Potential Impacts of Pharmaceutical Uses of Transgenic Tobacco: The Case of Human Serum Albumin (HSA)[1]

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May 2004

1. Selected Paper # 118832 prepared for presentation at the Annual meeting of the American Agricultural Economics Association, Denver, Colorado, August 1-4, 2004. This paper was partially supported by USDA-CSREES Grant No. 2001-52100-11250, but does not necessarily reflect the views of that agency.

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Abstract

The potential size and distribution of benefits from transgenic tobacco as a source of human serum albumin are estimated using an economic surplus model with imperfect competition. The results demonstrate that new products from bio-pharming applications stand to generate significant social benefits.

Keywords: Pharmaceutical uses of tobacco, economic surplus, monopsony

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Transgenic plants and animals have received considerable attention over the last decade as potential production sources for pharmaceutical drugs. Hiatt et al. (1989) were the first to produce antibodies in plants; subsequent experiments demonstrated that transgenic plants and animals can synthesize (at the laboratory scale) many of the proteins that are used by the pharmaceutical industry to produce drugs[1]. With laboratory success, the focus has more recently shifted to safety/efficacy studies (with some proteins currently being tested in human clinical trials), and to developing industrial scale production methods. Although no protein derived from transgenic plants or animals is presently on the market, there are indications that drugs derived from transgenic systems will be available to consumers in the foreseeable future.

Molecular farming (or bio-pharming) is a term used to describe the use of genetically modified plants or animals as production systems for therapeutic proteins. One of the benefits that molecular farming offers is the potential cost advantage, compared to current drug production methods. In fact, some empirical studies have shown that transgenic plants can produce recombinant proteins (proteins produced in the cells of genetically modified organisms) 10-100 times cheaper than cell culture systems[2] (Misson and Curling, 2000: Kusnadi et al., 1997). Moreover, molecular farming with transgenic plants may hold certain advantages over protein production using transgenic animals: plants have a greater ability to produce complex

[1] The term drug here indicates the final product sold in the market, whereas protein refers to the material from which the drug is made.

[2] Cell culture systems refer to bacterial or mammalian cells genetically modified to express a desired protein. Examples are Chinese Hamster Ovary and Escherchica Coli.

proteins, and they do not serve as hosts for mammalian pathogens (reducing the risk of contamination) (Cramer et al, 1996). Across the range of potential transgenic plants, some have suggested that tobacco represents an ideal vehicle for molecular farming because it is not used in the feed or food chain, and it is not highly regulated by food laws.

The purpose of this paper is to assess the potential size and distribution of benefits from molecular farming with (patented) transgenic tobacco. The study examines the case of producing human serum albumin (HSA) out of transgenic tobacco, a protein with widespread use. An economic surplus model is employed that allows for market power associated with the developer holding patent rights. The first section of the paper introduces HSA, its uses, current production methods and market characteristics along with a short description of the HSA production method using transgenic tobacco. The model, including the effects of the patent holder's market power, is then presented in the second section. Data sources and modeling results are given in the third section. The last section summarizes the findings and discusses the implications for fostering the emergence of the bio-pharming industry.

HSA Production and Market Characteristics

HSA is primarily used for blood volume replacement in medical situations involving severe burns, surgeries, and shock, and is more effective in these scenarios than cheaper, more available (crystalloid and non-plasma colloid) substitutes. It is also used as a stabilizer in pharmaceutical products and as a coating for medical devices. HSA is the most abundant protein in blood plasma[3], with one liter of plasma containing about 60 percent HSA (approximately 25 grams HSA/liter plasma).

[3] Plasma is the portion of blood that remains after red and white cells are removed.

Although blood plasma represents the richest source of HSA, there are problems associated with the purity of HSA obtained from human donor blood, currently the most available source of blood plasma. Donated blood plasma can carry viruses like Human Immunodeficiency Virus (HIV), Hepatitis C Virus (HCV), Hepatitis A Virus (HAV), and variant Creutzfeldt-Jakob disease (vCJD). Such viruses must be removed during the process of HSA recovery from donated plasma and, although historically HSA has been a safe product, it is constantly subject to potential risks of contamination.

Recovering HSA from blood plasma requires a series of steps. The most important steps in achieving purity are taken during a process known as Cohn fractionation, which provides semi-purified fractions of plasma that contain HSA (Lin et al, 2000). HSA is not the only protein recovered during the fractionation process; a variety of other therapeutic proteins such as polyvalent intravenous immune globulin (IVIG), Factor IX, Factor XIII, IVIG, Hepatitis B IgG, Rabies IgG, and Thrombin are obtained as well.

Companies that carry out plasma fractionation process millions of liters of plasma per year and provide several plasma-derived therapeutic proteins to the market. Until the early 1990s HSA was the driver of the fractionation industry (with US companies providing nearly 40 percent of the world supply). Since then, IVIG demand has been dictating the fractionation process and capacity (Colgan et al., 2000). In 2002, the world market value of IVIG was more than $2 billion, while the market value of HSA was slightly more than $1.5 billion.

Equivalent blood plasma products using DNA technologies, with recombinant therapeutic proteins, offer several potential advantages over human donor plasma. Most notably, because they are expressed in bacteria or animal cells, recombinant proteins are (theoretically) 100 percent risk-free from the viral contaminants that human plasma derived products may contain.

But under current technologies production costs are higher (as recombinant proteins are now produced using cell cultures grown in large tanks called bioreactors that are very expensive to built and operate).Currently, some therapeutic recombinant proteins have made it into the market and are competing with their plasma-derived counterparts as safety attributes appear to compensate for higher production costs. For example, Factor VIII and Factor IX are proteins derived from blood plasma that are used to treat hemophilia. Recombinant forms of these proteins became widely available in the early 1990's (O'Mahony, 1999), and since then their market share has been increasing considerably.

Beyond purity/safety issues, consistence of supply is also an important issue in HSA production. The fractionation industry has not always been capable of providing an adequate HSA supply and shortages have been encountered, particularly when there are shortages of donated human blood plasma. To address this issue, pharmaceutical companies have developed some recombinant versions of HSA. Recombumin^{R} is a recombinant albumin produced and patented by Aventis (a US pharmaceutical company), which completed large pivotal phase I clinical trials of the protein successfully in 2002. Recombumin^{R} will be used as a stabilizing agent for pharmaceutical and biologic products (Chuang et al. 2002). Aventis has not, however, pursued a recombinant version of the blood replacement form of HSA, because the product is in its infancy, and the FDA approval process is long and requires a significant financial commitment.

GM HSA from Transgenic Tobacco

Shortcomings in therapeutic protein production from blood plasma have inspired the production of recombinant proteins. For recombinant HSA production, molecular farming using

transgenic tobacco appears to hold great promise. In particular, cost savings associated with the purification process from tobacco are a strong incentive for pursuing GM HSA[4] technologies. Moreover, GM HSA should be free from viral contaminants, and, adjusting the acreages of tobacco planted can control for fluctuations in HSA supply.

The processes that tobacco biomass have to go through in order to achieve purified HSA for commercial purposes are quite different from those used to process HSA from blood plasma. Transgenic tobacco is grown in fields and collected as fresh plant material. To extract the protein from the fresh biomass, transgenic tobacco is ground, and then filtered and centrifuged. (see Millan et al., 2003 and Staub et al. 2000 for a review of the steps involved in obtaining the final product).

Production costs of GM HSA are influenced by two primary factors: protein expression level, and purification yield[5]. Plant cells can be modified to express a foreign protein in various cell structures such as the nucleus, intracellular fluid, oil bodies, or chloroplasts. HSA has been expressed in both the nuclei and chloroplast of transgenic tobacco, although research has shown that chloroplast expression can produce higher expression levels, eases purification, and increases yield, compared to other expression systems (Millan et al. 2003; Staub et. al., 2000). The expression level of GM HSA using chloroplasts can produce 3-4g per kg of fresh tobacco. Purification yield in laboratory levels is about 25 percent of the initial quantity in leaves. Improvement in both expression level and purification yield have a direct impact on GM HSA

[4] GM (genetically modified) HSA in the remaining text refers to HSA from transgenic tobacco.

[5] Expression level is the amount of the targeted protein produced in tobacco leaves. Purification yield is the amount of the targeted protein in its pure form that is recovered at the end of the extraction process.

production costs. The present study assumes that chloroplast expression will be used for commercial GM HSA production[6].

The Model

Because GM HSA has yet to reach the market, ex-ante welfare benefits are estimated in the present investigation. The majority of studies evaluating the benefits and distribution of technologies developed for agriculture have assumed perfectly competitive markets (see Alston, Norton and Pardey, 1995). However in this case the developer of GM HSA is likely to hold significant market power through its patent rights. Such imperfect competition cases in general fall into two categories: innovations in agricultural inputs that affect agricultural outputs (Moschini and Lapan, 1997; Falk-Zepeda, Traxler and Nelson, 2000); and, innovations in agricultural products that serve as raw materials to other industries (Wohlgenant and Lemieux, 1989; Alston, Sexton and Zhang, 1997; Huang and Sexton, 1996). The models capture research benefits and their distribution among suppliers of the input, producers and consumers. In the case of GM HSA, market power can be exerted by the pharmaceutical firms in both the output (HSA) and input markets (transgenic tobacco). In the output market, given patent protection, pharmaceutical companies are likely to exhibit pricing power in pharmaceutical markets. In the input market, pharmaceutical firms will be able to set the price for transgenic tobacco from farmers. Based on current experimental results, around 10,000 acres of transgenic tobacco could meet the world's demand for HSA. This acreage represents only about 2.4 percent of the total tobacco acreage in the US. Since the tobacco production in the US has been shrinking and the

[6] Personal interviews with representatives from Chlorogen Inc. (a biotech company working with HSA production from transgenic tobacco) have indicated that their efforts are directed that way.

need for transgenic tobacco accounts for a very modest fraction of the total acreage, the study assumes that pharmaceutical companies will contract with the growers and compensate them for their costs of production. As a result, the patent holder is a perfect monopsonist in the input market.

Although the largest five plasma fractionators serve 70 percent of the world plasma product market, currently there is little evidence of a price mark-up for the existing plasma-derived products. However, the firm that succeeds in producing GM HSA, completing safety/efficacy trials and obtaining FDA approval, will be the only provider in the market during its patent period. Therefore, the company can charge a price mark-up. The magnitude of this mark-up will depend on the difference between its marginal cost and the current marginal cost of fractionation industry. Under the assumption that the quality of GM HSA from transgenic tobacco will be the same as that of plasma-derived HSA, the pricing behavior of the firm can be characterized under two different scenarios based on the magnitude of the unit cost reduction. Using the terminology from Moschini and Lapan (1997), the innovation will be *drastic* if the patenting firm can charge its monopoly profit maximizing price (${}^{m}P^{0}$ in figure 2) and *non-drastic* if it cannot charge a monopoly price but, given the presence of blood plasma products, must involve a limit pricing rule and price ${}^{m}P^{1}$ (${}^{m}P^{1} < {}^{m}P^{0}$) instead.

Following Moschini and Lapan (1997) we assume that HSA's current production function is $y = f(x_0, z)$ and it can be produced with a new production function using the new technology according to $y = g(x_1, z)$ where $f(.,.)$ and $g(.,.)$ are strictly concave production functions. In our case x_0 represents the old input, blood plasma, and x_1 represents the new input, transgenic tobacco. Other inputs in the production function are represented by z. It is assumed that the patenting firm has enough capacity (or achieve enough capacity through licensing its

technology to other firms) to fulfill demand for HSA in the US market. In order to assess the size and distribution of benefits from transgenic tobacco use as a production vehicle for HSA the following information is needed: linear functional forms of supply and demand for HSA; price and quantity data on HSA production and consumption in the US; and unit production costs of HSA from transgenic tobacco. Surplus benefits are estimated only for the HSA market in the US for a one year period. Research and development costs of GM HSA are considered sunk costs.

Assuming linear functional forms of supply and demand, and having price, quantity, and elasticity information, equations of supply and demand can be easily obtained.

Demand for HSA in quantity dependent form may be stated as

$Q_d = \gamma - \delta P \quad (1)$

Supply of HSA in quantity dependent form may be stated as

$Q_s = \alpha + \beta P \quad (2)$

Price elasticity of demand is

$$\varepsilon = \left[\frac{\partial Q}{\partial P} * \frac{P}{Q}\right] \Rightarrow \frac{\partial Q}{\partial P} = \frac{\varepsilon Q}{P} \quad (3)$$

Under the linear demand assumption, the slope of the demand function is found by substituting the value of ε, ${}^{c}P^{0}$ (initial price), and ${}^{c}Q^{0}$ (initial quantity) in equation (3). The intercept of the demand function is found by substituting the slope, and initial price and quantity into equation (1).

The end result is the linear demand function which can be written in price dependent form as

$$P = \frac{\gamma}{\delta} - \frac{1}{\delta} Q \quad (4)$$

Linear functional form of supply is found following the same procedure. Supply of HSA in price dependent form is

$$P = \frac{\alpha}{\beta} + \frac{1}{\beta}Q \quad (5)$$

Several studies including Alston, Norton and Pardey (1995) have examined the errors due to assumptions made in modeling the size and distribution of research benefits. They state that 'in relation to total benefits, functional forms and elasticities are relatively unimportant compared with the nature of the supply shift', while in relation to the distribution of benefits, the results are very sensitive to elasticity assumptions (Alston, Norton and Pardey, p.208, 1995). In the absence of information on the specific nature of the supply shift, the suggestion is the use of a parallel shift (Alston, Norton and Pardey, 1995).

The parallel outward supply shift is represented as

$$P = \left(\frac{\alpha}{\beta} + k\right) + \frac{1}{\beta}Q \quad (6)$$

Where k is the size of the unit cost reduction expressed as cost savings for each unit of GM HSA produced compared to a unit of HSA from blood plasma.

For comparison a pivotal supply shift for the same unit is also employed and is represented as

$$P = \frac{\alpha}{\beta} + \left(\frac{1}{\beta} + k\right)Q \quad (7)$$

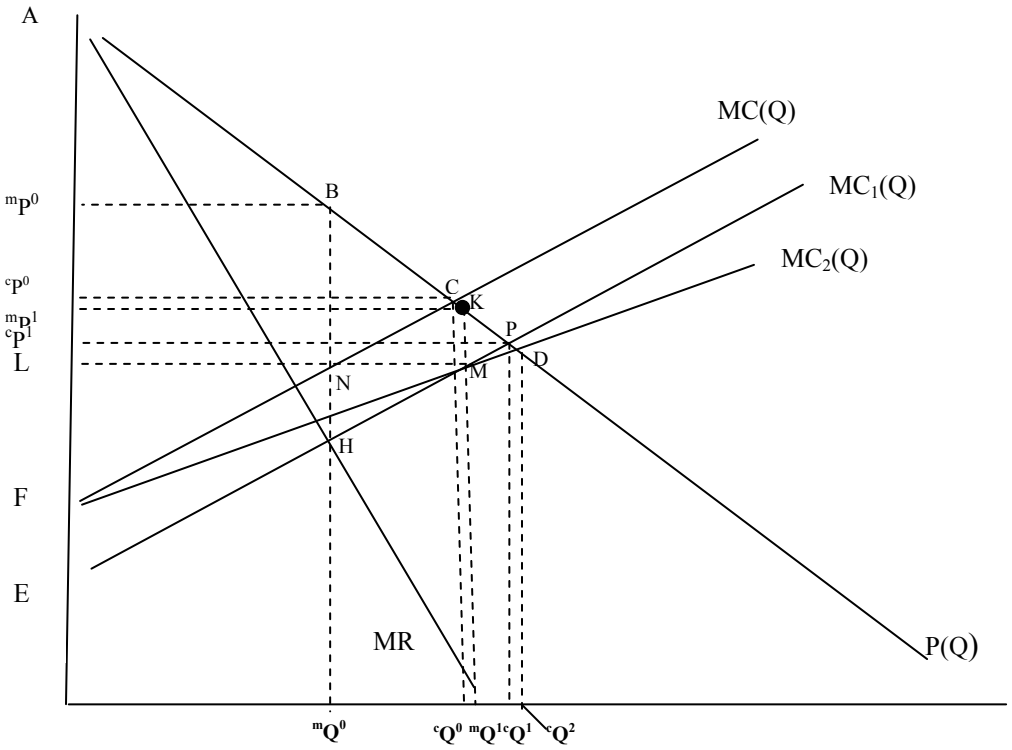
Model of Non-drastic Innovation

The market for HSA in the case of a non-drastic innovation is illustrated in figure 2. Again, the equal quality assumption ensures that consumers' buying behavior will not be influenced by price.

The non-drastic innovation can be represented using a limit price argument. The current HSA market is considered to be perfectly competitive with price reflecting marginal cost of the industry. P(Q) is the demand curve for HSA; MR is the marginal revenue curve that the

patenting firm faces. MC(Q) is the current supply curve of HSA market. $MC_1(Q)$ is the new supply curve after the introduction of the innovation, with a vertical parallel shift caused by a unit cost reduction in HSA production and $MC_2(Q)$ is the new supply curve with a pivotal supply shift caused by the same unit cost reduction. Under perfect competition the price of HSA is ${}^{c}P^{0}$ and the quantity supplied is ${}^{c}Q^{0}$. The firm that patents GM HSA production from transgenic tobacco will have lower production costs. In order to maximize its profits the patenting firm's optimal behavior would be to price at ${}^{m}P^{0}$. However, it cannot price above ${}^{c}P^{0}$ because in that case it loses all the market. Thus, the innovation is non-drastic and to maximize its profits the firm will price its product slightly lower than ${}^{c}P^{0}$ at ${}^{m}P^{1}$ and gain all the HSA market. At a price of ${}^{m}P^{1}$ consumers' gains are very small because ${}^{m}P^{1}$ is very close to ${}^{c}P^{0}$.

Figure 2. **HSA market with the entry of transgenic tobacco HSA (non-drastic innovation)**



To facilitate the analysis, monopoly price ${}^{m}P^{1}$ is considered the same as ${}^{c}P^{0}$ and ${}^{m}Q^{1}$ the same as ${}^{c}Q^{0}$ since the change in price from ${}^{c}P^{0}$ to ${}^{m}P^{1}$ is infinitesimal and does not really affect the quantity sold. Thus, consumer surplus does not change as long as the innovation is non-drastic. Producer surplus also remains the same when the supply shift is parallel because the area of triangle ${}^{c}P^{0}CF$ that represents the initial producer surplus is equal to the area of triangle LME that is the 'new' producer surplus. The change caused by the vertical parallel shift in this case is in the form of monopoly rents, equal to the area represented by rectangle ${}^{c}P^{0}CML$. Comparing this scenario to perfect competition there is a deadweight loss equal to the area of triangle CMP in case of a parallel supply shift. The size of the deadweight loss depends on the elasticities of supply and demand. Deadweight loss is smaller the more inelastic supply and demand and greater the more elastic supply and demand.

A parallel shift of the supply curve results in the following surplus changes[7]:

ΔTS = rectangle ${}^{c}P^{0}CML = ({}^{c}P^{0} - L) {}^{c}Q^{0}$

$\Delta CS = 0$

$\Delta PS = 0$

Profits = rectangle ${}^{c}P^{0}CML = ({}^{c}P^{0} - L) {}^{c}Q^{0}$

DWL = triangle CMP = $0.5 ({}^{c}P^{0} - L) ({}^{c}Q^{1} - {}^{c}Q^{0})$

With a pivotal supply shift of the same unit cost reduction, consumer surplus does not change and profits are the same as those of a parallel shift. However, changes in total surplus, change in producer surplus, and deadweight loss are different.

ΔTS = triangle CMF = $0.5 ({}^{c}P^{0} - L) {}^{c}Q^{0}$

[7] In the following formulas for surplus change calculation, point C and point K in figure 2 refer to the same point. Point K was introduced in the figure only for illustrative purposes of the limit price argument.

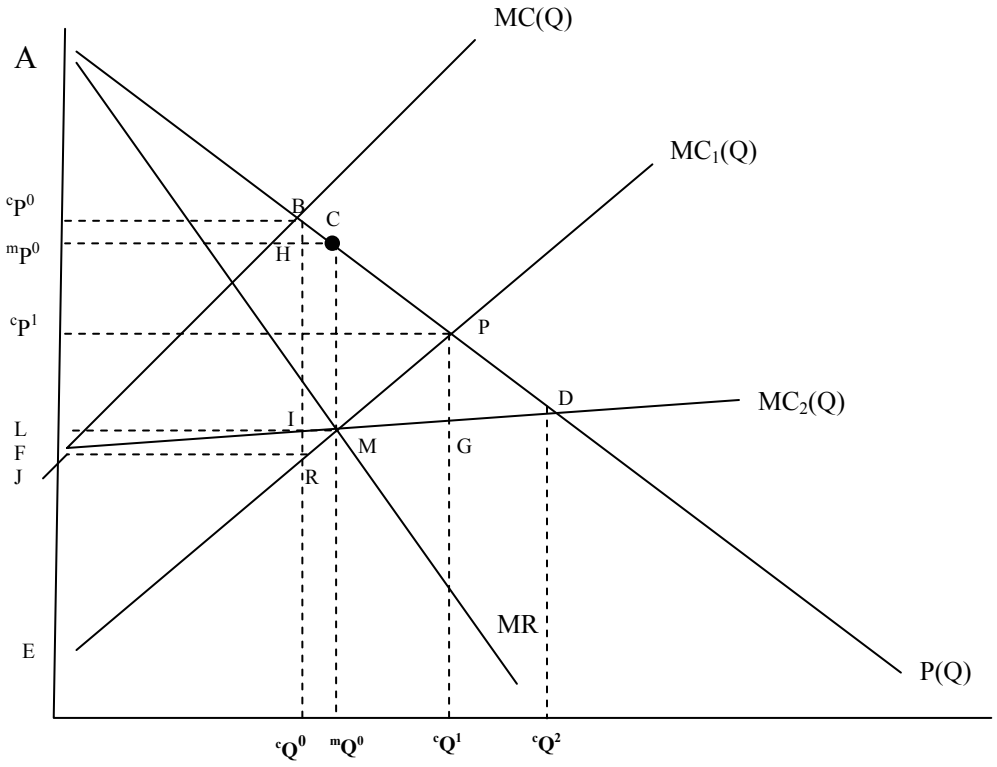
ΔPS = triangle ${}^{c}P^{0}CF$ – triangle LMF = 0.5 $({}^{c}P^{0} - F)\ {}^{c}Q^{0} - 0.5\ (L - F)\ {}^{c}Q^{0}$

DWL = triangle CMD = 0.5 $({}^{c}P^{0} - L)\ ({}^{c}Q^{2} - {}^{c}Q^{0})$

Model of drastic innovation

As stated above, when the innovation is drastic the firm that owns the patent of GM HSA can behave as a perfect monopoly. In figure 3 below, the profit-maximizing price of the monopoly (${}^{m}P^{0}$) is found by setting MR = MC. For some of the expected unit cost reductions scenarios, ${}^{m}P^{0}$ results to be less than the current competitive price (${}^{c}P^{0}$) of HSA, and the innovation is drastic. This outcome is important because besides generating profits for the patent holder, the innovation generates a positive change in consumer surplus.

Figure 3. **HSA market with the entry of transgenic tobacco HSA (drastic innovation)**



Surplus changes for a drastic innovation with a parallel shift are:

ΔTS = rectangle ${}^{c}P^{0}BH\,{}^{m}P^{0}$ + rectangle ${}^{m}P^{0}CML$ + triangle HBC + triangle RMI + rectangle LIRJ

$\Delta TS = ({}^{c}P^{0} - {}^{m}P^{0})\,{}^{c}Q^{0} + ({}^{m}P^{0} - L)\,{}^{m}Q^{0} + 0.5\,({}^{c}P^{0} - {}^{m}P^{0})\,({}^{m}Q^{0} - {}^{c}Q^{0}) + 0.5\,({}^{m}Q^{0} - {}^{c}Q^{0})\,(L - J) + (L - J)\,{}^{c}Q^{0}$

ΔCS = rectangle ${}^{c}P^{0}BH\,{}^{m}P^{0}$ + triangle HBC = $({}^{c}P^{0} - {}^{m}P^{0})\,{}^{c}Q^{0} + 0.5\,({}^{c}P^{0} - {}^{m}P^{0})\,({}^{m}Q^{0} - {}^{c}Q^{0})$

ΔPS = triangle RMI + rectangle LIRJ = $0.5\,({}^{m}Q^{0} - {}^{c}Q^{0})\,(L - J) + (L - J)\,{}^{c}Q^{0}$

Profits = rectangle ${}^{m}P^{0}CML = ({}^{m}P^{0} - L)\,{}^{m}Q^{0}$

DWL = triangle CMP = $0.5\,({}^{m}P^{0} - L)\,({}^{c}Q^{1} - {}^{m}Q^{0})$

For a pivotal shift of the same unit cost reduction, the profits are the same as in the case of a parallel shift. Other surplus changes are:

ΔTS = triangle LMF + triangle LIB + triangle HBC + rectangle HIMC

$\Delta TS = 0.5\,(L - F)\,{}^{m}Q^{0} + 0.5\,({}^{c}P^{0} - L)\,{}^{c}Q^{0} + 0.5\,({}^{c}P^{0} - {}^{m}P^{0})\,({}^{m}Q^{0} - {}^{c}Q^{0}) + ({}^{m}Q^{0} - {}^{c}Q^{0})\,({}^{c}P^{0} - {}^{m}P^{0})$

ΔCS = rectangle ${}^{c}P^{0}BH\,{}^{m}P^{0}$ + triangle HBC = $({}^{c}P^{0} - {}^{m}P^{0})\,{}^{c}Q^{0} + 0.5\,({}^{c}P^{0} - {}^{m}P^{0})\,({}^{m}Q^{0} - {}^{c}Q^{0})$

ΔPS = triangle LMF - triangle ${}^{c}P^{0}BF = 0.5\,(L - F)\,{}^{c}Q^{0} - 0.5\,({}^{c}P^{0} - F)\,{}^{c}Q^{0}$

DWL = triangle CMD = $0.5\,({}^{c}P^{0} - L)\,({}^{c}Q^{1} - {}^{c}Q^{0})$

Data

The elasticities, prices and unit cost reductions used to estimate surplus changes are now specified. Price elasticities of supply and demand are crucial for the surplus analysis. Information on the elasticity of supply for HSA is not available in the literature. Based on the complex nature of the fractionation industry and occasional presence of supply shortages, the supply elasticity of HSA is considered to be inelastic and is assumed to have a value of 0.5. On the demand side, consumers and hospitals seem to be sensitive to the price and availability of HSA. As mentioned,

hospitals often use HSA substitutes, because they are cheaper and offer a more steady supply. Published guidelines place albumin as an alternative choice when less expensive volume expanders are available (Colgan, Moody and White, 2000). A study of the Office of Technology Assessment (OTA) in the US Congress states that HSA market is sensitive to price changes, with consumers paying attention to price and source of service rather than the manufacturing source (OTA, 1985). Alexander, Flynn and Linkins (1994) estimated price demand elasticity for prescription drugs in the US to have a demand elasticity of -2.8. Ellison et al. (1997) estimated the own price elasticity of four generic drugs that need a doctor's prescription for consumption. The drugs in their study are part of the anti-infective category and are generally prescribed when common antibiotics are not effective in curing certain diseases. The elasticities ranged from –1.07 to –2.97. For the purpose of the study three demand elasticities in the elastic range will be taken in consideration: min. –1.07, avg. –2.02 and max. -2.97.

Price and quantity of HSA in the US market for the period from 1994-2003 in the US are shown in table 1 below (Marketing Research Bureau, 2004). The price of HSA has fluctuated extensively during that period. Norton, Alston and Pardey (1995) suggest the average price and quantity of the last three years be used for this type of analysis. Since the data for 2003 are estimates the average price and quantity from 2000 to 2002 are used.

Table 1. The Albumin Market in the US (1994-2000)

Year	Grams (000)	Price per gram
1994	106,500	$ 3.30
1995	110,875	$ 3.33
1996	109,188	$ 3.37
1997	100,625	$ 3.44
1998	99,250	$ 4.01
1999	82,188	$ 3.30
2000	74,225	$ 2.93
2001	85,438	$ 2.72
2002	87,375	$ 2.25
2003 *	88,000	$ 2.00

* Estimate

Source: Marketing Research Bureau (2004)

The magnitude of unit cost reduction (k) reflects the difference between the current HSA price and GM HSA production cost per unit and is a crucial parameter in the analysis. The value of the unit cost reduction in commercial scale based on experimental results from biotech companies is expected to be between $0.3 and $0.6 per gram. Because GM HSA is still at the laboratory level and the exact cost savings may still vary, the analysis includes a range of $0.1 up to $1.0 in order to capture a wider variety of the surpluses that may be generated.

Results

Table 2 shows estimated surplus changes under parallel and pivotal supply shifts. In the table, ε is the price elasticity of demand, K is the unit cost reduction as a percentage of initial HSA price, DTSm is the change in total surplus, DPS is the change in producer's surplus, and DWL is deadweight loss due to imperfect competition

Table 2. Economic surplus generated from a $0.1 to $1.0 unit cost reduction.

Parallel Supply Shift								Pivotal Supply Shift					
				ε =1.07	ε =2.02	ε =2.97				ε =1.07	ε =2.02	ε =2.97	
k ($)	K (% of P)	Profits	DTSm	DWL	DWL	DWL	DPS	Profits	DTSm	DWL	DWL	DWL	DPS
0.1	0.04	8,235	8,235	53	63	67	-	8,235	4,117	4,171	4,181	4,185	(4,117)
0.15	0.06	12,352	12,352	120	141	151	-	12,352	6,176	6,298	6,320	6,330	(6,176)
0.2	0.08	16,469	16,469	213	251	268	-	16,469	8,235	8,454	8,493	8,512	(8,235)
0.25	0.10	20,587	20,587	333	392	419	-	20,587	10,293	10,638	10,701	10,730	(10,293)
0.3	0.11	24,704	24,704	480	565	603	-	24,704	12,352	12,851	12,944	12,986	(12,352)
0.35	0.13	28,821	28,821	654	769	821	-	28,821	14,411	15,095	15,222	15,281	(14,411)
0.4	0.15	32,938	32,938	854	1,004	1,072	-	32,938	16,469	17,369	17,538	17,616	(16,469)
0.45	0.17	37,056	37,056	1,080	1,271	1,357	-	37,056	18,528	19,675	19,892	19,992	(18,528)
0.5	0.19	41,173	41,173	1,334	1,569	1,675	-	41,173	20,587	22,013	22,285	22,410	(20,587)
0.55	0.21	45,290	45,290	1,614	1,898	2,027	-	45,290	22,645	24,383	24,717	24,871	(22,645)
0.6	0.23	49,408	49,408	1,920	2,259	2,412	-	49,408	24,704	26,786	27,190	27,377	(24,704)
0.65	0.25	53,525	53,525	2,254	2,651	2,831	-	53,525	26,762	29,224	29,705	29,928	(26,762)
0.7	0.27	57,642	57,642	2,614	3,074	3,283	-	57,642	28,821	31,696	32,263	32,526	(28,821)
0.75	0.29	61,760	61,760	3,001	3,529	3,769	-	61,760	30,880	34,204	34,865	35,172	(30,880)
0.8	0.30	65,877	65,877	3,414	4,016	4,288	-	65,877	32,938	36,747	37,512	37,868	(32,938)
0.85	0.32	69,994	69,994	3,854	4,533	4,841	-	69,994	34,997	39,328	40,205	40,615	(34,997)
0.9	0.34	74,111	*74,411*	4,321	5,082	5,427	*150*	74,111	*37,228*	41,947	42,946	43,414	(37,056)
0.95	0.36	78,229	*79,573*	4,815	5,663	6,046	*672*	78,229	*39,891*	44,605	45,736	46,266	(39,114)
1	0.38	82,346	*84,740*	5,335	6,274	6,700	*1,197*	82,346	*42,570*	47,302	48,576	49,175	(41,173)

-The elasticity of supply is 0.5.
-Except for k and K, results are in thousands of dollars.

The total change in surplus varies from $8 million to $82 million for a parallel shift and from $4 million to $43 million for a pivotal shift, for unit cost reductions ranging from $0.1 to $1.0. As expected, benefits increase as the size of the unit cost reduction increases and total benefits for a pivotal shift are roughly half of those for a parallel shift. The case of HSA results in no benefits to consumers for a non-drastic innovation. As a result, only the deadweight loss is sensitive to the choice of elasticities. To see how deadweight loss varies with different values of supply elasticities, three different values are introduced in the Appendix. Tables A, B and C indicate results for supply elasticities of 0.25, 0.75 and 1.00, respectively. As expected, deadweight loss increases as supply becomes more elastic. Changes in producer surplus for a

pivotal shift are negative because the patent holder receives part of the initial producer surplus as profits.

Based on the data above, the innovation is non-drastic for unit cost reductions ranging from $0.1 to $1.0 when elasticity of demand is either -1.07 and -2.02 and it is drastic for unit cost reductions greater than or equal to $0.89 when the elasticity of demand is -2.97. This outcome is important for the analysis of the distribution of surplus because when the innovation is drastic consumers can benefit as well. For a unit cost reduction of $0.9 and a demand elasticity of -2.97 consumer surplus increases by $150,307 for a parallel shift and $172,398 for a pivotal shift. For the same demand elasticity and a unit cost reduction of $0.95, consumer surplus increases by $671,770 for a parallel shift and $777,271 for a pivotal shift. Consumer surplus increases by $1,196,921 for a parallel shift and by $1,397,250 for a pivotal shift when the unit cost reduction is $1.0. Producer surplus also changes when the innovation is drastic for a parallel supply shift. These consumer and producer surplus changes for drastic innovations are included in table 2 as part of the total benefits. Results for drastic innovations in table 2 and tables A, B and C in the Appendix are shown in italics.

Summary and Conclusion

This study estimates the benefits from the use of transgenic tobacco as a source of HSA. Because the novel application will be patented by a biotech or pharmaceutical firm, an imperfect competition model was applied to estimate the size and distribution of benefits. The results of the study suggest that the use of transgenic tobacco for HSA production may result in significant total surplus gains.

Patent holders are the major recipients of the benefits as long as the product is under patent even if the innovation is not drastic. These potential annual flows of monopolist's benefits appear sufficient to spur large research initiatives. Consumers, on the other hand, benefit from a drastic innovation but their benefits remain very small compared to the GM HSA producers. Furthermore, it appears that production of GM HSA will not have a significant impact on tobacco farmers since the acreage involved in transgenic tobacco production is relatively small compared to the total tobacco acreage in the US and they are likely to be contracted with to grow GM tobacco at cost.

Under most scenarios the expected unit cost reduction associated with the introduction of GM HSA results in a non-drastic innovation. However, a drastic innovation is within the reach of the current research and surprisingly may actually increase benefits to consumers.

As little attention has been given to genetically-modified agricultural crops for pharmaceutical uses, further explorations are necessary to shed more light on the benefits of the major private sector research initiatives being conducted on bio-pharming. Other areas for further research related to the introduction of GM HSA may be directed towards quality shifts in the supply of GM HSA since the product is considered to be safer than blood plasma HSA.

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Appendix

Table A. Economic surplus generated from a $0.1 to $1.0 unit cost reduction.

η=0.25

Parallel Supply Shift								Pivotal Supply Shift					
				ε=1.07	ε=2.02	ε=2.97				ε=1.07	ε=2.02	ε=2.97	
k	K (% P)	Profits	DTSm	DWL	DWL	DWL	DPS	Profits	DTSm	DWL	DWL	DWL	DPS
0.1	0.04	8,235	8,235	32	35	36	-	8,235	4,117	4,149	4,152	4,154	(4,117)
0.15	0.06	12,352	12,352	71	78	81	-	12,352	6,176	6,248	6,255	6,258	(6,176)
0.2	0.08	16,469	16,469	127	139	144	-	16,469	8,235	8,363	8,376	8,382	(8,235)
0.25	0.10	20,587	20,587	198	218	226	-	20,587	10,293	10,495	10,516	10,524	(10,293)
0.3	0.11	24,704	24,704	286	313	325	-	24,704	12,352	12,644	12,674	12,686	(12,352)
0.35	0.13	28,821	28,821	389	427	442	-	28,821	14,411	14,810	14,850	14,867	(14,411)
0.4	0.15	32,938	32,938	508	557	578	-	32,938	16,469	16,993	17,046	17,068	(16,469)
0.45	0.17	37,056	37,056	642	705	731	-	37,056	18,528	19,193	19,261	19,289	(18,528)
0.5	0.19	41,173	41,173	793	871	902	-	41,173	20,587	21,411	21,496	21,530	(20,587)
0.55	0.21	45,290	45,290	960	1,054	1,092	-	45,290	22,645	23,647	23,750	23,792	(22,645)
0.6	0.23	49,408	49,408	1,142	1,254	1,300	-	49,408	24,704	25,901	26,025	26,076	(24,704)
0.65	0.25	53,525	53,525	1,340	1,471	1,525	-	53,525	26,762	28,174	28,320	28,380	(26,762)
0.7	0.27	57,642	57,642	1,555	1,707	1,769	-	57,642	28,821	30,464	30,635	30,706	(28,821)
0.75	0.29	61,760	61,760	1,785	1,959	2,031	-	61,760	30,880	32,774	32,971	33,053	(30,880)
0.8	0.30	65,877	65,877	2,030	2,229	2,310	-	65,877	32,938	35,102	35,329	35,423	(32,938)
0.85	0.32	69,994	69,994	2,292	2,516	2,608	-	69,994	34,997	37,450	37,708	37,815	(34,997)
0.9	0.34	74,111	*74,283*	2,570	2,821	2,924	*86*	74,111	*37,149*	39,817	40,109	40,230	(37,056)
0.95	0.36	78,229	*78,997*	2,863	3,143	3,258	*384*	78,229	*39,530*	42,204	42,532	42,668	(39,114)
1	0.38	82,346	*83,710*	3,173	3,483	3,610	*682*	82,346	*41,196*	44,610	44,978	45,130	(41,173)

η - Elasticity of supply

Table B. Economic surplus generated from a $0.1 to $1.0 unit cost reduction.

η=0.75

Parallel Supply Shift								Pivotal Supply Shift					
				ε=1.07	ε=2.02	ε=2.97				ε=1.07	ε=2.02	ε=2.97	
k ($)	K (% P)	Profits	DTSm	DWL	DWL	DWL	DPS	Profits	DTSm	DWL	DWL	DWL	DPS
0.1	0.04	8,235	8,235	69	86	94	-	8,235	4,117	4,188	4,205	4,213	(4,117)
0.15	0.06	12,352	12,352	155	193	211	-	12,352	6,176	6,335	6,375	6,394	(6,176)
0.2	0.08	16,469	16,469	276	342	375	-	16,469	8,235	8,520	8,592	8,627	(8,235)
0.25	0.10	20,587	20,587	431	535	586	-	20,587	10,293	10,744	10,858	10,914	(10,293)
0.3	0.11	24,704	24,704	621	771	844	-	24,704	12,352	13,006	13,174	13,257	(12,352)
0.35	0.13	28,821	28,821	846	1,049	1,148	-	28,821	14,411	15,309	15,542	15,658	(14,411)
0.4	0.15	32,938	32,938	1,104	1,370	1,500	-	32,938	16,469	17,653	17,963	18,119	(16,469)
0.45	0.17	37,056	37,056	1,398	1,734	1,898	-	37,056	18,528	20,040	20,441	20,643	(18,528)
0.5	0.19	41,173	41,173	1,726	2,141	2,344	-	41,173	20,587	22,470	22,975	23,231	(20,587)
0.55	0.21	45,290	45,290	2,088	2,590	2,836	-	45,290	22,645	24,945	25,570	25,887	(22,645)
0.6	0.23	49,408	49,408	2,485	3,082	3,375	-	49,408	24,704	27,467	28,226	28,612	(24,704)
0.65	0.25	53,525	53,525	2,916	3,618	3,961	-	53,525	26,762	30,036	30,945	31,411	(26,762)
0.7	0.27	57,642	57,642	3,382	4,196	4,593	-	57,642	28,821	32,653	33,731	34,285	(28,821)
0.75	0.29	61,760	61,760	3,883	4,816	5,273	-	61,760	30,880	35,321	36,586	37,239	(30,880)
0.8	0.30	65,877	65,877	4,418	5,480	5,999	-	65,877	32,938	38,041	39,512	40,274	(32,938)
0.85	0.32	69,994	69,994	4,987	6,186	6,773	-	69,994	34,997	40,813	42,512	43,395	(34,997)
0.9	0.34	74,111	*74,511*	5,591	6,935	7,593	*200*	74,111	*37,298*	43,641	45,588	46,606	(37,056)
0.95	0.36	78,229	*80,021*	6,230	7,727	8,460	*896*	78,229	*40,209*	46,524	48,744	49,909	(39,114)
1	0.38	82,346	*85,544*	6,903	8,562	9,374	*1,599*	82,346	*43,151*	49,466	51,983	53,311	(41,173)

η - Elasticity of supply

Table C. Economic surplus generated from a $0.1 to $1.0 unit cost reduction.

η=1.00

Parallel Supply Shift								Pivotal Supply Shift					
				ε=1.07	ε=2.02	ε=2.97				ε=1.07	ε=2.02	ε=2.97	
k ($)	K (% P)	Profits	DTSm	DWL	DWL	DWL	DPS	Profits	DTSm	DWL	DWL	DWL	DPS
0.1	0.04	8,235	8,235	81	105	117	-	8,235	4,117	4,200	4,225	4,238	(4,117)
0.15	0.06	12,352	12,352	182	236	264	-	12,352	6,176	6,364	6,421	6,451	(6,176)
0.2	0.08	16,469	16,469	324	419	468	-	16,469	8,235	8,572	8,676	8,731	(8,235)
0.25	0.10	20,587	20,587	506	654	732	-	20,587	10,293	10,825	10,992	11,081	(10,293)
0.3	0.11	24,704	24,704	728	942	1,054	-	24,704	12,352	13,126	13,372	13,504	(12,352)
0.35	0.13	28,821	28,821	991	1,283	1,435	-	28,821	14,411	15,475	15,819	16,004	(14,411)
0.4	0.15	32,938	32,938	1,295	1,675	1,874	-	32,938	16,469	17,874	18,334	18,584	(16,469)
0.45	0.17	37,056	37,056	1,639	2,120	2,372	-	37,056	18,528	20,326	20,922	21,248	(18,528)
0.5	0.19	41,173	41,173	2,023	2,618	2,928	-	41,173	20,587	22,830	23,586	24,000	(20,587)
0.55	0.21	45,290	45,290	2,448	3,168	3,543	-	45,290	22,645	25,390	26,328	26,845	(22,645)
0.6	0.23	49,408	49,408	2,913	3,770	4,216	-	49,408	24,704	28,006	29,152	29,788	(24,704)
0.65	0.25	53,525	53,525	3,419	4,424	4,948	-	53,525	26,762	30,682	32,063	32,833	(26,762)
0.7	0.27	57,642	57,642	3,965	5,131	5,739	-	57,642	28,821	33,419	35,063	35,987	(28,821)
0.75	0.29	61,760	61,760	4,552	5,890	6,588	-	61,760	30,880	36,219	38,158	39,254	(30,880)
0.8	0.30	65,877	65,877	5,179	6,702	7,496	-	65,877	32,938	39,084	41,352	42,642	(32,938)
0.85	0.32	69,994	69,994	5,847	7,566	8,462	-	69,994	34,997	42,016	44,649	46,157	(34,997)
0.9	0.34	74,111	*74,591*	6,555	8,482	9,487	*240*	74,111	*37,359*	45,019	48,055	49,807	(37,056)
0.95	0.36	78,229	*80,381*	7,303	9,450	10,570	*1,076*	78,229	*40,489*	48,094	51,575	53,598	(39,114)
1	0.38	82,346	*86,188*	8,092	10,471	11,712	*1,921*	82,346	*43,669*	51,245	55,216	57,541	(41,173)

η - Elasticity of supply