READERS' APPENDIX to:

Innovation and Trade with Endogenous Market Failure:

The Case of Genetically Modified Products

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PROOFS

Proof of Proposition 1. As $\hat{z}$ increases, more land is allocated to the GM crop and less to the non-GM

crop, but total production of soybeans is unchanged (because yields are the same provided $p^n = p^g$).

Further, if $p^n = p^g = p^0$ European demand for the non-GM product is unchanged, whereas U.S. demand

is perfectly elastic and equal to $(1-\psi)D(p^0)$. Thus, if $\psi D(p^0) = \Theta(\hat{z})\pi_p(p^0)$, both markets clear at

this price. That is, if $\hat{z}$ is such that $\Theta(\hat{z}) \leq D(p^0)/\pi_p(p^0)$, then equilibrium prices are unchanged.

Proof of Proposition 2. Totally differentiating (16) and (17) yields

$$(28) \quad \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} dp^g \\ dp^n \end{bmatrix} = \begin{bmatrix} \pi_p(p^g)\theta(\hat{z})d\hat{z} \\ -\pi_p(p^n)\theta(\hat{z})d\hat{z} \end{bmatrix}$$

where

$$a_{11} \equiv -\left[\pi_{pp}(p^g)\Theta(\hat{z}) + \upsilon''(p^g) + \bar{\phi}_{gg}(\bar{p}^n, \bar{p}^g) \right] < 0$$

$$a_{12} = a_{21} \equiv -\bar{\phi}_{gn}(\bar{p}^n, \bar{p}^g) > 0$$

$$a_{22} \equiv -\left[\pi_{pp}(p^n)(L-\Theta(\hat{z})) + \bar{L}\bar{\pi}_{pp}(\bar{p}^n) - \bar{\phi}_{nn}(\bar{p}^n, \bar{p}^g) \right] < 0.$$

The signs for a_{11} and a_{22} come from the convexity of the profit and indirect utility functions whereas the sign for $a_{12} = a_{21}$ comes from the final goods being substitutes in consumption. Because $p^g < p^n$, realized yields per acre will be higher on non-GM lands. Solving (28) yields

$$(29) \qquad \begin{bmatrix} dp^g \\ dp^n \end{bmatrix} = (1/\Delta) \begin{bmatrix} a_{22} & -a_{12} \\ -a_{21} & a_{11} \end{bmatrix} \begin{bmatrix} \pi_p(p^g)\theta(\hat{z})d\hat{z} \\ -\pi_p(p^n)\theta(\hat{z})d\hat{z} \end{bmatrix}$$

where $\Delta = (a_{11}a_{22} - a_{12}a_{21}) > 0$. Because $p^g < p^n$ for $\hat{z} > z^0$, then $\pi_p(p^n) > \pi_p(p^g)$ (i.e., yields are positively affected by output price provided $\pi_{pp} > 0$). Thus, given price, total output declines as land planted with the GM crop expands. From (29), $(dp^n/d\hat{z}) = (\theta(\hat{z})/\Delta)(-a_{11}\pi_p(p^n) - a_{21}\pi_p(p^g))$.

Because $p^n \geq p^g$, then $\pi_p(p^n) \geq \pi_p(p^g)$. Further, $a_{11} < 0$, and, by the assumed Condition 1, $(a_{11} + a_{12}) < 0$, provided that $\pi_{pp} > 0$ or $v'' > 0$. Thus:

$(-a_{11}\pi_p(p^n) - a_{21}\pi_p(p^g)) > -\pi_p(p^g)(a_{11} + a_{21}) > 0$, proving $(dp^n/d\hat{z}) > 0$. And, from (29)

$[(dp^n/d\hat{z}) - (dp^g/d\hat{z})] = (-\theta(\hat{z})/\Delta)((a_{11} + a_{12})\pi_p(p^n) + (a_{22} + a_{21})\pi_p(p^g))$. Given convexity,

Condition 1 guarantees $(a_{11} + a_{12}) < 0$ and $(a_{21} + a_{22}) < 0$, proving $(dp^n/d\hat{z}) > (dp^g/d\hat{z})$.

As for part (iii) of Proposition 2, Europe's welfare can be written as $\bar{W} = \bar{L}\bar{\pi}(p^n(\hat{z})) + \bar{\phi}(p^n(\hat{z}), p^g(\hat{z}))$.

Thus, $(d\bar{W}/d\hat{z}) = [\bar{L}\bar{\pi}_p(p^n(\hat{z})) + \bar{\phi}_n](dp^n/d\hat{z}) + \bar{\phi}_g(dp^g/d\hat{z}) = \{[\bar{S}^n - \bar{D}^n](dp^n/d\hat{z}) - \bar{D}^g(dp^g/d\hat{z})\}$,

where $[\bar{D}^n - \bar{S}^n]$ is imports of the non-GM product and $\bar{D}^g$ is imports of the GM product. From

Proposition 2, $(dp^n/d\hat{z}) > 0$ and $(dp^n/d\hat{z}) > (dp^g/d\hat{z})$; thus, for $[\bar{D}^n - \bar{S}^n] > \bar{D}^g \geq 0$, the result is proven.

Proof of Proposition 3. From the solution to (19)-(21), and recalling (8)-(10), we have

(30)
$$\left(dp^b/dc\right)=-\left[\bar{L}\bar{\pi}_{pp}\left(p^f\right)+\bar{\phi}_{ff}+\bar{\phi}_{bf}\right]\Big/\Delta$$
$$\left(dp^f/dc\right)=\left[L\pi_{pp}\left(p^b\right)+\upsilon''\left(p^b\right)+\bar{\phi}_{bf}+\bar{\phi}_{bb}\right]\Big/\Delta$$

where $\Delta\equiv\left[L\pi_{pp}\left(p^b\right)+\bar{L}\bar{\pi}_{pp}\left(p^f\right)+\upsilon''\left(p^b\right)+\bar{\phi}_{ff}+2\bar{\phi}_{bf}+\bar{\phi}_{bb}\right]$ and $\bar{\phi}_{ij}\equiv\partial^2\bar{\phi}\left(p^f,p^b\right)\Big/\partial p^i\partial p^j$,

$i,j\in\{f,b\}$. Convexity of the profit and indirect utility functions guarantees that Δ is positive (the

excess supply function is positively sloped). If Europe does not consume the GM variety, the numerator

of the first line in (30) is negative, whereas that of the second is positive. But if Europe does consume the

GM product we cannot unambiguously sign both numerators (one must be positive). However, under the

assumed Condition 1, the numerator of the first line must be negative, and that of the second positive.

Proof of Lemma 1. See text.

Proof of Proposition 4. We have shown previously that $dp^b/dc<0$. The changes in home, foreign, and

hence world welfare are

$$\left(dW/dc\right)=\left[L\pi_p\left(p^g\right)+\upsilon'\left(p^b\right)\right]\left(dp^b/dc\right)=\left[S^n+S^g-D\right]\left(dp^b/dc\right)<0 \qquad \text{given: } p^b=p^g=p^n$$
$$\left(d\bar{W}/dc\right)=\left[\bar{L}\bar{\pi}_p\left(p^f\right)+\bar{\phi}_f\left(p^f,p^b\right)\right]\left(dp^f/dc\right)+\left[\bar{\phi}_b\left(p^f,p^b\right)\right]\left(dp^b/dc\right)=\left[\bar{S}^n-\bar{D}^n\right]\left(dp^f/dc\right)-\bar{D}^g\left(dp^b/dc\right)$$
$$\left(d\left(\bar{W}+W\right)/dc\right)=\left[\bar{L}\bar{\pi}_p\left(p^f\right)+\bar{\phi}_f\left(p^f,p^b\right)\right]=\left[\bar{S}^n-\bar{D}^n\right]<0 \; .$$

U.S. welfare declines because it is a net exporter, and the farmgate price declines. World welfare declines

because of the increased verification costs. Europe's welfare is reduced by the effective cost increase for

imports of the GM-free product (including verification costs), but Europe may benefit from the reduced

price of the GM product, so that the overall impact is ambiguous. Around $c=0$, all parties are hurt.

Proof of Proposition 5. Part (i) follows from the previous section and the immediately preceding

discussion where we have shown that, given $\hat{z}\leq z^0$, (a) if $c=0$, then prices are independent of z; whereas

(b) given $\hat{z} \in (0, z^0)$, p^b is a declining function of c, while p^f is an increasing function of c. Part (ii)

follows from the fact that the introduction of the GM product leads to a decline in the U.S. terms of trade.

The welfare gain to the United States due to the introduction of GM seeds is $\Delta W = \int_0^{\hat{z}} \eta(z)\theta(z)dz$,

whereas the welfare loss in the United States depends upon the magnitude of the decline in the terms of

trade. If verification costs are small, then the gains will outweigh the losses; however, for large enough

verification costs the introduction of GM product may lower U.S. welfare.

Proof of Proposition 6. Totally differentiating yields the following comparative statics effects:

(31)
$$\left(dp^b/dt\right) = -\left[\bar{\phi}_{fb} + \bar{\phi}_{bb}\right]/\Delta$$
$$\left(d\bar{p}^b/dt\right) = \left[L\pi_{pp}\left(p^b\right) + \bar{L}\bar{\pi}_{pp} + \upsilon''\left(p^b\right) + \bar{\phi}_{ff} + \bar{\phi}_{fb}\right]/\Delta$$

where $\Delta \equiv \left[L\pi_{pp}\left(p^b\right) + \bar{L}\bar{\pi}_{pp}\left(p^f\right) + \upsilon''\left(p^b\right) + \bar{\phi}_{ff} + 2\bar{\phi}_{bf} + \bar{\phi}_{bb}\right]$ and

$\bar{\phi}_{ij} \equiv \partial^2\bar{\phi}\left(p^f, p^b\right)/\partial p^i \partial p^j$, $(i, j) \in \{f, b\}$. Given the identity of U.S. prices for the two varieties,

$\left(d\bar{p}^f/dt\right) = \left(dp^b/dt\right)$. Under the assumption of Condition 1, we have $\left(d\bar{p}^b/dt\right) > 0 > \left(dp^b/dt\right)$. This

establishes the proof of parts (i) and (ii). The proof of (iii) follows from

$$\left(d\bar{W}/dt\right) = \left(\bar{L}\bar{\pi}_p + \bar{\phi}_f\right)\left(d\bar{p}^f/dt\right) + \left(\bar{\phi}_b\right)\left(d\bar{p}^b/dt\right) = \left(\bar{S}^n - \bar{D}^f\right)\left(d\bar{p}^f/dt\right) - \bar{D}^b\left(d\bar{p}^b/dt\right).$$

The first expression is the welfare gain due to the improved terms of trade on GM-free product imports

(U.S. prices decline), whereas the second term measures the loss due to the worsened gross terms of trade

on the GM product. Note that these costs operate like a tariff on the GM product, assuming the tariff

revenue is thrown away. Clearly, if GM-free imports are large enough, or if imports of the GM product

are low enough, the expression will be positive. Further, as t increases, net imports of GM-free goods

will increase; those of the GM product will decrease, so the expression is even more likely to be positive.

Proof of Lemma 2. Totally differentiating (22)-(23) and rearranging yields

$$(32) \qquad \begin{bmatrix} dp^n \\ dp^g \end{bmatrix} = \left(\frac{1}{\Delta}\right) \begin{bmatrix} a_{22} & -a_{12} \\ -a_{21} & a_{11} \end{bmatrix} \begin{bmatrix} b_n \\ b_g \end{bmatrix}$$

where

$$a_{11} = \left(\pi_{pp}\left(p^n\right)\left(L - \Theta(\hat{z})\right) + \bar{L}\bar{\pi}_{pp}\left(\bar{p}^n\right) + \bar{\phi}_{ff}\left(p^f, \bar{p}^b\right)\right) > 0$$

$$a_{12} = a_{21} = \bar{\phi}_{fb}\left(\bar{p}^n, \bar{p}^g\right) < 0$$

$$a_{22} = \left(\pi_{pp}\left(p^g\right)\Theta(\hat{z}) + v''\left(p^g\right) + \bar{\phi}_{bb}\left(p^f, \bar{p}^b\right)\right) > 0$$

$$\Delta = \left(a_{11}a_{22} - a_{12}^2\right) > 0$$

$$b_n = \left\{\theta(\hat{z})\pi_p\left(p^n\right)d\hat{z} - \left[\bar{L}\bar{\pi}_{pp}\left(\bar{p}^n\right) + \bar{\phi}_{ff}\left(p^f, \bar{p}^b\right)\right]dc - a_{12}dt\right\}$$

$$b_g = -\left\{\theta(\hat{z})\pi_p\left(p^g\right)d\hat{z} + a_{12}dc + \bar{\phi}_{bb}dt\right\}.$$

From (32) the following comparative statics are readily derived:

$$(33) \qquad \begin{aligned} \left(\partial p^n/\partial \hat{z}\right) &= \left(\theta(\hat{z})/\Delta\right)\left\{\left[\pi_{pp}\left(p^g\right)\Theta(\hat{z}) + v''\left(p^g\right)\right]\pi_p\left(p^n\right) + \left[\bar{\phi}_{bb}\pi_p\left(p^n\right) + \bar{\phi}_{bf}\pi_p\left(p^g\right)\right]\right\} > 0 \\ \left(\partial p^g/\partial \hat{z}\right) &= \left(-\theta(\hat{z})/\Delta\right)\left\{\left[\pi_{pp}\left(p^n\right)\left(L - \Theta(\hat{z})\right) + \bar{L}\bar{\pi}_{pp}\left(\bar{p}^n\right)\right]\pi_p\left(p^g\right) + \left[\bar{\phi}_{ff}\pi_p\left(p^g\right) + \bar{\phi}_{bf}\pi_p\left(p^n\right)\right]\right\} \end{aligned}$$

where the sign of $\left(\partial p^n/\partial \hat{z}\right)$ is determined with the help of Condition 1 [i.e., $\left(\bar{\phi}_{bb} + \bar{\phi}_{bf}\right) > 0$]. Again,

$\left(\partial p^g/\partial \hat{z}\right)$ cannot be unambiguously signed, except around $p^g = p^n$, in which case $\left(\bar{\phi}_{ff} + \bar{\phi}_{fb}\right) > 0$

suffices to imply $\left(\partial p^g/\partial \hat{z}\right) < 0$. However, regardless of the sign of $\left(\partial p^g/\partial \hat{z}\right)$, it must be true that

$\left(\partial p^n/\partial \hat{z}\right) > \left(\partial p^g/\partial \hat{z}\right)$, provided that the demand assumption holds.

Similarly, holding $\hat{z}$ constant, comparative statics for changes in c and t are

$$(34) \qquad \begin{aligned} \left(\partial p^n/\partial c\right) &= \left(-1/\Delta\right)\left\{a_{22}\left(\bar{L}\bar{\pi}_{pp}\left(\bar{p}^n\right) + \bar{\phi}_{ff}\right) - a_{12}^2\right\} < 0 \\ \left(\partial p^f/\partial c\right) &= \left(1/\Delta\right)\left\{a_{22}\pi_{pp}\left(p^n\right)\left(L - \Theta(\hat{z})\right)\right\} > 0 \\ \left(\partial p^g/\partial c\right) &= \left(\partial \bar{p}^b/\partial c\right) = \left(-a_{12}/\Delta\right)\pi_{pp}\left(p^n\right)\left(L - \Theta(\hat{z})\right) > 0 \end{aligned}$$

$$\left(\partial p^n/\partial t\right)=\left(\partial p^f/\partial t\right)=\left(-1/\Delta\right)\left\{a_{22}a_{12}-a_{12}\bar{\phi}_{bb}\right\}=\left(-a_{12}/\Delta\right)\left\{\pi_{pp}\left(p^g\right)\Theta(\hat{z})+v''\left(p^g\right)\right\}>0;$$

(35) $$\left(\partial p^g/\partial t\right)=\left(-1/\Delta\right)\left(a_{11}\bar{\phi}_{bb}-a_{12}^2\right)<0$$

$$\left(\partial\bar{p}^b/\partial t\right)=\left(1+\left(\partial p^g/\partial t\right)\right)=\left(1/\Delta\right)a_{11}\left[\pi_{pp}\left(p^g\right)\Theta(\hat{z})+v''\left(p^g\right)\right]>0.$$

Proof of Proposition 7. The impact on price and GM acreage for the case when $\hat{z}=z^0\left(c,t\right)$ is readily

demonstrated, using (32), by setting $p\equiv p^n=p^g$ (and hence $dp=dp^n=dp^g$), and by bringing $d\hat{z}$ to the

left-hand side of the equation. Doing so, and inverting, yields

(36) $$\begin{bmatrix} dp \\ dz^0 \end{bmatrix}=\left(\frac{1}{\Delta'}\right)\begin{bmatrix} \theta(\hat{z})\pi_p(p) & \theta(\hat{z})\pi_p(p) \\ -(a_{22}+a_{12}) & (a_{11}+a_{12}) \end{bmatrix}\begin{bmatrix} h_p \\ h_{\hat{z}} \end{bmatrix}$$

where

$$\Delta'\equiv\theta(\hat{z})\pi_p(p)\left(a_{11}+a_{22}+2a_{12}\right)>0$$

$$h_p=-\left\{\left[\bar{L}\bar{\pi}_{pp}\left(\bar{p}^n\right)+\bar{\phi}_{ff}\left(p^f,\bar{p}^b\right)\right]dc+a_{12}dt\right\}$$

$$h_{\hat{z}}=-\left\{a_{12}dc+\bar{\phi}_{bb}dt\right\}$$

and where a_{ij} are as defined in the proof of Lemma 2. Proceeding as earlier, using the same demand

assumptions, it is readily verified that

(37) $$\begin{array}{ccc} \left(dp(c,t)/dc\right)\in(-1,0) & & \left(dz^0(c,t)/dc\right)>0 \\ \left(dp(c,t)/dt\right)\in(-1,0) & \text{and} & \left(dz^0(c,t)/dt\right)<0 \end{array}$$

where $p^n=p^g=p$, whereas European prices are such that $p^f=\left(p+c\right)$ and $\bar{p}^b=\left(p+t\right)$. What

remains to be shown is the impact of higher t on monopoly profits. The result follows because, given the

corner solution, $\left(d\Pi^M/dt\right)\Big|_{z^0(c,t),\ p^n=p^g}=\left(d\Pi^M/d\hat{z}\right)\Big|_{z^0}\left(dz^0(c,t)/dt\right)<0$, where the sign follows because,

by virtue of the corner solution, $\left(d\Pi^M/d\hat{z}\right)\Big|_{z^0}>0$, and we have shown that $\left(dz^0(c,t)/dt\right)<0$.