Agricultural Price, Quantity, and Welfare Effects of Air Quality Improvements

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The failure to allow for significant crop quality effects in a partial-equilibrium model can lead to misleading inferences about the price, output and welfare implications of air quality improvements. It has been observed that air pollutants such as ozone, sulphur dioxide, and nitrogen dioxide affect the yield and quality of many crops. The economic benefit from improving air quality in crop producing regions has been measured using a partial-equilibrium approach which accounts only for supply shifting yield effects. It is shown that a yield-effect only model will underestimate output increases and benefits from an air quality improvement when commodity quality improvements as well as yield increases are forthcoming.

Among the range of detrimental consequences of air pollution is adverse impacts on agricultural productivity. For example, estimates recently presented by the Office of Technology Assessment, based upon data developed by the National Crop Loss Assessment Network (NCLAN), indicate that reducing ozone concentrations in 1978 to natural background levels would have increased U.S. average corn yields by 3 percent, wheat yields by 8 percent, soybean yields by 17 percent, and peanut yields by 30 percent. Economic assessments of the damages due to air pollution effects on agricultural productivity have traditionally been obtained as the product of yield changes predicted by biological dose response functions and prevailing market prices. Two potential defects in this approach were recently noted by Crocker. First, since agricultural commodity demands are inelastic, significant yield changes due to air pollution effects on productivity should give rise to commodity price changes which should in turn lead to market induced supply changes. Second, biological dose response functions will not provide accurate indications of yield changes, even at prevailing prices, if farmers can undertake changes in production practices and cropping patterns to diminish the losses resulting from air pollution exposure.

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To identify the price and quantity effects and the economic benefits resulting from agricultural productivity improvements due to air quality improvements in an economically sound manner, Crocker and others (e.g., Adams et al.) recommend the partial equilibrium procedures outlined by Freeman for estimating the productivity benefits of air quality improvements. The essence of this approach is to estimate the commodity supply and demand functions and the effects of air quality improvements on supply to generate predictions of price and quantity effects and changes in producer and consumer surpluses. Adams et al. followed the partial equilibrium approach in a study of the effects of air pollution on agriculture in California. The results of the study indicated substantial differences in the implications for damages and yield loss predictions between the traditional and partial equilibrium approaches.

Agricultural commodities are multi-attribute in character and the demand for these commodities is influenced by their attributes (Ladd). While biological research on the ramifications of air pollution on agricultural production has focused on yield effects, there is evidence to indicate effects on economically relevant aspects of product qualities. For example, high ozone concentrations have been observed to lower the oil content of soybeans, and to reduce the quality of cotton seed and lint (Heggestad and Christianson; Miller). This suggests that consumer behavior in agricultural commodity markets will reflect responses not only to price changes induced by commodity supply changes, but also to product quality changes.

In this note we suggest that applications of the partial equilibrium approach must consider commodity demand shifts as well as commodity supply shifts resulting from changes in the exposure of crops to air pollution stresses. Otherwise, misleading inferences about the price, output, and welfare implications of air quality improvements might be made. The analysis presented below begins with an overview of the fundamentals of the partial equilibrium approach suggested by Freeman and implemented in the study by Adams et al. To emphasize the issues, this approach is referred to as the "yield effects only" model. The "yield effects only" model is then modified to introduce quality effects which influence commodity demands. Comparisons between the two models show that ignoring relevant quality effects will bias estimates of price and quantity effects and economic benefits resulting from air quality improvements. In addition, since the quality of agricultural commodities is often imperfectly known by demanders (Berck and Rausser), some implications of quality uncertainty are considered. The paper is concluded with some comments on research needs.

Yield Effects Only

The fundamentals of the "yield effects only" framework for identifying the price and yield effects, and the economic benefits of air quality improvements, is illustrated by considering a simple market model. Let the inverse of the long-run market demand for a constant quality agricultural commodity be

$$(1) \qquad p = D(q)$$

where p is the price of the commodity and q is the quantity of the commodity. Given a negatively sloped demand curve it follows that $\partial D/\partial q < 0$. The inverse of the long-run market supply function is written

$$(2) \qquad p = S(q, a)$$

where a is the known ambient air quality. Given a positively sloped supply curve it follows that $\partial S/\partial q > 0$. With the assumption that ambient air quality increases the quantity supplied at any price, it follows that $\partial S/\partial a < 0$.

Let p_e and q_e denote the long-run equilibrium market price and quantity respectively. The latter is obtained by equating (1) and (2) and solving for output. The former may then be obtained by substituting the resulting q_e into (1). The effects of ambient air quality changes on p_e and q_e may be represented as follows. Let $E_{pa}{}^{o}$ denote the elasticity of p_e with respect to ambient air quality. Further, let $E_{qa}{}^{o}$ denote the elasticity of q_e with respect to a. These elasticities may be written:

$$(3) \qquad E_{pa}{}^{o} = \frac{dp_e}{da}\frac{a}{p_e} = \frac{\epsilon_{as}}{\epsilon_{qd} - \epsilon_{qs}}$$

$$(4) \qquad E_{qa}{}^{o} = \frac{dq_e}{da}\frac{a}{q_e} = \frac{\epsilon_{qd}\epsilon_{as}}{\epsilon_{qd} - \epsilon_{qs}}$$

where ϵ_{qd} is the price elasticity of demand, ϵ_{qs} is the price elasticity of supply, and ϵ_{as} is the elasticity of the quantity supplied with respect to ambient air quality.

The elasticities ϵ_{qd} and ϵ_{qs} will be respectively negative and positive, since $\partial D/\partial q < 0$ and $\partial S/\partial q > 0$. The elasticity ϵ_{as} will be positive under the assumption that agricultural productivity is improved with air quality improvements. With these signs, it follows that (3) is unambiguously negative while (4) is unambiguously positive. Consequently, given a negatively-sloped demand function, a positively-sloped supply function, and positive productivity effects of air quality improvements, it will be the case that such improvements reduce price and increase output in a market equilibrium in the simple "yield effects only" model.

The changes in the sum of the Marshallian consumer plus producer surplus resulting from an increase in ambient air quality in equilibrium may be written:

$$(5) \qquad NB_0 = \int_0^{q_e{}^1} (D(\theta) - S(\theta, a_l))dq - \int_0^{q_e{}^0} (D(\theta) - S(\theta, a_o))dq$$

where a_l is the improved level of air quality, a_o is the original air quality, $q_e{}^1$ is the post-air improvement equilibrium quantity, and $q_e{}^0$ is the pre-air improvement equilibrium quantity. This sum represents a measure of the economic benefits of the air quality improvements in the "yield effects only" model (Freeman; Harberger).

Yield and Quality Effects

There are a number of alternative approaches for introducing product quality in commodity models. Presently, however, there is no generally preferred approach (Hanemann; Ladd). For this analysis of both quality and yield effects we adopt a simple approach which permits the quality consideration to be readily integrated into the model outlined above. It is assumed that the commodity is constant in quality across producers and consumers during a market period. However, quality is allowed to vary from market period to market period with air quality changes between production periods. The inverse of the long-run market demand is now written:

$$(6)\qquad p = D(q, b(a))$$

where b(a) is an index of the quality of the agricultural commodity, which in turn depends upon ambient air quality. The quantity demanded at any price is assumed to be increased by air quality improvements because of commodity quality improvements. Accordingly, it is assumed that $\partial b/\partial a > 0$ and $\partial D/\partial b > 0$.

With this treatment of quality effects and the previous treatment of yield effects, the elasticities of equilibrium price and quantity with respect to air quality changes become:

$$(7)\qquad E_{pa}{}^{1} = \frac{\epsilon_{as} - \epsilon_{ad}}{\epsilon_{qd} - \epsilon_{qs}}$$

$$(8)\qquad E_{qa}{}^{1} = \frac{\epsilon_{qd}\epsilon_{as} - \epsilon_{ad}\epsilon_{qs}}{\epsilon_{qd} - \epsilon_{qs}}$$

where ϵ_{ad} is the elasticity of demand with respect to ambient air quality. There are two things to note regarding price and quantity effects in the "yield and quality effects" model. First, given that commodity quality improvements due to air quality improvements increase quantity demanded ($\epsilon_{ad} > 0$), the equilibrium price elasticity with respect to air quality improvements (7) is no longer unambiguously negative. Specifically, note that if $\epsilon_{ad} > \epsilon_{as}$, air quality improvements could result in increased long-run equilibrium commodity prices. The "yield effects only" model will result in biased estimates of price changes, because quality impacts are ignored.

Next, observe that while the quantity effect (8) remains unambiguously positive, the "yield effects only" model will, ceteris paribus, predict smaller quantity increases than the "yield and quality effects" model. To see this consider the difference between (4) and (8):

$$(9)\qquad E_{qa}{}^{1} - E_{qa}{}^{o} = \frac{-\epsilon_{ad}\epsilon_{qs}}{\epsilon_{qd} - \epsilon_{qs}}.$$

The sign of (9) is unambiguously positive. This implies that the elasticity of long-run equilibrium output in the "yield and quality effects" model exceeds the corresponding elasticity in the "yield effects only" model, which demonstrates the point.

The change in the sum of the Marshallian consumer plus producer surpluses due to an air quality improvement in the "yield and quality effects" model may be written:

$$(10)\qquad NB_1 = \int_0^{q_e{}^1} (D(\theta, b(a_l)) - S(\theta, a_l))dq - \int_0^{\hat{q}_e{}^0} (D(\theta, b(a_o)) - S(\theta, a_o))dq$$

where a_l and a_o are defined as above, $\hat{q}_e{}^0$ is the long-run equilibrium quantity associated with a_o, and $q_e{}^1$ is the long-run equilibrium quantity associated with a_l.

To compare the benefits indicated by the "yield effects only" model to the benefits indicated by the "yield and quality effects" model consider the difference between (5) and (10) for a given air quality change when the inverse demand function utilized in (5) is $D(q, b(a_o))$. At the original ambient air quality (a_o), the equilibrium prices and quantities will be identical for the two models. Thus, $q_e{}^0 = \hat{q}_e{}^0$. With the change to the higher ambient air quality (a_l), the equilibrium quantity indicated by the "yield and quality effects" model will exceed that indicated by the "yield effects only" model for the reason noted above. Consequently, $q_e{}^1 < \hat{q}_e{}^1$. With these comments, the difference between (5) and (10) can be written:

$$(11)\qquad NB_1 - NB_0 = \int_0^{q_e{}^1} (D(\theta, b(a_l)) - D(\theta, b(a_o))dq$$

$$(12)\qquad + \int_{q_e{}^1}^{\hat{q}_e{}^1} (D(\theta, b(a_l)) - S(\theta, a_l))dq$$

Given that $D(q, b(a)) > D(q, b(a_o))$ for any $a_o \leq a \leq a_l$, it follows that (11) is positive. Further, given that $D(q, b(a)) > S(q, a)$ for any $q_e < \hat{q}_e{}^1$, it follows that (12) is positive. Consequently, $NB_1 - NB_0 > 0$. This indicates that other things equal, the "yield effects only" model will underestimate the economic benefits resulting from air quality improvements if the appropriate model is the "yield and quality effects" model.

Uncertainty and Quantity

In the preceding analysis, it was assumed that the quality of the commodity is known by demanders. But it was noted previously that this assumption may not be reasonable in all cases. In order to suggest additional issues arising with air quality improvements we consider the response of an individual demander to changes in the distribution of quality due to air quality improvements when commodity quality is uncertain. An example would be an oil manufacturer who receives shipments of soybeans from various locations without knowing the oil content of the beans. The analysis is based upon a framework developed by Ratti and Ullah.

Consider a firm which produces a good using an agricultural commodity as an input. The production function is written:

$$y = g(\hat{q}, z) = g(bq, z) \tag{13}$$

where y is quantity of the good produced, q is the input of the agricultural commodity, b is the quality index for the agricultural commodity, $\hat{q} = bq$ is the effective or quality weighted agricultural commodity input, and z is some other factor. This specification implies that the quality of the agricultural commodity is agricultural-commodity input augmenting. It is assumed that $g_{\hat{q}} > 0$, $g_z > 0$, $g_{\hat{q}\hat{q}} < 0$, $g_{zz} < 0$, and $g_{\hat{q}z} > 0$. These assumptions imply that agricultural commodity quality improvements due to air quality improvements would increase demand for the commodity under conditions of certainty on prices and commodity quality.

The results of Ratti and Ullah's investigation imply the following when the quality of the agricultural commodity is uncertain and the production is described by the framework outlined above: (1) A mean-preserving change in the spread of the distribution of the quality of the agricultural commodity may either increase or decrease the quantity demanded at known prices if the firm is not risk neutral. If the firm is risk neutral a mean-preserving increase (decrease) in the spread of the distribution of the quality variable will decrease (increase) the quantity demanded at prevailing prices; (2) A spread-preserving change in the expected quality of the agricultural commodity may either increase or decrease the quantity of the agricultural commodity demanded at prevailing prices if the firm is not risk neutral. If the firm is risk neutral, a spread-preserving increase (decrease) in expected quality will increase (decrease) the quantity demanded at prevailing prices. (These results would also hold for individuals who are direct consumers of agricultural commodities affected by air quality, and who are utility maximizers.)

The implication of these comments is that air quality improvements which influence the distribution of the quality of the agricultural commodity will not unambiguously increase the quantity of the commodity demanded when quality is uncertain and firms are not risk neutral. This suggests that when air quality affects crop quality, and when crop quality influences commodity demand, and is uncertain, both price and quantity effects of air quality improvements are ambiguous.

Conclusion

The results of the foregoing analysis indicate that failure to allow for significant crop quality as well as yield effects can lead to misleading inferences about the magnitudes of price, output, and welfare implications of air quality improvements. At present, however, scientific understanding of quality effects of air pollution is not very advanced. Much of the research to date on air quality impacts on agriculture has concentrated on yield effects. There is only fragmentary evidence of quality effects. However, this does not mean they are insignificant. This is not the only area where knowledge is limited. State-of-the-art empirical economic models of product quality are not very advanced. Consequently, it appears that research on both fronts is necessary to provide reasonably accurate estimates of the effects of air improvements on agriculture.

References

Adams, R. M., T. D. Crocker, and N. Thanavibulchai. "An Economic Assessment of Air Pollution Damages to Selected Annual Crops in Southern California." *Journal of Environmental Economics and Management*. 1(1982):42–50.

Adams, R. M. and T. D. Crocker. "Economically Relevant Response Estimation and the Value of Information: Acid Deposition." *Economic Perspectives on Acid Deposition Control*, T. D. Crocker, Ed. (Boston: Butterworth Publishers, 1984). pp. 35–64.

Berck, P. and G. C. Rausser. "Consumer Demand, Grades, Brands, and Margin Relationships." In *New Frontiers in Econometric Modeling and Forecasting*. G. C. Rausser, Ed. (New York: North Holland, 1982). pp. 99–150.

Crocker, T. D. "Pollution Damages to Managed Ecosystems: Economic Assessments." In *Effects of Air Pollution on Farm Commodities*. J. S. Jacobson and A. A. Millens, Eds. (Arlington, VA: Isaak Walton League, 1982). pp. 103–24.

Freeman, A. M. *The Benefits of Environmental Improvement-Theory and Practice*. (Baltimore: Johns Hopkins University Press for Resources for the Future, 1977).

Hannemann, W. M. "Quality in Demand Analysis." In *New Frontiers in Econometric Modeling and Forecasting*. G. C. Rausser, Ed. (New York: North Holland, 1982). pp. 55–97.

Harberger, A. C. "Three Basic Postulates for Applied Welfare Economics. An Interpretive Essay." *Journal of Economic Literature*. 9(1971):785–97.

Heggestad, H. E. and M. N. Christianson. "Cotton." In *Effects of Air Pollution on Farm Commodities*. J. S. Jacobson and A. A. Millens, Eds. (Arlington, VA: Isaak Walton League, 1982). pp. 9–32.

Ladd, G. W. "Survey of Promising in Demand Analysis: Economics of Product Characteristics." In *New Frontiers in Econometric Modeling and Forecasting*. G. C. Rausser, Ed. (New York: North Holland, 1982). pp. 17–53.

Miller, J. E. "Soybeans." In *Effects of Air Pollution on Farm Commodities*. J. S. Jacobson and A. A. Millens, Eds. (Arlington, VA: Isaak Walton League, 1982).

Office of Technology Assessment. *Regional Implication of Transported Air Pollutants: An Assessment of Acidic Deposition and Ozone*. (July, 1982).

Ratti, R. A. and A. Ullah. "Uncertainty in Production and the Competitive Firm." *Southern Economic Journal*. 42(1976):703–10.