Genetically Modified Maize, Biodiversity, and Subsistence Farming in Mexico

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Abstract

Concern over the loss of genetic diversity in the world's field crops has increased due to the commercial introduction of genetically modified crops. Mexico is particularly sensitive to this issue, as it is the center of genetic diversity for maize and home to a large number of indigenous farmers who propagate this diversity. This paper analyzes to what extent the biodiversity of maize may be endangered as subsistence farmers are forced off their land. Off-farm migration is suggested as a potential rational response of farmers to the large and rapidly growing imports of maize from the U.S., a large share of which consists of genetically modified maize. The maize imports from the U.S. are seen not only as worsening the terms of trade of subsistence farmers but also as raising the risk of lower yields as indigenous varieties of maize may lose their resilience to environmental stress through contamination with genetically modified maize.

Key words: genetically modified maize, biodiversity, maize imports, subsistence farming, supply response of farmers, off-farm migration, Mexico.

JEL category: Q1, Q2, F18

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I   INTRODUCTION

In terms of caloric intake, maize is the number one crop in the world according to the statistics of the Food and Agriculture Organization (FAOSTAT). The issue of preserving the plant's genetic diversity is thus of significant policy importance. Even though several scientific studies have been conducted by now, the latest one being the European Commission report by Messean et al. (2006), a resolution of the issue of *transgenic*[1] contamination of Mexico's native maize varieties is not likely to occur in the near future.[2]

As the debate on genetically modified (GM) maize is ongoing, not only in Mexico following the 1998 moratorium on growing GM maize,[3] but also elsewhere, such as in Europe, this paper will add some fundamentally economic arguments to the debate as it pertains to Mexico.[4] In particular, it is examined how the current biodiversity of maize in Mexico may be endangered as subsistence farmers, who maintain and propagate the biodiversity, are forced off their land as a consequence of the large and rapidly rising maize imports from the U.S. These imports not only worsen the terms of trade of subsistence farmers, but, as much of the imported maize is of the GM variety (such as *Bt corn*[5]), they also raise the risk of lower yields as indigenous varieties of maize may lose their resilience to environmental stress through contamination with GM maize.

The paper is organized as follows. The subsequent section will provide some institutional background on the connection between biodiversity and maize farming in Mexico. This is followed by a section that examines empirically the impact on the behavior of Mexican maize farmers of arguably the most important economic event that has affected them since the mid 1990s: the very large increase in maize imports from the U.S. This is done for two reasons. First, there is not much point in arguing about the loss

in biodiversity through the impact of GM maize if one cannot predict that enough subsistence farmers with an interest in indigenous maize varieties will be left a decade from now to take on the job of preserving the biodiversity of maize. Second, by observing farmers' reactions to a major change in their economic environment, it may be possible to distill what drives farmers' behavior. That, in turn, will help predict how farmers may react to the lower yields that may arise from a contamination of their indigenous maize varieties with GM maize.

The section following the empirical analysis discusses to what extent the observed empirical regularities are consistent with a model of rational behavior of farmers. The model provides, among other things, a first explanation of the puzzling fact that output of maize has reacted very little to the sharp decrease in the price of maize since NAFTA was enacted in 1994 (Ackerman et al. 2003; Nadal 2000 and 2002). Based on this model, some tentative policy recommendations can be formulated on what set of economic policies and incentives may support the objective of preserving the current biodiversity of maize in Mexico.

II INSTITUTIONAL BACKGROUND

Since the beginning of the Green Revolution in the 1940's, modernization of agricultural practices in the developing world has attracted the attention of policy makers. Increasing the scale of farm production through technological innovation has regularly been promoted as a substitute for low-output indigenous agriculture. Subsistence farming is often viewed by governments as an indication of economic inefficiency, and its

eradication is perceived as a harbinger for a modern economy[6]. However, such views ignore that subsistence farmers, throughout the world, promote and protect the genetic diversity of native crop species and thus provide a significant public service to all of humanity. Due to their diversity, traditional varieties generally outperform modern varieties in the adverse conditions that the indigenous farmers face. The rich diversity of domestic varieties[7] not only meets local consumption requirements, which may be very specific,[8] but it also minimizes the agronomic risks posed by drought, climatic change, soil degradation, and insect infestation (Perales et al. 2003).

The genetic diversity that subsistence farmers propagate is also valuable to modernized agricultural nations, such as the United States. Capital-intensive farming in the industrialized world has created an increasing demand for genetically modified seeds that are resistant to pests or certain chemical applications. Industrial agriculturalists, due to the restrictions of mechanical farm production, can not promote genetic diversity and are not yet required to fully internalize the environmental degradation attributable to commercial fertilizers and pesticides. Thus, mechanized agriculture necessarily renders high levels of crop diversity economically infeasible. Potential pitfalls that attend low levels of crop diversity become evident when severe crop damage occurs due to disease or pest infestation, as happened in the United States in 1970 when approximately 25 percent of the U.S. maize crop was destroyed by the southern leaf blight (Boyce 1996; Nadal 2000).[9] Due to the ecological pressure of pests and disease, the average commercial life of a modified seed is only about seven years (Boyce 1996). Commercial plant breeders must continually use the genetic material from different varieties of a crop to obtain the desired pest and disease resistant qualities. Off-farm[10] conservation

methods, such as germ plasm banks, preserve the native varieties only at a specific moment in time and can not capture the evolutionary changes of the crop. Thus, off-farm conservation is only a compliment, not a substitute to the on-farm conservation performed by the farmers.

The incentive structure, which motivates the production process of the subsistence farmer, is markedly dissimilar to that of the conventional cash-crop farmer. This fact is clearly evident when one considers that U.S. producers do not face the same environmental and financial constraints as Mexican subsistence farmers, who are generally relegated to isolated lands marginally unfit for industrial agriculture, with no access to credit. A farmer who employs large amounts of physical capital expects to make a profit, while the expectation of the peasant farmer is to sell the surplus crop (if any), after own-consumption needs and seed requirements are met. Ashraf et al. (2005) contend that the agricultural provisions of the North American Free Trade Agreement (NAFTA) have had no discernible effect on the Mexican subsistence farmer. The initial fear that NAFTA would destroy the indigenous farmers of Mexico by forcing them to compete with the heavily subsidized farmers of the United States appears unfounded, as Mexican subsistence farmers have shown no significant agricultural diversification away from maize during a period in which the average price of maize in Mexico fell by 50 percent. Ashraf et al. (2005) also show that 75 percent of all the farmers surveyed report growing maize as their principal means of subsistence, while only 12-22 percent reported maize as the primary cash-crop. Of the poorest farmers surveyed from 1991-2000, 89-92 percent reported that maize was their primary crop for subsistence and 56-57 percent reported they did not produce maize to sell in the market. A survey of peasant farmers in

the Guanajuato region of Mexico by Smale et al. (2001) reveals that farmers unanimously recognize maize as a critical component of their livelihood and grow maize even when it is unprofitable to do so.

Mexican subsistence farmers use labor-intensive methods to cultivate several varieties of maize,[11] with different planting and harvest times, to hedge against environmental risk.[12] Accordingly, indigenous farmers, with smaller plots of land, have a comparative advantage in labor-intensive farming over their larger and less diverse counterparts. Seed varieties favored by modern agriculture require large amounts of chemical inputs and are bred for low-stress environmental conditions not suitable for the small-scale farmers in Mexico (Soleri and Cleveland 2001). Most indigenous farmers raise their crops on peripheral lands that are primarily rain-fed, as opposed to the heavily irrigated farmland of industrial agriculturists. However, the cultivation of different varieties of maize is not only implemented to mitigate the environmental constraints of production, where irrigation and fertilizers are not readily available. Smale et al. (2001) find the determining factor in the allocation of maize varieties is the differential in consumption preferences for specific varieties. Subsistence farmers have also been found to cultivate crop varieties for the purpose of ensuring that the seeds from these crops remain available in their community. Perales et al. (2005), in a study of maize diversity between neighboring towns in the Chiapas highlands, find that maize varieties are cultivated *"distinctly"* according to *ethnolinguistic* groups. The authors show that farmers continue to use local maize varieties even when a superior and otherwise acceptable substitute is available from neighboring farmers. Knowledge of genetic resources[13] is generally well-defined among indigenous communities, due to the significance of securing reliable food

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supplies (Bellon 2001).   Yet, diffusion of genetic knowledge between different *ethnolinguistic* groups is often costly due to language and ethnic barriers (Perales et al. 2005). Reluctance, on the part of indigenous farmers, to substitute away from their local maize varieties is cited as one possible explanation for the persistence of native varieties.

III   EMPIRICAL REGULARITIES

1 Data and Methodology

The empirical results make use of data published by the Food and Agriculture Organization (FAO). The FAO data set is rather limited and extends from 1991 to 2004 for most variables. There are no separate data on commercial and subsistence farmers available from FAO. The data used are defined in Table 1.

TABLE 1. VARIABLE DEFINITIONS

Variable	Definition
price	Producer price of maize (US $/ton)
imports	Import quantity of maize (1,000 tons)
area	Area harvested of maize (1,000 Ha)
yield	Yield per hectare of maize (tons/Ha)
cpi	Consumer price index, derived from the *cpi* inflation rate
mig	Off-farm migration, calculated as (population growth rate at t times agricultural population at t - 1) – agricultural population at t

Notes: All data relate to Mexico and cover the time period 1991-2004, except *price*, which ends in 2003. The data are taken from FAO, http://faostat.fao.org/default.aspx.

The estimates are based on the structural time series approach, which is also known as unobserved component modeling, as advocated by Harvey (1989, 1997) and as

implemented, among others, by Koopman et al. (2000).[14] Univariate structural time series models can be expressed as

$$y_t = \mu_t + \sum_i \sum_j \alpha_{ij} x_{i,t-j} + \varepsilon_t \qquad \text{for } t = 1,...,T,$$

where μ_t is a time-dependent intercept term, which is modeled as a stochastic process, and where the x_i are observed regressors as in ordinary least squares regression. The stochastic term μ_t captures unobserved influences driving the dependent variable. It is assumed to follow a random walk with time dependent drift (β_t). The drift parameter itself may follow a random walk,

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \qquad \eta \sim \text{NID}(0, \sigma_\eta^2)$$

$$\beta_t = \beta_{t-1} + \xi_t \qquad \xi \sim \text{NID}(0, \sigma_\xi^2).$$

Both μ_t and β_t are driven by white-noise disturbances, η_t and ζ_t. These disturbances are assumed to be independent of each other and of ε_t.[15] The general trend model can be tested down to a simpler form, such as a model with no drift parameter, for which μ_t would be written as

$$\mu_t = \mu_{t-1} + \eta_t \qquad \eta \sim \text{NID}(0, \sigma_\eta^2),$$

or, for example, a model with deterministic trend, which arises when the disturbances η_t and ζ_t have zero variance. OLS is a limiting case of the structural time series model. It arises when β_t and the variance of the disturbance terms η_t are both zero.

The advantage of the structural time series model over OLS is that it can capture movements in the data that are not represented by the observed independent variables. This can play a significant role in applications such as the present one where the data set is rather limited in the sense that potentially relevant variables are missing because they are not measured or are not known theoretically. In the absence of allowing for unobserved components in these cases, the left-out variables will typically show up in OLS estimates as spurious trends, unexplained lags on variables, or residual statistics that suggest misspecification. It should be obvious that the inclusion of unobserved stochastic components is a second-best approach, like all black-box methods.[16] Ideally, one would want to replace unobserved components with observed variables. Oftentimes, the movement of the unobserved components over time will provide some hints as to what variables may be driving them. Hence, unobserved component modeling may help in the process of identifying the data generating process. In fact, if all relevant variables are being employed in a particular application of structural time series modeling, no unobserved components should be statistically significant any longer and the model collapses to OLS.

2   Estimation Results

A key element in understanding the behavior of Mexican maize farmers is the relationship between maize imports from the U.S. and the producer price of maize in Mexico. Anecdotal evidence (Lambrecht 2005; Campbell and Hendricks 2006) suggests that farmers find it difficult to survive when the output price of maize drops. Most commentators take it for granted that the massive influx of U.S. maize into Mexico

following the implementation of NAFTA in 1994 is responsible for the decrease in the maize price. A recent study by the Word Bank (Fiess and Lederman 2004), however, appears to suggest that U.S. imports do not play much of a role for the price of maize.

Since there is little statistical evidence of a stochastic trend, the structural time series model that explains the maize price as a function of maize imports and maize yield collapses to OLS. A negative sign is expected for the explanatory variables *imports* and *yield*. The estimated equation in log-linear format for the time period 1991 to 2003 is given as

$$\ln price = 7.11 - \underset{(0.00)}{} 0.173 \underset{(0.001)}{\ln imports} - 0.582 \underset{(0.072)}{\ln yield}$$

$$R^2 = 0.8251, Auto = 0.53, LB = 0.40, JB = 0.81, Het = 0.54,$$

where p-values are provided in parenthesis underneath the estimated coefficients. P-values are also given for a test of first-order autocorrelation (*Auto*), the Ljung-Box test of autocorrelation up to lag order four (*LB*), the Jarque-Bera normality test (*JB*), and a test for heteroskedasticity (*Het*). None of the p-values suggest any statistical problem at conventional levels of statistical significance. The estimates suggest that a 10 percent rise in imports has lowered the maize price by 1.7 percent over the sample period. Since imports tripled over the period from the pre-NAFTA average for the years 1991 to 1993 to the year 2004, this elasticity estimate suggests that imports are responsible for about a fifty percent drop in the price of maize.

Based on previous research (Fiess and Lederman 2004) and anecdotal evidence (Lambrecht 2005; Campbell and Hendricks 2006), the acreage cultivated of maize has reacted little to the dramatic change in the price of maize since the implementation of

NAFTA. This observation is consistent with regressions on the FAO data. Similar to the price equation, no unobserved component appears significant for the regression of acreage on the price of maize ($price_{-1}$) and the consumer price index (cpi_{-1}), both lagged by one year,[17]

$$\ln area = \underset{(0.00)}{9.38} - \underset{(0.819)}{0.075} \ln price_{-1} - \underset{(0.647)}{0.044} \ln cpi_{-1}$$

$$R^2 = 0.0948, Auto = 0.83, LB = 0.61, JB = 0.54, Het = 0.23,$$

Although there is no statistical problem evident with the estimated equation, it clearly does not explain acreage. Neither the price of maize nor the consumer price appears to influence acreage.

It is often suggested that maize farmers may be forced to leave the agricultural sector and migrate to the cities as economic conditions worsen on the farm (Lambrecht 2005). A worsening of conditions could be associated with lower output prices, rising inflation, or lower yields associated with a contamination of the maize crop with GM maize. The migration data used in this study are derived from FAO data on total population growth and agricultural population figures (Table 1). Migration is explained as a function of the acreage and yield of maize. As more acreage is planted, one would expect more work opportunity for agricultural workers. This should reduce migration. Similarly, as yields go up, everything else constant, subsistence farmers are better off. Again, this should reduce off-farm migration. Over the time period 1991-2004, the structural time series model contains a smooth trend, which is brought about by the variance of η being zero in combination with the variance of ξ being positive. The estimated coefficients of the fixed regressors and some statistical adequacy tests are given as

$$\ln mig = 7.35 - \underset{(0.02)}{0.097} \ln area - \underset{(0.10)}{0.085} \ln yield$$
$$\underset{(0.00)}{}$$

$$R^2 = 0.846, Auto = 0.20, LB = 0.90, JB = 0.98, Het = 0.29,$$

Starting the regression sample one year later in 1992 raises the parameter values of both *area* and *yield* considerably. At the same time, the unobserved trend becomes statistically insignificant. An OLS regression over the period 1992-2004 yields

$$\ln mig = 7.76 - \underset{(0.00)}{0.119} \ln area - \underset{(0.00)}{0.298} \ln yield$$
$$\underset{(0.00)}{}$$

$$R^2 = 0.9137, Auto = 0.84, LB = 0.44, JB = 0.65, Het = 0.58,$$

where none of the statistical adequacy tests suggests a statistical problem.

The regressions explaining off-farm migration for Mexico for the 1990s and early 2000s suggest that increases in both acreage and yield have a retarding effect on migration. Given that maize acreage has changed little since the early 1990s, while yields have been rising somewhat, the results indicate that off-farm migration would have been higher in the absence of these two trends. They also reveal that a drop in yields that may be brought about by GM maize contaminating the traditional maize varieties may have significant consequences for off-farm migration.

IV A MODEL TO EXPLAIN THE OBSERVED BEHAVIOR

The purpose of this section is to check whether the empirical regularities described in the last section are consistent with common assumptions of maximizing behavior on the part of farmers. This is done by postulating a simple utility maximization problem for a maize farmer and checking whether the empirical findings can be encompassed by this model. An analysis of this type is useful for two reasons. First, there has been some

suggestion (Fiess and Lederman 2004) that farmers have somehow behaved irrationally in response to the large decrease in the maize price. Second, without an understanding of the core driving forces behind farmers' behavior, it is difficult to formulate economic policy prescriptions about preserving biodiversity.

The farmer's decision problem is to maximize a constant relative risk aversion utility function,

$$u = \frac{\left[\theta^\alpha (m - \bar{m})^\beta s^\delta\right]^{1-R}}{1-R},$$

where utility depends on consuming (a) a given fixed amount of maize that is taken from own production (θ), (b) household products that are purchased from outside the farm (m and $\bar{m}$), and (c) leisure (s). R is the coefficient of relative risk aversion and α, β and δ are weight parameters. It is assumed that a certain minimum number of household products need to be purchased off the farm. This minimum is identified as $\bar{m}$. Following the Stone-Geary utility function, household products purchased off-farm (m) are assumed to raise utility only to the extent that their quantity exceeds the required minimum.

Utility is maximized subject to a time constraint and a budget constraint. According to the time constraint, total available time, which is set to unity for simplicity, has to be divided between leisure (s), time spent working on the farm (n), and a certain amount of time that is tied directly to the acreage planted, ιa,

$$1 = s + n + \iota a,$$

where a is the acreage or land that is under cultivation. Maximization of the utility function is also subject to the budget constraint

$$p^* \left[z\left(a^\eta n^\varphi + \omega a\right) - \theta \right] = p(\omega a + m + \bar{m}),$$

where the left-hand side of the budget constraint is the revenue from selling maize in the open market and where the right-hand side contains all expenditures on off-farm goods and services.

Revenue from selling maize is the product of the market price of maize (p^*) and the quantity of production that is not destined for own consumption (θ). Production is assumed to be given by the production function

$$y = z\left(a^\eta n^\varphi + \omega a\right),$$

where z is a productivity parameter. There are four production factors: land or acreage planted (a), labor (n), capital, and supplementary factors purchased in the market. Only two of these four factors, land and labor, are treated as decision variables of the farmer. The parameters η and φ are their corresponding weights in the production function. Capital is assumed constant and normalized to unity for simplicity.

The fourth factor of production is given by the term ωa.[18] It encompasses such items as fertilizer or rented farming machinery. This term may also include hired farm workers. The latter requires the additional assumption that the wages of farm workers are proportional to the price of household goods and services (p). All factors of production purchased off-farm are assumed to be linearly dependent on the acreage under cultivation (a), with the proportionality factor ω. By allowing for off-farm purchases of factors of production, the model can encompass the decision problem of farmers who are not subsistence farmers. The decision problem of a subsistence farmer is nested within this more general setting: it results by setting the parameter ω equal to zero.

p is the price of market goods and services purchased off-farm. There are two types of goods and services that are purchased off-farm, those related to the production of maize discussed above (ωa) and those related to household consumption (m and $\bar{m}$). The non-production items purchased off-farm include a required part $\bar{m}$ and the optional amount m. For simplicity, it is assumed that the farmer does not enter the credit market. Hence, all off-farm purchases, whether for production or household use, have to be paid for from the market sale of maize.

The maximization of the farmer's utility gives rise to the standard Lagrangian function

$$\max_{\{a,m,n\}} L = \frac{\left[\theta^{\alpha}(m-\bar{m})^{\beta}(1-n-\iota a)^{\delta}\right]^{1-R}}{1-R} + \lambda\left[p^{*}\left[(za^{\eta}n^{\varphi}+\omega a)-\theta\right]-p(\omega a+m+\bar{m})\right],$$

where variable s has been substituted out by the time constraint. The variables acreage (a), off-farm purchases of household items (m), and labor input (n) are the farmer's decision variables. In principle, this maximization problem is of a type that is easy to solve by standard methods. However, in this particular case, the specification of the two constraints prevents a simple reduced-form solution of the first-order conditions for the decision variables. To get around this problem, the comparative static properties of the model are derived from a numerically specified version of the model. The numerical assumptions are split into two groups, those that relate to the economic environment and encompass prices and multi-factor productivity,

$$p^{*} = p = 1, z = 2,$$

and those that relate to farmers,

$$\theta = \bar{m} = 0.5, \alpha = \beta = \delta = 1, \iota = 0.05, R = 0.5, \eta = \varphi = 0.5, \omega = 0.2.$$

A distinction is made between subsistence farmers and market-oriented or commercial farmers. Since subsistence farmers are assumed to not engage in market transactions for factors of production, the value of ω is zero for them. By contrast, the assumption $\omega > 0$ identifies a commercial maize farmer who is engaging in market transactions, not only for household goods and services but also for factors of production.

The values of the endogenous variables that solve the maximization problem for the commercial and the subsistence farmers, respectively, are given as follows,

Commercial farmer: $a = 8.572, m = 3.200, n = 0.180, s = 0.391, y = 5.914, u = 1.454$
Subsistence farmer: $a = 6.677, m = 1.986, n = 0.334, s = 0.332, y = 2.986, u = 0.994$

Table 2 presents comparative static results for a decrease in the price of maize, a rise in the price of off-farm goods and services, and a drop in total factor productivity. All changes are assumed to be on the order of 25 percent.

The two price changes are of particular interest for evaluating the empirical results of the previous section. Their impact on farmers will be discussed first. Both the commercial farmer and the subsistence farmer react to an increase in the price level of off-farm products similar to how they do to a decrease in the price of maize. This is not surprising as either price change worsens the terms of trade of farmers. As a consequence of the price changes, farmers purchase fewer off-farm products for household consumption (m), work more (n), and spend less time on leisure (s). With a constant level of consumption of maize (θ) utility (u) has to go down for both types of farmers.

Commercial farmers and subsistence farmers respond differently to a worsening of their terms of trade with their decision variable acreage (a). Commercial farmers decrease

acreage, while subsistence farmers increase acreage. The different response is a direct result of the assumption that subsistence farmers do not purchase factors of production off-farm. Despite the different response of acreage, both farmers increase output.

TABLE 2. COMPARATIVE STATIC RESULTS FOR THE THEORETICAL MODEL

Variables	Commercial Farmer			Subsistence Farmer		
	$p \uparrow 25\%$	$p^* \downarrow 25\%$	$z \downarrow 25\%$	$p \uparrow 25\%$	$p^* \downarrow 25\%$	$z \downarrow 25\%$
a	8.445	8.393	8.571	6.957	7.050	7.236
m	2.287	2.063	2.000	1.589	1.490	1.427
n	0.219	0.233	0.238	0.348	0.353	0.362
s	0.359	0.347	0.333	0.304	0.295	0.276
y	6.095	6.155	4.714	3.111	3.153	2.427
u	1.133	1.042	1.000	0.814	0.764	0.716

The evidence provided by Ackerman et al. (2003), the empirical results of the last section, and the work of Fiess and Lederman (2004) suggest that the farming sector in total has not reacted to the price decrease in maize with a reduction in output or acreage. Both have held steady or have even slightly increased. The fact that output has not fallen in response to the sharp drop in the price of maize is fully consistent with the theoretical model. Both commercial and subsistence farmers are predicted to raise maize output. There is little irrational about this behavior when one considers the constraints maize farmers are likely to face.

The empirical results for total farming also suggest that acreage does not respond significantly to a fall in the price of maize or a rise in the consumer price index. This is consistent with the comparative static results of Table 2 insofar as commercial farmers

are predicted to change their acreage in exactly the opposite direction of subsistence farmers. Their actions may cancel out in the aggregate. If the acreage of commercial farmers is more accurately measured than that of subsistence farmers in Mexico, and/or if subsistence farmers are constrained in the expansion of acreage due to lack of usable land, then the comparative static results may suggest a slight decrease in acreage at the aggregate level, which appears to be suggested by the officially measured acreage figures for the period after 1994.

Given that the comparative static results are sufficiently consistent with the empirical evidence, it is interesting to analyze what the theoretical model implies on how maize farmers, and in particular, subsistence farmers would react to the contamination of their fields with GM maize. The comparative static results try to capture the contamination scenario by assuming that a contamination decreases total factor productivity by a quarter.

Such an assumption may be justified for a number of reasons. Given the difficulty of identifying infected maize, it will be almost impossible to stop the process of contamination. Most likely, contaminated maize will be reused as seed even if an infection is obvious if for no other reason than lack of funds on the part of subsistence farmers to root out the contamination and start with clean seed for several seasons. How a contamination is ultimately affecting the indigenous gene pool of maize and the properties of maize is an open question. However, it appears fairly certain that total output of maize will be declining as farmers are unfamiliar with the agronomic properties of the new contaminated seed stock. In addition, the GM maize varieties are not intended for reuse as seed and GM maize is more dependent on fertilizer and pesticide, which

subsistence farmers are not using to any significant degree.[19] In addition, the new hybrid maize varieties may be less resistant to severe weather, in particular drought, because GM maize is intended for irrigated fields. All this suggests an increase in the risk of catastrophic crop loss for subsistence farmers. This may be approximated by assuming that, on average, total factor productivity declines.

The comparative static results of Table 2 reveal that a decrease in total factor productivity will induce subsistence farmers to raise acreage, but without output going up together with acreage. As work effort also rises and the ability to purchase off-farm products for household use declines, the utility level declines perceptively. A 50 percent decline in z, which is twice that depicted in Table 2, reduces utility to less than half the value reported in Table 2. Hence, a more significant drop in productivity than the 25 percent shown in Table 2 may force a large number of subsistence farmers to sell out and leave the farm. This is consistent with the predictions of the estimated migration equation of the previous section, which suggests that migration out of agriculture is firmly tied to maize yields: lower yields induce migration out of agriculture.

When seen in conjunction with the empirical analysis of the last section, the predictions of the theoretical model suggest at least two conclusions that are of relevance for the preservation of biodiversity in Mexico.

First, further sharp increases in imports of maize from the U.S. will likely cause many subsistence farmers to leave their land and migrate to the cities of Mexico or the U.S. This is independent of whether there is any contamination of the indigenous varieties of maize with GM maize. The fact that, so far, acreage has hardly reacted to the surge in imports from the U.S. and the subsequent large decrease in the price of maize or the fact

that output has even increased as price has dropped, should not be taken as a sign that Mexican maize farmers are not under stress. On the contrary, both are a sure sign that farmers do react to the price decrease and that they react rationally. Their response entails more work effort, fewer purchases of off-farm products for household use, and, as a consequence, lower levels of utility. This will make off-farm migration ever more likely over time. However, if subsistence farmers leave the countryside in large numbers, the current levels of biodiversity can not be maintained: with no subsistence farmers, there is no biodiversity. Again, this is completely independent of the issue of contamination of the gene pool by GM maize.

Second, the analysis has suggested that a contamination of the indigenous varieties of maize with GM maize may have similar consequences as a further reduction in the relative price of maize. However, this conclusion is based on the as yet unproven assumption that any maize variety that is an unplanned hybrid of the indigenous varieties and GM maize will be more susceptible to environmental stress, such as droughts and pest infestation, than the current indigenous varieties and, as a consequence, average yields of maize farmers decline.

V   SUMMARY AND CONCLUSIONS

The purpose of this paper has been to model the economic behavior of Mexican maize farmers in order to predict what would be needed from an economic perspective to ensure continued biodiversity.

To that end, the paper has tried to establish empirically the connection between the large imports of maize from the U.S., the price of maize, acreage planted, and off-farm migration. The results suggest that U.S. imports have depressed the price of maize. Acreage, however, has reacted little. Finally, both declining acreage and maize yields are key driving forces of off-farm migration.

The paper has also developed a simple theoretical model to examine whether the empirical results are consistent with rational behavior on the part of farmers and to suggest policy actions to maintain biodiversity. The comparative static properties of the theoretical model are consistent with the key empirical facts. In particular, it is shown that little or no decline in acreage and an increase in production are fully consistent with a declining relative price of maize. But as maize farmers work more and can afford ever fewer off-farm products, their utility levels decline considerably, which will eventually induce them to leave the farm in search of employment in the urban areas of Mexico or the U.S. The theoretical model also suggests that, if contamination of their indigenous maize varieties with GM maize is lowering productivity, then subsistence farmers will likely react to such as contamination in a manner that is similar to that of a reduction in the relative price of maize: they choose to migrate off-farm.

Off-farm migration, however, has significant consequences. First, as many indigenous farmers stop production, the maize gene pool will contract, possibly by a very sizable amount. Although it is difficult to foresee all the consequences of such a result, it does not appear to bode well for the future security of the world's food supply since Mexico is home to the world's only self-sustaining genetic repository for maize. Second, as farmers leave their land, possibly in large numbers, Mexico's cities are likely to experience

significant stress when the now landless farmers arrive and are looking for employment. Based on past experience, it appears unlikely that a large number of former subsistence farmers will find employment. An increase in illegal immigration to the United States is a likely consequence.

In the light of these results, the key policy issue appears to be how to stop a sufficient number of subsistence farmers from leaving their land. That is the prerequisite of keeping biodiversity, even in the absence of GM maize contamination. Given political reality, maize will continue to be imported from the U.S. Some effort may be worthwhile to contain the growth rate of imports. If that is not politically feasible and the relative price of maize continues to decline, cash subsidies need to be considered to keep farmers on the job. These subsidies would be the price to be paid for maintaining the biodiversity. They would constitute a transfer scheme that internalizes the positive external effects that are derived from biodiversity. The subsidies would also be the price to pay to keep Mexican farm workers from illegally immigrating to the U.S. Since Mexico, the U.S., and the world at large reap the benefits of continued Mexican biodiversity, it appears sensible to pay for the subsidies from an international fund rather than from the budget of a single country.

To prevent farmers from leaving their land because of the possibly negative consequences of GM contamination on the yields of domestic varieties it would appear sensible to continue the moratorium on the production of GM maize in Mexico until further research is available on the impact of GM maize on the biological properties of indigenous maize varieties. It would also appear useful to stop state-owned distributors of

maize from moving imported GM maize into areas of Mexico where indigenous varieties are grown to eliminate the possibility of accidental contamination.

NOTES

[1] *Transgenic* denotes contamination of native plant varieties with genetically modified varieties.

[2] Qist and Chapela (2001) allege that GM maize has polluted the native varieties in the Oaxaca region of southern Mexico. This article set off a firestorm of debate (Hodgson, 2002) and has come under intense scrutiny from the scientific community. The primary concern is that GM varieties could displace native varieties and possibly cause introgressive hybridization with the wild relatives of maize, such as *teosinte,* which would forever alter the gene pool.

[3] The Mexican moratorium was enacted largely due to strong political opposition from activist groups representing the country's indigenous farmers, not due to scientific evidence. The ban does not include other genetically modified crops and it does not include imports of GM maize for the purpose of consumption. See in this context Gilbreth and Otero (2001) for an overview of the armed uprising against the Mexican government in the wake of NAFTA.

[4] A non-economic approach is taken by the recent report on maize and biodiversity in Mexico published by the Commission for Environmental Cooperation (2004), and the background studies that were commissioned for that report.

[5] *Bacillus thuringiensis* is a soil bacteria that is toxic to certain pests, especially the European corn borer. *Bt-toxin,* genetically derived from the above mentioned bacteria and currently patented by Monsanto Co., creates crystalline formations on the stalks of maize which act as insecticide.

[6] See Nadal (2002) for an account of the agriculture reform measures taken by the Mexican Government after signing the North American Free Trade Agreement (NAFTA) in 1994.

[7] Boyce (1996) notes that the subsistence farmers of Mexico have also incorporated hybrid modified seeds for years, and artificially selected for desirable traits from these seed stocks. Most researchers agree that this assimilation of "improved" seeds into the gene pool is at a very low level. However, GM seeds pose different risks that are not yet well understood by either the farmers or commercial plant breeders (McAfee 2003).

[8] Mexico's *ethnolinguistic* diversity. with more than 200 language groups among the indigenous peoples, is believed to facilitate local attachments to specific maize varieties (Perales et al. 2005).

[9] According to Boyce (1996), *Bipolaris maydis*, the fungus responsible for Southern Leaf Blight, was infective to plants with the genetic makeup shared by approximately 85percent of the maize grown in the U.S. in 1970.

[10] *Ex situ: off site.* Organizations such as the International Maize and Wheat Improvement Center (CIMMYT) are engaged in facilitating the genetic diversity of wheat and maize to aid developing countries in establishing food security and overall agricultural productivity. See Bellon (2001).

[11] Although this paper only concerns the effects of GM maize, it should be noted that subsistence farmers in Mexico have shown some preferences for creolized varieties derived from cross-pollination between native varieties and modern hybridized varieties. However, Bellon et al. (2005) have shown that in areas with high genetic diversity such as Chiapas, farmers are relatively indifferent to the benefits of creolization.

[12] American farmers often use several different varieties of maize with different plant and harvest dates, albeit on separate plots of land. This was pointed out to one of the authors in a conversation with Matthew Garner, a Tennessee farmer.

[13] This is also one of the central themes of Diamond (1997).

[14] In SAS, unobserved component modeling can be found in the ETS package under the name UCM.

[15] After estimation of the model parameters, a Kalman filter is applied to determine the state vectors μ_t and β_t for each time period.

[16] For completeness, it should be mentioned that more unobserved components can be added to a structural time series model than just a stochastic trend. Other components may be a stochastic cycle or a stochastic seasonal or a stochastic autoregressive component.

[17] The consumer price index is included because it has been suggested (Campbell and Hendricks 2006) that its increase has caused subsistence farmers to raise acreage.

[18] This term is added linearly into the production function for mathematical convenience. As an alternative, it could be added multiplicatively as $(1 + \omega a)$ without changing the gist of the comparative static analysis.

[19] In fact, distributors of genetically modified maize varieties mandate that new seed is purchased for every new planting season. This raises intellectual property rights issues. Compare on that the controversial 2001 Monsanto Inc. vs. Percy Schmeiser verdict in Canadian Supreme Court. Schmeiser was convicted of patent right violation for saving and knowingly replanting the seeds from his canola field, after being infected with Roundup-Ready®Monsanto Co. canola.

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