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# The Calculation of Returns to Research in Distorted Markets

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(Accepted 9 August 1988)

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## Abstract

Oehmke, J.F., 1988. The calculation of returns to research in distorted markets. *Agric. Econ.*, 2: 291–302.

Most of the empirical literature calculating rates of return to publicly sponsored research assumes that research is the only relevant government intervention. For most countries this assumption is untenable. This paper shows that improperly measuring government induced market distortions can severely bias research rate of return calculations. If the interaction between successful research and other government interventions increases the cost of the other interventions, then neglecting market distortions unambiguously increases the calculated rate of return.

Three examples of government induced distortions show that the magnitude of the upward bias in calculated rates of return can be extremely large – in some cases more than 100 percentage points. A normative implication is that governments should account for interactions between research and price interventions when determining research support levels. A positive implication is that existing government research funding patterns are more readily explainable as reasonable behavior by a government that accounts for these interactions.

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## Introduction

Most countries in the world engage in publicly sponsored agricultural research. Many of these countries justify public research expenditures on the basis of estimated internal rates of return to research, and cite the large empirical literature indicating that these rates are quite high (for surveys, see Evenson et al., 1979; Norton and Davis, 1981; Ruttan, 1982). However, much of this empirical literature calculates rates of return (RORS) based on the assumption that publicly sponsored research is the only relevant government intervention. For most of the world's agriculture this assumption is untenable.

The purpose of this paper is to show that interactions between agricultural research programs and agricultural price interventions can significantly affect ROR calculations. The paper focuses on the interactions between research and

the government interventions of target prices and output subsidies. A simple model shows that accounting for these interventions unambiguously lowers the estimated research ROR. Three examples suggest that the differences in estimated RORs can be quite significant: in two of the examples research can have a negative overall impact, and yet the usual ROR calculation can show a high positive ROR.

This result has both normative and positive implications for research analysis. The normative implication is that if the target price or export subsidy program is taken as given (say for income redistribution or food security reasons), then it may be socially desirable for the government to restrict research expenditures relative to the level that would be optimal in the absence of price interventions. The positive implication is that government research funding patterns, which are considered to be somewhat puzzling (Ruttan, 1982; Oehmke, 1986), may be explainable if one accounts for the interactions between government research and price policies.

The next two sections of the paper discuss the formula defining the rate of return, and show that incorrectly accounting for nonresearch market distortions imparts an upward bias to the ROR calculations. Section 3 presents examples showing the extent of the bias. Methodological and policy implications are discussed in Section 4, and Section 5 presents concluding remarks.

## 1. Interpreting the rate of return formula

The marginal ROR to research undertaken at time  $t=0$  is defined to be  $r = 1/\beta - 1$ , where  $\beta$  solves:

$$\sum_{t=0}^{\infty} \beta^t (dPS_t/dR_0 + dCS_t/dR_0 - dG_t/dR_0) = 0 \quad (1)$$

In equation (1),  $PS$  is producers' surplus,  $CS$  is consumers' surplus,  $G$  is government expenditures,  $R$  is research expenditures, and  $t$  is the time parameter.

The first concern that arises in empirically calculating the derivatives appearing in (1) is that of a misspecified model of the crop or agricultural sector. Although recent advances appropriately allow for more general models of the agricultural sector,<sup>1</sup> they have not yet examined the implications of government price interventions for estimated research RORs. Since most countries intervene in their agricultural sector in some way, this lack seems especially conspicuous.

<sup>1</sup>For example, Akino and Hayami (1975) examined research in an open economy, Edwards and Freebairn (1984) included benefits to neighboring countries, Hayami and Herdt (1977) included home consumption, and Lindner and Jarrett (1978) and Rose (1980) explored the consequences of alternate assumptions about how research affects the supply function.

Alston et al. (1988) graphically analyse the effect of policy interventions on research benefits. However, they do not extend their analysis to the calculation of RORs.

A second concern in the empirical implementation of (1) is the attribution of government costs to individual programs when there are multiple government programs. The problem is the following: if only direct research expenditures are included in research costs, then estimated ROR can be quite high. However, society could be worse off by undertaking the research program because the increased price program costs (due to research induced supply shifts) could more than offset any increases in social surplus due to the research. Put another way, the problem is that a research program may look socially desirable if one assumes that the price policy does not cost the taxpayers anything, yet the same research program may appear socially undesirable if the price policy costs are correctly included in the calculations.<sup>2</sup>

## 2. Effect of distortions on the ROR formula

This section examines the effects that market distortions have on research RORs calculated by (1). The result of this examination is that market distortions will lead to overestimates of marginal RORs for a wide variety of circumstances.

For illustrative purposes, consider the special case in which research occurs only at time 0 and has an instantaneous response. Assume further that research is the only exogenous change to the model. Then this assumption leads to the simplifications  $dPS_t/dR_0 = dPS_s/dR_0$  for  $s, t \geq 0$ , and similarly for the consumers' surplus term. Also,  $dG_0/dR_0 = dG_t/dR_0 + 1$ , for  $t \geq 1$ .

In this special case, the equation determining the ROR becomes:

$$\left[ dPS/dR_0 + dCS/dR_0 - dG/dR_0 \right] \left[ \sum_{t=0}^{\infty} \beta^t \right] - 1 = 0 \quad (2)$$

where unnecessary subscripts have been suppressed. When  $|\beta| < 1$ , the second bracketed expression equals  $1/(1-\beta)$ . By substituting  $1/(1+r)$  for  $\beta$  and solving for  $r$ , the rate of return is represented as:

$$r = (dPS/dR_0 + dCS/dR_0 - dG/dR_0) / (1 - [dPS/dR_0 + dCS/dR_0 - dG/dR_0]) \quad (3)$$

whenever the right-hand side denominator is positive. When this denominator is negative, then returns are positive in every period, and the ROR is undefined.

An examination of equation (3) shows that  $r$  is decreasing in  $dG/dR_0$ :  $\partial r / \partial (dG/dR_0) < 0$ . This is equivalent to the statement that if research costs

<sup>2</sup>Formally, the optimum is attained by equating the marginal benefits of research with the marginal costs of research. The marginal costs are properly defined to be the change in total budget expenditures as research outlays are increased infinitesimally. That is,  $MC = \partial G / \partial R$ , where  $G$  represents total government expenditures, and  $R$  is research expenditures. When research programs affect nonresearch budget costs, it is possible to have  $\partial G / \partial R \neq 1$ .

increase, *ceteris paribus*, then the ROR to research falls. Now consider the term  $dG/dR_0$ . Suppose that successful research shifts out the supply curve, which then increases the cost of the price intervention (a partial list of interventions with this property is found in Alston et al., 1988). Attributing these costs to the research program increases  $dG/dR_0$  over what it would be if only direct research expenditures were counted. Hence accounting for these increased government costs unambiguously lowers the returns to research.<sup>3</sup> Although this result is easy to obtain, it is extremely important because the previous literature either explicitly or implicitly ignores nonresearch costs (cf. Akino and Hayami, 1975; Lindner and Jarrett, 1978). It follows that the estimated returns to research found in this literature are biased upwards.

The driving force behind this result is the interpretation of the expression  $dG/dR_0$ . If  $dG/dR_0$  is interpreted in a manner that leads to an underestimate of its true value, then the calculated ROR will be an overestimate of the true ROR. Thus if the econometrician incorrectly calculates  $dG/dR_0$ , he has also incorrectly calculated the ROR. In situations where output is subsidized, the typical mistake is to underestimate  $dG/dR_0$  and hence to overestimate the research ROR.

It is also important to note that the interpretation of  $dG/dR_0$  is independent of the assumptions used to derive (3). That is, even using the generic equation (1), whenever the econometrician underestimates  $dG/dR_0$ , he overestimates the marginal ROR to research.

### 3. Examples

This section presents examples illustrating the severity of the upward bias in ROR calculations. In each example, the simplifying assumptions maintained in the previous section are preserved, so that (3) can be used to calculate the research ROR. In each example, three methods of calculating the ROR to research are used: each method corresponds to a different interpretation of the relationship between  $G$  and  $R$ . The first method assumes that there is no relevant price intervention (even though this is not true in our hypothetical economies); this is perhaps the most commonly used assumption. Note that in this case government expenditures are implicitly assumed to equal the direct research budget, so that  $G_0 \equiv R_0$  and  $dG_0/dR_0 = 1$ . The second method recognizes that the output market is affected by the price intervention, and that this may influence domestic supply, domestic demand, or world price. However, in this method any increases in the costs of the price intervention are attributed to the price program. Hence the only government costs used in calculating the

<sup>3</sup>This result does not depend on the assumptions made to obtain (3). An examination of (1) shows that  $\partial r / \partial (dG_t/dR_0) < 0$  for all  $t$ , so that explicitly accounting for nonresearch program costs lowers the estimated rates of return in the more general case.

research ROR are the direct research expenditures. In this method,  $G_0 > R_0$  because the price program costs are included in  $G_0$ , but  $dG_0/dR_0 = 1$  because it is assumed that research does not affect these costs. The third method recognizes that the market is affected by the price intervention, and includes in the measure of research costs any increase in the price program expenditures that are caused by research induced shifts in the supply curve. For this method  $G_0 > R_0$  and  $dG_0/dR_0 > 1$ .

The first example is that of a small, open, importing economy (Fig. 1). Initially the supply and demand curves are represented by  $S$  and  $D$ . The government provides a production subsidy of amount  $s$ . Since the world price  $P_w$  is exogenously given to the economy (by the small country assumption), the effect of the subsidy is to increase the producer price from  $P_w$  to  $P_w + s$ . This increases quantity produced from  $Q_0$  to  $Q_1$ , at a government cost of  $Q_1s$ . The government also engages in research, whose effect is to shift the supply curve from  $S$  to  $S'$ . When  $S'$  is the relevant supply curve the quantity produced under the subsidy is  $Q_2$ , and the government costs of the subsidy increase to  $Q_2s$ .

We suppose that the supply and demand curves are constant elasticity:

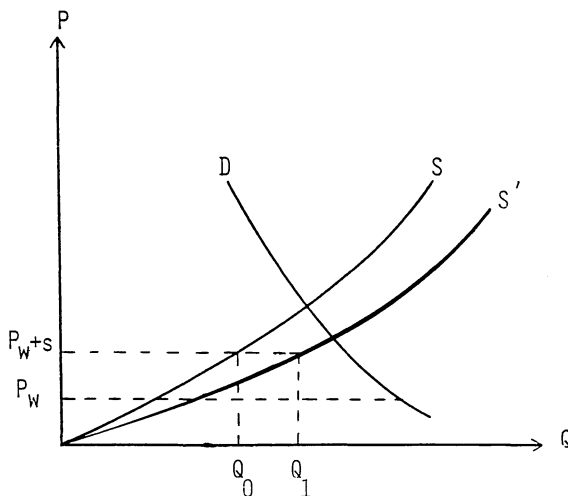


Fig. 1

A small open economy with an output subsidy

Method 1	Method 2	Method 3
$s \equiv 0, G = R, dG/dR_0 = 0$ ROR = 60%	$s > 0, G > R, dG/dR_0 = 0$ ROR = 137%	$s > 0, G > R, dG/dR_0 > 0$ ROR = 56%

$S(P, R) = \alpha(R)P^\sigma$  and  $D(P) = \zeta P^{-\epsilon}$ . Research affects the supply curve through the parameter  $\alpha$ , and according to the relation  $\alpha = \alpha_0 + \rho R$ . We specify the following parameter values:  $\alpha_0 = 4 \times 10^3$ ,  $\sigma = 0.6$ ,  $\zeta = 1.5 \times 10^6$ ,  $\epsilon = 0.5$ , and  $\rho = 2.5 \times 10^{-4}$ . Let the world price be  $P_w = 130$  and let the subsidy be  $s = 40$ , so that the subsidy per unit is approximately 30% of the world price (although the examples are not intended to represent particular countries, the parameter values are chosen so that the agricultural product can be thought of as wheat, with quantities in tons and prices in US \$/t. The results are suggestive of what could happen in typical cases).

Rates of return to research are calculated by each of three methods. Method 1 assumes that the subsidy does not exist, so that  $s = 0$ ,  $G = R$ , and  $dG/dR = 1$ . In this case the calculated ROR to research is 60% (Fig. 1). Method 2 assumes that the subsidy exists and that the relevant producer price is  $P_w + s$ . But it also assumes that the increase in subsidy expenditures from  $Q_1s$  to  $Q_2s$  is not attributable to research, even though the increased quantity supplied is directly attributable to the research program. That is, method 2 accepts  $s > 0$ , and  $G > R$ , but maintains the assumption that  $dG/dR = 1$ . By this method the estimated ROR is 137%. The increase over Method 1 in the ROR is attributable to the fact that Method 2 recognizes that the new technique is applied to a larger quantity of output (because of the subsidy). In Method 3, the increased subsidy expenditures are counted as research program costs. In this case, the expression  $dG/dR$  includes not only any direct increase in  $R$ , but also the increase  $(Q_2 - Q_1)s$  that would not have occurred in the absence of research. By Method 3 the calculated ROR falls to 56%.

Calculation by Methods 1 and Method 3 produce similar RORs, although Method 3 yields a slightly lower estimate. It can be shown algebraically that for the subsidy in a small economy this is generally true. The upward bias to the rate of return calculations is greatest when Method 2 is used, providing an estimate that is twice those of Methods 1 and 3. Sensitivity analysis suggested that the magnitude of the upward bias is not affected by small changes in the chosen parameter values.

The second example is of an output subsidy in a closed economy. In this case the output price is determined by the equilibrium condition  $S(P + s) = D(P)$ . Initially the supply and demand are given by  $S$  and  $D$ , and the equilibrium price is  $P_0$  (Fig. 2). At this equilibrium, suppliers produce quantity  $Q_0$ , and receive a total subsidy of amount  $sQ_0$ . Government-sponsored research causes the supply curve to shift out to  $S'$ . The equilibrium price falls to  $P_1$  and the equilibrium quantity rises to  $Q_1$ . The subsidy costs rise to  $sQ_1$ .

The supply and demand functions are assumed to take constant elasticity forms parameterized as above, with parameter values  $\alpha = 4 \times 10^6$ ,  $\sigma = 0.6$ ,  $\zeta = 30 \times 10^6$ ,  $\epsilon = 0.5$ , and  $\rho = 5 \times 10^{-4}$ . The subsidy is set at a value  $s = 40$ . The

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t, metric tonne = 1000 kg.

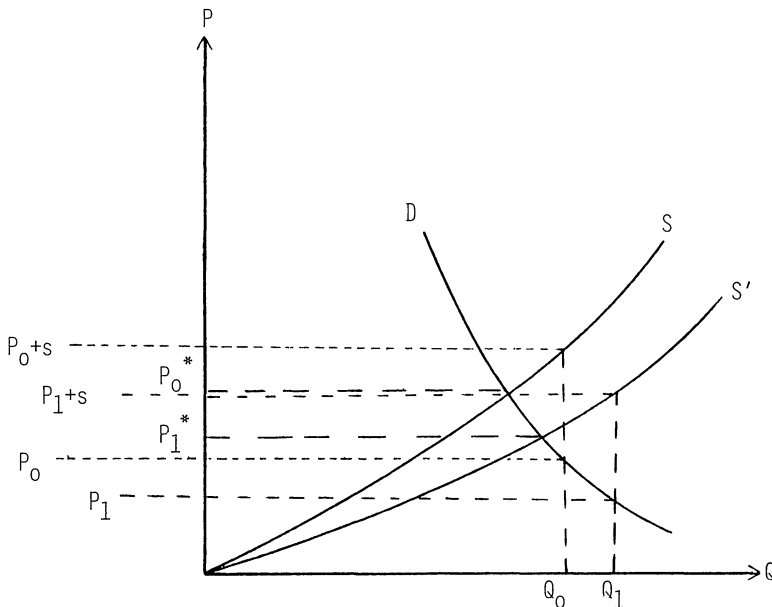


Fig. 2

A closed economy with an output subsidy

Method 1	Method 2	Method 3
$s \equiv 0, G=R, dG/dR_0=0$ ROR=33%	$s > 0, G > R, dG/dR_0=0$ ROR=42%	$s > 0, G > R, dG/dR_0 > 0$ negative returns

demand price determined by the equilibrium condition for this economy is  $p=123$ , so that the subsidy is approximately 25% of the supply price,  $p+s=163$ .

In this example method 1 assumes that the subsidy does not exist, so that prices are  $P_0^*$  and  $P_1^*$  before and after the research, respectively. As above this method assumes  $s \equiv 0, G=R$ , and  $dG/dR=1$ . By Method 1 the calculated ROR to research is 33% (Fig. 2). Method 2 acknowledges the subsidy, but does not attribute the increased subsidy costs of  $s(Q_2 - Q_1)$  to research. For Method 2  $s > 0, G > R$ , but  $dG/dR=1$ . The calculated ROR is 42%. Method 3 attributes the costs  $s(Q_2 - Q_1)$  to research, and so finds  $s > 0, G > R$ , and  $dG/dR > 1$ . By Method 3 the calculated ROR is negative. That is, the increased budget costs of the subsidy more than outweigh any increases in social surplus due to successful research.

The third example is that of a large, net exporting country that has imposed a target price in the agricultural market. We denote the target price by  $P_t$ , and assume that it is strictly greater than the world price (Fig. 3). The target price



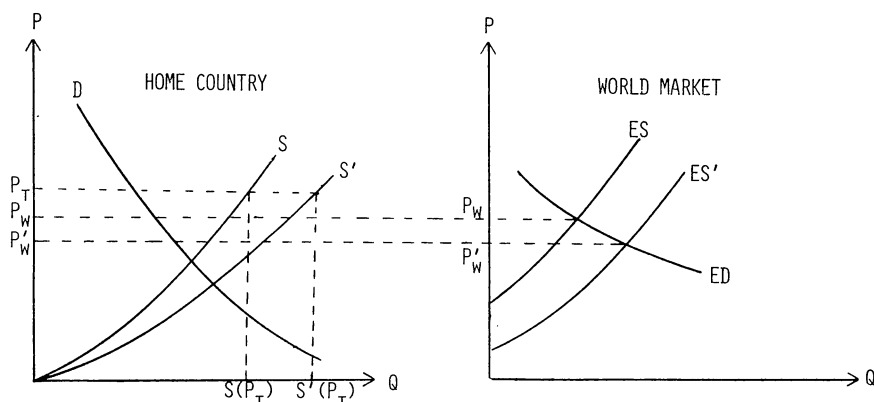


Fig. 3

A large open economy with a target price

	Method 1	Method 2	Method 3
	$P_t \equiv P_w, G = R, dG/dR_0 = 0$	$P_t > P_w, G > R, dG/dR_0 = 0$	$P_t > P_w, G > R, dG/dR_0 > 0$
$\rho = 5 \times 10^{-4}$ $P_t = 130$	ROR = 39%	ROR $\rightarrow +\infty$	ROR = 1%
$\rho = 2.5 \times 10^{-4}$ $P_t = 130$	ROR = 16%	ROR = 133%	ROR < 1%
$\rho = 5 \times 10^{-4}$ $P_t = 150$	ROR = 39%	ROR $\rightarrow +\infty$	negative returns

is the relevant price for domestic supply decisions:  $S = S(P_t)$ . The excess supply in the large country is defined to be the difference between supply and demand:  $ES(P_w) \equiv S(P_t) - D(P_w)$ . The world price is determined by the market clearing condition  $ES(P_w) = ED(P_w)$ , where  $ED$  is excess demand in the rest of the world. Successful research shifts out the domestic supply curve from  $S$  to  $S'$ . This in turn shifts out the excess supply curve from  $ES$  to  $ES'$ , and hence lowers the equilibrium world price from  $P_w$  to  $P'_w$ .

The costs of the target price program are equal to the difference between the price received by producers and the price guaranteed by the government, times the quantity produced. Thus the costs are  $(P_t - P_w) S(P_t)$ . After the research is completed, these costs become  $(P_t - P'_w) S'(P_t)$  in the ceteris paribus situation where  $P_t$  is constant. Note that since  $P_w > P'_w$  and  $S(\cdot) < S'(\cdot)$ , the target price program costs have unambiguously risen due to the research program.

We assume constant elasticity forms for the relevant curves:  $S(P) = (\alpha_0 + \rho R)P^\sigma$ ,  $D(P) = \zeta P^{-\epsilon}$ , and  $ED(P) = \kappa P^{-l}$ . We specify the follow-

ing parameter values to be constant throughout this example:  $\alpha_0 = 4 \times 10^6$ ,  $\sigma = 0.6$ ,  $\zeta = 3 \times 10^8$ ,  $\epsilon = 0.5$ ,  $\kappa = 4 \times 10^{10}$ , and  $\iota = 1.4$ . We examine two values for the research coefficient:  $\rho = 2.5 \times 10^{-4}$  and  $\rho = 5 \times 10^{-4}$ .

For a target price of  $P_t = 130$  the world price is  $P_w = 123.5$ . When  $\rho = 2.5 \times 10^{-4}$  the ROR estimated by Method 1 (assuming  $P_t \equiv P_w$  and  $G = R$ ) is 16%. Under the second method, when  $P_t = 130$  but it is still assumed that  $G = R_0$ , the estimated ROR is 133%. However, when the increase in target price program costs are attributed to the research program (Method 3), ROR falls to less than 1%. For a value  $\rho = 5 \times 10^{-4}$ , the differences between the methods are even more pronounced. By the first method,  $\text{ROR} = 39\%$ . The second method suggests that net returns are positive in every year, including year 1 when the research monies are spent. This leads to an estimated ROR diverging to  $+\infty$ . However, the third method reveals an ROR just slightly lower than 1%. Again, this example clearly shows that the estimated ROR is extremely sensitive to the underlying assumptions. Moreover, it suggests that previous empirical studies using Method 1 or Method 2 may have severely overestimated the internal rate of return to research.

#### 4. Policy and methodological implications

Method 3 is the appropriate method for estimating marginal RORs to research. In this method any *ceteris paribus* change in the costs of price interventions due to research funding is attributed to the research program. The formal representation of this statement is obtained by manipulating the identity  $G \equiv R + NR$ , showing that government expenditures equal research expenditures plus nonresearch expenditures. Here nonresearch expenditures include the cost of price interventions in the agricultural markets. Differentiating the identity shows  $dG/dR = 1 + \partial NR/\partial R$ . The partial derivative  $\partial NR/\partial R$  is a part of the marginal cost of research that should not be neglected. Since the costs of price intervention are nonresearch government costs, increases (or decreases) in the costs of these programs caused by research projects are correctly accounted for by including them in the marginal costs of research. Hence these costs must be included in accurate marginal ROR calculations. But this is exactly what the third method does.

The first implication for the econometrician is that he must be aware of and accurately model the relevant agricultural markets and nonresearch price interventions. While this is not a new comment, it cannot be stressed enough. Consider again Example 3, of a large open economy with a target price. Ignoring the target price (Method 1) yields high positive rates of return and would lead to a policy implication to increase research funding. However, correctly accounting for the target price shows a negative return to research and suggests a policy of restricted research funding. Hence the policy recommendations are extremely dependent on the accuracy of the model and the method of account-

ing for nonresearch government interventions. The normative implication of this analysis is that policy makers should take into account interactions between programs when making funding decision. In particular, the evaluation of research projects should not be done in isolation from the evaluation of other government interventions.<sup>4</sup>

The second implication is that data collection must be done with careful attention to the ROR methodology. Consider the case of a developing country that is a net importer of food even though its producers are subsidized as in Example 1. Suppose the project entails primary data collection on prices received by farmers. Then the econometrician or the data collector must know whether the data he has collected is representative of  $P_1$ ,  $P_1 + s$ , or  $P_1^*$ . Moreover, the price received may depend on the buyer, with government-sponsored cooperatives or parastatals including the subsidy in the sale price when other market participants do not. Lack of attention to these and similar problems could result in an inaccurate or unusable data set.

As a consequence, policy recommendations to increase research funding levels should be closely examined. It may be that the research program does provide an extremely worthwhile use of public funds, and that funding should be dramatically increased. However, it may also be that the ROR calculations are biased upwards and are inappropriate for policy analysis.

These results suggest a possible explanation for the observed research RORs. Observed RORs are quite high for almost all types of agricultural research in almost all countries (Evenson et al., 1979; Norton and Davis, 1981; Ruttan, 1982). However, many of the studies cited in these reviews do not explicitly account for market distortions. Hence it is possible that the explanation for at least some of the observed high rates of return to research is that the calculations are inaccurate, and in particular, too high.

This paper also highlights the need for positive examinations of agricultural policy decisions. Positive explanations of government policy formation need to be aware of what interactions (if any) take place between those policy makers responsible for research funding decisions and those responsible for price and other interventions. It is also important to realize that these interactions can be instigated by the policy makers, by outside forces such as donor agencies, or by constituencies such as political interest groups or urban consumers. Government behavior may be modeled more accurately by explicitly considering how political interactions determine government policy objectives, and by determining how interactions between various government programs affect the objectives (e.g. Oehmke and Yao, 1987). For example, it has puzzled economists that countries justify research expenditures on the basis of high returns,

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<sup>4</sup>This applies not only to research policy determination, but also to price policy determination. For discussions of the effects of technological advance on price policy evaluation, see Carter, 1985; or Rodgers, 1985. For interactions between price policy and pesticide regulation see Lichtenberg and Zilberman, 1986.

but do not invest more money in research that yields extremely high rates of return (Ruttan, 1982; Oehmke, 1986). The explanation consistent with this paper is that governments or their constituents consider the effects of research induced supply shifts on other government program expenditures. Thus the usual ROR calculations overstate the government's perception of research benefits. This suggests that research ROR calculations that account for the market and budget cost interactions may be better predictors of government funding levels than are the current ROR calculations.

## Conclusions

This paper shows that improperly measuring government induced market distortions can severely bias research ROR calculations. An algebraic analysis shows that when research increases the cost of price interventions, then improperly measuring the distortions associated with the price interventions unambiguously imparts an upward bias to the RORs.

Examples of rate of return calculations illustrate the severity of the overestimated values. Three types of government induced distortion are considered: output subsidies in a small importing economy; output subsidies in a closed economy; and target prices in a large open economy. In each case the ROR is estimated using three different methods: the first ignores the intervention; the second accounts for the market effect of the intervention, but does not account for increased intervention costs due to research induced supply shifts; the third method of ROR calculation accounts for both the market and government budget effects of the intervention and its interaction with research. The examples indicate that estimated RORs can diverge by one hundred percentage points or more across the methods. They also show that the first two methods can yield high calculated RORs when the third method indicates negative returns.

The results have both positive and normative implications. The positive implication is that government research funding patterns are more readily explainable when the interactions between research and other government programs are explicitly analyzed. The normative implication is that the government should account for both research costs and price intervention costs when determining research support levels (and price intervention levels). To attain a true optimum, the government should simultaneously determine research support and price intervention levels, accounting for the interactions of the two programs on the benefits and costs of the policy package.

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