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ECOLOGICAL DISTRIBUTION, AGRICULTURAL TRADE LIBERALIZATION, AND IN SITU GENETIC DIVERSITY

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Genetic diversity in crop plants is crucial for long-term world food security. This diversity is sustained in the field primarily by poor farmers in developing countries, who receive no compensation for providing this external benefit to humankind. When agricultural imports displace local production in centers of genetic diversity, this threatens both rural livelihoods and the continued provision of this external benefit. The North American Free Trade Agreement's impact on Mexican maize farming illustrates the problem. The prospects for remedial policies are shaped by the distribution of the costs and benefits of action and inaction.

1. INTRODUCTION

The economic case for trade liberalization rests on its capacity to extend the much-vaunted efficiencies of the free market. As trade barriers are lifted, producers are expected to reallocate land, labor, and capital to those activities in which they wield a comparative advantage, abandoning the production of other commodities which can now be imported more cheaply. The result is a larger economic pie which in principle, if seldom in practice, could benefit all concerned.

But with this extension of the market comes a corresponding extension of market failures. Trade liberalization can exacerbate the inefficiencies which result from the fact that external costs and benefits are not reflected in market prices. Say that country A produces corn at a lower internal cost (and hence lower market price) than country B, but in so doing generates larger external costs via pollution and natural resource degradation. A shift of corn production to country A from

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country B, brought about by trade liberalization, will increase the magnitude of these external costs. Conversely, if corn producers in country B generate external benefits (that is, positive externalities) in the form of the conservation and evolution of crop genetic diversity, then liberalization will decrease the magnitude of these benefits. In both cases, the competitive advantage of corn producers in country A over those in country B rests at least in part on the faulty accounting of the market.

Recent discussions of 'environmental dumping'-trade at prices which fail to reflect environmental impacts-have generally shared two limitations. First, they have focused exclusively on negative externalities. Second, they have assumed that in trade between developing countries (the 'South') and industrialized countries (the 'North'), dumping will flow from the former to the latter; that is, producers in the poor, backward South will undercut producers in the more environmentally responsible North.[1]

This essay focuses primarily, though not exclusively, on positive externalities which are crucial for long-run world food security: the conservation and evolution of *in situ* genetic diversity in crop plants. For reasons related to the historical origins of humankind's major food crops, this diversity is located primarily in the countries of the South. In the absence of corrective policies, agricultural liberalization can lead to the displacement of production in centers of diversity by low-priced imports from the North. This exacerbates the genetic erosion which has already occurred with the spread of 'modern' varieties in the South.

The essay is organized as follows. Section 2 discusses ecological distribution that is, the distribution of the costs and benefits associated with environmental externalities-and its implications for the political economy of policy-making. Section 3 provides an overview of the geographical distribution and importance of *in situ* genetic diversity in major food crops. Section 4 illustrates the threat which agricultural liberalization poses to this diversity with the case of Mexican maize under the North American Free Trade Agreement (NAFTA). Section 5 concludes with some reflections on the prospects for remedial policies.

2. ECOLOGICAL DISTRIBUTION AND THE POWER-WEIGHTED SOCIAL DECISION RULE

Environmental externalities have distributional consequences. Some parties benefit from negative externalities: by imposing external costs on others, they avoid internalizing the costs of pollution control or natural resource conservation, in effect receiving a subsidy from those who bear the external costs.[2] Similarly, the fact that those who produce positive externalities cannot internalize the benefits means that, in effect, they pay a tax.

Conventional economic theory suggests that environmental policies-regulations, fiscal incentives, and the creation of marketable instruments such as emission permits-should be guided solely by the pursuit of efficiency, following the normative rule of cost-benefit analysis:

$$\max \sum_i b_i,$$

where b_i = the net benefit to the i^{th} individual (and costs are counted as negative benefits). That is, net benefits summed over all individual members of society should be maximized, constrained of course by available resources.[3] Benefits and costs are denominated in monetary terms, and the fact that some people wield more purchasing power than others gives them greater weight in cost-benefit calculations. But the formula treats all individuals (or more precisely, all dollars) the same, in that a dollar benefit (or cost) to one person counts exactly as much as a dollar benefit (or cost) to any other.

Practice often departs from this normative theory. Environmental policies alter not only the size of the economic welfare pie, but also its distribution. Social decisions may accord greater weight to the benefits (or costs) of some people than to the benefits (or costs) of others. If so, the outcomes can be described as following a power-weighted social decision rule **(PWSDR):**

$$\max \sum_i \pi_i b_i,$$

where ?$_i$ = the power of the i^{th} individual. That is, social decisions maximize net benefits *weighted by the power of those who receive them.* The **PWSDR** corresponds to the cost-benefit rule only in the special case where all individuals are equally powerful (Boyce, 1994).

Just as individual preferences-and the underlying utility functions of neoclassical theory-are revealed by individual choice, so social preferences-and the underlying distribution of power-are revealed by social choice. When the government intervenes to remedy a market failure, we can infer that the power-weighted benefits of those who gain from that intervention exceed the power-weighted costs of those who lose. When the government does not remedy a market failure, we can infer that the power-weighted costs of those who would lose from remedial policies exceed the power-weighted benefits of those who would gain. More generally, the *extent* to which the government intervenes (since intervention is not simply a binary yes-or-no matter) will reflect the balance of power between winners and losers.

Ecological distribution is thus of interest not only because it captures an important, and often neglected, dimension of the impact of environmental policy on human well-being, but also because it sheds light on the distribution of power in society, and thereby on the political economy of the policy-making process itself.

3. IN SITU GENETIC DIVERSITY

Genetic diversity in humankind's major food crops underpins long-term world food security by providing the raw material needed for future crop adaptations to changing pests, pathogens, and environmental conditions. The erosion of this diversity is today a cause for serious concern.

Modern agriculture is characterized by a much higher degree of varietal uniformity than traditional agriculture. This uniformity facilitates high land productivity, but at the same time it increases vulnerability to large-scale crop failures due to plant disease and pest epidemics (NAS, 1972). In response to this genetic vulnerability, plant breeders continually seek to incorporate genes for resistance to emerging pests and pathogens into new varieties. The average life-span of a modern variety for many crops is today less than a decade, after which the variety is replaced by new ones bred for resistance to newly evolved threats. This 'diversity through time' offers a partial substitute for diversity at any given point in time (Duvick, 1984).

The genetic raw material for this varietal relay race comes from the diverse traditional varieties bequeathed to us by earlier generations of farmers.[4] Concerns about the erosion of this genetic diversity have arisen primarily in response to the spread of modern 'high-yielding' (or more precisely, highly fertilizer-responsive) varieties within the agriculture of developing countries. But international trade is a second route by which modern varieties (in this case grown elsewhere) displace traditional varieties.

3.1 Centers of Diversity

In the 1920s, the eminent Russian botanist N.I. Vavilov identified the centers of origin of the world's principal food crops. He found a strong correlation between these ancient centers of origin and modern centers of genetic diversity (see Figure 1). This association is weaker in the case of crops such as wheat, which have a very long history of geographical diffusion, but Vavilov's basic insight is today generally accepted among plant scientists (Hawkes, 1983).

The centers of origin and diversity of the world's major food crops are located in developing countries. Rice originated in the eastern Indian subcontinent, with a secondary center of diversity in north China. Wheat originated in the fertile crescent spanning parts of present-day Turkey, Syria, and Iraq, with secondary centers in Ethiopia and central Asia. Maize originated in what is now southern and central Mexico and Guatemala. Potatoes originated on the Andean slopes of Peru.

Comprehensive data on the international distribution of genetic diversity do not exist. A country-level indicator can be derived, however, from the seed samples

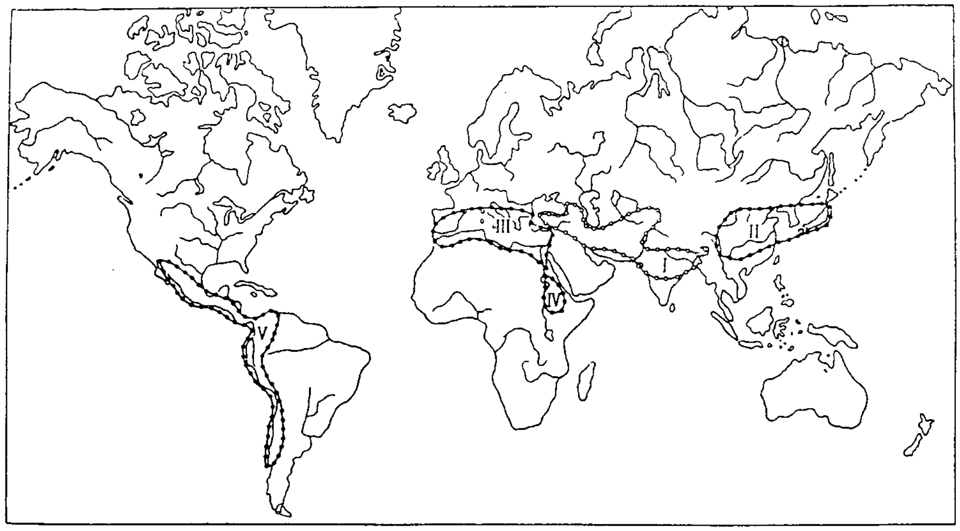

Figure 2. Centers of origin of the most important cultivated plants

Note: *I.* Southwestern Asia; II. Eastern Asia; III. the Mediterranean area; IV. Abyssinia and Egypt; V. mountain areas of Mexico, Central America, and South America.
Source: Vavilov (1926/1992, p. 127).

held in the world's most comprehensive international gene banks. The number of accessions from a given country, divided by an acreage-based area measure, provides an index of genetic diversity.[5] While not a perfect measure collections are uneven across countries, and some accessions are duplicates-this index serves as a useful first approximation of the geographical distribution of crop genetic diversity.

Table 1 presents data on accessions held at the maize gene bank at CIMMYT (the International Center for Maize and Wheat Improvement) in Mexico, the leading international center for maize research. CIMMYT's gene bank held 13,211 maize accessions as of May 1995, of which Mexico accounted for 32%, the largest share of any country. Among major maize-producing countries (with 500,000 hectares or more annually sown to the crop in 1992-1994), Mexico ranks highest on the diversity index, with a value more than one hundred times that of the United States.

Table 2 presents comparable data on accessions held at the rice gene bank at IRRI (the International Rice Research Institute) in the Philippines, the leading international center for rice research. IRRI's gene bank held 80,894 accessions as of April 1996, of which India accounted for 19%, the largest share of any country. Among major rice-producing countries, India ranks highest on the diversity index. A number of other Asian countries also appear to have considerable genetic diversity in rice by this measure.

Table 1
Maize Germplasm Accessions in CIMMYT Gene Bank and Genetic Diversity Index

Country	Number of Accessions	Maize Acreage (1992-94 average, 000 ha)	Genetic Diversity Index*
Mexico	4220	7536	289.8
Brazil	2508	12992	146.3
Guatemala	590	709	82.4
Nepal	212	763	28.9
Colombia	153	732	21.2
Argentina	152	2430	14.7
Ethiopia	29	1100	3.5
United States	43	28047	2.0
China	25	20821	1.3
Angola	6	746	0.8
Malawi	5	1275	0.6
Uganda	4	501	0.6
Zimbabwe	4	1196	0.5
India	4	6052	0.3
Pakistan	2	878	0.3
Philippines	3	3240	0.3
Kenya	2	1388	0.2
Thailand	2	1218	0.2
Egypt	1	821	0.1
Nigeria	1	1567	0.1

Sources: Number of accessions provided by CIMMYT, as of May 1995. Acreage data from the FAO *Production Yearbook 1994*.
* Genetic diversity index = $V/A^{0.3}$, where V = number of accessions and A = maize acreage.

The general picture emerging from the data in Tables 1 and 2 is thus consistent with Vavilov's principle as to the correlation between centers of origin and centers of diversity.

3.2 In situ and ex situ Conservation: Complements, not Substitutes

In response to the long-term threat posed by genetic erosion, national and international agencies have collected and stored seed samples in *ex situ* (off-site) germplasm banks. These *ex situ* collections give plant breeders ready access to genetic diversity, and provide crucial insurance against losses of in *situ* (on-site, or in-the-field) genetic diversity. However, they do not provide a satisfactory substitute for in *situ* genetic diversity for three reasons.

First, gene banks are not completely secure. The seeds must be stored under controlled temperature and humidity conditions, and periodically regenerated by planting to harvest new seed (Roberts and Ellis, 1984). The world's largest maize germplasm collection is in what used to be called Leningrad; the second largest is

Table 2
Rice Germplasm Accessions in IRRI Gene Bank and Genetic Diversity Index

Country	Number of Accessions	Rice Acreage (1992-94 average, 000 ha)	Genetic Diversity Index*
India	15750	41958	646.3
Indonesia	8563	10921	526.2
Philippines	4571	3277	403.1
Malaysia	2798	668	397.6
Thailand	5619	8898	367.2
China	7839	31202	351.6
Bangladesh	5540	10028	349.3
Sri Lanka	2120	804	285.0
Laos	1421	581	210.5
Nepal	1488	1387	169.8
Cambodia	1483	1742	158.1
Myanmar	1884	5673	140.9
S. Korea	1098	1151	132.5
Cote D'Ivoire	862	535	130.9
United States	1107	1250	130.3
Madagascar	1004	1185	120.1
Vietnam	1637	6492	117.6
Japan	1104	2152	110.4
Pakistan	1073	2089	108.3
Guinea	675	979	85.5
Brazil	894	4518	71.6
Nigeria	534	1704	57.3
Iran	195	602	28.6
Egypt	63	539	9.6
N. Korea	7	617	1.0

Sources: Number of acessions provided by International Rice Research Institute, as of April 1996. Acreage data from the FAO *Production Yearbook 1994*.
* Genetic diversity index = $V/A^{0.3}$, where V = number of accessions and A = rice acreage.

in the capital of what remains of Yugoslavia (Plucknett et al., 1987, p. 120). The viability of the seeds in these collections is an open question. Even in relatively wealthy and stable countries such as the United States, plant breeders often complain of inadequate funding for seed collection maintenance from financially strapped governments.[6] Irreplaceable material in gene banks has been lost due to human errors and mechanical failures. At the International Center for the Improvement of Maize and Wheat (CIMMYT) in Mexico, for example, maize collections from the 1940s have been lost (Wade, 1974, p. 1187). 'Back-up copies' of Mexican maize varieties at the U.S. National Seed Storage Laboratory in Fort Collins, Colorado, were also destroyed (Raeburn, 1995, pp. 62-63).

Second, many genetic attributes can be ascertained only by growing the plants in micro-habitats similar to those from which they originated. For example, the fact that a particular variety has a gene which enables the plant to withstand droughts at four-week intervals will not be apparent unless the plant is grown under those specific conditions. The alternative of expressing such genetic attributes in laboratory growth chambers is extremely costly.

Finally, even if it were possible to establish perfectly secure gene banks (which it is not), these could store only the existing stock of genetic diversity at any point in time. The ongoing process of evolution, which created this diversity and continues to generate a flow of new varieties, cannot be stored; it can happen only in the field. Plant breeders can develop new crosses from the existing stock, but they cannot replicate the flow of new raw material from *in situ* evolution.[7]

This is not to imply that gene banks are unimportant. On the contrary, their loss would be catastrophic. The world needs more gene banks, better funding for them, and greater investment in professional training for plant breeders whose knowledge is an essential complement to the gene banks (Wilkes, 1992). Modern plant breeding has played a central role in the tremendous growth in world food output in the past 50 years. And as recent experiences in war-torn Nicaragua and Cambodia have shown, *in situ* biodiversity is also vulnerable to losses, in which case ex *situ* collections can provide crucial back-up copies (Plucknett et al., 1987, p. 94).

In sum, *ex situ* collections are necessary, but not sufficient. They are best regarded as complements to *in situ* biodiversity, rather than as substitutes for it.

More than two decades ago, the botanist Hugh Iltis (1974) called for ‘the deliberate and permanent preservation of selected specific local genetic landscapes, scientifically justified, politically negotiated, and perhaps internationally subsidized.’ In a similar vein, the U.S. National Academy of Sciences recently concluded that *in situ* conservation ‘may be particularly valuable for conserving landraces [traditional varieties] in regions with crop diversity, thus allowing continued adaptation and evolution’ (National Research Council, 1993, p. 128).

In situ conservation of genetic diversity is not necessarily incompatible with technological change. The adoption of high-yielding varieties and high-input technology can and often does co-exist with on-going cultivation of traditional varieties.[8] But in the absence of policies to encourage *in situ* conservation, further losses in genetic diversity are certain. Efforts to prevent these losses so far have been very modest relative to needs (Wilkes, 1992). Mexican maize, now facing competition from an influx of U.S. imports under the North American Free Trade Agreement (NAFTA), is a case in point.

4. NAFTA AND MEXICAN MAIZE

Some 5,000 years ago, farmers in what is now Mexico domesticated maize[9] (see Figure 2). In terms of its cumulative impact on human well-being, this surely ranks among the great technological achievements of history. Over the millennia, maize cultivation spread among the indigenous peoples of the Americas. With

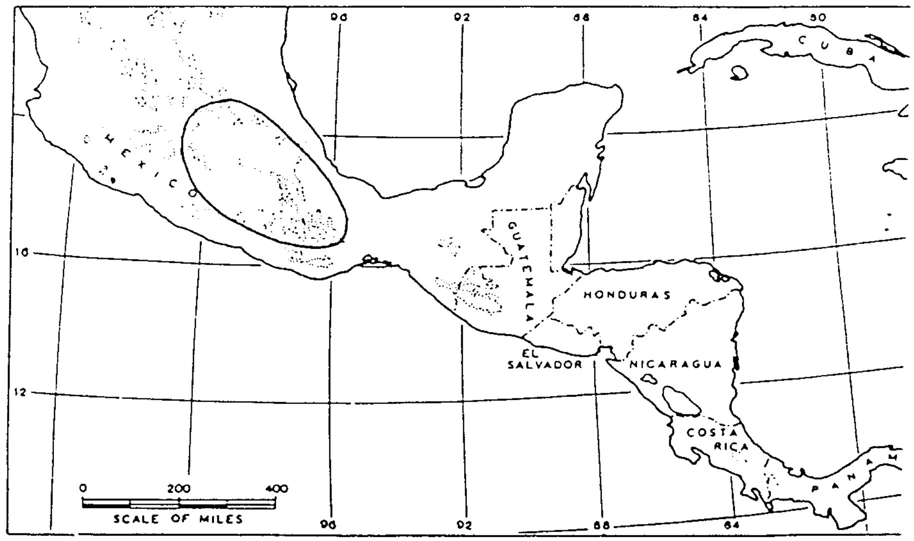

Figure 2. Presumed center of origin of maize

Source: Hawkes (1983, p. 3).

Figure 3. Maize germplasm collection sites, 1943-1952

Source: Wellhausen et al. (1952, p. 41).

the arrival of the Europeans it eventually spread across the globe, but central and southern Mexico remained the center of genetic diversity in maize, consistent with Vavilov's principle. When scientists collected maize germplasm in the 1940s and 1950s, they found an remarkable profusion of varieties in this region (see Figure 3).

4.1 Evolutionary Gardens

The *campesinos* of southern and central Mexico today grow approximately 5,000 different varieties of maize.[10] In a single village in Oaxaca, for example, researchers Raul and Luis Garcia-Barrios (1990) found that peasants distinguished among 17 different environments in which they grew 26 different maize varieties.

Scientists refer to the Mexican *campesino* farmers' hilly, rainfed maize plots as 'evolutionary gardens,' or 'gardens of chaos' (Wilkes, 1992, pp. 24-26). The 'cultivated natural capital' of crop varieties is complemented by the 'natural capital' of the wild and weedy relatives of the crop species (Martinez-Alier, 1993, p. 110). Here maize and its wild relative, teosinte, continue to evolve under the pressure of natural selection. Introgression, back-and-forth hybridization between maize and teosinte, augments the evolutionary process. As the environment changes and as new strains of insect pests and plant diseases evolve, the interaction between nature and human purpose yields a stream of new varieties adapted to changing conditions. Mexico's *campesinos* thus not only maintain and reproduce a vast *stock* of maize varieties; they also manage an ongoing evolutionary flow of new varieties.

4.2 Competition from the United States

Maize is today the leading crop in both Mexico and the United States. In the U.S. it covers one-seventh of the arable land; in Mexico it covers nearly one-third. The U.S., with average yields of 7.4 metric tons per hectare (mt/ha), produces roughly 200 million mt of maize each year on some 300,000 farms; Mexico, with average yields of 2.0 mt/ha, produces roughly 14 million mt on 2.7 million farms (see Table 3). Most U.S. maize is used as animal feed; most Mexican maize is consumed directly by people in the form of *tortillas.*

U.S. production techniques differ dramatically from those of the Mexican *campesinos. Six* maize varieties account for almost half of the U.S. acreage; only a few hundred, most of which are closely related, are available commercially. With much area under few varieties, U.S. maize is genetically vulnerable to insect and disease epidemics, as was dramatically illustrated when the southern corn leaf blight destroyed one-fifth of the nation's crop in 1970 (National Academy of Sciences, 1972; Walsh, 1981). To keep ahead of the rapidly evolving pests, plant breeders must release a constant stream of new maize varieties. On average, commercial

Table 3
Corn Agriculture in Mexico and the United States

	Mexico	United States
Production:		
Area (million hectares)	7.3	27.1
Share in total cropland (%)	31.7	14.4
Yield (metric tons/ha)	2.0	7.4
Output (million mt)	14.6	201.5
Number of farms (million)	2.7	0.3
Input use:		
Area fertilized (%)	70	97
Area under hybrids (%)	33	100
Area irrigated (%)	15	80
Area treated with herbicides (%)	NA	96
Area treated with insecticides (%)	NA	29
Tractors/farm worker	0.02	1.5
Varietal diversity:		
Number of varieties available	5000	454
Share of top six varieties (% of area)	NA	43

NA = not available.
Sources: Appendini (1992); Duvick (1984); Food and Agriculture Organization of the United Nations (1992); Scott (1992a,b); United States Department of Agriculture (1993); United States Department of Commerce (1988); and Wilkes (1993).

maize varieties in the U.S. are replaced every seven years (Duvick, 1984, p. 164).

Ninety-six percent of U.S. maize acreage is treated with herbicides, and about one-third with insecticides. Although comparable data are not available for Mexico, usage there is lower, particularly amongst small farmers." The herbicides and insecticides used on U.S. maize have contaminated groundwater supplies in a number of states (see Table 4). A five-year survey conducted by the U.S. Environmental Protection Agency (1990) found that atrazine, the most widely used herbicide in corn fields, was present in the water of one in every 60 community water systems and in one in 140 private wells nationwide. Citing concerns as to human cancer risks and effects on aquatic organisms, the Environmental Protection Agency (1994) launched a Special Review of atrazine and two closely related herbicides, which could eventually lead to restrictions or a total ban on their use.

By the standard of market prices, U.S. maize production is more ‘efficient’ than Mexico’s.[12] When NAFTA was negotiated, U.S. maize cost about $110 per ton at the border, while in Mexico maize farmers received $240 per ton.[13] The Mexican government has long restricted maize imports to protect domestic growers. Under NAFTA that protection is being phased out over a 15-year period. The controversial nature of this measure, striking close to the heart of traditional Mexican culture,

Table 4
Top Pesticides in U.S. Corn Agriculture, 1992

Name	Annual use, 17 major corn-growing states (million pounds)	Acreage treated (%)	Detected groundwater contamination from normal agricultural use (number of states)
Herbicides:			
Atrazine	54.9	69	13
Metolachlor	41.3	30	5
Alachlor	40.1	27	12
Cynazine	26.7	20	6
Insecticides:			
Terbufos	6.3	8	5
Chlorpyrifos	6.2	8	–
Fonofos	2.0	3	2
Carbofuran	1.6	2	3

Sources: United States Department of Agriculture (1993, pp. 8-9); Ritter (1990, p. 4); and Extension Toxicology Network (1989, p. 3).

is reflected in the fact that this is the slowest phase-out of protection for any commodity under the trade agreement.[14]

The price advantage of U.S. maize has four sources: (1) natural factors, notably better soils, more regular rainfall, and a killing frost which reduces pest populations in the U.S. corn belt; (2) farm subsidies which reduce the U.S. market price;[15] (3) the exclusion of environmental costs such as groundwater contamination from market prices, which is of greater importance in the U.S. where agrochemical use is more intensive; and (4) the failure of market prices to capture the value of the maintenance of genetic diversity by Mexican maize farmers.

4.3 The Displacement of *Campesino* Maize

NAFFA will not totally eliminate Mexican maize production. Large-scale Mexican growers on the best soils, many of whom use U.S.-style production techniques including commercial hybrid varieties, irrigation, and intensive agrochemical applications, will be able to compete successfully; and very small-scale traditional growers producing solely for their own household consumption might be less sensitive to the market price (see Table 5).[16] NAFTA is expected to result in the contraction of Mexico's maize acreage in coming years, however, as cheaper imported maize from the U.S. displaces domestic production. This reflects a shift in Mexican government policy which predated the signing of NAFTA: in December 1991 the Ministry of Agriculture planned to reduce the country's corn acreage by one-third by 1996 by cutting subsidies and protection in the name of 'modernization' (Solis, 1991). In 1994, the first year of the treaty,

Table 5
Farm Size Distribution in Mexican Corn Agriculture

Corn acreage (hectares)	Farms (%)	Harvested area (%)	Production (%)	Sales (%)
< 2.5	65.0	30.5	34.4	17.3
2.5-10	32.8	55.2	50.9	57.4
> 10	2.2	14.3	14.7	25.3

Source: Appendini (1992, p. 132).

U.S. grain exports to Mexico increased by more than one-third (Browne, 1995, p. 2).

Estimates of the number of Mexican maize farmers who will eventually be displaced by U.S. imports vary widely. Much of the abandoned maize land is likely to be converted into cattle pastures, which require far less labor. Relatively conservative estimates predict that hundreds of thousands of *campesinos* will migrate to Mexican cities (and perhaps to the U.S.) as a result. Upper-end predictions run as high as 15 million people including family members - one-sixth of the Mexican population.[17]

The extent of *campesino* displacement in Mexico could be mitigated by government measures to support 'modernization' of maize production (that is, a shift toward hybrids, irrigation, and higher use of purchased inputs) and diversification to other crops (de Janvry, Sadoulet, and Gordillo de Anda, 1995).[18] Such support would represent a marked departure from the recent trend toward cutbacks in marketing, credit, and technical assistance services for Mexican farmers. Even if such a policy reversal were forthcoming, these measures would not necessarily arrest the loss of *in situ* genetic diversity in maize; indeed, they could accelerate it.

5. POLICY IMPLICATIONS

Hours after NAFTA went into effect in January 1994, peasants in the southern Mexican state of Chiapas launched the Zapatista uprising, declaring that the trade agreement represented a 'death sentence' for Mexico's indigenous peoples (Fox, 1994; Perera, 1994). As the foregoing discussion suggests, Mexican *campesinos* are not the only parties who will be harmed by free trade in maize with the United States-at prices uncorrected for environmental costs and benefits. In their efforts to defend their livelihoods, Mexican maize farmers have potential allies among environmentalists and others worldwide who recognize the importance of sustaining *in situ* genetic diversity in this critical food crop. The prospects for appropriate policies are likely to hinge on the mobilization of this support.

5.1 NAFTA and Maize: Winners and Losers

The impact of liberalization of the corn trade between Mexico and the United States on ecological distribution arises from both positive and negative externalities. Positive externalities, in the form of the conservation and evolution of *in situ* genetic diversity, are generated south of the border, and benefit humankind at large. Negative externalities, associated with intensive agrochemical use, are concentrated in the U.S. (though they also arise in 'modern' Mexican maize farming). Under free trade-in the absence of remedial policies-traditional Mexican growers will sell at prices which fail to reflect the full social benefit of their production, while U.S. producers sell at prices which fail to internalize environmental costs.

The principal winners and losers are depicted in Table 6. The main winners from corn trade liberalization are the U.S. corn producers and grain traders, who gain a substantial new market, and Mexican consumers who can now buy corn more cheaply. The extent to which Mexican consumers will benefit from lower prices is complicated, however, by the fact that many, particularly in urban areas, have long bought corn at subsidized prices; hence the main effect may be to ease the fiscal burden of the Mexican government. [19]

The most immediate losers are the Mexican corn producers, whose livelihoods are undercut by cheap imports. The environmental impacts of corn production create two further groups of losers: (i) future human generations worldwide, whose food security will be diminished by the reduction of *in situ* genetic diversity in maize, and (ii) those adversely affected by the agrochemical pollution resulting from increased U.S. corn production.

It would be difficult to place monetary values on these externalities, but related exercises suggest that the sums involved are large. The National Academy of Sciences (1993, pp. 317-319) estimates the value of *ex situ* rice germplasm, simply in terms of its contribution to modern 'green revolution' varieties, at roughly $400 million per year, and states that calculations for maize give a similar result.[20] I know of no attempts to calculate the economic value of *in situ* crop diversity, but if this is a necessary complement to *ex situ* collections, as argued above, then such valuations should be ascribed jointly to both.

Table 6
Winners and Losers from Free Trade in Maize

Winners	Losers
* U.S. corn producers and grain traders * Mexican consumers and/or government	* Mexican corn producers * future generations world-wide (due to loss of genetic diversity) * U.S. residents adversely affected by agro-chemical pollution

With respect to pesticide use, Pimentel et al. (1992) estimate the external costs in the United States at $8.1 billion/year, equivalent to more than 10% of the annual value of U.S. crop production.[21] This estimate is incomplete in that it excludes water and soil pollution, and omits possible human health effects such as cancer and sterility.

5.2 Prospects for Remedial Policies

The governments of the industrialized nations have long protected their farm sectors with tariffs, quotas, and subsidies; agriculture is sometimes described as 'the world's most protected industry.[22] The stated rationales for agricultural protection-the safeguarding of employment, political stability, cultural values, national food security-are probably at least as compelling in Mexico today as they ever were in the United States, Europe, or Japan. In the case of Mexican maize, however, there is a further powerful rationale for protection: the need to sustain genetic diversity in one of humankind's most important food crops.

In practice, trade policy is often shaped more by private interests than by the public interest. Economists have long argued that the costs of trade protection to consumers generally exceed the gains to producers. The balance of power between them is invoked to explain the resilience of protectionism, as smaller numbers and larger per capita effects confer a political advantage to producer interests.[23] Here too, one can observe the operation of the power-weighted social decision rule.

If it could muster sufficient political will to do so, the Mexican government could implement unilateral measures to protect *campesino* maize. Trade policy is among the possible measures. Import restrictions 'imposed for the protection of plants or animals, including measures for protection against disease, degeneration or extinction' have been recognized as legitimate as far back as the 1946 Canada Mexico Trade Agreement (Charnovitz, 1993, p. 10072). While NAFTA rules out the imposition of anti-dumping duties in response to differences in environmental standards, it contains exception clauses derived from GATT which permit environmental measures 'necessary to protect human, animal or plant life or health' and 'measures relating to the conservation of living and non-living exhaustible resources.'[24]

While ecological tariffs or other import restrictions on maize are a feasible response, they are not first-best policies. In principle, a more efficient alternative would be ecological subsidies: payments to Mexican maize farmers to reward their contribution to the public good via *in situ* conservation of genetic diversity. Subsidies have several advantages: they can be targeted exclusively to those farmers who grow traditional varieties; they do not raise food prices to consumers; and they may prove easier to reconcile with the current provisions of NAFTA. One problem with subsidies, however, is the need to ensure that these flow to those who con serve genetic diversity, and not to others. Administrative corruption and lack of information can pose serious practical difficulties in this regard.

A further drawback of subsidies, of course, is that they constitute a claim on the public exchequer, whereas tariffs would bring in revenues. Given the fact that the benefits of genetic diversity accrue to current and future generations worldwide, this financial burden is one which the international community can be asked to share. One proposal in this vein is to tax royalties from seed sales and devote the proceeds to germplasm conservation (Barton and Christensen, 1988; National Research Council, 1993, p. 42). Such a mechanism could support *in* situ as well as ex situ conservation.

Whatever the choice of policy instruments-tariffs, subsidies, or nonmarket incentives-it should be emphasized that *in* situ conservation need not mean 'freezing the genetic landscape' (Iltis, 1974), much less freezing the social landscape. Many farmers cultivate both traditional and modern varieties. Furthermore, no hard dividing line separates the two: the evolution of 'traditional' varieties over time can and sometimes does involve the incorporation of genetic material from 'modern' varieties. Breeding and selection with the diversity objective in mind could produce profitable near-traditional varieties, with a positive net effect on genetic diversity.[25] In any event, broad-based improvements in the livelihoods and economic security of rural Mexicans will be critical to the success of *in* situ conservation: if *campesinos* must move to the city to survive, the micro-habitats which have been sustained by their labor will be lost, and with them the maize varieties adapted to them.[26]

International political backing, as well as financial support, is needed for Mexican initiatives to protect genetic diversity in maize. Recent history has demonstrated that the main domestic protagonists of traditional maize varieties – the *campesinos* – today exercise little leverage over Mexican government policy. The *campesinos* could have important allies internationally, however, among all those concerned with genetic diversity's role in world food security.

5.3 Concluding Observations

In the increasingly globalized world economy, we can no longer rest assured that poor farmers in developing countries will underwrite the long-term well-being of humankind by sustaining *in situ* genetic diversity in our key food crops. The geographical isolation and political resistance of these farmers are eroding in the face of both technological change and trade liberalization. Unless innovative policies are implemented to reward farmers for their contributions to the public good, we cannot expect these contributions to continue.

If the balance of power which governs social decisions were dictated by exogenous factors beyond human agency, political economy would be a dismal science indeed. History teaches a more hopeful lesson: people can organize to change the balance of power and thereby alter the course of events. Building international cooperation to sustain *in situ* genetic diversity will put this capacity to a challenging test. One element of the solution will be to devise ways to compensate the farmers who perform this valuable service.

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NOTES

1. For discussions, see Daly (1993); Chichilnisky (1994); Copeland and Taylor (1994); and Munasinghe and Gupta (1995).

2. Templet (1995, p. 143) observes that firms which externalize costs reap 'a subsidy, internal to the firm, consisting of unspent pollution control dollars'; he terms this a 'pollution subsidy.'

3. In the language of welfare economics, application of this rule yields a potential Pareto-improvement: with a larger pie, some people could be made better off while making no one else worse off. In strict Paretian terms, however, the result is 'efficient' only if the winners actually compensate the any losers to achieve this outcome.

4. Plant breeders rely heavily on selected 'elite' breeding lines for the production of new hybrids. The traditional 'landraces' from the farmers' fields provided the original genetic material in these lines, and landraces continue to be used as the main source for introducing greater diversity into them. For

$$I = V/A^z,$$

where V =the number of varieties (proxied by gene-bank accessions), A = the acreage under the crop, and z is a parameter expressing the variety-area relationship given constant diversity. In Tables 1 and 2, z is set to a value of 0.3, following a mathematical rule of thumb commonly used by biologists for the species-area curve (Mann and Plummer, 1995, pp. 55-56).

6. For example, Duvick (1984, p. 176) remarks: "I reserve my most severe condemnation for those government agencies ultimately responsible for funding of our germplasm collections. Our national stinginess in collecting, storing, renewing and describing the collections is inexcusable, not only in regard to our national obligations, but also in regard to our responsibility to the entire world." See also Sun (1986), Cohen et al. (1991), and Raeburn (1995, Ch. 2). Similar complaints have been voiced regarding the collections of the International Agricultural Research Centers (Goodman and Castillo-Gonzales, 1991).

7. For further discussion of the need and potential for in situ conservation of crop genetic resources, see Prescott-Allen and Prescott-Allen (1982), Altieri and Merrick (1987), and Brush (1992, 1995).

8. See Bellon and Taylor (1993), Bellon and Brush (1994), Brush (1995), and Louette and Smale (1996).

9. The domestication of maize is often dated 7,000 years ago, but recent evidence has led some paleobotanists to revise this to 4,700 years ago (Fritz, 1994). The literature on the origins of maize is reviewed by Minc and Vandermeer (1990, pp. 81-95); for an account of the timing controversy, see Wilford (1995).

10. H. Garrison Wilkes, personal communication, 1993. The exact number is unknown, not only because no one has attempted a complete inventory, but also because the definition of a 'variety' is problematic. Recent advances in genetics make it possible to ascertain the extent to which two plants contain identical genes, but even then a definitional problem remains: what percentage of genes must the two plants have in common to be termed the same variety?

11. A 1994 survey of *ejido* maize producers found that only 35% used herbicides, insecticides, or fungicides. For small farmers (cultivating less than 2 hectares), medium farmers (2-10 hectares), and large farmers (more than 10 hectares), the shares using any of these pesticides were 15%, 34%, and 51 %, respectively (calculated from data reported by Secretarfa de Reforma Agraria, 1995, pp. 5.17 and 5.19).

12. Even environmentalists, who might be expected to know better, have accepted this narrow standard of efficiency. In a recent publication of the Worldwatch Institute, for example, Kane (1995) writes that under NAFTA, "The Mexican corn sector will be hit hard because U.S. production is more efficient, its yields far higher."

13. Scott (1992a). Levy and van Wijnbergen (1992, p. 496) report similar figures for 1989, and note that the price paid by urban consumers in Mexico was held below the world market price.

14. Mexican resistance to U.S. corn imports was one of the most difficult issues in the negotiation of NAFTA's agriculture chapter. In return for the 15-year phase-out, Mexico agreed to allow the immediate duty-free import of up to 2 million mt of U.S. corn per year (Thurston and Negrete, 1992).

15. These subsidies include direct payments, credit programs, price supports, and publiclyfinanced agricultural research and extension. Based on a review of 75 separate programs available to U.S. farmers, the Canadian government estimated U.S. corn subsidies at $50/ton (roughly $1.45/ bushel) in the mid-1980s (Clark, 1986). The U.S. Department of Agriculture (1994, p. 362) calculates that U.S. producer subsidies peaked at $54/ton in 1987 and declined to $21/ton in 1992. Calculated producer subsidies for corn in Mexico were higher-$122 and $113/ton in the same years-but these policies tended to raise rather than reduce market prices (USDA, 1994, pp. 226, 233). U.S. subsidies have been further reduced in subsequent years, as have Mexican subsidies (Browne, 1995). For U.S. corn farmers, unlike their Mexican counterparts, NAFTA provides a cushion against the income impact of declining subsidies (Bradsher, 1992).

16. A recent World Bank study (L6pez et al., 1995) reports that 'low capital-input' farmers in Mexico are less responsive to price changes (and more likely to grow principally corn) than wealthier farmers. The authors regard this as unfortunate, and recommend policies to 'improve the efficiency with which the sector adjusts to new incentives.'

17. Estimates prepared for the World Bank indicated that in the first five years of NAFTA, between 145,000 and 300,000 farmers could abandon their land (DePalma, 1993). Jose Luis Calva of the National Autonomous University of Mexico predicted that total rural out-migration, including family members, could reach 15 million people (Calva, 1992, p. 35). For other estimates, see Levy and Wijnbergen (1991a, 1991b), Robinson et al. (1991), and Harvey and Marblestone (1993). De Janvry, Sadoulet and Gordillo de Anda (1995) argue that likely labor displacement has been overestimated since roughly half of *ejido* maize growers do not produce market surpluses. Even among these growers, however, some households may shift to cheap imported corn to meet consumption needs, resulting in further contraction of maize acreage.

18. In a similar vein, Levy and van Wijnbergen (1995) advocate a program of public investment in land improvements, notably irrigation, to offset losses to Mexican maize farmers.

19. For an *ex ante* analysis, see Levy and van Wijnbergen (1992).

20. For discussion of the valuation of genetic diversity, see Swanson, Pearce and Cervigni (1994); and Swanson (1996). For a skeptical view, see Martinez-Alier (1993).

21. The 1992 Census of Agriculture placed the total market value of U.S. crop output at $75.2 billion (U.S. Department of Commerce, 1994, p. 8).

22. See, for example, Bradsher (1992). In recent years the governments of the industrialized countries have moved to ease agricultural protection, but the reductions achieved have been modest (see Ingco, 1995).

23. See, for example, Ray (1990). Recent efforts to endogenize trade policy have explicitly incorporated political influence (for surveys, see Baldwin, 1989; and Hillman, 1989).

24. NAFTA Article 2101.1. For discussion, see Charnovitz (1993) and Wilkinson (1994).

25. For further discussion of policies to promote *in situ* conservation, see Brush (1992, 1995).

26. For an analysis of the relationship between rural depopulation and environmental degradation, see Garcia-Barrios and Garcfa-Barrios (1990).

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