology or biodiversity. In addition to the internal irreversible effects due to changes in pesticide use, internal irreversible costs may be necessary to incur due to changes required in the composition of quasi-fixed inputs. For example, herbicide tolerant soybeans allow no-till (zero tillage) planting and a higher planting density, implying different soybean planting machinery may be optimal (Lambert and Lowenberg-DeBoer, 2003). The second salient feature follows directly, namely, the investment or adoption decision results in changes in uncertain returns that span future time periods. As noted by W and K, the uncertain stream of returns involves both private pecuniary and public types of returns. The uncertainty characterizing the decision goes beyond the stochastic nature of production. Given the multiple period return stream associated with adoption, the choice is made in a context of uncertain future input and output prices, as well as input availability. In sum, these sources of uncertainty affect the net benefit stream that can be expected from the irreversible investments that constitute the act of adoption.

The relative willingness-to-pay introduced in Section II allowed for uncertainty by including a stochastic shock for crop output. However, in the setting of transgenic crop adoption, managers also face stochastic prices and input quantities. The harvest price for soybeans and fertilizers, pesticides, fuel and other farm inputs are not known with certainty at the date of adoption. Importantly, when a technology is not universally dominant, strategic response by vendors of an entire, or components of, competing technology can be expected to result in price reductions. The timing and magnitude of these competitive responses are uncertain for the farmer.

Given these conditions, the timing of the act of adoption becomes an important control variable for the farmer. Irreversible investment requirements, uncertain pay-offs, and the option to adopt (flexibility) directly affect the willingness-to-pay for the new technology. The agent is viewed as recognizing that information will change over time, and as having priors concerning the nature of those changes in the net present value and irreversibly cost and benefit streams. The real options approach supposes that an investor has the opportunity to buy (go long) a call option, valued at F. This option provides the right, but not the obligation, to adopt transgenic crops. The value of this call option for adoption of a technology i by incurring irreversible costs, I, and benefits, R, for crop c by farmer j can be written in general form as:

$$F = F(\Omega, I, R, t) \geqslant 0. \tag{2}$$

where the value of the option depends on (a) the *relative discounted* willingness-to-pay for the new technology i for crop c defined as:[1]

$$\Omega_{j,t} = \int_{t=1}^{t=\infty} \omega_{jc}^{i} e^{\alpha t} e^{-\mu t} dt = \frac{\omega_{jc}^{i}}{\mu_{\omega'_{jc}} - \alpha_{\omega'_{jc}}},^{2} \tag{3}$$

where $\alpha_{\omega_{jc}^{i}}$ is the expected growth rate of the relative willingness-to-pay ω_{jc}^{i} and $\mu_{\omega_{jc}^{i}}$ interpretable as the risk adjusted annual return derived from the Capital Asset Pricing Model (CAPM), (b) the irreversible costs, I and (c) the irreversible benefits, R. As Equation 3 indicates, the model is autonomous implying the time variable can be dropped as a dependent variable.

The dynamic characteristics of Ω, I, and R are defined next. $\alpha_{\Omega} \equiv \alpha_{\omega_{jc}^{i}}$ are also defined and it is assumed that Ω, I, and R, follow uncorrelated geometric Brownian motion processes:

$$\begin{aligned} d\Omega &= \alpha_{\Omega} \Omega dz \\ dIR &= \alpha_{I} IR + \sigma_{I} Irdz \end{aligned} \tag{4}$$

The geometric Brownian motion is a nonstationary, continuous-time stochastic process in which α_i is a constant drift rate, σ_i is the constant variance rate, and dz is the Wiener process, with $E(dz) = 0$ and $E(dz)^2 = dt$. The geometric Brownian motion is the limit of a random walk (Cox and Miller, 1965), hence it is consistent with the assumption of log-normality of the stochastic variable with zero drift. The expected value of this process grows at the rate α. A constant positive growth rate assumes that the willingness-to-pay grows continuously over time, that is, the innovation becomes increasingly attractive for adoption. This does not exclude the possibility that in any future period, $V_{jc}^{i'}(\rho_{jc}^{i'}) > V_{jc}^{i}(\rho_{jc}^{i})$. The implicit assumption made is that technology adopters can switch between the two technologies without bearing any additional costs. Solving this model using the approach by McDonald and Siegel (1986) and as explained in more detail in WandW provides the following result:

$$\left(\frac{\omega}{IR}\right)^{*} = \frac{\beta_1}{\beta_1 - 1}(\mu_{\Omega} - \alpha_{\Omega}) \tag{5}$$

where ω represents the willingness-to-pay as defined in Equation 1, IR the net irreversible costs, μ the discount rate defined as the risk-adjusted rate-of-return, α_{Ω} the drift rate of the stochastic process of ω and

$$\beta_1 = \frac{1}{2} - \frac{\delta_{IR} - \delta_{\Omega}}{\sigma_{\Omega}^2 + \sigma_{IR}^2} + \sqrt{\left(\frac{\delta_{IR} - \delta_{\Omega}}{\sigma_{\Omega}^2 + \sigma_{IR}^2} - \frac{1}{2}\right)^2 + \frac{2\delta_I}{\sigma_{\Omega}^2 + \sigma_{IR}^2}}.$$

III. INTERPRETATION OF THE ADOPTION RULE

Under uncertainty, irreversibility and flexibility, the ratio of annual benefits, ω, and net irreversible costs, (ω/IR), has to exceed $(\omega/IR)^{*} = (\beta_1/(\beta_1 - 1))(\mu_{\Omega} - \alpha_{\Omega})$ if the technology is to be adopted. For exogenously given IR, ω must be greater than ω^*, whereas in the deterministic case, $\omega > 0$, implies adoption. In the deterministic case, if $\omega(w) > 0$, pricing power exists. The seed price w can increase while adoption maintains until $\omega(w) = 0$. If net irreversible costs and uncertainty are considered,

$$\left(\frac{\omega}{IR}\right)^{*} \equiv \gamma \tag{6}$$

call γ the pricing barrier and by Equation 5

$$\gamma = \frac{\beta_1}{\beta_1 - 1}(\mu_{\Omega} - \alpha_{\Omega}) \tag{7}$$

For any exogenously given IR,

$$\omega^{*} \equiv \gamma \bar{I} \bar{R} \tag{8}$$

pricing power exists if:

$$\omega(\underline{w}) > \omega^{*} = \gamma \bar{I} \bar{R} \tag{9}$$

and, again, technology vendors can increase the seed price until $\omega(\underline{w}) = \omega^{*} = \gamma \bar{I} \bar{R}$.

An important second result is the effect of irreversible benefits. If there are no irreversible costs, yet irreversible benefits exist, then current period willingness-to-pay would be $\omega + R$, implying the pricing power of the technology supplier would increase. If there are irreversible costs, the impact of one unit of irreversible benefits is the ratio $\beta_1/(\beta_1 - 1) > 1$. Clearly, this case clarifies the interest of the technology vendor in promoting the magnitude of R, while downplaying the existence of I. This strategy clearly increases the pricing power. Again, an important example is the case of soybeans, where adoption of zero tillage systems increased with the introduction of herbicide tolerant soybeans providing environmental benefits of reduced

[1] The relative willingness to pay includes changes in the value of the alternative technology induced by strategic responses of vendors of those technologies or their components, e.g. price changes for pesticides for non-transgenic crops. In general, recall ω_{jc}^{i} is defined relative to the next best technology as in Equation 7.

[2] The motivation for choosing the risk-adjusted rate of return is that the risk of the additional benefits could be tracked with a dynamic portfolio of market assets. $\mu_{\omega_{jc}^{i}} = r + \phi\sigma\rho(\omega_{jc}^{i}, m)$, where r is the risk-free rate of return, ϕ the market price per unit of risk, σ the variance parameter, and $\rho(\omega_{jc}^{i}, m)$ the coefficient of correlation between the asset or portfolio of assets that track ω_{jc}^{i} and the whole market portfolio.

soil erosion, pesticide and fuels use (Fawcett and Towery, 2003). An adoption of zero tillage requires a change in land management practices including farm equipment (Lambert and Lowenberg-DeBoer, 2003).

IV. QUANTITATIVE RELEVANCE OF THE IRREVERSIBILITY EFFECT

The pricing power of the monopolistic technology provider depends on the parameter values defining β. The effects of parameter changes on pricing power are analysed by using Monte-Carlo simulation for selected parameter ranges. The ranges for parameter values are shown in Table 1. For all parameters a rectangular distribution was assumed.

Parameter combinations violating model assumptions were deleted from the sample. A linear function approximating the hyper-plane was estimated. The results of the linear approximation are provided in Table 2. As the goodness-of-fit with 97.8% is already very high, results including second order effects are not reported. The negative coefficients on the two drift rates indicate the positive impact of an increase in future annual benefits or net irreversible costs on pricing power.

Calculating the drift rate elasticity of the pricing power at the mean, reported in Table 3, provides a value of about −0.039. A 1% increase in the drift rate reduces the pricing barrier γ by about 0.039% and increases the pricing power of the monopolist. An increase in future uncertainty and in the discount rate increases the pricing barrier γ. The variance rate elasticity of the pricing power at the mean provides a value of about 0.46 and the discount rate elasticity of the pricing power at the mean provides a value of about 0.51. A change in the discount rate or the variance rate has about a ten times stronger impact on pricing power than a change in the drift rate.

V. CONCLUSIONS

Many technologies provide irreversible benefits, e.g. reduced erosion and pesticide and fuel use. If the adopter of the technology considers those social benefits in his private decision making as well, his willingness-to-pay for the technology increases, increasing the pricing power of the technology provider. Irreversible costs of adopting the new technology, e.g. change in farm equipment, reduce the willingness-to-pay for the technology. The importance of irreversible benefits is greater in the case where irreversible costs are present. This together provides an economic argument that explains why technology providers emphasize the irreversible environmental benefits of their technology.

The pricing power of a technology provider decreases with an increase in the discount rate and future uncertainty. An increase in future benefits increases the pricing

Table 1. *Parameter ranges used for Monte-Carlo simulation*

α_{IR}	α_{Ω}	σ_{IR}	σ_{Ω}	μ
−0.05 to 0.08	−0.05 to 0.08	0.10 to 0.60	0.10 to 0.60	0.05 to 0.15

Table 3. *Elasticities of pricing power at the mean level using first order results*

	α_{Ω}	α_{IR}	σ_{Ω}	σ_{IR}	μ
Elasticities	−0.0386	−0.0387	0.4602	0.4610	0.5150

Table 2. *Linear approximation of the pricing power including first-order effects*

	Coefficient	Std. Error	t-statistic	Prob.
C(1)	−0.112646	0.000384	−293.0278	0.0000
C(2)	−0.759945	0.002033	−373.8811	0.0000
C(3)	−0.757656	0.002031	−373.1018	0.0000
C(4)	0.387532	0.000517	749.2061	0.0000
C(5)	0.386833	0.000517	747.7261	0.0000
C(6)	1.515313	0.002704	560.4844	0.0000
R-squared	0.978110	Mean dependent var		0.294230
Adjusted R-squared	0.978107	S.D. dependent var		0.097459
S.E. of regression	0.014420			
Sum squared resid	7.770318			
Log likelihood	105404.8			

Notes: Dependent Variable: γ
Method: Least Squares
Sample: 137 374
Included observations: 37 374
γ=C(1)+C(2)*α_{IR}+C(3)* α_{Ω}+C(4)* σ_{IR}+C(5)* σ_{Ω}+C(6)* μ

power. A linear approximation of the results from a Monte-Carlo simulation indicates a ten times stronger effect of a change in the variance rate and the discount rate than a change in the drift rate.

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