YIELD RESPONSE TO PRICES:

IMPLICATIONS FOR POLICY MODELING

by

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Abstract

We examine the determinants of own-price output supply response in policy models, focusing primarily on the OECD-PEM equilibrium displacement model. Reviewing expert assessments and econometric literature estimates we find that there is evidence to both support and challenge the relatively high supply response of a model like the OECD-PEM. We also consider possible avenues of reconciliation between evidence that supports and challenges the assumed supply response in the OECD-PEM model. Our analysis of supply response in the OECD-PEM case and from reviewing literature leads us to recommend that future econometric investigation be focused on the role of farm household owned resource mobility as it contributes to agricultural supply response.

Keywords: Supply response, Yield elasticity, Policy models

JEL Codes: Q11, Q12, Q18
1. Introduction

The OECD’s Policy Evaluation Matrix (OECD-PEM) is a partial equilibrium framework for analyzing the quantitative impacts of agricultural liberalization on key variables of interest such as production, trade, prices, and farm income (OECD, 2001). Agricultural supply response in the OECD-PEM is represented by the combined effects of factor substitution in production, factor supply elasticities to agricultural sectors, and the relative importance of production factors in the overall cost structure of each sector. Like other models where supply response is built up from assumptions on factor substitution and supply possibilities, the OECD-PEM is prone to generate significantly higher supply response estimates than are conventionally assumed or estimated from a direct supply relationship (Keeney and Hertel, 2005).

The importance of getting supply response correct is critical to analysis of policy. The literature on structural adjustment and the debate over price incentives versus public investment in technology as means of stimulating agricultural growth in developing countries yielded several broad surveys of supply response all emphasizing the key role of accurately assessing supply response (Chhibber, 1989; Rao, 1989; Schiff and Montenegro, 1997). For OECD countries where interest in domestic policy influence on agricultural production is piqued due to ongoing agricultural negotiations in the WTO, policy modeling efforts have similarly drawn attention to the issues of supply response in agriculture. Keeney and Hertel (2005) using the GTAP Applied General Equilibrium model, show that adoption of the OECD-PEM parameters for factor substitution and supply response in Canada and the United State, results in decidedly different predictions (from those obtained using standard GTAP assumptions) of the impacts of farm policy changes in those countries.

This report offers a survey of the historical literature on supply response, with a particular emphasis on that component owing to the price responsiveness of crop yields. We bring together the various estimates of yield response to price and policy changes for comparative analysis based on the elements used to generate the estimates1. The focus on yields' contribution to supply response places our attention squarely on farm-level decision making and the extent to which farmers adjust input use to influence yields in response to changes in relative prices. Direct estimates of yield and price relationships are scant in the literature leading us to draw on additional work on crop yield response from the agronomy and agricultural economics literatures. In order to view this diverse literature through a common lens, we use the OECD-PEM framework as a vehicle for dividing aggregate supply response into two parts: that due to input substitution (and hence yield response) and that due to factor supply. This permits us to assess how well the current level of implied yield response is supported by the empirical evidence. In turn, this analysis gives way to a discussion regarding the appropriateness of the OECD-PEM’s parameters and key assumptions. We find that the evidence on aggregate vs. farm-level yield response is quite different and we explore several potential avenues for reconciliation of these diverse findings.

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1 Our keyword literature search spanned EconLit, AGRICOLA, and AGEC ION Search among major agricultural academic indices. Additional electronic search was conducted using Google Scholar. Index searches of the Canadian Journal of Agricultural Economics and various Staff/Working/Technical Paper series were also conducted.
Finally, we draw on these insights in providing recommendations for future OECD-PEM development.

The remainder of this document is organized as follows: Section 2 describes the analytical framework we use and offers a comparison of the implied yield response in OECD-PEM to that of another trade simulation model with explicit representation of yield-price response. Section 3 focuses specifically on the case of U.S. corn yield response and the implications of using these empirical estimates of yield elasticity in setting the U.S. parameters for factor supply elasticity in the OECD-PEM framework. Section 4 reviews the broader empirical literature that tends to support low yield responsiveness to prices. Section 5 reviews empirical literature that falls on the opposite side of that debate and more closely matches the assumptions of the OECD-PEM model. Section 6 discusses lines of reconciliation that argue for differing yield response in an aggregate model of medium to long-run nature relative to that found in many econometric estimates. The final section concludes with recommendations for future OECD-PEM analysis and model development and an appraisal of the usefulness of the current assumptions.

II. Yield Response in the OECD-PEM Model for North American Countries

Abler (2001) reviews the econometric evidence on factor substitution possibilities in North America and provides the recommendations used in the OECD-PEM framework for key substitution parameters. Abler (2001) is able to draw on 57 studies estimating elasticities of substitution in agriculture for the United States, and nine and three studies for Canada and Mexico respectively. The vast majority of these are estimated from the dual approach, widely adopted due to the solid theoretical and empirical underpinnings. Abler’s (2001) review of factor substitution stands in sharp contrast to that for factor supply. For factor supply he finds much less information to draw from, more variability in the estimates, and much less consistency between 1) the estimated relationship and the OECD-PEM behavioral framework and 2) the frameworks of the reviewed empirical studies. Given the substantial evidence to draw from and well understood and theoretically consistent framework of the factor substitution evidence, we take these as given in the analysis to follow. In short, if we can be confident in knowing anything, then the factor substitution relationships reported by Abler (2001) are the logical choice. Taking the factor substitution values as given then provides with an organizing framework from which to move forward in our analysis of yield response in North America.

Table 1 depicts the parameter estimates adopted in the OECD-PEM framework for substitution between and among the three input categories of land, farm-owned inputs, and purchased inputs. Abler (2001) assesses the sixty-plus studies mentioned earlier to arrive at the values in Table 1 as recommendations for appropriate point estimates of substitution elasticities. Beginning with Abler’s elasticities of substitution in Table 1 we make use of the theoretical restrictions of symmetry and homogeneity of factor demands to complete the matrix of Allen-Uzawa elasticities of substitution (AUE) which fully characterizes the production function for a given sector. In particular, once symmetry is applied to fill in all of the off-diagonal elements the homogeneity restriction can be used to calculate the own AUE for an input via the formula

\[ \sigma_{ij} = \frac{-\sum_{j \neq i} s_j \sigma_{i,j}}{s_i} \]

where \( i \) and \( j \) index factors of production,
s represents the factor cost share and $\sigma$ represents an AUE. The own-price AUE represents the ability to substitute away from a given input and for the case of $i = \text{land}$ it represents the upper-bound on the yield elasticity in the OECD-PEM. It is the upper bound, since it implicitly assumes a perfectly elastic supply (constant supply price) for all the non-land inputs.

Hertel (1989) provides the analytical solution for the elasticity of supply $\epsilon_{k}^{S}$ in a sector $k$ where limited factor mobility is present and characterized by finite elasticities of factor supply. This expression is reproduced in equation (1). The solution requires augmenting the diagonal of the matrix of AUE by subtracting from the own-price AUE the elasticity of factor supply ($\eta_{i}$) divided by the factor cost share ($c_{i}$). This augmented matrix is then inverted and its elements are summed. Inverting the resulting sum yields the supply elasticity implied by the factor supply, substitution, and intensity assumptions. Factor supply elasticities are taken from the PEM model. We include the additional argument $\lambda$ as a scalar measure of overall factor immobility. Changing this value allows us to proportionally adjust the factor supply parameters for non-land inputs. The initial value of the factor supplies are set such that $\lambda = 1$ reproduces the same degree of factor mobility present in the supply elasticity assumptions of the OECD-PEM model. Values greater than one reduce factor mobility and proportionally scale down the factor supply elasticity impacts in equation (1). Reducing the value of $\lambda$ below 1 scales up supply elasticities proportionally implying greater factor mobility.

$$
\epsilon_{k}^{S} = \left[ \begin{array}{cccc} 
\sigma_{1,1} - \left( \frac{\eta_{1}}{\lambda c_{1}} \right) & \sigma_{1,2} & \sigma_{1,3} & \sigma_{1,4} \\
\sigma_{2,1} & \sigma_{2,2} - \left( \frac{\eta_{2}}{\lambda c_{2}} \right) & \sigma_{2,3} & \sigma_{2,4} \\
\sigma_{3,1} & \sigma_{3,2} & \sigma_{3,3} - \left( \frac{\eta_{3}}{\lambda c_{3}} \right) & \sigma_{3,4} \\
\sigma_{4,1} & \sigma_{4,2} & \sigma_{4,3} & \sigma_{4,4} - \left( \frac{\eta_{4}}{\lambda c_{4}} \right) 
\end{array} \right]^{-1} \times \left[ \begin{array}{c} 1 \\
1 \\
1 \\
1 
\end{array} \right]
$$

(1)

In the subsequent analysis, we choose to vary the factor supply elasticities parametrically due to the paucity of econometric evidence offered by the literature (see Abler, 2001, for an exhaustive review) and because of their importance for determining factor rewards and farm welfare change in addition to output effects. Since we are interested in examining the responsiveness of yields to price changes, we will assume that land is in fixed supply (to a given crop) throughout this analysis. In order to focus squarely on yield response, we artificially set $\eta_{\text{land}} = 0$, so that the only way to increase supply is through increases in yields. This permits us to trace out the yield response of a given farm sector to price, under a variety of assumptions about non-land factor supplies. Figure 1 traces the

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2 Also see Gardner (1979) for the two factor case and more exposition on determinants of supply elasticity in partial equilibrium models with multiple outputs and factor markets.
value of the yield elasticity resulting from equation (1) for Canadian wheat when varying the factor mobility assumption for values of \( \lambda \in (0,10]\).

In Figure 1 we see that when land is perfectly immobile and all other factors are perfectly mobile (\( \lambda \rightarrow 0 \)) that equation (1) returns the own-price AUE for land in Canadian wheat which is equal to 1.46. This is the upper bound on the yield elasticity, given the production function parameters supplied by Abler (2001). When \( \lambda \) is equal to one equation (1) provides the OECD-PEM point estimate for Canadian wheat yield elasticity of 0.63. Increasing factor immobility (moving rightward on the curve) results in declining yield response. Indeed, in the limit, when the farm cannot vary the availability of any of the inputs, yield response goes to zero. In practical terms, if fertilizer and pesticide use cannot be increased, and if labor and machinery hours cannot be increased, there is no way that Canadian wheat farmers can increase yields in response to higher prices.

The two darkened triangles in Figure 1 are of particular interest, as they correspond to the Upper and Lower bounds on the yield elasticity as determined by the endpoints of the parameter ranges given in Abler (2001) for the factor supply elasticities to Canadian wheat. These range from a yield response of 0.81 at the high end when factor supply elasticities are doubled to a yield response of 0.23 at the low-end when the factor supply elasticities are reduced by eighty percent. Additionally, the importance of the own-price AUE for land is evident here as it represents the upper bound (long-run value) for yield response. By extension, one cannot ignore the importance of the cost share assumption on land as it plays a key role in determining the own AUE for land as given in the following formula:

\[
\sigma_{\text{land,land}} = \frac{-\sum_{j\neq \text{land}} s_j \sigma_{\text{land,j}}}{s_\text{land}}
\]  

(2)

Clearly, the larger is the share of land in the assumed cost structure of a sector the lower the yield response curve from Figure 1 will be since there is less opportunity to substitute away from land in the production process. This sensitivity to the cost share of land in wheat production is illustrated by the dashed line of Figure 1 which has been drawn under the alternative assumption that the cost share of land in Canadian wheat is increased to 0.25 from its base value of 0.21.\(^3\)

Using equation (1), we calculate yield elasticities for each North American region and crop pairing in the OECD-PEM and present these in Table 2. Due to similarity in the AUE assumptions and relatively similar cost shares of land across crops we find the values presented in the column OECD-PEM which range from a low of 0.54 for U.S. oilseeds to 0.83 for U.S. rice. The remainder of the yield elasticity estimates lie between 0.63 and 0.72. These elasticities are quite large, representing values in excess of those often assumed for total supply elasticity (in the medium run) for a given crop when considering both yield and acreage allotment contributions to supply change.

\(^3\) Since the cost shares must sum to one, there is a need for a commensurate reduction in some other costs. In this case we reduce the cost share associated with purchased inputs.
For comparison purposes we report in the second column the assumed yield elasticities incorporated into the ERS/PSU Trade Model of Stout and Abler (2004) and based on estimates and assumptions originally undertaken at FAO to support the FAO World Food Model. These range from a low value 0.00, to a high value of 0.20 as a high value. Witzke (2005), suggests that these low estimates are characteristic of other modeling assumptions on yield response such as the Food and Agricultural Policy Research Institute (FAPRI) model, and WATSIM (maintained by the International Food and Policy Research Institute) where yield changes are determined by low price response and considerably larger trend growth. Indeed, Witzke (2005) notes that it is not uncommon for yield response in particular sectors to be exogenously determined based entirely on trend growth estimates and with the full extent of supply response to output prices being determined by acreage allocation.

The final column of Table 2 solves the yield elasticity equation for a $\lambda$ value in the OECD-PEM model that reproduces the ERS/PSU yield point estimate. Multiplying all of the non-land supply elasticities for the particular sector and country by one over this value of $\lambda$ reproduces the ERS/PSU value using equation (1). For example in the case of rice supply in Mexico solving the yield equation for unknown lambda with 0.16 as the target elasticity we find that lambda = 5.4. This implies that the supply elasticities should be reduced to twenty percent of their assumed levels. In this case, the supply elasticity of farm-owned inputs would be 0.1 and the purchased factor supply elasticities would be 0.5. In this way, lambda values in the right-hand column give us a way of interpreting what factor supply elasticities need to be in each country and to each sector were we to take the ERS/PSU (World Food Model) assumptions on yield response as targets. For some of these such as Canadian and Mexican oilseeds, and U.S. wheat and coarse grains we see that the implied factor supply response reduction is drastic implying nearly fixed factors supplied to these sectors in each case.

Table 3 continues the comparison between the two models. From the first entry in column one, we see that, on average across all of North America, the OECD-PEM yield response is 0.45 percentage points larger than that in the ERS/PSU model. So on average the OECD-PEM yield response is over four times as large as that from the ERS/PSU model. The third column gives an estimate of lambda that minimizes the absolute deviation between the OECD-PEM’s implied and ERS/PSU’s explicit yield elasticity, i.e. the choice of lambda in equation (1) that provides the closest overall match to ERS/PSU yield elasticities. The final two columns provide the resulting factor supply elasticities. The values for farm-owned supply elasticities implied by the yield elasticity targets are quite low, with only the farm-owned supply elasticity in the United States remaining above the lower bound OECD-PEM value of 0.10. In the case of purchased inputs supply, all of the values represent inelastically supplied purchased inputs. While these are close (with the exception of Canada)

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4 The base factor supply elasticities in the OECD-PEM model are the same for all countries (with the exception of farm-owned inputs in Mexico) with elasticities of 2.5 and 0.4 (0.5 in Mexico) for purchased inputs and farm-owned inputs respectively.

5 We solve this as an optimization problem of the form $\min_{\lambda} \theta = \sum_k |\epsilon_k^{PEM} - \epsilon_k^{ERS/PSU}|$, subject to equation (1).
to the lower bound OECD-PEM value, inelastically supplied purchased inputs would seem to characterize a fairly extreme short run scenario.

This comparison of the OECD-PEM and ERS/PSU yield elasticities serves to frame the debate present in the empirical and policy analysis literature over whether farmers adjust inputs at a significant level in an effort to adjust expected yields in accord with changes in relative prices. Most empirical work aimed at directly estimating the supply elasticity has been conducted in the Nerlovian tradition, with planted acreage serving as the proxy for intended increase in output, whereby yield changes are either ignored or assumed to follow some trend ascribed to disembodied technical progress. In contrast, empirical work focused on a derived supply elasticity tends to find significant yield response to variable input (particularly fertilizer) applications in direct estimation of response curves or find significant land and variable input substitution parameters in the case of indirect estimations of technology as would be conducted in a cost function estimation.

Several attempts have been made to directly estimate the responsiveness of yields to changes in relative prices, and it is this empirical work we focus on in the sections to follow. The findings from the literature are quite varied, as might be expected, given the diversity of data, methods, and results discussed in the supply response surveys that were conducted in the past thirty years by Askari and Cummings (1977), Chhibber (1989), Henneberry and Tweeten (1991), and Rao (1989). In the next section we look at the specific case of U.S. corn, the crop that has been most often studied for tests of yield responsiveness to relative price changes. We survey this literature next, organizing the estimates based on the period of study, the empirical approach, the data used (level of aggregation and length of time series), and the significance of findings.

III. Yield Response for U.S. Corn

There is limited empirical work attempting to estimate the yield response of crop production to price changes. Most direct supply estimation has been focused on changes in acreage planted as a proxy for total supply or worked from total output without distinguishing acreage and yield effects. Houck and Gallagher (1976) note this point, arguing that focus on the acreage decision as a proxy could lead to considerable underestimation of supply response and that the biological nature of agricultural production, the lags from planting to harvest, and the influence of climate on yields makes the decisions taken after that of acreage allocation potentially important in determining total supply response. If crop rotations are optimally chosen over several periods and are costly to alter then adjustments to improve yields may be the primary recourse farmers have for adjusting supply to movements in relative prices.

Houck and Gallagher (1976) set out to test the hypothesis that there is a significant response of yields to prices. They choose aggregate corn yield in the United States to test their hypothesis and this section focuses on their estimates and the research articles that arose to update and refine this particular study. This set of studies on US corn yields represents the only consistently studied crop-country pairing for yield-price relationships and thus provides a relevant foundation from which to investigate the more sporadic estimates reviewed in sections four and five.
Table 4 presents six estimated elasticities from three studies using only data from the United States and one study (that of Lyons and Thompson, 1981) that estimates yield response from an international panel from the FAO data set on yields and prices. The Houck and Gallagher (1976) study offers the highest and lowest estimates of the six using U.S. data. These authors conduct a number of single equation estimates using U.S. corn yield as the dependent variable and the lagged fertilizer to corn price ratio as the key explanatory variable. The equations differ based on their treatment of trend and policy influence to condition the estimation.

The low yield response of 0.24 (HG Lower) is the result of an estimation of yield on relative prices with a linear trend and a dummy variable that reflects the acreage reduction program’s (ARP) influence on corn decisions. The high yield response of 0.76 (HG Upper) occurs in the authors’ estimation that includes the acreage planted as an independent variable and logarithmic trend growth. Houck and Gallagher (1976) argue that the logarithmic trend is appealing for corn yields because it produces decaying growth in trend yields that are consistent with a number of productivity indices in machinery and other non-farm inputs use that indicate increases at a decreasing rate. The estimated elasticity of 0.69 is from Houck and Gallagher’s (1976) preferred specification which features the dummy variable for ARP and the logarithmic trend. The authors’ argue that this single equation model produces the best fit for the sample and that all of their results indicate that empirical investigations into supply response that omit yield response underestimate the supply elasticity.

Menz and Pardey (1983) investigate U.S. corn yield growth focusing on the assumption of non-linear (logarithmic, square root) trend versus linear trends. They note that Houck and Gallagher’s (1976) assumption embodies the assumption that technological growth in yields is approaching a plateau, a conception shared with others during the slowed growth in yields observed during the early 1970s. They estimate yield response to nitrogen and non-nitrogen inputs with the two non-linear and linear trend assumptions. They find that in pair-wise testing of linear versus non-linear specifications they fail to reject any of the three on statistical grounds. They conduct their test of a plateau in yield growth using the linear trend and find they can reject the plateau hypothesis when accounting for the fertilizer price increases and corn blight experience of the early 1970s.

Menz and Pardey (1983) proceed to re-estimate Houck and Gallagher’s (1976) yield price response equation to see if the significant relationship holds up over the extended period 1951-1980. Houck and Gallagher (1976) acknowledge that price volatility was considerably smaller during their study period than in the early 1970s, and Menz and Pardey (1983) find that indeed the yield price response is lower over the 1972-1980 period and is not statistically different from zero based on the coefficient estimate. They also replicate the earlier period of estimate of Houck and Gallagher (1976) finding a significant coefficient producing an elasticity of 0.61 (MP Pd1) (where the difference is attributed to the omission of Houck and Gallagher’s (1976) weather index). In contrast to the differing in time effects of price as an explanatory variable Menz and Pardey (1983) find that a break in the yield-nitrogen relationship over the two periods can not be identified statistically. This leads them to conclude that the yield-price specification is ill-conceived as a means of explaining yield changes vis-à-vis the inclusion of inputs in the estimating equation.
Choi and Helmberger’s (1993) analysis of the yield response of corn yields directly addresses the conclusion of no significant price response of corn yield to prices. They offer that the common finding of a significant response of fertilizer demands to crop prices can only be explained by intended changes in yields on the part of farm operators. They proceed to estimate a yield price relationship in a two equation system. The yield response equation features fertilizer use, acreage harvested, program diverted acres, weather, and trend growth in yield. Fertilizer use (demand) is estimated in the prior stage as a function of the output to fertilizer price ratio. Combining the production elasticity of fertilizer and the price elasticity of fertilizer demand the authors arrive at a corn yield elasticity of 0.27. Their use of nitrogen to explain yields is consistent with the Menz and Pardey (1983) recommendation, and they soundly reject the notion that yield price relationship is irrelevant for the period ranging 1964-1988. These authors cite serious multicollinearity problems in the estimation of a technology trend with fertilizer use and find it necessary to exclude the trend variable from yield equations to estimate the relationship, potentially biasing their estimates of yield response to fertilizer.

Another study estimating a yield-price relationship for U.S. corn was conducted by Kaufman and Snell (1997). They pool census observations of statewide yields and regress them on a number of indicators representing key climate variables for each of six stages in corn plant growth that contribute to yield. Along with the seventeen climate indicators they include six economic variables on input use, machinery, and farm size. Their specification yields a good fit and the estimated regression coefficients provide results that are consistent with a number of crop-weather models and production function studies. These authors note the consistency of their finding with the range offered by Houck and Gallagher (1976), but report an elasticity near zero at the mean values.

Lyons and Thompson (1981) estimate of the yield price elasticity for corn is also included in Table 4. Their estimate is based on a cross-country study of yield response to the fertilizer price ratio. Peterson (1979) argued for the use of cross-country estimation of aggregate supply response for agriculture, citing the improved estimates arising from differing price regimes mitigating the problems of collinear prices observed in time series based estimates and the complication with deciphering long run response. The Lyons and Thompson (1981) estimate provides the lowest value in Table 4. These authors meet great difficulty in constructing country-specific explanatory variables determining yield change such as weather or technology change. As such they are left with an estimation of country yield on price and country fixed effects modeled as dummy variables. Further, they are not able to estimate slope shifters with the country effects so that their single estimate of yield response across countries is difficult to evaluate.

Figure 2 follows the same approach as for Figure 1. It organizes the information from Table 4 along the graph of yield response for U.S. coarse grains which is consistent with the PEM model assumptions on technology – permitting factor mobility to absorb the

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6 In an earlier version of this paper the Kaufmann and Snell (1997) estimate of the yield elasticity was incorrectly reported as 0.65, which is the upper bound on yield elasticity reported by those authors. The authors thank Tim Searchinger for bringing their attention to this error. Though the Kaufmann and Snell work remains of interest, we exclude it from the analysis because it is unclear how the elasticities with respect to price are calculated from their 1997 article.
difference in outcomes. Viewed through the factor mobility/technology lens, we see a great deal of variation in the implied factor mobility elasticities in the estimates. As with Figure 1, we report the upper and lower OECD-PEM values given the range on the elasticities of factor supply. Note that nearly all of the yield elasticity estimates fall within the range implied by the OECD-PEM range of factor supply elasticities. These estimates tend to be close to the OECD-PEM mean value of 0.69 which matches nicely with the recommendation of Houck and Gallagher (1976).

Of course it is possible that the scope for yield response has been changing over time. The date of the studies used here remains a source of concern for evaluating current yield and price relationships. Choi and Helmberger (1993) represent the estimates with the most recent data and find small significant response, though they have difficulty dealing with trend yields in their estimates. Finally, it should be noted that these estimates are for U.S. corn whereas the OECD-PEM yield elasticity is representative of all coarse grains. In general we would expect yield response to diminish as we aggregate due to the adjustment of resources within category, so that the OECD-PEM point elasticity might be higher than is supported by some of the corn-specific estimates of yield response.

Having covered the case of U.S. corn in detail, capitalizing on the collection of information on yield price relationships, we now turn to the more disparate evidence on other crops in North America and their responsiveness of yields to prices. Since this literature is rather polarized, we explore it from the two extreme perspectives, first considering the evidence suggesting that there is little economically significant yield response to prices, and then considering evidence in support of the alternative hypothesis.

IV. The Case for Lack of Yield Response

In this section we review studies that feature findings that tend to support the notion that yields are not responsive to prices. Following on the preceding discussion of corn in the United States, we begin by looking at yield response in coarse grains in the U.S. We follow that by reviewing estimates in turn for U.S. oilseeds, other U.S. crops, and other sources of evidence on yield response. Estimates of yield price elasticities discussed in this and the next section as well as relevant information about the studies are presented in Table 5 (U.S.) and Table 6 (other countries).

4.1 U.S. Coarse Grains

The yield elasticities for U.S. corn estimated above tend to support the yield response implied by the factor supply elasticities in OECD-PEM with several values near the central value of 0.69. The ERS/USDA trade model’s parameters for coarse grains in the United States are quite low ranging from 0.00 for cereal grains, 0.02 for corn, and 0.04 for oats. While the studies specific to corn tend to support significant yield response (both statistically and as a share of total supply response), other econometric studies support very low or insignificant yield response.

Reed and Riggins (1982) attempt to refine the estimates of Houck and Gallagher (1976) by focusing on the influence of weather on crop yields at a more disaggregate level.
They estimate a yield price relationship for ten different extension areas in Kentucky over the period 1960-1979. Their only statistically significant estimate is for a negative price coefficient in the yield equation. They find in contrast to Houck and Gallagher (1976) that weather changes (rainfall and temperature) are much more important than are changes in relative prices in determining yield. The authors argue that their approach has better micro-foundations for testing producer response to yields due to the disaggregate unit of observation.

Ash and Lin (1987) estimate yield equations for a number of crops and resource regions in the United States using data from the period 1956-1986. Their estimates generally result in yield elasticities in response to prices that are on the low end of the 0.90 to 0.25 range implied by the OECD-PEM factor supply parameters. For most cases the estimated coefficients on price are not significantly different from zero. In the Ash and Lin (1987) corn yield equations, prices are not included as independent variables. They find low significant yield response to nitrogen ranging from 0.17-0.25 which for any inelastic estimate of fertilizer demand to corn price would imply a small yield response to prices. Ash and Lin (1987) estimate yield price relationships for other coarse grains and find significant value of 0.19 for barley and insignificant elasticities for sorghum of 0.19 and 0.24.

Ash and Lin (1987) also estimate yield as a function of the fertilizer price for oats but fail to report the elasticity or information necessary to calculate it. They do find a significant negative relationship between yields and fertilizer price implying significant yield response. The Ash and Lin (1987) equations differ by crop but in general they find that linear time trends explain most of the variability in yields over time. Similar to Reed and Riggins (1982) they find that weather variation measured in deviations from average rainfall and temperature are of primary importance in explaining the remaining variation in yields once the trend is removed. Brandt, Kruise, and Todd (1992) estimate both oats yield and acreage equations for the corn belt and northern plains regions of the United States using time series data from 1965-1985. They find a yield price elasticity of 0.04 for both regions, and this is statistically insignificant from zero.

In many of the Ash and Lin (1987) estimates harvested acreage is included as an explanatory variable in the yield equation as a means of controlling for the possibility of supply increases forcing producers onto marginal lands or acreage reduction programs permitting them to idle this last. This phenomenon, known in the literature as slippage, was measured by Love and Foster (1990) in a simultaneous equation system with fertilizer demand and yield equations. Their separate estimates of these two elasticities can be combined to form a yield price elasticity in the manner of Choi and Helmberger (1993) and the result is a yield elasticity with respect to price lying between 0.05 (using the output price) and 0.08 (using the fertilizer price).

One source of difference among the estimates included here is the treatment of the acreage influence on yields and the implied change in land quality. It is typically hypothesized that as acreage is removed from production (through acreage controls) that least productive acreage is first removed and therefore per acre yields respond positively. Houck and Gallagher (1976) find this to be an inferior measure of program influence and Just (1993) notes the difficulty in ascribing causality to acreage movements in single sector studies that
do not account for relative output price movements and the potential for high quality land to be bid away to another crop.

In summary, the broader evidence on yield response of coarse grains in the United States contrasts rather sharply to the studies discussed in this section, which find much lower yield responses that can rarely be distinguished statistically from zero. The ERS/PSU yield elasticities originally noted for comparison with the OECD-PEM parameters are likely inspired by the findings in this section.

4.2 U.S. Oilseeds

The ERS/PSU parameters for yield elasticities range from 0.10 for soybeans to 0.04 for other oilseed products. Choi and Helmberger (1993) repeat their analysis previously described in Section 3 for soybeans and wheat. They find fertilizer demand quite price responsive for soybean producers but that the yield effects of increasing fertilizer use are quite small. Combining these two observations, the authors report an elasticity of 0.13 of soybean yield to product price for soybeans. Love and Foster (1990) also provide analysis of yield response to fertilizer inputs and fertilizer demand response to prices for soybeans. Their low estimate of soybean yield response to fertilizer inputs generates a yield price elasticity that is effectively zero. It is likely that fertilizer use in soybean estimation does not proxy very well for other yield-increasing input use (e.g. chemical weed control) so that the usefulness of price relationships derived from fertilizer demand equations is suspect.

Love and Foster’s (1990) primary interest for including soybeans in their estimation is to capture the cross commodity aspects of acreage diversion and the influence of soybean prices on the slippage rates for wheat and corn. The role of corn and soybean enterprise allocations and the influence of yields is prominent in two studies conducted by Miner (1981; 1983) for soybean production in Minnesota and for the United States. Miner’s research finds a limited role for fertilizer in explaining soybean yields similar to the other studies mentioned. He also finds that, in contrast to fertilizer, other purchased input prices do not exhibit enough variability to achieve significance in his estimating equations. Miner concludes that, where corn and soybeans compete for planting, both the soybean and corn price can be found to exert significant influence on soybean yields. He attributes the cross-price output effect as being attributable to acreage allocation. Extending this he argues that to the degree that other yield increasing inputs follow acreage to the soybean enterprise when acreage is released due to decreased corn prices that that a significant yield to input price relationship could be distinguished.

Miner’s (1981; 1983) estimates of the direct effect on soybean yields of the soybean price are significantly different from zero. The author does not provide adequate information to construct the actual yield price elasticity but the reported parameter and estimating equation indicates for most historical yield and price ratios that the estimated elasticity would be on the same order as that of Choi and Helmberger (1993) and Love and Foster (1990).

The OECD-PEM yield elasticity for U.S. oilseeds is measured at 0.53 (see Table 1). It is the lowest yield elasticity in the model, primarily due to the low share of fertilizer use. The lower bound on the OECD-PEM yield elasticity calculated from the minimum values
for factor supply elasticities is 0.21. In summary, the limited empirical evidence on soybean yield response supports the lower yield elasticity in the OECD-PEM model, but the response levels are consistent only for the low-end of OECD-PEM factor supply parameters.

4.3 Other U.S. Crops

This section reviews literature on wheat and rice yield response in the U.S. There is limited evidence to draw from in terms of direct estimates, so we draw on other sources of discussion that tend to support low yield response of these crops in conjunction with estimated elasticities.

Choi and Helmberger (1993) extend their analysis to U.S. wheat and find a yield elasticity of 0.03 that is not statistically distinguishable from zero. Similarly, the Love and Foster (1990) results generate a yield elasticity in that same range. Ash and Lin (1987) estimate wheat yield response for four regions in the United States and find similarly low yield price elasticities for all regions excepting the corn belt where the value is 0.20. The ERS/PSU model of the wheat sector assumes no yield response to prices for wheat production.

While the zero response assumption for U.S. wheat represents the smallest yield-price response for any North American crop, the 0.20 value for U.S. rice production represents the largest. Ash and Lin (1987) estimate rice equations for each of the six U.S. rice producing states, but only include a price variable for the state of Mississippi. Their estimate is significant and represents an elasticity of 0.18, close to the value from the model ERS/PSU model. Ito, Wailes, and Grant (1985) also estimate a U.S. rice yield elasticity finding a short-run value of 0.11 and long-run value of 0.31.

Ash and Lin (1987) point to irrigation and temperature as key inputs in rice production. Temperature requirements limit the area of potential rice growth, and the cost of irrigation provides the primary physical input determining yield. Irrigation costs are also important to wheat production, due to the regions where it is grown in the U.S. receiving less rainfall and having generally poorer soils. Ash and Lin (1987) point to technological change and adoption of semi-dwarf varieties that can make better use of nitrogen in the production of grain protein as accounting for most historical yield changes.

Several authors point to the role of varietal selection and crop rotation as key decisions in determining wheat yield. Johnson and Ali (1979) report that the economically optimum rate of nitrogen application is relatively insensitive to changes in nitrogen prices due to the behavioral dominance of crop and fallow rotations. Other authors have noted that the end use of wheat and the dependence on the protein content may provide important explanations for failure of wheat yields to respond to prices. The yield response of the wheat crop likely differs from the protein content response and thus estimates of the crop yield response are confounded by the potential quality premia offered based on protein content (Fraser, 2000; Barkley and Porter, 1996).

4.4 Additional Evidence
The issue of wheat protein price premia has been found to have similar importance in studies of Canadian wheat supply (Smith, McKenzie, and Grant, 2002). These authors find similar confounding effects of yield response to price due to decisions made in effort to maximize returns with respect to the discontinuous price term in the profit equation arising from dependence on the protein content which is responsive to nitrogen application.

No direct estimates of the yield-price relationship in Canadian crops were found in the literature search. Several national level studies of technical efficiency and technical growth have been conducted and the findings of Giannakis, Schoney, and Tzouvelekas (2000) suggest that yield changes are dominated by technology driven growth and differential adoption. Both the Smith, McKenzie, and Grant (2002) and Giannakis, Schoney, and Tzouvelekas (2000) studies report production elasticities of yield to fertilizer application that are in the neighborhood of 0.20. Thus, for any inelastic response of fertilizer demand to output prices these studies support a small yield elasticity with respect to fertilizer inputs. Both studies focus only on fertilizer inputs as the purchased input, presumably due to the difficulties of multicollinearity in purchased input use over time cited by Miner (1981) and others.

The lack of information drawn directly from studies of Canadian agriculture can be partially mitigated by relying on information from the studies in the United States due to similarity of the agricultural sectors of the two countries in terms of production units and practices. However, the lack of studies to draw on in the case of Mexico is more troubling. As a developing country with a significant fraction of the population involved in peasant agricultural production, there is little basis for assuming a similar supply response in Mexico to that in the other two North American countries. Several studies in developing countries have found an overall lack of supply response in terms of marketed surplus of agricultural production from semi-subsistence farming. This would lend indirect support to the notion of low yield response in Mexican agriculture. Sain and Lopez-Pereira (2002) study yield growth of Maize in Mexico and Central America and identify lack of yield growth and limited response to market signals in peasant and small-scale commercial farming as a key indicator of lack of response.

The ERS/PSU assumptions of yield response offer the only direct evidence on yield response to prices for Mexico and Canada. These estimates are given in Table 1. In general the elasticities for Mexico and Canada indicate higher yield response for coarse grains than for oilseeds (in contrast to the U.S. assumptions of that model) and are quite inelastic with the highest value being 0.18. ERS/PSU.

Herdt (1970) and Guise (1969) provide early estimates of yield-price relationships for a developing country (India) and a developed country (New Zealand). Herdt (1970) estimates a total supply elasticity for the Punjab region in India, built up from regional regression estimates of acreage and yield response over two periods, 1907-1946 and 1951-1964. He finds the supply elasticity to be small in the early period with a value of 0.21, with over half of the value contributed by yield response to prices. For the latter period, Herdt (1970) finds that the yield elasticity has grown from 0.11 to 0.19, but that the contribution of yields to total supply elasticity has fallen to around one-third – in light of an overall increase in the supply response in India.
Guise (1969) estimates a yield-price elasticity for wheat in New Zealand over the period 1918-1967. He finds a value similar to that of Herdt (1970) and other estimates reported in this section with a range of 0.13 to 0.18. Binswanger et al. (1987) estimate a cross country supply elasticity of total crop supply from both yield and acreage equations. They find that the only significant price response to prices is found in acreage allocation, but that it is relatively small. They find that country specific variables such as infrastructure and population measures are most important in determining cross-country variability in supply.

Acreage response has indeed been the dominant feature in estimates of crop supply response, particularly when trying to identify the influence of both price and policy on changes in output (Morzuch, Weaver, and Helberger, 1980; Lin et al. 2000). This is consistent with the Murray-Prior and Wright (2001) conclusion that farm management decisions fail to respond to small price changes viewing them as temporary variations, while responding to large price changes with enterprise shifts and the associated reallocation of factors of production.

But why are yields so unresponsive to prices? Plateau response functions represent a plausible explanation for the insensitivity of yields to changes in relative prices, particularly when only fertilizer is considered in the production response. The economic optimum fertilizer application can not change with changes in the ratio of output to fertilizer prices for spline function estimates of plateau functions. Only in the case that other inputs cause changes in the kink point between the linear and zero response sections of the functions can optimal response change. Mjelde et al. (1992) use plateau response to explain limited increases in input intensity when farm programs allow updating of program yields which should provide incentive to improve yields. Lanzer and Paris (1981) find that linear response and plateau (LRP) estimations provide response curve fits that are as consistent with the data as other smooth functions and that modeling with LRP allows a better accounting of nitrogen influence.

Plateau response as an explanation for lack of yield response falls prey to the often limited agronomic view of yield response. It is certainly dependent on the view that nutrient availability is the only important constraint in the crop decision making. We return immediately in the next section to some cross-disciplinary work with agronomic foundations that supports economic behavior on yield response.

V. The Case for Significant Yield Response

5.1 Agronomic Research into Yield Response

The primary appeal of plateau functions from an agronomic standpoint rests in von Leibig’s “law of the minimum” stating that the most limiting input ultimately determines the response level. The work espousing the LRP generally is focused on nutrient response and lack of substitution across macronutrients (nitrogen, phosphorous, and potassium) determining biological activity. Frank, Beattie, and Embleton (1990) are able to reject the LRP representation for experimental data on agronomic response and find that input substitutability among macronutrients can not be rejected when considering plateau growth patterns. Other agronomic research similarly point to yield response to inputs at levels that affect decision making.
One such area is the cross-disciplinary investigation into profitability and adoption of precision agriculture and site-specific decision making in crop production. A common claim is that farmers fail to respond to price changes because the implied optimum changes in inputs is smaller than can be applied with precision by farming techniques. The studies by Bullock and Bullock (2000) and Bullock, Lowenberg-DeBoer, and Swinton (2002) point to the adoption of comprehensive site information on soils and previous yield values and application techniques that allow for variable applications across these sites as evidence that farmers set expected yield values in a profit-maximizing manner and make their input decisions in line with that information.

5.2 Yield-Price Relationships

Abler (2001) reviews most of the published research and expert assumptions on substitution possibilities in crop production. The results presented in his review overwhelmingly support the hypothesis that farmers adjust yields in response to relative prices, as he finds the average substitution elasticity between land and purchased inputs to be 1.4 in the United States. The average value (relying on far fewer estimates) is lower but still relatively large for Canada at 0.5. Each of these averages represents a substitution elasticity that is roughly four times larger than that between farm-owned inputs (capital and labor) and purchased inputs. This is somewhat striking difference when one considers that policy analysis typically relies so little on the land and purchased inputs substitution possibilities in explaining output change. Alternatively, labor/capital replacement by purchased inputs is often cited for its key contribution in explaining the sizable exit of farm-employed resources from agricultural to non-agricultural use when evaluating policy related developments of the past fifty years.

Abler’s (2001) review is the primary source determining the OECD-PEM yield elasticities that were presented in Table 2 and provides overwhelming evidence that, from the factor substitution side, yield response can be an important determinant of supply response. In Section III, empirical work directly measuring the yield-price relationship was presented that is quite consistent with the implied OECD-PEM yield elasticity level for U.S. coarse grains. In addition to those estimates, other estimates of the price impact on yields lend support to the level of yield response present in the OECD-PEM.

Tweeten and Quance (1969) find a short-run elasticity of yield for aggregate U.S. crops to be 0.15 and a long run elasticity of 1.50. This range of estimates coincides with the factor immobility and yield elasticity values evidence for the U.S. crops in the OECD-PEM. In Figure 3 below we see that if we take the factor immobility measure to be zero on the x-axis we have long run elasticities that assume perfectly elastic non-land factor supplies which defines the long run. A simple averaging of these long-run elasticities provides a value 1.62 which is close to the Tweeten and Quance (1969) value. Those authors define the short-run as two years which would imply some reduction in the factor supply parameters from OECD-PEM’s base assumption. Reducing the farm-owned and purchased inputs elasticities to 20 percent of their value gives rise to an average yield elasticity of 0.24. The high yield response of rice and the fact that its importance is likely overstated in the simple average would improve the agreement between the Tweeten and Quance (1969) estimates and the OECD-PEM yield response for the United States.
In addition to the Tweeten and Quance (1969) aggregate estimates, Hazell (1984) finds that, at the U.S. state level, yields for corn became more correlated following the high price volatility of the early and mid-1970s when standard deviations of corn prices increased some 75% over the levels observed from 1950-1970. Hazell (1984) argues that these larger price swings and the tightening of yield correlations across states support significant, and similar, response across the corn producing states.

In other countries, Pomareda and Samayoa (1979) use a simulation approach over cropping alternatives to arrive at a 0.50 yield elasticity estimate for maize production in Guatemala. Mushtaq and Dawson (2003) use an error-correction framework to model the equilibrium dynamics of yield and price relationships. Their study of Pakistani wheat production finds yield elasticities of 0.15 in the short run and 0.70 in the long run.

5.3 Yield Response and Agricultural Policy

As discussed in Section IV, most studies of policy impacts on supply have been conducted using acreage response alone, assuming yield response to prices to be insignificant. The justification behind this is that acreage allocations represent the strongest signal of farmer’s intended output decisions and that other input applications will tend to follow the acreage decision. These results provide a limited picture of supply response in the face of major policy changes, which offer natural experiments for testing the hypothesis of a negligible yield-price relationship.

Guyomard, Baudry, and Carpenter (1996) analyze the European Common Agricultural Policy reforms that reduced price support levels and finds significant reductions in yields in response to lower support prices. Benjamin and Houee (2005) find also that European yields in general are responsive to prices under the reformed CAP, yet find little evidence that combined area payment and set-aside schemes influence yields.

Hayami and Ruttan’s (1971) work on induced innovation provides a useful lens through which to investigate yield response under policy changes (Just, 1993). Induced innovation implies that if factor markets are efficient in allocating rewards, that demands for innovation and speed of adoption will be determined by relative prices. The scarcity of land in Japan and agricultural labor in the United States is the cornerstone example of their work comparing the factor price explanations for technology development and adoption of land and labor saving technologies.

Tobacco policy changes in the United States offer an ideal natural experiment of yield increasing technology production and adoption dependent on relative factor rewards (Foster and Babcock, 1993). Tobacco production is unique because of the many restrictions on exchange of allotments and the legal penalties of growing over quota. Prior to 1965 tobacco marketing allotments were allocated based on acreage in production. During the period spanning the tobacco program’s onset in 1933 to 1964 when acreage allotments were in place tobacco yields grew at the extraordinary rate of 4.3 percent per year, with the largest increases coming in years following significant reductions in the acreage allotment. Clearly yields responded to the strong price incentive provided by the program. Since program acreage was limited, yields offered the only vehicle for responding to the higher program.
prices and the combination of research and development and producer decisions capitalized on this opportunity.

However, in 1965, the tobacco program was altered. From this point on, marketing quotas were specified in terms of total output (pounds of tobacco). This meant that there was no longer such a strong incentive to boost yields. Program output could be met either by adjustments to acreage or to yields. During this period, yield growth dropped dramatically to just 0.5 percent per year. This suggests that, contrary to what many authors have assumed the so-called “trend rate of growth in yields” may itself be quite responsive to price signals. It suggests, furthermore, that over the longer run, the combination of research and on-farm behavioral responses to higher prices can generate significant changes in yield.

VI. Lines of Reconciliation

The evidence presented in sections III-V represent a set of diverse findings for the yield component of supply response. Just (1993) points to the diminishing stock of knowledge regarding supply elasticities as evidenced by continued variability in supply response estimates and the resultant lack of any foundation for forward looking-analysis of the supply side in agricultural policy. He highlights (among other things) level of aggregation, number of equations, and price expectations as areas where differences may lead to differing outcomes. Complications from aggregation arise when the assumptions underpinning microeconomic optimization are applied to aggregations of diverse producers. Supply response estimation is dominated by single equation estimates which lead to potential biases from omitted variables or simultaneity, as well as leaving little information to determine the appropriate length of run for which the elasticity estimate represents the adjustment process. Persistence of relatively naïve price expectations also contributes to lack of information on the appropriate length of run. The examination of these issues offers a potential means of reconciling the differences in measured responses of agricultural yields to prices.

6.1 Aggregation Issues

Offutt, Garcia, and Pinar (1987) examine the aggregation issue and find that yield variability declines significantly when aggregating to the state and regional level versus county and farm-level analyses of U.S. corn production. This has important implications for the relative explanatory power of technology and weather in yield response. Wu and Adams (2002) compare regional aggregate versus micro-level acreage response and find that predictions from estimated responses using aggregated data provide better fits than aggregated farm-level response estimates. In particular, they find that the latter produce too little supply response to price changes.

Hertel, Stiegert, and Vroomen (1996) provide a model-based reconciliation of limited farm-level yield response to prices, on the one hand, and econometric evidence of significant sector-level responses on the other. They focus in particular on the elasticity of substitution between land and nitrogen in corn production in the Eastern Corn Belt region of the United States. These authors are able to reconcile a near zero land-fertilizer substitution elasticity at the farm level with a sector value (for Indiana corn producers) of 1.15.
They do so by appealing to the presence of heterogeneous corn producers and the potential for compositional changes in the sector. In particular, they observe wide differences in the rate of nitrogen fertilizer application in corn production— even after controlling for land characteristics. They assume that these differences are farmer-specific and they then group Indiana corn farmers into 23 distinct classes, depending on their fertilizer application rates (which are assumed to remain unchanged in response to relative prices). When the fertilizer/land price rises, profits accruing to the fertilizer intensive managers fall relatively more, and they lose acreage— at the margin— to more fertilizer efficient managers. The key parameter in this model is the responsiveness of land rental contracts to changes in profitability. Given the observed heterogeneity of producers, Hertel Stiegert and Vroomen (1996) are able to reconcile the absence of farm level substitution with the aggregate nitrogen-land substitutability of 1.15 using a rate of land turnover that was within the historically observed range.

The source of farmer heterogeneity in Hertel, Stiegert, and Vroomen (1996) is ascribed to entrepreneurial capacity, an omitted input into the production function. Heterogeneity in terms of managerial ability is well founded in studies of supply response. As Peterson (1991) states maintaining productivity on large farms equal to that of small farms requires considerably more management input, and the fact that large farms tend to have higher productivity indicates that the quality of the input must be higher. He further ascribes the increased fertilizer and chemical use on large farms (that account for significant yield gaps) as evidence of significant complementarity between managerial skill and purchased inputs.

Other studies have found that consistently high yield performance on the same farm over time (Urcola, Schnitkey, Irwin, and Sherrick, 2004) and across crops (Goodwin and Mishra, 2002) can be attributed to producer human capital characteristics that are indicative of managerial ability. In terms of behavioral response, Hansen (2004) finds that farm-level elasticities of fertilizer demand from a panel data set exhibit significant variation in response coefficients when conditioned on farm and operator characteristics. Daberkow and McBride (2004) find similar importance characteristics in describing the response of U.S. corn producers to the 2001 increase in nitrogen prices.

6.2 Number of Estimated Equations

Just (1993) proposes that convenience, more than data limitations, is the primary motivation for single equation modeling of supply relationships. He addresses the typical availability of data for each level of aggregation and argues that omitted equations for demands for variable inputs and adjustment of fixed allocatable inputs contribute to bias in the single equation estimates. If nothing else, the efficiency of the supply response coefficient should improve with the additional behavioral relationship being jointly estimated. Recent work by Arnade, Kelch, and Leetmaa (2002) estimate simultaneous yield and profit relationships derived from a profit function for three European countries. They find strong yield response for farm products in some countries and near zero or negative values in others. Griffiths, Thomson, and Coelli (1999) also estimate area and yield equations...
and find their system estimation significantly improves the accuracy of output forecasts for Australian wheat.

An extreme interpretation of this direction would involve including all relevant equations in a general equilibrium formulation that accounts for non-agricultural sector influences as well as those in agriculture. Chiibber (1989) and Schiff and Montenegro (1997) in their reviews of aggregate supply response for agriculture both suggest that dynamic general equilibrium estimates are larger than typical response estimates. They cite the explicit inclusion of factor markets, and the role of price induced technology growth through capital formation as the many features that enhance the view of supply response.

Household equilibrium models represent a similar extreme in terms of behavioral relationships as they account explicitly for separate demands on farm owned inputs in the estimation. Lopez (1984) examines household supply response in Canada and finds household and off-farm occupational demands to be important in determining the output response of agricultural products as well as the substitution possibilities between purchased and farm-owned inputs. The importance of Lopez’ (1984) finding is that for a developed country he finds that production and consumption decisions are non-separable. This line of reasoning has been prevalent in explaining diminished supply response in developing countries.

As such, the multiple equation or more complete specification approach offers conflicting views on supply response relative to single equation estimates. The micro-oriented household framework (for cases of non-separable household decision making) generally would find smaller output response whereas the general equilibrium estimates would tend to support larger estimates. The concern over estimating more of the relevant relationships would seem to favor the two equation system of Choi and Helmberger (1993) which considers both fertilizer demand and output response to fertilizer. The narrow focus on fertilizer likely understates yield response however, particularly given advances in other chemical input usage that contribute to yield beyond the replacement of mechanical and physical labor.

6.3 Formation of Price Expectations

Nearly all of the reviewed studies in this paper relied on a simple lagged price as the expectation of future prices. Just (1993) argues that this type of price expectation omits the potential for transitory beliefs in price changes and thus may be an important source of low response estimates. Diebold and Lamb (1997) argue that the use of OLS estimators with the adaptive expectations formulation of Nerlove in estimating supply response leads to violation of the sampling properties required to establish efficiency and unbiasedness. They find in Monte Carlo experiments that much of the wide variation in supply response estimates can be traced to inappropriate estimation properties. Shonkwiler (1982) shows that a mixed expectations and rational expectations formation of prices are inferior to the adaptive expectations in his estimation of Florida escarole supply.

Among simpler formulations that do not rely on naïve expectations but do not entail the complex explanations of expectation formation, Foster and Mwanaumo (1994) find that a rational distributed lag price expectation performs best for capturing the dynamics of maize
response in Zambia. Morzuch, Weaver, and Helmberger (1980) and numerous other studies have made use of basis adjusted futures prices in the United States with good success and estimates that in general support a larger supply response.

In summary, the possibility of reconciling the diverse estimates presented in sections III-V might be quite limited. Most are aggregate, single equation estimates with naïve price expectations. What we can draw from this is that finding evidence in support of both small and large response is to be expected. We now turn to our conclusions and recommendations for OECD-PEM based modeling and parameters based on the implied yield response vis-à-vis that found in empirical literature.

VII. Conclusions and Recommendations

In this report, we have used the OECD-PEM framework as a lens through which to view the competing estimates of crop yield response to output price. This framework has the virtue of explicitly identifying the sources of supply response, which are shown to hinge on the ability to substitute other inputs for land, the elasticity of supply of these other inputs, and the share of each input in overall economic costs. The scope for reconciling the estimates that favor and disfavor the OECD-PEM’s implied yield response using the guidelines in Section VI appears limited for the purpose of choosing a ‘best’ estimate. Most are single equation estimates and the multiple equation estimates focusing on fertilizer appear to be too narrowly focused.

The yield and acreage estimations of Tweeten and Quance (1969) and Herdt (1970) likely show more promise. The estimates from Tweeten and Quance (1969) were shown to coincide nicely with the factor supply-varying, length of run dependent, yield curves implied in U.S. OECD-PEM parameters. In terms of the level of aggregation, there is some support for lower response for more disaggregate units (Reed and Riggins, 1982), but as Hertel, Stiegert, and Vroomen (1996) show, these can be reconciled when considering land turnover among farmer-managers of differing abilities. In terms of price expectations, there is little basis to distinguish the evidence. The cointegration error-correction model of Mushtaq and Dawson (2003) shows promise for future models of simultaneous yield and price relationships in agriculture as it makes use of the advances in techniques that remedy several econometric issues that plague time series analysis in a parsimonious manner consistent with the notion of economic equilibrium.

Our analysis of OECD-PEM yield elasticities focused on factor supply response and the implied length of run when these parameters are adjusted. Aside from the Tweeten and Quance (1969) estimates for crop aggregates, there is limited information to distinguish the estimates of either low or high yield response. The Houck and Gallagher (1976) logarithmic time trend likely places their estimates into more of a long-run framework since the decaying influence of disembodied technology is less able to absorb year to year variability. Additionally, their formulation has the potential to fit better with the model of technological progress represented as a discrete advance in technology and a declining influence on aggregate productivity as adoption progresses. The panel data approach of Kaufman and Snell (1997) featuring a time series only for Census years likely tends toward a medium to long run estimate as well. The five year gaps in observations should be more indicative of adjustment to permanent rather than transitory price changes. As mentioned earlier, the
Choi and Helmberger (1993) estimates feature the two equation approach, but maintain a narrow focus on nitrogen response as a determinant of yields. For other sectors, evidence indicates that oilseed yield response should be lower than for nitrogen-dependent crops. This is confirmed in the OECD-PEM representation but not in the alternative ERS/PSU model’s collection of assumptions. Little evidence on wheat and rice response exists that can be compared to OECD-PEM estimates for the United States, but the weight of evidence on the corn sector suggests there is merit in maintaining estimates in the current OECD-PEM parameter range.

In terms of non-U.S. North America, the evidence supports yield response in Canada and the United States being similar. We would expect yield response to be depressed in Mexico due to the lower scale of commercialization in agricultural production sectors and the potential for missing markets. Figure 4 below plots yield response curves for all three North American countries’ coarse grains sectors and confirms the reduced supply response for Mexico. Downward adjustment of factor supply parameters for Mexico would seem appropriate to better distinguish the supply response gap that we would expect to persist.

Our assessment finds the yield response arising from the OECD-PEM model to be consistent with the limited empirical evidence for the medium to long run period of adjustment. Aggregation across commodities probably indicates that some downward adjustment of the yield elasticities would be preferable to account for the minor crops contained in a sector like coarse grains that are likely less responsive to price outcomes. The relative yield response across sectors seems justified by the results presented here and points again to the factor supply elasticities as a means of dampening yield response across crops. More work on the foundational parameters of factor supply in the model that would better tie down the period of adjustment should be considered in any model revision in an effort to reduce yield response predictions.

In examining OECD-PEM yield elasticities we have focused on the factor supply assumptions and our recommendations for further model development rest in this area. The relative lack of evidence to support the current parameters from Abler (2001), and the assumption of common elasticities across countries both point to these parameters as an area where model development should be focused. The current range of potential factor supply elasticities is very large and encompasses most of the estimated yield responses reviewed in this study. Narrowing this range with some additional econometric work would be quite useful for policy analysis. Furthermore, a distinction between short-run (one year) and long-run (3-5 years) elasticities would be very useful.

The importance of these parameters for yield response provides clear cause to consider extended work in this area in support of the OECD-PEM effort to analyze agricultural policies. The importance of these parameters in determining factor income and response to differential policy instruments further points to improving the empirical underpinnings along this front. Econometric estimates that consider the role of heterogeneity of farms in developed countries, the possibility of asymmetric response to labor market signals, and the investment-savings decisions of farm households with respect to farm business and off-farm opportunities would all seem to be important foundational considerations in the response of farm-owned factors for normative analysis of the many
dimensions of impacts that must be considered when modeling agricultural policy changes in the OECD countries.
VIII. References


Table 1. Substitution Elasticities in the OECD-PEM Framework

<table>
<thead>
<tr>
<th>Country</th>
<th>Farm-owned</th>
<th>Purchased</th>
<th>Farm-owned</th>
<th>Purchased</th>
<th>Purchased</th>
<th>Purchased</th>
</tr>
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<tr>
<td>Canada</td>
<td>0.10</td>
<td>0.50</td>
<td>0.90</td>
<td>0.10</td>
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<tr>
<td>Mexico</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.15</td>
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<td></td>
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<td>United States</td>
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<td>0.50</td>
<td>0.80</td>
<td>0.15</td>
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Table 2. OECD-PEM and ERS/PSU Yield Elasticities

<table>
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<tr>
<th>Country</th>
<th>Sector</th>
<th>OECD-PEM</th>
<th>ERS/PSU</th>
<th>Lambda</th>
</tr>
</thead>
<tbody>
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<td>Canada</td>
<td>Wheat</td>
<td>0.63</td>
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<td>Coarse Grains</td>
<td>0.67</td>
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<td>Oilseeds</td>
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<td>0.07</td>
<td>21.5</td>
</tr>
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<td>Wheat</td>
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<td>8.0</td>
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<td>Coarse Grains</td>
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</tr>
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<td>Oilseeds</td>
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<td>0.02</td>
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<td>Rice</td>
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<tr>
<td>United States</td>
<td>Wheat</td>
<td>0.67</td>
<td>0.00</td>
<td>Inf.</td>
</tr>
<tr>
<td></td>
<td>Coarse Grains</td>
<td>0.69</td>
<td>0.02</td>
<td>72.9</td>
</tr>
<tr>
<td></td>
<td>Oilseeds</td>
<td>0.54</td>
<td>0.10</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>Rice</td>
<td>0.83</td>
<td>0.20</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Source: Authors' calculations and Stout & Abler (2004).

Table 3. OECD-PEM and Factor Supply Elasticity Adjustments

<table>
<thead>
<tr>
<th>Country</th>
<th>Average Deviation</th>
<th>( \lambda^* )</th>
<th>Factor Supply Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Farm-owned</td>
</tr>
<tr>
<td>All No. Amer.</td>
<td>0.45</td>
<td>7.16</td>
<td>0.06</td>
</tr>
<tr>
<td>Canada</td>
<td>0.58</td>
<td>21.64</td>
<td>0.02</td>
</tr>
<tr>
<td>Mexico</td>
<td>0.46</td>
<td>7.16</td>
<td>0.07</td>
</tr>
<tr>
<td>United States</td>
<td>0.34</td>
<td>3.63</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Source: Authors' calculations.
Table 4. U.S. Corn Yield Elasticity Estimates

<table>
<thead>
<tr>
<th>Authors (Abbrev.)</th>
<th>Time Period</th>
<th>Data</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houck and Gallagher (HG Upper)</td>
<td>1951-1971</td>
<td>Time series of national yields</td>
<td>0.76 ( t = 6.33 )</td>
</tr>
<tr>
<td>Houck and Gallagher (HG Rec.)</td>
<td>1951-1971</td>
<td>Time series of national yields</td>
<td>0.69 ( t = 6.32 )</td>
</tr>
<tr>
<td>Houck and Gallagher (HG Lower)</td>
<td>1951-1971</td>
<td>Time series of national yields</td>
<td>0.28 ( t = 3.59 )</td>
</tr>
<tr>
<td>Menz and Pardey (MP Pd 1)</td>
<td>1951-1971</td>
<td>Time series of national yields</td>
<td>0.61 ( t = 5.17 )</td>
</tr>
<tr>
<td>Choi and Helmberger (CH)</td>
<td>1964-1988</td>
<td>Time series of national yields</td>
<td>0.27 ( t = 2.80 )</td>
</tr>
<tr>
<td>Lyons and Thompson (LT)</td>
<td>1961-1973</td>
<td>Pooled time series of national yields (14 countries)</td>
<td>0.22 ( t = 3.13 )</td>
</tr>
</tbody>
</table>

Source: See references indicated by author names in column 1.
Note: The t-values accompanying estimates are not for the elasticity values (excepting Lyons and Thompson) but are the reported t-values for the price coefficient from the estimated model.
Table 5. United States—Yield Elasticities with respect to Output Price

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Estimate</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Crops (Short Run)</td>
<td>0.15 SDZ</td>
<td>Tweeten and Quance (1969)</td>
</tr>
<tr>
<td>All Crops (Long Run)</td>
<td>1.50 SDZ</td>
<td>Tweeten and Quance (1969)</td>
</tr>
<tr>
<td>C. Grains Barley (Lake States)</td>
<td>0.19 SDZ</td>
<td>Ash and Lin (1987)</td>
</tr>
<tr>
<td>C. Grains Cereal Grains</td>
<td>0.00 A</td>
<td>Stout and Abler (2004)</td>
</tr>
<tr>
<td>C. Grains Corn</td>
<td>0.27 SDZ</td>
<td>Choi and Helmberger (1993)</td>
</tr>
<tr>
<td>C. Grains Corn</td>
<td>0.02 A</td>
<td>Stout and Abler (2004)</td>
</tr>
<tr>
<td>C. Grains Corn (1951-1971)</td>
<td>0.61 SDZ</td>
<td>Menz and Pardey (1983)</td>
</tr>
<tr>
<td>C. Grains Corn (1951-1971) (Model III)</td>
<td>0.76 SDZ</td>
<td>Houck and Gallagher (1976)</td>
</tr>
<tr>
<td>C. Grains Corn (1951-1971) (Model I)</td>
<td>0.24 SDZ</td>
<td>Houck and Gallagher (1976)</td>
</tr>
<tr>
<td>C. Grains Corn (1972-1980)</td>
<td>0.44 NSDZ</td>
<td>Menz and Pardey (1983)</td>
</tr>
<tr>
<td>C. Grains Corn (Kentucky)</td>
<td>Negative NSDZ</td>
<td>Reed and Riggins (1982)</td>
</tr>
<tr>
<td>C. Grains Oats</td>
<td>0.04 A</td>
<td>Stout and Abler (2004)</td>
</tr>
<tr>
<td>C. Grains Oats (Corn Belt)</td>
<td>0.04 NSDZ</td>
<td>Brandt, et al. (1992)</td>
</tr>
<tr>
<td>C. Grains Oats (Northern Plains)</td>
<td>0.04 NSDZ</td>
<td>Brandt, et al. (1992)</td>
</tr>
<tr>
<td>C. Grains Sorghum (Northern Plains)</td>
<td>0.19 NSDZ</td>
<td>Ash and Lin (1987)</td>
</tr>
<tr>
<td>C. Grains Sorghum (Southern Plains)</td>
<td>0.24 NSDZ</td>
<td>Ash and Lin (1987)</td>
</tr>
<tr>
<td>Oilseeds Canola</td>
<td>0.04 A</td>
<td>Stout and Abler (2004)</td>
</tr>
<tr>
<td>Oilseeds Rapeseed</td>
<td>0.04 A</td>
<td>Stout and Abler (2004)</td>
</tr>
<tr>
<td>Oilseeds Soybeans</td>
<td>0.13 SDZ</td>
<td>Choi and Helmberger (1993)</td>
</tr>
<tr>
<td>Oilseeds Soybeans</td>
<td>0.10 A</td>
<td>Stout and Abler (2004)</td>
</tr>
<tr>
<td>Rice All Rice</td>
<td>0.20 A</td>
<td>Stout and Abler (2004)</td>
</tr>
<tr>
<td>Wheat All Wheat</td>
<td>0.03 NSDZ</td>
<td>Choi and Helmberger (1993)</td>
</tr>
<tr>
<td>Wheat All Wheat</td>
<td>Negative SDZ</td>
<td>Epplin (1997)</td>
</tr>
<tr>
<td>Wheat All Wheat</td>
<td>0.00 A</td>
<td>Stout and Abler (2004)</td>
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<tr>
<td>Wheat All Wheat (Pacific)</td>
<td>0.08 NSDZ</td>
<td>Ash and Lin (1987)</td>
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<tr>
<td>Wheat Spring Wheat (No. Plains)</td>
<td>0.04 NSDZ</td>
<td>Ash and Lin (1987)</td>
</tr>
<tr>
<td>Wheat Winter Wheat (Corn Belt)</td>
<td>0.20 SDZ</td>
<td>Ash and Lin (1987)</td>
</tr>
<tr>
<td>Wheat Winter Wheat (No. Plains)</td>
<td>0.04 NSDZ</td>
<td>Ash and Lin (1987)</td>
</tr>
</tbody>
</table>

Notes: A—Assumed in the ERS/PSU model.
NSDZ—Based on a parameter estimate that is not statistically different from zero.
SDZ—Based on a parameter estimate that is statistically different from zero.
SimLP—Simulated elasticity from experiments with an LP model.
Table 6. Other Countries—Yield Elasticities with respect to Output Price

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Estimate Source</th>
<th>Commodity</th>
<th>Estimate Source</th>
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<tbody>
<tr>
<td><strong>MULTIREGION</strong></td>
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<td><strong>CANADA</strong></td>
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<tr>
<td>All Agriculture</td>
<td>Wheat Equivalents (q/ha)</td>
<td>1.25-1.66 SDZ</td>
<td>Wheat</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Coarse Grains</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Corn</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Soybeans</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rapeseed</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Canola</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oats</td>
</tr>
<tr>
<td>All Crops</td>
<td>Output Index/ha</td>
<td>0.05 NSDZ Binswanger et al (1987)</td>
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<tr>
<td>Coarse Grains</td>
<td>Corn</td>
<td>0.22 SDZ Lyons and Thompson (1981)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td><strong>MEXICO</strong></td>
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<td>Wheat</td>
<td>All Wheat</td>
<td>0.16 A Stout and Abler (2004)</td>
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<td>Coarse Grains</td>
<td>Corn</td>
<td>0.14 A Stout and Abler (2004)</td>
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</tr>
<tr>
<td>Coarse Grains</td>
<td>Cereal Grains</td>
<td>0.16 A Stout and Abler (2004)</td>
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<tr>
<td>Oilseeds</td>
<td>Soybeans</td>
<td>0.18 A Stout and Abler (2004)</td>
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<td>Oilseeds</td>
<td>Rapeseed</td>
<td>0.02 A Stout and Abler (2004)</td>
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</tr>
<tr>
<td>Oilseeds</td>
<td>Canola</td>
<td>0.02 A Stout and Abler (2004)</td>
<td></td>
</tr>
<tr>
<td>Coarse Grains</td>
<td>Oats</td>
<td>0.04 A Stout and Abler (2004)</td>
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</tr>
<tr>
<td><strong>GUATEMALA</strong></td>
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<tr>
<td>Coarse Grains</td>
<td>Corn</td>
<td>0.50 SimLP Pomareda and Samayoa (1979)</td>
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<tr>
<td><strong>PAKISTAN</strong></td>
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<td>Wheat</td>
</tr>
<tr>
<td>Wheat</td>
<td>Wheat (Short-run)</td>
<td>0.16 SDZ Mushtaq and Dawson (2003)</td>
<td>Wheat (Long-run)</td>
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<tr>
<td></td>
<td>Wheat (Long-run)</td>
<td>0.70 SDZ Mushtaq and Dawson (2003)</td>
<td></td>
</tr>
<tr>
<td><strong>NEW ZEALAND</strong></td>
<td>Wheat</td>
<td>0.14 SDZ Guise (1969)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All Wheat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:  
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SDZ—Based on a parameter estimate that is statistically different from zero.  
SimLP—Simulated elasticity from experiments with an LP model.
Figure 1. Canadian Wheat Yield Elasticity in OECD-PEM

Canadian Wheat Yield Response

- Own-price AUE Canadian Wheat: 1.46
- Yield Elasticity of PEM:
  - Upper Bound: 0.81
  - Lower Bound: 0.23
- Yield Elasticity Curve with increased Land Cost Share

Factor Immobility (Lambda)
Figure 2. Yield Elasticities for U.S. Corn and Implications for Factor Mobility in the PEM
Figure 3. Yield Response in PEM for all U.S. Crops
Figure 4. Cross-country Yield Response in the OECD-PEM Model