THE APPROPRIATE MODEL FOR THE CHOICE OF AGRICULTURAL INPUTS: PRIMAL, DUAL, OR OTHER

by David Zilberman

Agricultural inputs --pesticides, water, and land-- are becoming the subject of a growing number of policies and regulations. The environmental problems and public health externalities that may stem from the use of pesticides and soil and the public good nature of groundwater provide theoretical justification to consider public intervention in he use of these inputs. Applied economic analysis has been playing a growing role in assessing and even determining policies affecting these inputs, and economists are faced with a growing challenge of developing methodologies to understand and assess the use of agricultural inputs.

The paper assesses alternative strategies for econometric modeling and the analysis of the use of agricultural inputs. It starts by discussing the merits of duality-based frameworks and continues with two applications --water use and pesticide-- that show some of its limitations. The paper concludes that there is no clear and generic way for analyzing empirically agricultural input use. The modeling approach depends on data availability and degree of detail and the aggregation of problems considered. Moreover, modeling requires an understanding of the actual agricultural principles behind the specific use of agricultural input and even development of a simpler model incorporating agricultural and economic considerations to obtain a believable and realistic framework.

The Paradoxical Performance of Duality Models

The ingenuity of empirical duality models is that they incorporate a behavioral assumptions (profit maximization), and readily available data (mostly nominal data on prices, cost shares, and costs and also data on quantities such as output and input use lands) are incorporated to obtain unobservable demand and supply parameters and key technological and taste parameters. The use of duality allows estimation of models consistent with neoclassical theory and provide a useful relationship and easy transition to conduct welfare economic assessments of policies and regulations.

The key for usefulness and applicability of duality models in particular situations is the realism and relevance of the theory behind it for these situations. In particular, duality models that are derived under cost minimization and/or profit maximization assumptions are useful for situations where these assumptions are approximations of reality.

The 1950s-1960s were full of debates regarding key assumptions used in economic analysis. Simon and the behavioralists argued against the realism of profit maximizing, mostly on grounds of bounded rationality. Friedman's response was not direct but was very constructive. He argued that neoclassical theory is built under the assumption that people behave “as if” they maximize profit. In essence, his approach suggests that, as long as the empirical hypotheses derived from profit maximization are supported by the data, the profit maximization model is relevant and useful. This perspective justifies the emphasis that has been given in the economic literature to empirical tests based on duality models. In essence, these tests serve to test and identify situations when the profit maximization assumption is useful.

Friedman's outlook provides a useful perspective to evaluate estimates of duality models. When the duality approach is used to estimate production function parameters, the estimated production function is not necessarily the "true" technical production function. It is the "as if" production function, reflecting a technology consistent with observed data, profit maximization, and competition. In other words the true production function may be different than the one estimated, and actual decision rules may be different than implied by profit maximization, but the data the "true" relationships generated were used to derive the estimated production function under the profit maximization assumption.

Another key debate of the 1950s-1960s is the Cambridge controversy (Harcourt). The key issue in this controversy was the existence and usefulness of the concept of aggregate production function. The Cambridge, England, economists argued that application of microeconomics (by neoclassical economists such as Solow at Cambridge, Massachusetts) theory at aggregate (sectoral and economy-wide) levels to analyze growth and productivity problems was groundless. In particular, they were critical of the notions and definitions of aggregate inputs (particularly capital) implied by these aggregate analyses.

Conceptual models, such as the one by Houthakker and Johansen, established a microeconomic approach to derive aggregate production relationships and provided some justification to their use. Friedman's approach to positive analysis provides a test for the usefulness of these concepts; namely, aggregate notions of cost and production functions are useful as long as they perform well empirically. Applied duality models have been used to show that this is the case. These models are adapted to employ data that are available at aggregate levels (costs, share of costs, and prices). Works, such as the one presented previously by Huffman and Evenson and the ones presented in Antle and Capalbo's book, have resulted in reasonable and useful estimates of parameters reflecting aggregate behavior of the agricultural sector in several countries.

It seems that the performance of applied duality with microlevel data has been less impressive than with aggregate data. While these models, in essence, have vindicated the notion of aggregate production function, they have not accomplished a similar feat to profit maximization behavior in the farm level. In essence, however, that is not very surprising. Conceptual models of firm and farm behavior have realized the limitations of the simpler full information profit maximization model and have been engaged in analyzing more complex microlevel decision frameworks. Such frameworks address problems of risk aversion, imperfect markets, incomplete information, dynamic adjustments, sequential decision making, etc. While there have been attempts to extend duality approach to incorporate such considerations (see Epstein for a modeling dynamic duality and Pope, Chavas, and Just for a framework for duality modeling under uncertainty), they have not been extensively applied, and the superiority of duality models in microlevel modeling have not been established.

Policies regulating agricultural natural resources, such as pesticides cancellation, water use, and drainage controls and soil management regulations, require a rather detailed understanding of farm level behavior and production choices. The following sections demonstrate the limitations of empirical microlevel modeling based on simpleminded profit maximization and introduce some alternative approaches.

Allocation of Water Among Crop --Primal, Dual, and Behavior Alternatives

Three recent papers (Just, Zilberman, and Hochman; Chambers and Just; and Just, Zilberman, Hochman, and Barshira) have analyzed empirically a data base from Israel. It contained information about the behavior of about 160 farmers in two villages during an eight-year period. These farmers grew five crops and, for each farmer, there were data on annual output and revenue and land allocation for each crop as well as on total water use and expenditures and expenditures on other purchased inputs. Data on allocation of water and other expenditures among crops were not available. Actually, one of the objectives of the study that collected the data was to develop a methodology to predict these allocations.

Just, Hochman, and Zilberman have taken a primal approach and estimated Cobb-Douglas production function parameters for each of the crops. They used a simultaneous equation system with equations corresponding to both the production functions and first-order conditions that follow from profit maximization and can be estimated given data limitations. Chambers and Just used a duality approach (a flexible profit function model) for estimating non-joint input technologies for the five crops. On the surface, it seems that duality-based approach is superior to the primal (Cobb-Douglas) approach. That is the verdict of when the abilities of the two approaches to explain the data are compared using statistical hypothesis-testing procedures. The duality-based estimates, however, end up with positively sloped demand relationships -- input demands of the primal models are well behaved (negatively sloped). Finally, comparison of the predicted input allocation among crops by the two approaches makes one very uneasy about the relevance and usefulness of the duality-based approaches for this case.

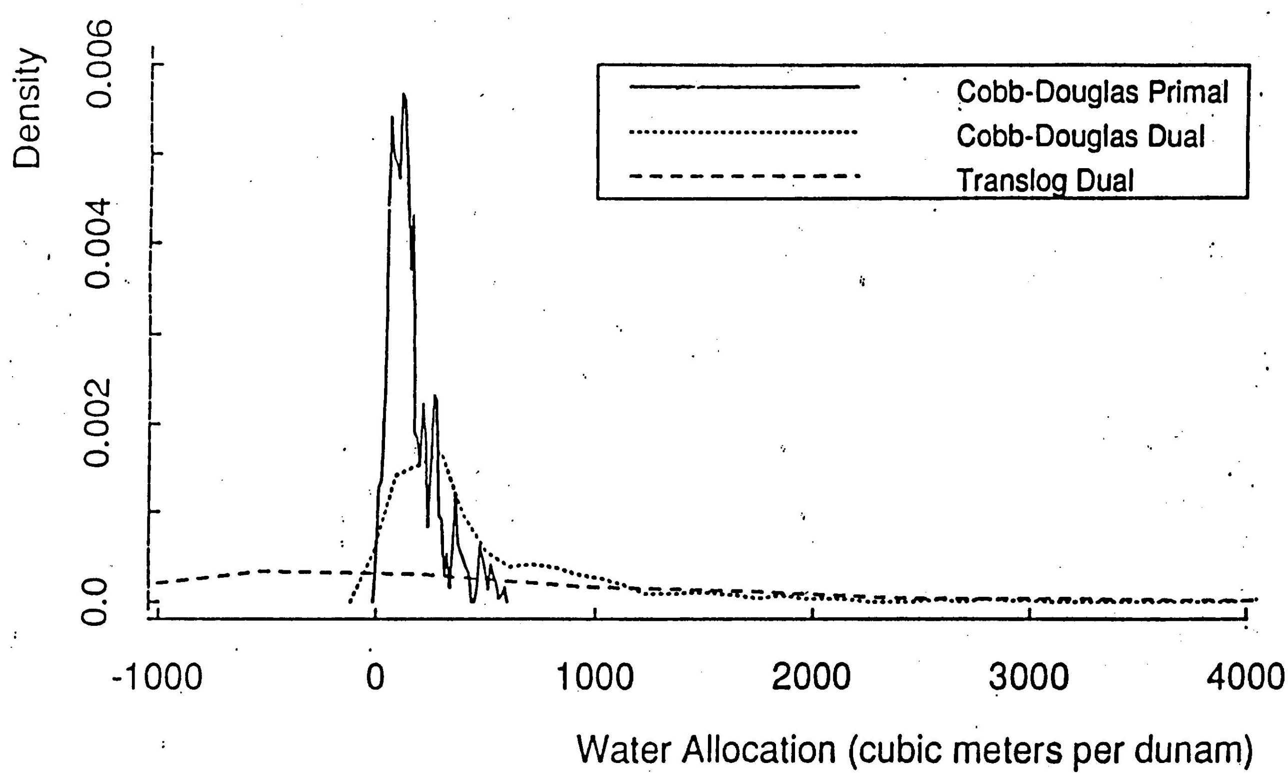


Figure 1. The water allocation distribution for melons

Figure 1 shows distributions of estimated water allocation per dunam of melons for the available data points. The actual range of annual water use per acre should not be negative and should not exceed 1,000 cubic meters per dunam. The "best" estimates based on duality suggest that in some cases farmers applied large negative quantities of water and in others flooded their fields with 4,000 cubic meters per dunam. The Cobb-Douglas primal estimates constrain the predicted value in a much more reasonable range. One plausible reason for the failure of the duality estimates to predict water allocations among crops is that the estimation procedure did not incorporate some reasonable constraints on the estimated parameters (e.g., constraints that will assure non-negativity of applied water per dunam). The unconstrained structure resulted in a very good fit overall but failed to address critical details. Obviously, incorporating several hundred non-negativity constraints to the duality model makes estimation unfeasible; therefore, it seems that the usefulness of duality-based estimation is very limited for this Israeli micro data.

While the Cobb-Douglas primal estimates of input allocations among crops are much better than the duality-based ones, they were not viewed as believable to the leadership of the two villages for which they were estimated. In Just, Zilberman, Hochman, and Barshira, we describe an alternative approach to estimate the allocation of inputs among crops. This approach did not aim to explain the technology --only to explain water and other expenditures allocation. It does not use profit maximization rules for allocation of inputs but relies on a very simple formula. The quantity per acre of input j allocated by farmer i at year t to crop $k(x_{jitk})$ can be decomposed to four elements --a farmer effect (α_{ji}), a time effect (β_{jt}), crop effect (γ_{jk}), and a random noise (ε_{ijtk})

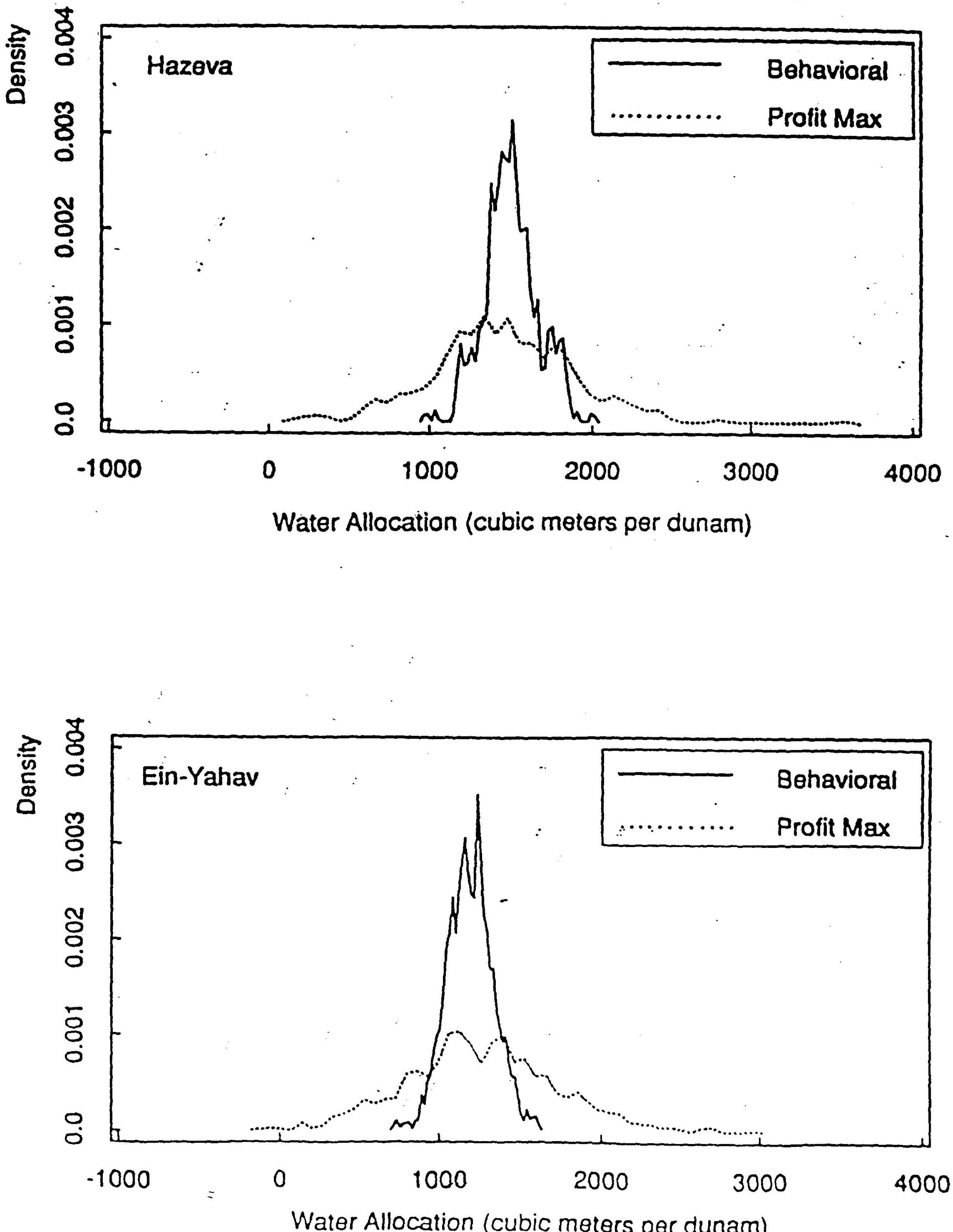
(1) $$x_{jitk} = \alpha_{ji} + \beta_{jt} + \gamma_{jk} + \varepsilon_{ijtk}.$$

The authors interpreted the formula as corresponding to a behavioristic modeling to the farmers' activities. Following interviews with farmers in the region, it was suggested that these farmers view technology as having constant returns to scale, and input-land ratios are determined regardless of size. Furthermore, communication between the farmers and activities of extension agents lead to emergence of regional norms input land. ratios that represented desired average behavior and varied every year. Individual farmers deviated from these norms following their specific land qualities, beliefs, and abilities, etc. Changes in the norms over time corresponded to adjustment following changes in prices, technology, learning, etc. This behavioristic model does not disagree with the notion that farmers pursue profit --it only argues that adjustment and learning are slow, uncertainties are substantial, and farmer behavior does not adjust automatically to changes in economic conditions. In any case the simple model in equation (1) allows to estimate the regional norms for every crop and year as well as the individual deviations.

Just, Zilberman, Hochman, and Barshira show that, based on standard statistical tests, the behavioristic model does not explain the data much better (and sometimes even worse) than profit maximization-based formulation. But, as Figure 2 demonstrates, the distribution of water-land ratios is distributed with a reasonable range of values that corresponds very well to the range of values recommended by farm advisors. Furthermore, none of the predicted values is extremely out of hand (negative or very high water use levels). On the other hand, the profit-maximization based models resulted in a significant number of predicted water-land ratios that are not rational.

The behavioristic model does not provide a final answer; on the contrary, it suggests that duality or primal models that are based on simple profit maximization rules are not sufficient to capture farmer behavior and, hence, to use it to decipher technology. We are challenged to better incorporate learning and adjustment considerations in modeling farmer behavior, and better empirical modeling of behavior may lead to better ability to estimate the implied technologies.

Figure 2. The Water Allocation Distribution for Peppers



Risk Aversion and Pesticide Use

Pesticides are among the most scrutinized and regulated agricultural inputs. Existing legislation and regulatory structure frequently lead to the assessment of specific (rather than clustered) materials. Economists are asked to provide estimates of market benefits and patterns of use of the regulated materials. This type of analysis requires detailed data and knowledge of the agro-economic systems involved. The available data (or lack of) eliminates the feasibility of using econometric estimates in most cases, and economists have to rely on Delphi methods to elicit guesstimates from experts in order to conduct welfare analyses of proposed cancellations (see Lichtenberg, Park, and Zilberman's study on welfare impacts associated with the cancellation of parathion).

Econometrics can play a more useful role in estimating impacts and use of patterns of groups of pesticides (fungicides, herbicides, etc.)[1] or strict management approach (IPM or CPM). Some recent studies, however, suggest that duality may be of limited use in such estimation, and the empirical analysis has to be explicit about the specification of production.

Most empirical studies of production systems in agriculture have viewed impacts of inputs or farmer's welfare through their impacts on (expected) cost and (expected) yields. Under these assumptions, duality could have been used very effectively for estimation of input choices. More recent studies on pesticides have recognized these other dimensions of contributions of pesticides, and the incorporation of these dimensions reduce the applicability of duality and require introduction of alternative modeling strategies.

Antle's recent work emphasizes two aspects that were addressed by what is basically a primal approach. One is risk and the other is interseasonal dynamics. Pest infestations and, hence, pest damage are random and are not known at the start of the season when some decisions are taken. When a farmer is taking the IMP route, his/her spraying decision is made only at the midseason after the infestation level is known. Antle presents the farmer decision problem as a sequential choice problem under risk. He argues that choice of pest management techniques affect both mean and risk of profit. With risk, he allows for risk aversion and obtains an estimatable relationship derived' under expected utility assumption when expected utility is approximated by its three first moments.

Antle's application for the study of pesticide use in California processing tomatoes verified that (1) adopters of IMP reacted to pest population status in their pesticides choices, (2) farmers in the region had risk-aversion behavior, (3) insecticides were marginally risk reducing, and (4) the IPM program increased the producer gain.

Modeling Pesticides Impact on Quality

Vegetables and fruits use pesticides very intensively and account for a substantial share of pesticide use nationwide. Product characteristics, in particular timing and quality, affect substantially the prices received for specialty crops. These characteristics may be affected by pesticides, and these impacts are partially responsible for pesticide use patterns and

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[1] Measurement of input quantities for each group may be a problem. Possible solutions include aggregating quantities of effective material used (when there is sufficient knowledge on relative effectiveness of one pound of each chemical) or expenditures as measures of input use.

should be incorporated in modeling pesticide choices.

The importance of quality impacts of pesticides was illustrated by Babcock, Lichtenberg, and Zilberman. Their modeling approach of quality effect is a variant of the hedonic pricing approach (Rosen). The model distinguishes between several types of variables --output denoted by y, quality denoted by q, characteristics denoted by a vector C, damage control inputs (including pesticides) denoted by the vector X, and regular inputs (some inputs may be damage control and regular) denoted by vector Z. These variables give rise to three types of relationships:

1. Expected output production function $y = f(Z)[1 - L(X)]$ where $f(Z)$ is a potential output which is produced by regular input. $L(X)$ is a fraction of yield lost due to two pest damages (of different types). Damage control inputs include pesticides and cultural activities like pruning that reduce yield losses.

2. Quality production function $q = h(C)$. It is assumed that quality is a function of characteristics. Characteristics can be variables such as size, color, degree of insect damage, and degree of disease damage.

3. Characteristic production functions $C_i = g_i(Z,X)$. Each characteristic is a function of regular and damage control inputs.

This specification of the technology is likely to be complemented by assuming that price is a function of quality $P = P(Q)$ and, thus, producer choice determines yield and price through quality.

This framework was applied with field data from North Carolina The data were collected from 47 apple orchards during a four-year period. It contained physical information on yield, insect, and disease damages; a fraction of fruit sold as fresh; insecticides, fungicides, and other chemical uses; a measure of pruning effectiveness; and weather parameters. In the empirical analysis, a percentage of fruit sold on the fresh market was used as the measure of quality. The extent of insect damage and disease damage was used as a characteristic; insecticides, fungicides, and pruning were damage control inputs; and non-pesticide inputs (including pruning) were regular inputs.

The econometric estimation did not include any behavioral equations --only three types of physical relationships. The loss function was exponential --a form very well accepted by entomologists, and this form introduced severe nonlinearities to the system. The potential output production function $f(Z)$, quality function $h(C)$, and characteristic production function $g_i(Z,X)$ have a Cobb-Douglas form. The estimation procedure was designed to avoid simultaneity problems. The preventive (rather than reactive) use of pesticides in North Carolina was very helpful in this respect.

None of the empirical estimates was unreasonable, and results helped to illuminate some important points. First, quality effects matters. It was found that insecticides have very small (no significant) impacts on yield. Their major impact is on quality; they improve quality by reducing insect damages. Fungicides were found to improve both yield (reducing fungi disease loss) and quality. With reasonable prices, the analysis suggests that quality counts for about one-third of benefits associated with pesticides in the sample.

A second finding is that there is considerable scope for substitution between chemical and agronomical control in reducing both yield losses and disease damage. Pruning was found to be an excellent substitute for fungicide --reducing the profit-maximizing fungicide level by up to threefold as pruning quality improves.

Third, the results verified the point made by Lichtenberg and Zilberman (1986) that use of a Cobb-Douglas production function to model yield effects of pesticides leads to substantial overestimation of productivity of pesticides and results in exaggerated recommendations for pesticide use.

The data used in the Babcock, Lichtenberg, and Zilberman study are quite unique. It has detailed physical information and not a monetary one. Therefore, the approach should be modified for other applications with more balanced data sets. Two possible modifications include:

1. For a more complete hedonic price approach, what is referred to here as characteristics should be used as quality measures, and the set of characteristics should be extended to include size, color, etc. When farm-gate price data are related to characteristics, one can obtain a hedonic price equation. This equation, combined with production functions of output and characteristics, can be used for estimation of technical and behavior parameters derived from a profit maximization (or other behavioral assumption) of a firm that can control output and characteristics by its choice of inputs.

2. When prices and quantities are broken down according to grading categories, production framework can be applied. Here one can experiment with both primal and dual specifications. This approach has to realize that grading criteria are changing quite frequently and the analysis should be limited to short time periods when grading is consistent.

Pesticides as Spoilage Loss Retardants

The effects of pesticides on product characteristics are not restricted to impacts on immediate taste and appearance. Some of the pesticides which are subject to much controversy --in particular fungicides like alar and captan-- are used to reduce spoilage and extend product shelf life and storability. Actually, there is substantial use of chemical pesticides for post-harvest treatment to reduce crop losses in storage. Understanding these uses of pesticides requires modeling the impacts of pesticides on crop storage and output and price dynamics. Lichtenberg and Zilberman (2002) introduced a framework that addresses these issues. Their framework is particularly useful for analyzing impacts of fungicides use on storage problems of fruits such as apples and pears when storage affects dynamics within season. A similar model can be developed for the post-harvest use of pesticide in grains when storage may be of much longer duration.

In the case of fruits considered, the harvesting season is quite short and the products are rather perishable. However, the combined use of cold storage and fungicides allowed storing the fruits up to nine months and resulted in the availability of fruits almost throughout the year. Even with the improved storage, there are some storage losses, and they tend to increase as the season progresses. Furthermore, storage is a costly activity and, if demand does not vary substantially over time, the increase in cost of storage combined with the increase in product losses will lead prices to increase and consumption to decline during the season. This phenomenon has been verified empirically by Archibald, Brown, and Zilberman.

Lichtenberg and Zilberman (2002) presented a simple two-period model to highlight the outcomes associated with the use of fungicides as a loss retardant. They assumed that a perfectly competitive industry produces a total amount Q_T at a cost $C(Q_T) > 0$. An amount Q_1 is offered for sale at a price p_1. The rest, $Q_T - Q_1$, is placed in storage at a cost $S(Q_T - Q_1)$ to be sold in the second period. Marginal costs of both production and storage are increasing. Spoilage occurs during storage at a rate $\delta(x)$, where x is a spoilage-retarding pesticide ($\delta' < 0$, $\delta'' > 0$) purchased at a price w. The amount remaining at the second period, $Q_2 = (1 - \delta(x))(Q_T - Q_1)$, is offered for sale at a price P_2. The periodic interest rate is denoted by r.

The profit maximization problem of the industry is to choose Q_1, Q_T, and x to

$$\max p_1Q_1 + p_2(1 - \delta(x))(Q_T - Q_1)/(1 + r) - C(Q_T) - S(Q_T - Q_j) - w\,x.$$

At period i the industry is facing negatively sloped demand denoted by $Q_j = D_i(P_i)$. The equilibrium conditions they derive include:

(1) $P_1 = C'(Q_T)$

(2) $P_2 = (P_1 + S')(1 + r)/(1 - \delta)$

(3) $Q_1 = D_1(P_1)$

(4) $Q_2 = D_2(P_2) = (Q_T - Q_1)(1 - \delta)$

(5) $-P_2\,\delta'(x)(QT - Q1)\ /\ (1 + r) = w.$

Condition (1) states that price in the first period is equal to marginal cost of production. According to (2), the price is increasing over time. The increase will reflect the cost of discounting and spoilage as well as the marginal storage cost.

Obviously, from equations (3) and (4), when demand does not change much, output will decline over time. Condition (5) states that pesticides will be used to a level when the value of its marginal production in loss reduction $P_2\,\delta'(x)/(1 - r)$ is equal to its price.

Comparative statics analysis suggests that a tax on pesticides use (or a policy that reduces the marginal effectiveness of pesticides as a spoilage retardant) tends to reduce pesticides use and consumption in period 2. The impacts on total production and consumption in period 1 depends on the elasticity of demand in period 2. If demand for consumption in period 2 is inelastic, pesticides tax leads to an increase in total production while reducing consumption in the first period. The reason for this impact is that, with low elasticity of demand, the tax results in a relatively small reduction in consumption at period 2, more output has to be produced for period 2, and can be consumed in the first period to overcome the increased spoilage loss. If demand in period 2 is elastic, a pesticides tax will lead to a reduction in total production while increasing consumption in the first period. With the tax and large elasticity output in the second period declining substantially, that will allow a reduction in output and increase in period 1 consumption.

The analysis also suggests that a tax on storage will not necessary reduce pesticide use. The tax will decrease total output, storage increase consumption in period 1, and consumption in period 2. But if output demand is inelastic, the reduction in period 2 consumption is relatively small and, since total output declines and period 1 consumption increases, the output for period 2 is provided by higher pesticides use.

The two-period framework presented here can be expanded to n periods. Lichtenberg and Zilberman (2002) argue that it can lead to a system of estimatable equations including an hedonic price equation estimating price behavior over time and an output dynamics equation. They demonstrate it using linear specifications to show how most coefficients (demand, taste, and storage cost parameters) can be estimated from output and price behavior. Moreover, the analysis suggests that imposing a strong structure on the dynamics of the spoilage reduction effects of pesticides may allow estimating key parameters of this process.

Not all the parameters of the system can be estimated econometrically. If a chemical has been used for a long time for reducing spoilage, its cancellation is assessed, estimates of the impacts of alternative methods on spoilage has to be obtained from experts. It can be incorporated in a general equilibrium framework to estimate a new equilibrium and assess the impact of the new policy.

Conclusions

This paper argues that there is no one prescribed way to analyze policy impacts affecting agricultural inputs. The approach chosen depends on the degree of aggregation and on data availability. Moreover, the key criteria to assessing empirical results is their realism and common sense, not the "theoretical purity" of the methodology employed.

Duality-based approaches have a strong edge in dealing with aggregate quantity-in analysis of economy-wide or sector-wide problems. Many issues associated with agricultural resource regulation involves less detailed analysis. In these cases, a clear grasp of the problems and its physical aspects are needed before modeling and econometrics are utilized. Conventional approaches that present impacts of policies as changes of supply response parameters are quite often too simplistic and unrealistic. The economist has to dig into the "dirt" of the problem (to learn technical details) and that may result in precious findings. In essence, theory does not end before empirical research begins.

Analysis of many agricultural resource problems requires developing a new theory or model applicable to a rather specific set of circumstances but insightful and realistic nevertheless. Furthermore, many of these "micro theories" have insights that apply to much larger circumstances than originally envisioned.

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