Optimization of Policy Goals in the Context of a Sector Model

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Abstract

This article investigates the possibilities of including policy choices directly into a sector model that simulates an economic equilibrium It uses a mathematical programming framework because these models have wide applicability in agricultural sector analysis The objective function is quadratic because the authors assume demand functions are linear They formulate a policy choice model which they apply to Mexican agriculture

Keywords

Policy modeling, mathematical programming, Mexican agriculture

Introduction

Incorporating a policy choice problem into a sector programming model directly is usually impossible because the sector model's objective function and constraint set are designed to simulate the equilibrium outcome of decentralized decisionmaking (*5*)[1] Imposing a policy maximand on the model will destroy the simulating character of the outcome Imposing policy constraints on the model will create a similar problem

This article explores a special case in which the policy maximand and the market-simulating maximand coincide They coincide when policymakers wish to maximize consumer plus producer surplus Although the sum of surpluses is not a welfare measure in itself, Willig has shown that it can often be a good approximation of a true welfare measure (*13*)

The empirical problem formulated in this article is how to allocate a fixed Government budget to subsidies of several targeted crops in Mexico [2] Given that the Mexican Government wishes to subsidize its agricultural sector to benefit both producers and consumers, a question arises about the most efficient allocation of crop subsidies The analysis covers Mexico's eight principal crops corn, wheat, sorghum, rice, soybeans, dry edible beans, safflower, and sesame In analyzing the results, we give particular attention to the effects of policies on trade, because these crops have been assigned priority under recent Mexican programs aimed at attaining food self-sufficiency

Methodology

Mathematical programming models have become progressively more sophisticated The use of the programming framework is still limited, however, in terms of conducting systematic and comprehensive agricultural policy analyses Although these models are useful in determining the impacts of specific policies, they are far less valuable in formulating complete statements of policy problems and in identifying "optimal" policy instruments

The policy-cum-simulation problem is inherently a two-level maximization problem (*4*) A policy objective function is maximized subject to policy limits (such as budget constraints) *and* subject to maximization of the market-simulating objective function This problem cannot be solved by normal mathematical programming algorithms, in fact, there is no procedure for obtaining the global joint

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[1] Italicized numbers in parentheses refer to items in the References at the end of this article

[2] We selected these crops because they might help achieve other objectives, such as food self-sufficiency, which are not explicitly stated in the model If these other objectives are explicitly stated, then we must move from a single to a dual-level programming framework to model the Mexican policy problem (*1*)

maximum However, local point optima can be found in some cases (*3*)

In view of these difficulties, the typical procedure for analyzing policy options is to solve the sector model (with market simulating maximand) repeatedly, under different values of policy *parameters* The consequences of different policies can thereby be explored The literature contains numerous examples of this procedure (*2, 7, 12*) The procedure clearly requires prior specification of potentially interesting policy options, it does not permit formal maximization of a policy objective function Nevertheless, economists have conducted some fairly systematic explorations of the "policy-feasible space" in this way (*1, 6, 10*)

Thus, policies are generally treated as exogenous in the usual sector model framework For example, demand or supply functions are shifted to reflect taxes or subsidies, or tariffs are added to world prices After these policies are incorporated, the solution can be interpreted as a market equilibrium under Government intervention

Our approach, however, differs somewhat because the model itself determines values of policy variables The objective function is still the maximization of producer plus consumer surplus But, because the objective function contains policy choice variables, its purpose is no longer only to describe market behavior It now describes the market's reaction to a given allocation of subsidy funds, and it simultaneously evaluates alternative outcomes and allocates subsidies in a way that maximizes the surpluses The problem is essentially a two-level problem (*3*) which is collapsed to one level in this special case If the public- and private-sector problems were to diverge (for example, if the policy problem were to maximize employment rather than producer and consumer welfare), then the one-level approach would no longer be valid and a two-level model would apply

The "optimal" crop subsidy program will be a function of the Government decision rule (that is, the maximization of the net sum of producer plus consumer welfare), the set of policy instruments available to policymakers, the size of the Government budget, and the behavior of the private sector in response to Government intervention (namely, the implicit or explicit supply and demand functions) Thus, the interaction of the public and private sectors is especially important when the policy problem is formulated

We formulated this "optimal" subsidy model for the small-country case with fixed costs and linear demands as follows

$$\text{Max} \sum_i (a_i x_i^c + \tfrac{1}{2} b_i x_i^{c\,2}) - \sum_i c_i x_i^p + \sum_i s_i x_i^p + \sum_i p_i^e x_i^e - \sum_i p_i^m x_i^m \qquad (1)$$

Subject to

$$R x^p \leq \bar{r} \qquad [\lambda_j] \; j = 1, \; , M \text{ resources} \qquad (2)$$

$$-x_i^p + x_i^c + x_i^e - x_i^m \leq 0 \qquad [\pi_i] \; i = 1, \; , N \text{ crops} \qquad (3)$$

$$\sum_i s_i x_i^p \leq \bar{g} \qquad [\theta] \qquad (4)$$

$$s_i \leq \bar{s}_i \qquad [\phi_i] \; i = 1, \; , N \text{ crops} \qquad (5)$$

The endogenous variables include

x^c = a vector of quantities demanded,
x^p = a vector of quantities produced,
p^c = $a + bx^c$ = a vector of domestic consumer prices, where the matrix (b_i) is a diagonal matrix of demand slopes,
x^e = a vector of exports,
x^m = a vector of imports, and
s = a vector of output subsidies

The exogenous variables include

p^e = a vector of world prices for exports,
p^m = a vector of world prices for imports,
c = a vector of unit costs of production,
R = technology matrix, where r_{ji} is the quantity of the jth resource or input used to produce one unit of crop i,
$\bar{r}$ = a vector of resource constraints,
$\bar{g}$ = the Government budget constraint,
$\bar{s}$ = a vector of crop subsidy upper bounds, and
$\lambda, \pi, \theta, \phi$ = Lagrangian variables associated with the constraints

Formulated in this manner, the model includes several new quadratic terms in the objective function and a quadratic budget constraint Forming the Lagrangian results in the dual problem and the rules by which the optimal subsidy program is selected

$$L = \sum_i \left(a_i x_i^c + \tfrac{1}{2} b_i {x_i^c}^2\right) - \sum_i c_i x_i^p + \sum_i s_i x_i^p + \sum_i p_i^e x_i^e - \sum_i p_i^m x_i^m + \sum_j \lambda_j \left(\bar{r}_j - \sum_i r_{ji} x_i^p\right) + \sum_i \pi_i \left(x_i^m - x_i^e - x_i^c + x_i^p\right) + \theta \left(\bar{g} - \sum_i s_i x_i^p\right) + \sum_i \phi_i \left(\bar{s}_i - s_i\right) \quad (6)$$

The main first order conditions are

$$\frac{\partial L}{\partial x_i^c} = a_i + b_i x_i^c - \pi_i \leq 0 \qquad i=1, \ldots, N \quad (7)$$

or

$$a_i + b_i x_i^c = \pi_i \qquad \text{for } x_i^c > 0$$

$$\frac{\partial L}{\partial x_i^p} = - c_i + s_i - \sum_j \lambda_j r_{ji} + \pi_i - \theta s_i \leq 0 \qquad i=1, \ldots, N \quad (8)$$

or

$$\pi_i = c_i + \sum_j \lambda_j r_{ji} + \theta s_i - s_i \qquad \text{for } x_i^p > 0$$

[Shadow price] = [marginal cost of production] + [marginal cost of resource use] + [implicit cost of budget restriction] − [output subsidy]

The first equilibrium condition states that, for each commodity, the implicit valuation, or shadow price, equals the market price This is the usual equilibrium condition The second first-order condition states that, for each commodity, the shadow price equals the marginal cost of production plus the implicit marginal cost of resource use plus the shadow price of the budgetary restriction minus the value of the crop subsidy In other words, the price can now be less than marginal cost, by the amount of the subsidy, adjusted for the opportunity cost of budgetary funds

Thus, the presence of policy variables in the model is reflected in the second first-order condition Equilibrium prices are modified by the subsidies and the shadow value of the Government budget constraint The figure depicts an output subsidy for a single commodity and its impact on the equilibrium price

In the figure, q^o is the unsubsidized market equilibrium quantity, and q^s is the quantity when a subsidy s is in effect The price symbols are p^p = producer price, p^o = unsubsidized market price, and p^c = consumer price

The figure is a conventional diagram of market equilibrium under a subsidy with one exception the difference $(p^p - p^c)$ is no longer equal to the nominal subsidy, but rather to the true subsidy, taking into account the opportunity cost of Government funds Relating the figure to equations (7) and (8), we have

$$p^p - p^c = s(1 - \theta) \quad (9)$$

where the subscript i has been dropped for convenience

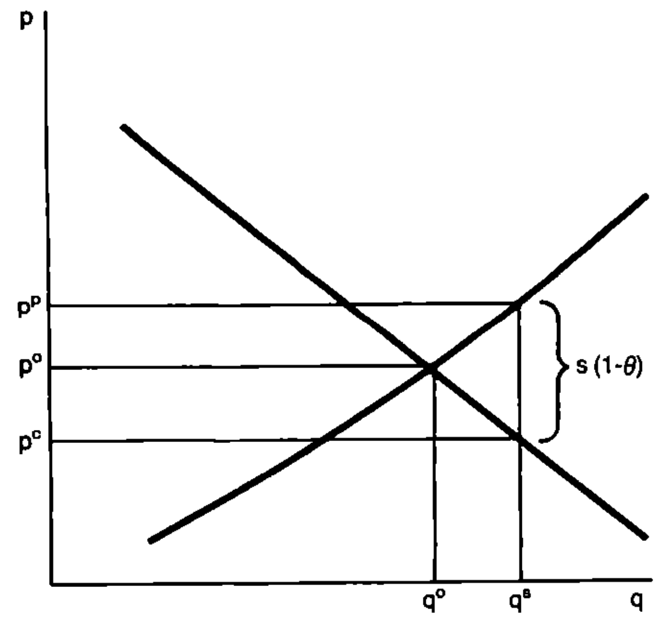
Equation (9) follows because equation (7) says that $\pi_i = p_i^c$ and equation (8) says that $\pi_i = p_i^p - s(1 - \theta)$

Application to Mexican Agriculture

The sector model used for this research is described in detail in (*1*)[3] It was adapted from the World Bank's model of Mexican agriculture (CHAC) (*11*)

[3]The development of the technical coefficients and demand parameters for the original 1968 CHAC model is well-documented (*11*) The technical coefficients and resource constraints were updated to 1980 for this research based primarily on aggregate trends Price elasticities of demand were assumed fairly stable over time Income elasticities were derived from several sources (*1*)

Modified Equilibrium under Subsidies



The model's base solutions were good representations of actual supply and demand in Mexican agriculture in both 1968 and 1980 The base variants were modified subsequently to form the optimal subsidy version

Whereas the original CHAC model was expressed in a linear programming format through a linear approximation procedure (*11*), the quadratic terms of our model have not been approximated The model was solved with MINOS, a mathematical programming algorithm that uses a reduced gradient method for solving large-scale problems with nonlinearities in the objective function and/or the constraint set (*9*)

In modifying the original model, one needs two kinds of parameters the total subsidy budget available ($\bar{g}$ in equation (4)) and the upper limits on subsidy rates by crop ($\bar{s}_i$, in equation (5)) We arbitrarily varied the values of these parameters in different solutions We used three sets of illustrative values, which were not unrealistic for Mexican agriculture and policy in 1980 to define the following three main alternative solutions

Case	Total subsidy budget	Upper bounds on crop subsidies
	Billion pesos	
1	25	1,000 pesos/ton[1]
2	25	40 percent of equilibrium prices
3	35	40 percent of equilibrium prices

[1]At 1980 prices, the 1,000 peso subsidy limit represented the following percentage subsidies of base-year prices sorghum, 29, corn, 28, paddy rice, 27, wheat, 23, soybeans, 16, safflower, 13, beans, 9, and sesame, 5

Tables 1-6 present the three alternative solutions In case 1, the model chose seven of eight targeted crops–rice, safflower, dry beans, sesame, corn, sorghum, and wheat—to subsidize at the upper subsidy limit Total subsidies to the three most important targeted crops—corn, sorghum, and wheat—are clearly the largest, therefore, they make the largest contributions to the value of the objective function Tables 1 and 2 also show that allocating subsidies to these three crops increases their total supplies Corn output increases 13 percent over the equilibrium solution with no subsidies, sorghum output increases 4 percent, and wheat output increases 14 percent. However, output decreases for the other four subsidized crops Both rice and safflower output decline 5 percent, dry edible bean output declines 6 percent; and sesame output falls 37 percent Sesame exports also decline 40 percent These declines occur because the crop substitution effects are stronger than the output effects of the subsidies

The supplies of alfalfa, sugarcane, barley, and cotton, and of nontargeted crops not eligible for subsidies decline significantly in absolute terms Small absolute declines, but large percentage reductions, are indicated for minor crops such as lima beans (-15 percent) and flaxseed (–62 percent) Declines in total output of important export crops (tomatoes, melons, and vegetables) range from only 1 percent to 6 percent,[4] strawberry output declines slightly more (10 percent)

[4]We assume that Mexico is a price taker in all foreign commodity markets This assumption is unrealistic in the case of most fresh vegetable and fruit trade, especially in the winter months when Mexico's production competes with Florida's production for the U S market Other research based on CHAC focuses on the fresh vegetable- and fruit-producing regions of Mexico and relaxes the small-country assumption (*12*)

Table 1—Case 1: Commodity impacts of subsidy program[1]

Crop	Subsidies: Solution	Subsidies: Upper bound	Consumption	Exports	Imports	Production	Change in production from base solution[2]
	Pesos per ton		*1,000 tons*				*Percent*
Garlic			47 3	15 0		62 3	-1
Alfalfa			17,033 0			17,033 0	-6
Cotton			1,814 4	175 0		1,989 4	-4
Rice	1,000	1,000	606 8			606 8	-5
Sugarcane			13,926 2		400 0	13,526 2	-12
Squash			224 3			222 43	-2
Safflower	1,000	1,000	411 0			411 0	-5
Peanuts			166 4			166 4	-6
Onions			205 7	100 0		305 7	-1
Barley			650 7		200 0	450 7	-22
Dry chili			30 3	5 0		35 3	NC
Green chili			224 4	20 0		244 4	NC
Strawberries			161 4	60 0		224 1	-10
Beans	1,000	1,000	960 2			960 2	-6
Chick peas			347 5	100 0		447 5	NC
Lima beans			50 4			50 4	-15
Tomatoes			902 7	355 0		1,257 7	-1
Sesame	1,000	1,000	75 0	60 6		135 6	-37
Flaxseed			21 3		17 0	4 3	-62
Corn	1,000	1,000	9,840 4		242 6	9,597 8	13
Cantaloup			295 4	100 0		395 4	-5
Potatoes			745 4			745 4	-1
Cucumber			51 2	150 0		201 1	NC
Watermelon			615 7	100 0		715 7	-6
Sorghum	1,000	1,000	4,344 8			4,344 8	4
Soybeans	0	1,000	557 4		557 4	0	NC
Wheat	1,000	1,000	3,769 6			3,769 6	14

Blanks indicate not applicable NC = No change [1]Total available budget is 25 billion pesos Individual subsidies limited to 1,000 pesos per ton [2]Base model solution is the equilibrium solution with no subsidies

Table 2—Case 1: Policy impacts of subsidy program[1]

Item	Unit	Amount	Change from base[2]
			Percent
Budget	10 million pesos	1,929 8	
Objective	do	42,012 7	5 0
Exports	do	1,399 0	5 0
Imports	do	547 8	-50 0
Net trade	do	851 2	120 0
Employment	1,000 work years	2,471 8	6
Food grains	1,000 tons	13,367 4	13 5
Consumer surplus	10 million pesos	28,174 4	-9 0
Sector income	do	13,982 6	51 0

Blanks indicate not applicable NC = no change [1]Total available budget is 25 billion pesos Individual subsidies limited to 1,000 per ton [2]Base model solution is the equilibrium solution with no subsidies

Our conclusion is that important crop substitution occurs in Mexico among crops in the basic grain and oilseed group Substitution between crops in this group and most major export crops is less important Furthermore, the fact that production of some subsidized crops declines highlights the importance of considering the price ratios among targeted crops (as well as between targeted and nontargeted crops) when one formulates a crop subsidy program In other words, if a goal of this subsidy program had been to stimulate output of all targeted crops, as was the case for the Sistema Alimentario Mexicano (SAM) program, the desired objectives would clearly not have been met

Tables 3 and 4 present the results when the total budget constraint is again 25 billion pesos, but

Table 3—Case 2: Commodity impacts of subsidy program[1]

Crop	Subsidies: Solution	Subsidies: Upper bound	Consumption	Exports	Imports	Production	Change in production from base solution[2]
	Pesos per ton		*1,000 tons*				*Percent*
Garlic			47 8	15 0		62 8	NC
Alfalfa			18,083 9			18,083 9	NC
Cotton			1,892 3	175 0		2,067 3	NC
Rice	1,464	1,464	636 2			636 2	NC
Sugarcane			15,723 4		400 0	15,323 4	NC
Squash			227 8			227 8	NC
Safflower	0	3,123	432 5			432 5	NC
Peanuts			181 6			181 6	NC
Onions			209 1	100 0		309 1	NC
Barley			691 3		115 7	575 6	NC
Dry chili			30 4	5 0		35 4	NC
Green chili			225 2	20 0		245 2	NC
Strawberries			189 2	60 0		249 2	NC
Beans	1,279	4,349	1,025 4			1,025 4	NC
Chick peas			347 5	100 0		447 5	NC
Lima beans			59 5			59 5	NC
Tomatoes			918 9	355 0		1,273 9	NC
Sesame	0	7,436	115 4	100 0		215 4	NC
Flaxseed			28 2		17 0	11 2	NC
Corn	1,412	1,412	9,840 4		1,356 3	8,484 1	NC
Cantaloup			318 2	100 0		418 2	NC
Potatoes			752 0			752 0	NC
Cucumber			52 0	150 0		202 0	NC
Watermelon			658 6	100 0		758 6	NC
Sorghum	1,357	1,357	4,163 0			4,163 0	NC
Soybeans	0	2,537	557 4		557 4	0	NC
Wheat	1,777	1,777	3,714 2		418 9	3,295 3	NC

Blanks indicate not applicable NC = No change [1]Total available budget is 25 billion pesos Individual subsidies limited to 40 percent of equilibrium prices [2]Base model solution is the equilibrium solution with no subsidies

Table 4—Case 2: Policy impacts of subsidy program[1]

Item	Unit	Amount	Change from base[2]
			Percent
Budget	10 million pesos	2,500	
Objective	do	42,655	6 2
Exports	do	1,479 2	NC
Imports	do	1,091 8	NC
Net trade	do	387 4	NC
Employment	1,000 work years	2,456 5	NC
Food grains	1,000 tons	11,779 4	NC
Consumer surplus	10 million pesos	31,023 7	NC
Sector income	do	11,774 6	27 0

Blanks indicate not applicable NC = no change [1]Total available budget is 25 billion pesos Individual subsidies limited to 40 percent of equilibrium prices [2]Base model solution is the equilibrium solution with no subsidies

when individual crop subsidies are limited to 40 percent of the current market price (For example, the subsidy limit on corn is 1,412 pesos per ton, which is 40 percent of the equilibrium price generated with the sector model in the absence of Government intervention) The optimal allocation of the budget is to subsidies of corn, sorghum, wheat, and rice (which are subsidized at the upper limit) and to dry beans (which are subsidized below the upper limit) However, soybeans, sunflower, and sesame are not subsidized This solution makes it clear that when the subsidy limits are raised, it is optimal to specialize the subsidy policy and confine it to fewer crops (The objective function's value is higher in case 2 than in case 1) Byproducts of that specialization are lower employment and lower net imports

Table 5—Case 3 Commodity impacts of subsidy program[1]

Crop	Subsidies: Solution	Subsidies: Upper bound	Consumption	Exports	Imports	Production	Change in production from base solution[2]
	Pesos per ton		1,000 tons				Percent
Garlic			47 2	15 0		62 2	-1
Alfalfa			16,029 0			16,029 0	-11
Cotton			1,745 2	175 0		1,920 2	-7
Rice	1,464	1,464	612 8			612 8	-4
Sugarcane			13,651 6		400 0	13,251 6	-14
Squash			222 8			222 8	-2
Safflower	3,123	3,123	437 5			437 5	1 1
Peanuts			160 1			160 1	-12
Onions			204 8	100 0		304 8	-1
Barley			638 0		200 0	438 0	-24
Dry chili			30 2	5 0		35 2	-1
Green chili			224 1	20 0		244 1	NC
Strawberries			161 1	60 0		221 1	-11
Beans	4,349	4,349	1,029 0			1,029 0	35
Chick peas			347 5	100 0		447 5	NC
Lima beans			49 6			49 6	-17
Tomatoes			889 2	355 0		1,254 2	-2
Sesame	7,436	7,436	144 1	100 0		244 1	13
Flaxseed			17 0		17 0		-100
Corn	1,412	1,412	9,840 4		439 8	9,400 6	11
Cantaloup			287 0	100 0		387 0	-7
Potatoes			737 7			737 7	-2
Cucumber			50 4	150 0		200 4	-1
Watermelon			607 9	100 0		707 9	-7
Sorghum	1,357	1,357	4,399 7			4,399 7	6
Soybeans	0	2,537	557 4		557 4	0	NC
Wheat	1,777	1,777	3,714 2		61 3	3,652 9	10 9

Blanks indicate not applicable NC = No change [1]Total available budget is 35 billion pesos Individual subsidies limited to 40 percent of equilibrium prices [2]Base model solution is the equilibrium solution with no subsidies

Table 6—Case 3: Policy impacts of subsidy program[1]

Item	Unit	Amount	Change from base[2]
			Percent
Budget	10 million pesos	3,315 6	
Objective	do	43,370 4	8 0
Exports	do	1,479 2	NC
Imports	do	644 7	-41 0
Net trade	do	834 5	115 0
Employment	1,000 work years	2,462 4	2
Food grains	1,000 tons	13,053 5	10 8
Consumer surplus	10 million pesos	26,566 0	-14 0
Sector income	do	16,948 3	83 0

Blanks indicate not applicable NC = no change [1]Total available budget is 35 billion pesos Individual subsidies limited to 40 percent of equilibrium prices [2]Base model solution is the equilibrium solution with no subsidies

Tables 5 and 6 show that when the budget constraint is increased to 35 billion pesos (and individual subsidy constraints remain at 40 percent of market value), it is possible to include all targeted crops, except soybeans, in the subsidy program It also becomes "optimal" to increase production of all subsidized crops, except rice, at the expense of production of nontargeted crops Again, the most important substitutes are alfalfa, sugarcane, barley, and cotton, which register the largest absolute declines There are important percentage shifts from lima beans, flaxseed, strawberries, and peanuts In this case, too, the impact on other export crops is marginal, production decreases 1-6 percent

In all three cases, the subsidy expenditures reallocate welfare between consumers and producers, and they benefit producers The apparent cause is that supplies are reduced for many more crops than they are increased With demand functions that are generally price-inelastic, coupled with import restrictions, this effect raises producer incomes and lowers consumer welfare Thus, the optimal subsidy programs lead to price and quantity adjustments that bring about a higher level of the sum of surpluses, but lower aggregate consumer welfare (This result does not occur for all crops individually) This finding may suggest that maximization of the sum of surpluses, with no distributional weights, may not be the goal that most policymakers would prefer

Implications

Some tentative policy-oriented conclusions emerge from our analysis

1 Maintaining relative price ratios among crops targeted for self-sufficiency is important if supplies of all targeted crops are to increase, otherwise, substitution in the production of these crops can decrease the output of some of them

2 Programs designed to subsidize the producers of this targeted set of basic commodities appear to have positive effects on most goals of Mexican policymakers, which include increasing employment, food grain production, and net foreign exchange earnings (because import cost savings outweigh lost export earnings) But, these programs have net negative impacts on total consumer surplus (This analysis does not tell us how different consumer groups are affected)

3 Larger allocations of public funds to subsidy programs, although clearly able to generate additional sector income, do not necessarily imply additional benefits in terms of other Government goals For example, the 33-billion-peso subsidy program (tables 5 and 6) sets off a chain of crop substitution effects which had smaller positive employment impacts than the 19-billion-peso program (tables 1 and 2) Thus, one policy goal, such as increasing producer income, can be inconsistent with another, such as generating additional farm employment

Furthermore, the analysis suggests a number of implications for U S -Mexican trade and competition

1 Output price subsidies for the targeted crops, of the magnitude considered in this study, appear to have little impact on the supply and export of many fresh horticultural products Cotton and sesame are the Mexican export crops for which substitution with grains is most important Thus, Mexico's role in world cotton markets would continue to diminish under this policy scenario

2 Mexican price policies considered here would reduce grain and oilseed imports, at least in the short run However, grain imports would not be eliminated or even dramatically reduced by the use of these policy instruments alone

3 Because of production substitution between food (corn and wheat) and feed grains, the relative prices of subsidized crops in Mexico could have important implications for the composition of grain and other basic commodity imports

Finally, this analysis has demonstrated that there are workable opportunities for policy analysis with sector programming models that agricultural economists have barely explored Our analysis strongly suggests, however, that when multiple crops are involved in the setting of policies, one cannot predict *a priori* the net effects of the overall policy package on some national economic goals Hence, a detailed numerical analysis is necessary for a full exploration of policy consequences

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