Commodity Program Slippage Rates for Corn and Wheat

H. Alan Love and William E. Foster

Slippage rates for corn and wheat are estimated using a simultaneous system explaining per-acre yields, input usages, technical change, and levels of participation in government programs. Soybeans are included due to cross-compliance requirements and because they substitute for corn in production. Slippage rates for wheat are in the range of 29–37% and for corn in the range of 48–58%. The results imply that efficient design of commodity programs must account for the slippage of aggregate yields due to changes in land quality and the use of constrained resources over fewer acres.

Key words: commodity programs, corn, slippage, soybeans, wheat.

This article presents estimates of commodity program slippage rates for aggregate corn and wheat yields for 1964 to 1986. Broadly speaking, slippage is the increased per-acre yields associated with government acreage control programs. The term describes the frequently observed phenomenon that the level of commodity production decreases proportionately less than the number of acres idled in response to these programs. This paper defines slippage rates algebraically by:

$$s = -\frac{\Delta Y}{Y}\frac{\Pi}{\Delta \Pi}, \tag{1}$$

where Y is aggregate per-acre yield and Π is the ratio of land planted with a crop to total land, planted and diverted, for that crop. That is, if A represents acreage planted and D represents acreage diverted for government programs, then $\Pi = A/(A + D)$. The proportion of land diverted is $(1 - \Pi)$, and $\Delta\Pi$ is change in proportion planted from year to year. ΔY is year-to-year change in aggregate yield.[1] This article presents a method for estimating this slippage rate as the elasticity of per-acre yields with respect to changes in the proportion of land diverted and for testing whether it is a significant factor in historical changes in the average per-acre production of corn and wheat. The estimates reported suggest slippage rates for corn have ranged from 48–58% and for wheat from 29–37% over the period examined. These estimates are significant both in a statistical sense and in the sense that rates in this range would compromise the efficacy of government production controls.

While slippage is critical in the practical measurement of gains and losses to producers and consumers from government intervention in agricultural markets, there are few studies that attempt to directly measure its effect. There is consensus, however, that slippage rates range from 20–40%. For example, Gardner esti-

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[1] One should note the difference between our definition of slippage and the definition sometimes associated with the total effects of diversion requirements. Our definition only refers to the change in production from actual diversions. Another definition is the change in total production brought about by changes in the diversion requirement. This latter fuzzier definition would include the effect of any changes in market price incentives due to decreases in acres diverted (an indirect effect) and the effect of changes in the mix of program participants influenced by changed incentives related to the requirement. For example, Ericksen reports that actual crop acreage is reduced only 50–60% for every acre idled in government programs. For a discussion of this alternative approach to slippage, see Ericksen and Collins.

mates slippage at approximately 35% (p. 60); Tweeten suggests a 40% slippage rate (p. 315); and Weisgerber, using county-level data for 1966, estimates that diverted acres would yield 80–90% of nondiverted acres. In a study more closely related to this one, Norton estimates total-supply equations for several crops (derived from aggregate profit-maximizing assumptions) and finds slippage rates for corn of approximately 31% and for wheat of 34%.

The following section discusses sources of slippage generally. The third section of the paper discusses the components of change in yields and draws out how the concept of slippage may be introduced into a functional representation of aggregate per-acre production. The fourth section presents a practical means of estimating slippage rates for corn, wheat, and soybeans through a simultaneous system explaining per-acre yields, input usages, and levels of participation in corn and wheat programs. Soybeans are included in the analysis because cross-compliance requirements dictate that diverted land cannot be used for other commodities and because corn and soybeans are close substitutes in production. The fifth section presents the results of system estimation and the estimates for slippage rates for 1964 to 1986.

Sources of Slippage

There are two primary sources of slippage. First, and most importantly for this study, farmers take their least productive land out of cultivation in order to meet any land diversion requirements for program benefits. This is a widely accepted belief regarding farmer behavior supported both by theoretical and conceptual work (e.g., Rausser, Zilberman, and Just) and by data on acreage diverted, as in the study by Weisgerber. As farmers idle land with below-average yield for program compliance, the average per-acre yield from land remaining in production must rise. Thus, as farmers find commodity programs more attractive, average land quality rises and aggregate per-acre yield increases.

Secondly, individual farmers may achieve additional gains in productivity on nondiverted acres as a result of allocating fixed resources over a reduced number of acres. Such resources include farm family labor and the quality of management farmers are able to devote to individual acres of land. To farmers this source of increased productivity may be easily distinguished from the effect of land quality, but in terms of aggregate data the difference between this source and that of land quality is difficult if not impossible to detect.

For completeness, one may identify two additional sources of slippage that may aid in explaining changes in commodity yields over a longer period of time. A third source of slippage derives from altered incentives government programs may offer farmers to intensify use of productive resources on cultivated land. Although presently "decoupled" from production, target payments in the past have been based on farmers' historical yields and farmers' proven yields. As a result, farmers may look at target prices and other government payments when making marginal production decisions. Acreage diversion programs may have encouraged increased production from program participants who responded to the potential for future payments growing with personal program yields. In fact, to the extent that farmers currently anticipate future updating of program yields based on farm histories, there may exist an on-going response to target payments. Moreover, all farmers, participants and nonparticipants, may be able to benefit from the existence of programs that significantly alter the probability distribution of market prices (e.g., diversion programs reduce supply thereby raising market price). Nonparticipants expand production in response to higher market prices without having to accept any costs derived from land diversions.

Finally, a source of longer term slippage is incentives to increase production per acre through technological innovation. If government programs serve to raise equilibrium market price, farmers may respond by adopting new technologies more quickly. Furthermore, since participation in government programs (for wheat and feedgrains) generally requires idling land, technological adoption may be biased toward yield-enhancing technologies.

This article focuses on the first two sources of slippage: increased average land quality and constrained resource use. As mentioned, the effects of these two sources are extremely difficult to differentiate with aggregate data, and this analysis considers them indistinguishable. Our analysis of aggregate per-acre yields does not take into account the indirect effects of slippage due to increased output prices and the associated increases in production from nonparticipants.

The Components of Yield Changes

Aggregate per-acre production for a given crop may be concisely described by:

$$Y = Y(t, X, Q, W), \tag{2}$$

where per-acre yield, Y, is a function of: time, t, representing technological change (i.e., a shifter in the production function); purchased inputs, X, choice variables in an optimization problem in which crop production plays a part; the average quality of cultivated land, Q; and random elements without any particular trend, W, such as rainfall. Q also can be thought of as representing levels of constrained resources per acre of cultivated land; increases in these per-acre levels are additional sources of yield improvement. This presentation, however, refers only to an increase in average land quality as a source of slippage.

By differentiating the yield equation with respect to time and holding the random elements at some fixed level (i.e., their mean), the components of change in yield over time may be represented in the style of Solow:

$$\frac{\dot{Y}}{Y} = \lambda + \alpha_X \frac{\dot{X}}{X} + \alpha_Q \frac{\dot{Q}}{Q}, \tag{3}$$

where λ is the rate of technological change, α_X is the elasticity of production with respect to the inputs X, α_Q is the elasticity of production with respect to average land quality, and $\dot{Y} = dY/dt$, $\dot{X} = \partial X/\partial t$, and $\dot{Q} = \partial Q/\partial t$. If technical change is neutral with respect to purchased inputs and land quality, the above equation is a straightforward description of how growth in agricultural crop yield may proceed. First, increases in output per acre may occur through systematic increases in technology. The parameter λ represents gains in the productive efficiency of all resources, purchased inputs as well as land. Second, changes in applications of purchased inputs, X, lead to changes in yield, all else constant.

Finally, changes in average land quality of acres in production, brought about in major part by land diversion programs, alter average yield. This third component describes what is known as program slippage. Practically speaking, land quality, Q, is not observable; however, the proportion of land in production, Π, is. As proportion planted grows, average land quality must fall since rational farmers first divert least productive land. Replacing Q in equation (3) with the proportion of land in production, Π, allows interpretation of the parameter $-\alpha_Q$ as the slippage rate. If program slippage is slight, then the parameter $-\alpha_Q$ will be approximately zero. Slippage is expected to vary inversely with proportion planted. As land diversions increase, remaining acreage is likely to be more similar in quality and slippage will be less.

The Estimation of Slippage Rates for Corn and Wheat

This section presents a simultaneous system of equations representing the per-acre production of three related crops for the estimation of slippage rates for corn and wheat. The third crop considered is soybeans in recognition of its competition for land with corn. Because corn and soybeans are produced in many of the same areas of the country, diversions of land from corn production also might affect aggregate soybean yields in the same way they do corn yields, and slippage also may be applicable to soybeans. As land enters the corn program, there likely would be a fall in the amount of soybean acreage relative to what would have been planted in the absence of the program. This would improve the average per-acre quality of soybean producing land and hence increase the per-acre yield of soybeans.

The simultaneous system involves eight equations: three per-acre production functions, three per-acre fertilizer demand equations, and two equations explaining the proportion of a crop's planted acreage to all acreage, planted and diverted. The following representation of aggregate production functions for per-acre yield at time t allows direct estimation of slippage rates:

$$Y_{it} = K_{yi} F_{it}^{\alpha_{i7}} e^{\alpha_{i1} t + \alpha_{i2} \Pi_{it} + \alpha_{i3} R_{it} + \alpha_{i4} R_{it}^2 + \alpha_{i5} M_{it} + \alpha_{i6} M_{it}^2} e^{\phi_{yit}}, \tag{4}$$

where Y_i represents the yields for the ith crop (i = corn, wheat, soybeans); K_{yi} is a constant; F_i is the level of fertilizer use for each crop; the time index t accounts for technological changes ($\alpha_{i1} = \lambda$ from expression (3) above); Π_i is the proportion of land planted in the crop (the proportion of corn acreage in the soybean equation); R_i is the difference in monthly rainfall in inches from a 10-year moving average ending in year $t - 1$; and M_i is the difference in temperature in degrees from a 10-year moving average ending in year $t - 1$.[2] Linear and squared terms for temperature and rainfall are both included to obtain a second-order approximation of weather effects. The quadratic term is included to admit the possibility that weather effects on yield may not be strictly increasing or decreasing over the variable range. The normally distributed error term, ϕ_{yit}, represents all other unobserved influences on yields uncorrelated with the weather variables, but not necessarily uncorrelated with fertilizer use or the proportion of land cultivated (the subscript y represents yields, i the crop). Note that in what follows, the indicator of crops, i, is dropped when referring to generic definitions, and that the subscripts y, f, and p refer to equations representing yield, fertilizer demand, and proportion planted.

There is a high degree of complementarity among various purchased inputs: fertilizer, pesticides, hybrid seed, tillage, and so forth. These inputs are used as a blend. High multicollinearity among variable inputs makes estimation of all individual input effects very difficult. For simplicity the empirical analysis uses fertilizer as the representative purchased input because of the dominant role it plays in changing yields. The simple sum of applied pounds of nitrogen, potash, and phosphates makes up the variable termed fertilizer use. Fertilizer data are found in *Agricultural Resources: Inputs,* U.S. Department of Agriculture (USDA).[3]

Since no available measure of average land quality exists, the proportion of planted acreage to all crop acreage planted and diverted, Π, serves as a proxy. This proxy has the added advantage of representing the effects on per-acre production brought about by the relaxation of resource constraints due to diversions. Average land quality is inversely related to Π. As more acres are diverted, average land quality in production rises, but the proportion planted falls.[4] Thus, the a priori expectation of the influence of Π is negative. Π is constructed for corn and wheat from data on program diversion requirements and compliance rates found in respective issues of *Outlook and Situation Reports* (USDA). (Target prices, discussed below, also are found in these *Reports.*)

The functional form for the yield equations is selected to allow easy extraction of relevant elasticities. The data are insufficient to support estimation of more flexible functional forms or to differentiate among several similar functions within the relevant range of Π. An important consideration in selecting equation (4) is that it allows for nonconstant slippage which varies with Π. Constant fertilizer elasticity is a reasonable assumption and widely used. As a practical matter, weather terms are placed in the exponent because the data are negative for some years.

The use of the proportion-planted variable, Π, in estimation offers a straightforward representation of the slippage rate, s_t, at any time:

$$(5) \qquad s_t = -\frac{\partial Y}{\partial \Pi}\frac{\Pi}{Y} = -\alpha_2 \Pi_t.$$

As the level of diversions increases, Π decreases and the slippage rate, s_t, decreases. This representation incorporates the assumption that slippage is marginally greatest at low levels of diversions, implying that the effectiveness of acreage controls grows with higher levels of compliance.

Aggregate fertilizer use and the proportion of land under production are random variables endogenously determined with crop yields, suggesting joint estimation with the yield equations. Per-acre fertilizer use (lbs./acre) for crop i, F_i, is a function of the price of fertilizer represented by a price index, P_F, and of the expected price of the commodity, P_{Ei}, represented by an average of the high and low of the futures price in March for September de-

[2] The data used derive from Teigen and Singer. Rainfall (in inches) for corn and soybeans is measured by the monthly average rainfall in the Corn Belt for the months of June, July, and August and for wheat by the monthly average rainfall in the Northern Plains for the months of March, April, May, and June. Temperature (in degrees Fahrenheit) is measured by an average of daily averages for the same months in the same regions. The authors will provide a fuller description to interested readers upon request.

[3] Data are available from the authors upon request.

[4] A reviewer's comment led us to test whether the specification for slippage is linear or nonlinear. We tested several specifications for the proportion-planted variable, including a quadratic, logarithmic, and Box-Cox. No specification dominated another. Therefore, because of our prior beliefs in the decreasing slippage rate over greater diversions, we have retained that specified in equation (4). The reviewer also suggested that, in addition to the proportion-planted variable, the absolute level of acreage planted influenced yields. That is, *ceteris paribus,* changes in the variable A would influence yields for a constant Π. We did not, however, find any statistical evidence of an independent effect on aggregate yields due to changes in aggregate acreage per se.

livery. Futures price data derive from various issues of the Chicago Board of Trade's *Annual Reports*. For each of the three crops, the demand for fertilizer is:

$$F_{it} = K_{if} P_{Fi}^{\beta i1} P_{Eit}^{\beta i2} e^{\phi_{fit}}. \tag{6}$$

Fertilizer use should fall with an increase in its own price and rise with an increase in expected commodity price. The normally distributed error term, ϕ_{fit}, reflects all other unobserved influences and is assumed independent of prices, but not necessarily of errors in other equations (the subscript f represents fertilizer demand).

Finally, the proportions of land in production for corn and wheat are functions of the relative profitability of program nonparticipation to participation and the diversion requirements for program benefits, Dr_i (i = corn, wheat). The ratio of expected price, P_{Ei}, to program target price, P_{Ti}, approximates the relative per-acre profitability of nonparticipation. The proportion planted is expected to increase as this ratio increases. Dr_i is expressed as a percentage and is expected to have a negative effect on proportion planted if program participation is profitable. The proportion-planted variable, Π_i, (i = corn, wheat) is defined as a limited dependent variable ranging over [0, 1]. The equation is specified in log-odds ratio form:

$$\ln\left(\frac{\Pi_{it}}{1 - \Pi_{it}}\right) = K_{ip} + \gamma_{i1}\left(\frac{P_{Ei}}{P_{Ti}}\right)t + \gamma_{i2} Dr_{it} + \phi_{pit}. \tag{7}$$

Again, the error term, ϕ_{pit}, is assumed independent of the regressors, but not necessarily of the errors in the other equations (the subscript p represents the proportions planted).

Results

Table 1 presents the results of three-stage-least-squares estimation of the eight equations. The system of equations is estimated using the 3SLS routine in the statistical package SHAZAM (White). Where appropriate, the equations are in log-linear form. The R^2 reported are calculated as $R_i^2 = 1 - e_i'e_i/y_i'y_i$, where e_i is the vector of residuals and y_i is the dependent variable for the ith equation.

Without exception, the coefficients are of anticipated signs and are, for the most part, highly statistically significant. More importantly, the coefficients on the proportion-planted variables in the yield equations are highly significant. A joint test that yields of the three crops are unresponsive to the proportion of land planted leads to rejection of the hypothesis at the 95% confidence level. These results indicate that slippage is an important factor in determination of aggregate yields.

Components of year-to-year changes in corn, wheat, and soybean yields are easily calculated from the estimated per-acre production functions as suggested by equation (3). The contributions of technological change to the growth in yields are calculated as:

$$\frac{\partial Y}{\partial t}\frac{1}{Y_t} = \alpha_1. \tag{8}$$

The estimate of the rate of technical change is considerably higher for corn than for wheat: 2.39% versus .90%. For soybeans, the annual rate of technological change is 1.27%.[5]

The contribution of purchased inputs, as measured by fertilizer use, is variable over time as input levels change from year to year. The estimates of the contribution of purchased inputs to changes in yield for each crop are given by the elasticity of yield with respect to fertilizer changes multiplied by the percent change in fertilizer use:

$$\frac{\partial Y}{\partial F}\frac{F_t}{Y_t}\frac{\Delta F_t}{F_{t-1}} = \alpha_7 \frac{\Delta F_t}{F_{t-1}}, \tag{9}$$

where α_7 is the elasticity of yield with respect to fertilizer use and $\Delta F = F_t - F_{t-1}$. The contribution to yield of each year's change in proportion planted is also variable and given by the elasticity of yield with respect to changes in the proportion planted multiplied by the change in the proportion planted:

$$\frac{\partial Y}{\partial \Pi}\frac{\Pi_t}{Y_t}\frac{\Delta \Pi_t}{\Pi_{t-1}} = \alpha_{2i}\Pi_t \frac{\Delta \Pi_t}{\Pi_{t-1}}, \tag{10}$$

where α_2 is the coefficient on the proportion-planted variable for either corn or wheat.

Figures 1, 2, and 3 graphically present the estimates of the components of changes in yield.

[5] The results of other estimations not reported here suggest that not accounting for slippage effects produces estimates of technological contribution to yield growth that are biased. In the case of corn and soybeans, the decrease in the estimate of λ ($=\alpha_1$) is approximately 20%. For wheat, however, the estimate without slippage of the rate of technical change is over 30% higher than that obtained when accounting for land diversions.

Table 1. Regression Estimates (1964-86) of Simultaneous System

Equation[a]	Corn Per-Acre Yield (bu./ac.)	Wheat Per-Acre Yield (bu./ac.)	Soybeans Per-Acre Yield (bu./ac.)	Corn Fertilizer Use (lbs./ac.)	Wheat Fertilizer Use (lbs./ac.)	Soybean Fertilizer Use (lbs./ac.)	Proportion[b] Planted Corn	Proportion[b] Planted Wheat
Regressor[a]				Coefficient Estimate (Asymptotic *t*-ratio)				
Constant	3.691 (4.801)	3.083 (8.657)	3.429 (16.443)	6.314 (18.865)	4.232 (17.078)	4.603 (14.019)	5.132 (3.235)	5.172 (8.040)
Technical Change[c]	0.0239 (5.588)	0.009 (1.969)	0.0127 (4.455)	0.024 (7.705)	0.041 (18.854)	0.041 (8.608)		
Fertilizer Use (lbs./ac.)	0.155 (1.163)	0.109 (1.013)	0.012 (0.256)					
Proportion Planted	−0.575 (−2.494)	−0.369 (−3.004)	−0.382 (−2.611)					
Precipitation (Inches)[d]	0.045 (1.906)	−0.045 (−1.598)	0.052 (3.397)					
Precipitation Squared	−0.011 (−0.405)	−0.017 (−0.363)	−0.024 (−1.491)					
Temperature (Degrees F)[d]	−0.045 (−3.837)	−0.015 (−3.072)	−0.011 (−1.517)					
Temperature Squared	−0.010 (−1.598)	0.002 (1.045)	−0.005 (−1.185)					
Expected Own Market Price[e]				0.334 (3.661)	0.260 (3.765)	0.632 (5.575)		
Fertilizer Price[f]				−0.505 (−3.367)	−0.362 (−2.934)	−0.650 (−3.090)		
Ratio Own Market to Target Price							1.081 (1.054)	0.824 (1.701)
Diversion Requirement							−19.413 (−4.746)	−15.599 (−9.360)
R^2	.85	.81	.76	.74	.94	.78	.59	.85

[a] Yields and fertilizer applications and output and fertilizer prices are in logarithmic form. See text for exact variable definitions.
[b] Proportion of acreage planted to total acreage planted and diverted. Equation specified in log-odds ratio form.
[c] Technical change is measured by a yearly time index (1960 = 1).
[d] Weather data in percent deviations from 10-year average.
[e] Expected market prices represented by the average of the high and low of the futures price in March for September delivery.
[f] Fertilizer price is measured by an index (1977 = 100).

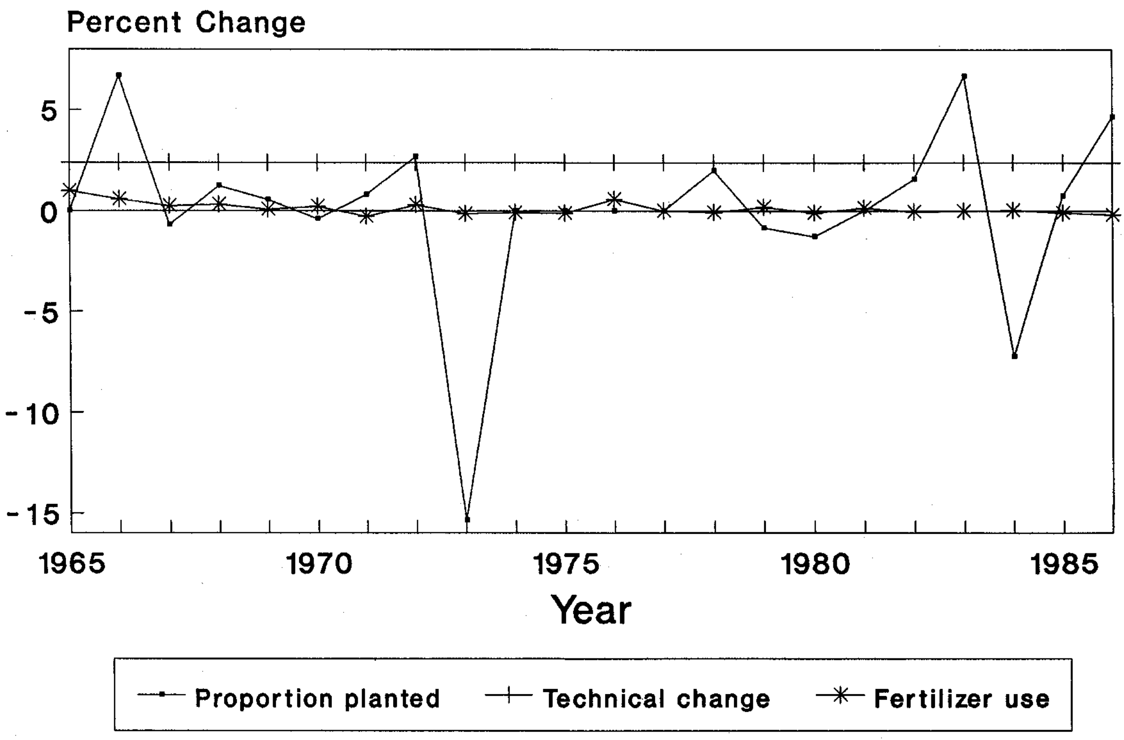

Figure 1. Components of yield growth—corn

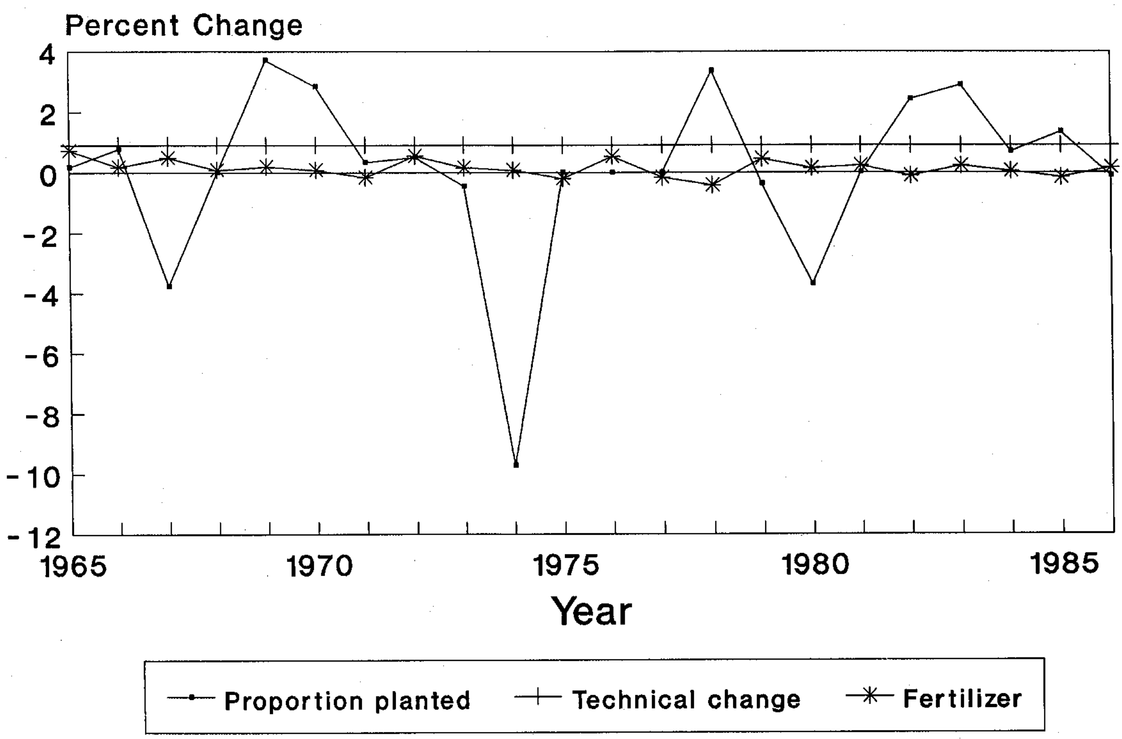

Figure 2. Components of yield growth—wheat

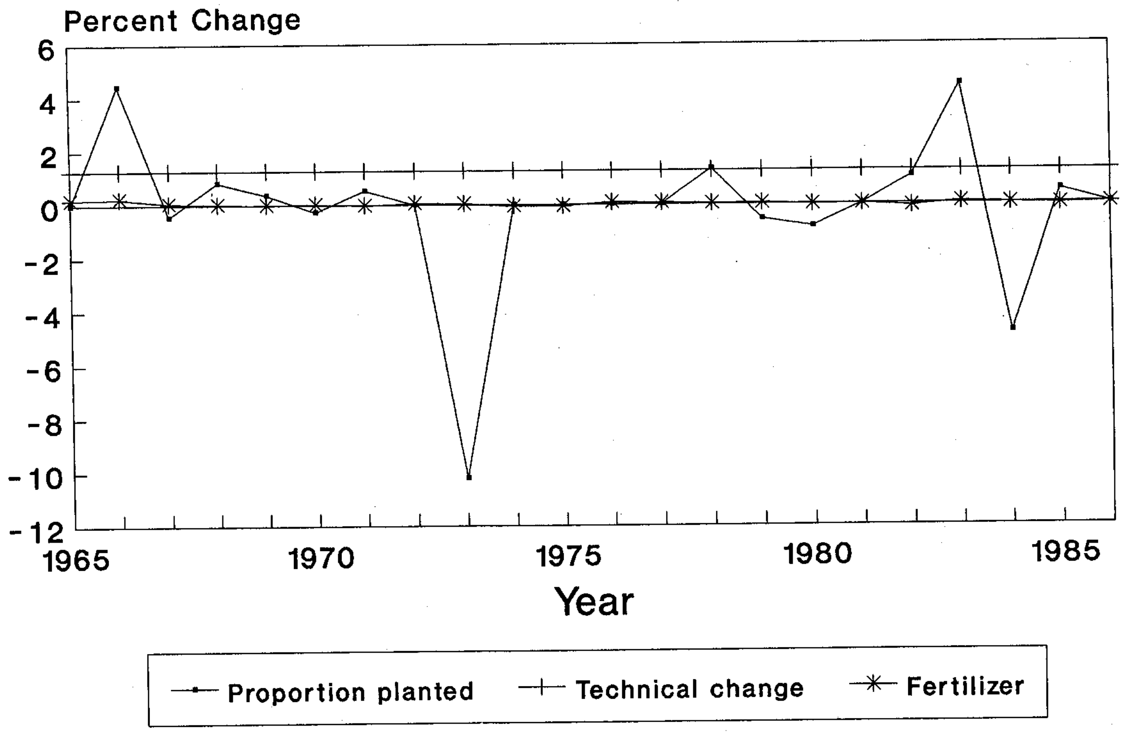

Figure 3. Components of yield growth—soybeans

The results indicate that technological change has been far more important in the growth of corn yields than it has been for wheat. Indeed, the contribution of technical change for corn is more than twice as large. In contrast, changes in the proportion of land cultivated have effects on wheat and corn yields of approximately the same magnitude. Historically, increasing proportion planted has accounted for up to a 10% reduction in wheat and soybean yields and up to a 15% decrease in corn yield. The greatest reduction in estimated per-acre yield occurred in 1973 when farm programs suddenly became unattractive relative to the previous year and farmers expanded acreage planted. On the other hand, there were several years when program compliance was more profitable and farmers removed low quality land from production in response to acreage diversions. During these periods, yields rose approximately 4% for wheat and soybeans and 7% for corn. Fertilizer use has accounted for fairly small changes (less than 1%) in average yield for the three crops. However, a high degree of multicollinearity between the time trend, representing technological change, and fertilizer use may account for this result.

Yearly estimates of slippage rates are presented in figure 4 and are derived from the formula $s = -(\partial Y/\partial \Pi)(\Pi/Y) = -\alpha_2\Pi$. As noted above, slippage rates are higher for the first acre taken out of production ($\Pi = 1$) and decline as more acres are diverted for commodity programs. The slippage rate for wheat ranges from approximately 29% to 37% and for corn from 48% to 58%. In the case of soybeans rates of slippage due to land diversions for the corn program range from 30% to 38%.

In the case of wheat the estimated slippage rates are similar to those assumed by Gardner and those estimated in Tweeten (40%) and in Norton (34%). The estimated slippage rates for corn are higher than estimated by Norton (31%). Two possible explanations for the disparity of results immediately present themselves. First, Norton derives slippage rates by dividing the coefficient associated with gross acreage diverted in a total supply function by the average per-acre yield of the crop over the period of estimation (1956 to 1982). Calcu-

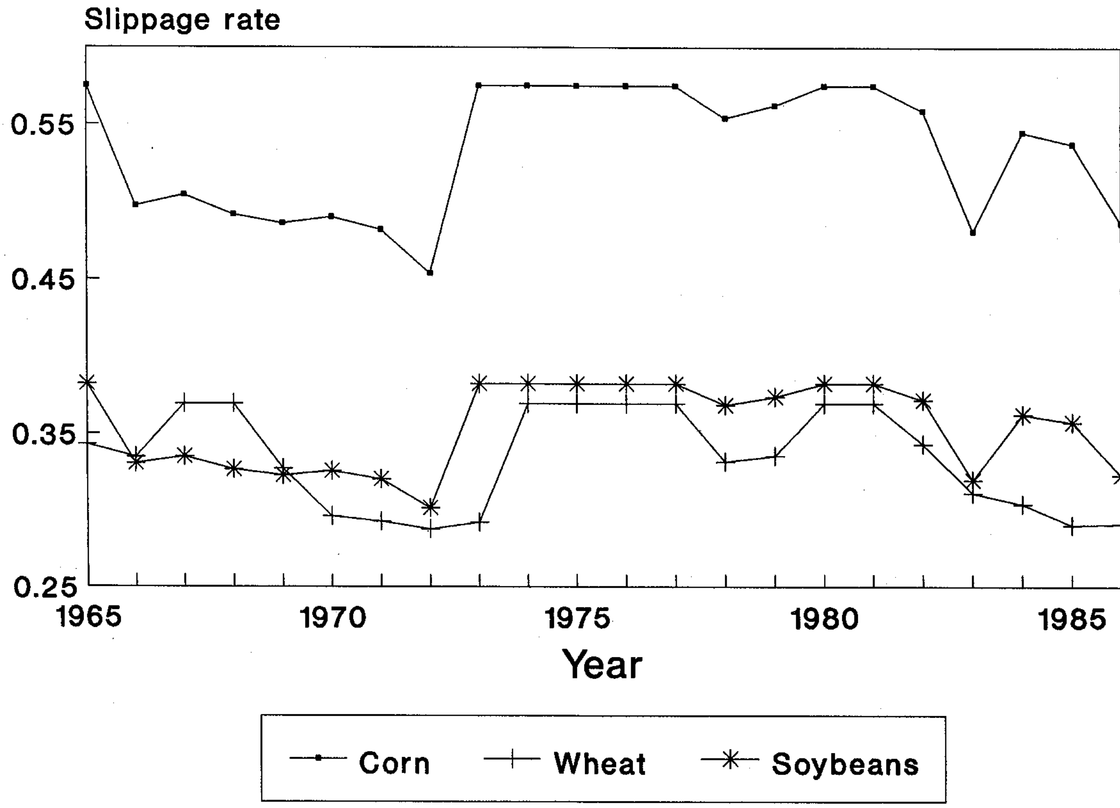

Figure 4. Calculated slippage rates

lations using average yields in the latter part of the period would produce smaller slippage rates. Second, and more importantly, the coefficient estimates which Norton employs do not account for the simultaneity of diversion and production decisions.

Slippage undermines the efficacy of government land diversion programs meant to raise market prices. Slippage has two notable political economic effects: (*a*) by depressing prices, consumers are made better off and producers worse off than if acreage reductions were accomplished without slippage, and (*b*) the cost to the government (or, more appropriately, taxpayers) in the form of deficiency payments increases over what would exist without slippage. For example, in analysis not reported here, we performed simple numerical simulations with a constant-elasticity demand curve (elasticity of .3) and perfectly elastic input supply curves that demonstrate the effect of slippage on equilibrium prices. Results suggest that expected corn prices without slippage relative to those with slippage range from 8% higher for diversions rates of 5% ($1 - \Pi = .05$) to over 60% higher for diversion rates of 30% ($1 - \Pi = .30$).

Conclusion

This article offers a method of directly estimating slippage rates from aggregate per-acre production functions. The study presents a practical means of estimating slippage rates for corn, wheat, and soybeans through a simultaneous system explaining per-acre yields, input usages, technical change, and levels of participation in corn and wheat programs. Soybeans are included in the analysis because of cross-compliance requirements and because corn and soybeans are close substitutes in production. The proportion of land planted to a crop relative to the total land, planted and diverted, for that crop serves as a measure of land quality.

Land diversion programs appear to play a significant role in explaining changes in corn, wheat, and soybean yields. Slippage rates for wheat are in the range of 29–37% but for corn in the range of 48–58%. The results of this paper imply that efficient design of commodity programs must account for the slippage of aggregate yields due to changes in land quality and the use of constrained resources over fewer acres.

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