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Is livestock research unproductive? Separating health maintenance from improvement research

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Abstract

Studies of the rates of return to research have usually been based on the implicit assumption that if there were no research, then there would be neither growth nor decline in output or productivity. In the case of livestock, particularly in southern Africa, which has a sub-tropical disease ecology and a long history of disastrous losses due to disease, the assumption is especially unreasonable. It ignores the losses that would have occurred in the absence of livestock health research, resulting in underestimation of rates of return. This study draws on data from South Africa to illustrate the magnitude of the error, by separating the maintenance effects of animal health research from output increases due to animal improvement research. This is possible because health and improvements research are conducted at separate research institutes and there are data on cattle deaths due to disease, which allows the effects of health expenditures to be calculated. Explicitly, taking the negative effect of diseases into account considerably increases the returns to the livestock research of the South African Agricultural Research Council (SAARC). Instead of a ROR of 18% for animal research in total, the result is a ROR of at least 35% for animal health research and 27% for improvements research, suggesting a minimum underestimation of about 50%. These results suggest that livestock research is productive, once it is properly decomposed. The implication is that all ROR estimates that implicitly assume that with no research, there would be no change in output, or productivity, must be severely biased downwards.

JEL classification: Q16

Keywords: Livestock; Maintenance research; Returns to R&D

1. Introduction: returns to livestock R&D

Since the seminal work of Griliches (1958), a substantial literature has developed on assessing the benefits to investment in agricultural research. The most frequently used measures of the effectiveness of research are estimates of the rate of return (ROR), usually the marginal internal rate of return (MIRR), and for agricultural research these returns have typically been high. The most recent summary of this work from Evenson (1998) shows a median ROR of 40% from 260 studies. Separate estimates have been derived for the different components of the agricultural sector and for various stages of the research process. While the returns from aggregate studies remain high, the returns to individual components have been more variable.

Table 1 reports the results of the rather limited number of studies that have looked explicitly at the

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Table 1
Rates of return to R&D on livestock, with comparisons

Study and year	Country and period	Coverage	Source	Method	IRR (%)
Peterson (1967)	USA, 1915–1960	Poultry	Echeverría (1990)	Econometric	21–25
Duncan (1972)	Australia, 1948–1969	Pastures	Evenson (1998)	MFP[a]	58–68
Bredahl and Peterson (1976)	USA, 1969	Livestock	Echeverría (1990)	Econometric	47
		Dairy			43
		Poultry			37
		Cash grains			36
Eddelman et al. (1977)	USA, 1978–1985	Beef cattle and forage	Echeverría (1990)	Economic surplus	15
		Swine			52
		Dairy			38
		Wheat			46
Wennergren and Whitakker (1977)	Bolivia, 1966–1975	Sheep	Echeverría (1990)	Economic surplus	−48 to 44
Norton (1981)	USA, 1969	Livestock	Echeverría (1990)	Econometric	56–111
		Dairy			27–50
		Poultry			30–56
		Cash grains			31–57
Smith et al. (1983)	USA, 1978	Beef, swine and sheep	Echeverría (1990)	Econometric	22
		Poultry			61
		Dairy			25
Fox (1986)	Canada, 1944–1983	Livestock	Evenson (1998)	MFP[a]	150
Huot et al. (1988)	Canada, 1964–1984	Swine	Echeverría (1990)	Economic surplus	45
Hust et al. (1988)	Canada, 1968–1984	Swine	Evenson (1998)	Econometric	45
Widmer et al. (1988)	Canada, 1968–1984	Beef	Echeverría (1990)	Economic surplus	63
Evenson (1989)	USA, 1952–1982	Livestock	Evenson (1998)	MFP[a]	11
Evenson (1991)	USA	Applied livestock	Evenson (1998)	Decomposition	11
Norton and Ortiz (1992)	USA, 1987	All agriculture	See references	Econometric	30
		Dairy			0
		Poultry			46
		Other livestock			55
Kumar et al. (1992)	India, 1969–1985	Cattle	Evenson (1998)	MFP[a]	29
Huffman and Evenson (1993)	USA, 1950–1982	Public R&D livestock	See references	MFP[a]	Negative
		Private R&D livestock			86.6
		Public extension livestock			Negative
Evenson et al. (1994)	Indonesia, 1979–1982	Meat	Evenson (1998)	Yield decomposition	0
Fox (1995)	Canada, 1968–1984	Sheep	See references	Econometric	20.5
		Swine			43.5
		Beef cattle			61.5
		Poultry			47–58
		Dairy cattle			109–110
van Zyl (1996)	South Africa	Aggregate	See references	Profit function	44
		Horticulture and fruit			100
		Livestock			0–5
		Crops			30

[a] Multi-factor productivity (MFP) indicates that a two-stage approach was used, in which the MFP index is calculated first and then explained by R&D and other variables.

livestock sector.[1] Other areas are included where possible since the comparisons are most useful when the same techniques have been applied across the board. The results are a little surprising in that the first study that offers comparisons (Bredahl and Peterson, 1976) ranks livestock top, with higher returns than dairy, poultry or grain crops. The next comparative study (Eddelman et al., 1977) ranks swine highest, followed by wheat, dairy and finally beef cattle and forage, with an IRR of only 15%. Norton (1981) also ranks livestock above dairy, grains and poultry, but Smith et al. (1983) find far lower returns for animals, and Wennergren and Whitakker (1977) raise the possibility of negative returns for sheep. Thus, these relatively early studies present mixed results on the returns to different enterprises, but there is certainly no clear indication that animal R&D is less productive.

The only survey of livestock production research (Norton and Peterson, 1991) reports a dozen studies with RORs ranging from 97%, for dairying in Canada (an earlier version of Fox, reported in Table 1) to 11% for livestock in the US (an early version of Huffman and Evenson, also reported in Table 1). Although the techniques have become more sophisticated, this more recent work still fails to reach a clear conclusion. The Canadian studies show high returns, with beef cattle ranking above poultry, and sheep last, in a recent summing up by Fox (1995). Fox's (1986) result for livestock in Canada is the highest ROR in Table 1. At the other extreme, Evenson's several US studies all show relatively low returns on animals, but Norton and Ortiz (1992) find that livestock (beef, swine and sheep) have the highest returns.

Huffman and Evenson's (1993), pp. 198–199) findings for the USA are entirely negative for public R&D and are influential partly because they are well explained. They report aggregate regional multi-factor productivity (MFP) indices for the USA from 1950 to 1982, for both crops and animals. Crop MFP grew at 2.0% per annum, as compared with 1.6% for animals, but the regional results suggest that genetic improvements in the major field crops have been more rapid than for beef cattle and pigs. Livestock MFP grew at 2.5% per annum in the regions where chickens are important and at 1–2% in the dairy regions, but at only 0.6–0.7% where beef cattle pigs and sheep are relatively important.

Lower growth does not automatically mean lower RORs, since expenditures may have been lower for animals, but this seems not to be the case. Indeed, whereas Huffman and Evenson's MIRR to total public investment in crops from 1950 to 1982 was 47%, for livestock it was negative. Although the return to pre-technology science research was 83.2%, this was swamped by the negative returns to applied livestock research, which accounted for the bulk of expenditures. The situation for private research is entirely different, with a MIRR at 86.6% (Table 1).

Huffman and Evenson suggest that the lack of returns is partly a matter of reverse causality. States with extensive cattle and sheep ranching attempted to correct low MFP growth by increasing expenditures, so that the allocation between animal enterprises is sub-optimal. Thus, the ROR to public livestock research is low partly because the mix is wrong. It is also possible that research costs are higher, due to the cost of facilities, and that the long biological cycle may depress returns, as it does for tree crops.

The conventional wisdom now tends towards the view that returns to public research on extensive animal rearing may be below the average.[2] The private sector now plays a leading role in more intensive animal production activities, such as poultry and pigs (see Thirtle et al., 1997, on the UK situation) precisely because returns are high. However, these perceptions are based almost entirely on studies of the western developed countries. Indeed, only the last item (van Zyl, 1996) in Table 1 is for an African country, and although the South African Agricultural Research Council (SAARC) appears to have high returns for crops and horticulture and fruit, the return to livestock research is not significantly different from zero.

van Zyl's (1996) estimates are from a profit function, estimated with three output groups to allow these separate calculations. But, if empirical studies are to be used to guide the allocation of research resources, these results need to be more carefully investigated. The returns to crop research are in the normal range

[1] See Table 1 for information on the sources of the studies cited in the this section.

[2] Despite some high returns to livestock in his earlier work, Norton now tends to agree, citing the high costs and long duration of livestock research projects as possible causes. We thank him for responding to our query.

and although the ROR on horticulture and fruit is very high, deciduous fruit and grapes have done well and there has been exceptional progress with the irrigated fruit crops such as mangoes.[3] Horticulture is an area where the combination of good prospects and high levels of appropriability has led to the private sector playing a major role. Indeed, horticulture research was one of the first areas to be privatised in the UK, when in 1990, the Agricultural and Food Research Council's Institute of Horticultural Research became Horticulture International and the horticultural research stations run by the Ministry of Agriculture, Fisheries and Food were also privatised (Thirtle et al., 1997). However, the very low return to animal R&D in South Africa was not a prior expectation and suggestions that research funding should be reallocated led to an extensive series of further investigations at lower levels of aggregation.[4]

Systematically low returns to animal research seem to be at odds with common sense. Clearly, research on animal health should produce substantial benefits, as poor livestock health remains one of the main constraints to livestock development in many developing countries. In sub-Saharan Africa losses due to diseases are estimated at 2 billion US$ (bUS$) per year, of which half can be attributed to direct losses due to mortality, and the other half to indirect losses through reduced growth, fertility, and work output (Umali et al., 1992). Having opted not to vaccinate, in 1995 Botswana experienced an outbreak of contagious bovine pleuropneumonia, which led to all 310,000 cattle in Ngamiland being destroyed. They were valued at 359.6 million Pula (750 million Rand or 150 million US$). Without the research expenditures of the SAARC and the vaccination program of the Department of Agriculture, there is little doubt that neighbouring South Africa would have suffered serious losses too. Similarly, SAARC research to improve animal production must have made significant contributions to the higher milk yields, calving rates and live weights that have been recorded. So, how is it that even for South Africa, van Zyl (1996) estimated the ROR to animal research at 5% or even lower?

[3] The figure is perhaps biased upwards because it is picking up the returns to irrigation, which are considerable, partly because the price of irrigation water is well below its true value.

[4] These results are reported in Thirtle et al. (1998b).

This paper suggests that the low ROR estimates in previous studies are the result of ignoring the losses that would have occurred in the absence of animal health research. The next section briefly reviews livestock diseases in sub-Saharan Africa before explaining how the effects of maintenance and improvement research can be decomposed. Section 3 develops a two-equation model of livestock research, in which the ROR to animal improvements is separated from the ROR to animal health research. The model is fitted to South African data. Section 4 explains the estimation methods and presents the results, which are compared with the outcome of fitting the conventional model. Then, the ROR estimates derived in Section 5 show the extent of the bias when deaths from disease are not incorporated. This is followed by a brief conclusion, which points out that maintenance research is ignored in almost all studies, not just in agriculture, and this must impart a downward bias to the ROR estimates.

2. Measuring research benefits: livestock research in South Africa

A crucial assumption inherent in measuring research benefits is that if there were no research, then there would be neither growth nor decline in output or productivity, all else being equal. In fact, without R&D, productivity would decline due to physical, biological and economic changes, that make existing technologies less suitable and effective. With respect to crop production, salination in irrigated areas is an example of physical change. An example of biological change is natural selection that allows pests to mutate and again damage a crop which had been bred for resistance. Similarly, the obsolescence of high-energy use machinery in the wake of the oil crisis demonstrates the case of economic change.

Blakeslee (1987) invoked the help of the Red Queen to explain the importance of maintenance research (Carrol, 1994):

> "A slow sort of a country!" said the Queen. "Now, here you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"

Blakeslee estimated econometrically that as much as 90% of R&D may not be productivity enhancing, but may be necessary to prevent productivity losses. A more widely accepted estimate from Adusei and Norton (1990), based on a survey of US agricultural researchers, reported that they classified about one-third of their efforts as maintenance research. The figure for livestock, at 26.5%, was significantly lower than for crop research.

It follows that in ROR calculations, the assumption that R&D explains only positive growth is not at all defensible because it will generally produce estimates that are biased downwards. The assumption is not made because it is believable, but because there are normally no data to allow an alternative approach, i.e. to measure the productivity losses that would have occurred in the counter-factual case where no research takes place.

2.1. Livestock diseases in southern Africa, with special reference to South Africa

Sub-Saharan Africa has a much broader spectrum of infectious disease among animals than any other region (Coetzer et al., 1994), so not accounting for the losses that would have occurred in the absence of animal health research would lead to a greater underestimation of returns to livestock research.

The impacts of different types of animal diseases vary greatly. Diseases have typically been separated into two broad groups: erosive diseases (such as tick-borne disease) and more serious epizootic or transboundary diseases (such as foot and mouth, rift valley fever, lumpy skin disease, rinderpest, and contagious bovine pleuropheumonia, known as CBPP). Epizootic or transboundary diseases are much more important in terms of threatening large numbers of livestock and thereby livelihoods over wide geographic areas. Outbreaks of these diseases can result in explosive losses.

The most devastating case of animal disease in Africa was the rinderpest outbreak in the late 19th century. It spread over almost the entire continent within 10 years, killing an estimated 10 million cattle (Geering et al., 1999). In South Africa, the livestock losses from this disease disrupted agricultural production and transportation. Human malnutrition was widespread and, combined with high levels of malaria, caused thousands of deaths (Vogel and Heyne, 1996). A more recent example is the 1995 CBPP outbreak in Botswana, which spread rapidly throughout the Ngamiland region where all the cattle were slaughtered as part of the eradication strategy. Townsend et al. (1998), used a social account matrix to estimate the losses and put the annual cost at no less than 1 billion Pula.

CBPP affects 27 African countries, with estimated losses of up to 2 billion US$ per year (Geering et al., 1999). Foot and mouth outbreaks in Angola, Mozambique, South Africa, and Zimbabwe have caused major production losses through loss of meat and milk production and draught power. Export revenues have also been lost because markets in Europe, North Africa, and the Pacific Rim are hesitant to import animal products from regions where contagious diseases are prevalent.

While earlier outbreaks of epizootic diseases in southern Africa were contained, and in some cases eradicated, their prevalence and distribution has increased recently (Thomson, 1997). The control of these diseases, which has strong public good connotations, falls within the domain of the public sector. Although animal diseases are not a current problem in some southern African countries such as South Africa, the potential losses are considerable. This review suggests that the funding allocated to animal health maintenance is necessary and casts some doubt on the very low rate of return estimate noted above. [5]

2.2. The livestock research system in South Africa

This concern is especially relevant in a country like South Africa, where the livestock sector plays a dominant role. Over the past several decades, livestock products have accounted for about 40% of the total value of agricultural output, which is not surprising since approximately 80% of the agricultural land is not suitable for crop production, but can maintain livestock.

Support services have made important contributions in the development of this sector. The five relevant SAARC research centres are the Animal Improvements Institute, the Animal Products and Animal Nutrition Institute, the Range and Forage Institute,

[5] There are related literatures on animal health, such as studies of damage control (e.g. Young and Haantuba, 1998) and ex ante estimates of the considerable gains possible from disease eradication (Falconi et al., 1999).

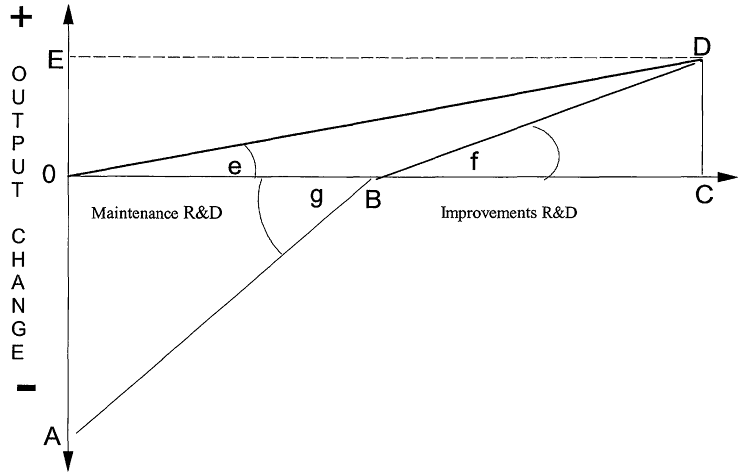

Fig. 1. Separating maintenance and improvement R&D.

the Onderstepoort Veterinary Institute and the Onderstepoort Institute for Exotic Diseases. The research of the first two of these is predominantly livestock improvement work, which should increase production and productivity, while the last two health institutes are involved mainly in maintenance research. The Range and Forage Institute could be classified under either heading as it both produces improved technologies and is responsible for the range environment, in the sense of "maintaining the condition of the veld".

2.3. A simple model decomposing R&D expenditures

Thus, maintenance and improvement expenditures can be separated and treated differently, which is a prerequisite for the analysis that follows.[6] Fig. 1 illustrates this decomposition and the potential errors that result when it cannot be made. Changes in output, or productivity are measured on the vertical axis and R&D expenditures on the horizontal axis. The origin (0) corresponds to the implicit assumption that no R&D will result in no output change. But, with no R&D in the livestock sector, production would decline by 0A, so that 0B of maintenance research expenditures are necessary to maintain output, or 'keep in the same place'. Thus, 0B is the break even level of maintenance R&D that keeps output constant. Then, if BC were spent on improvement research, output, or productivity, increases by CD, which is equal to 0E on the vertical axis.

The conventional model, which does not take account of the potential loss, 0A, would give an estimate the ROR to expenditure 0C as $\tan(e) = CD/0C$. Whenever maintenance expenditures are required to 'keep in the same place', this measure will be lower than the true ROR to improvement research, which is measured by $\tan(f) = CD/BC$. The return to maintenance research, which is measured by $\tan(g) = 0A/0B$, is in this case greater than the ROR to improvements research, though this is arbitrary.[7] It is worth noting that $\tan(e) = CD/0C$ is actually the average return, whereas $\tan(f) = CD/BC$ is the marginal return to improvements research, which must always be greater than the average when there is maintenance research. The error arises because the R&D expenditure used to account for the output gain is 0C rather than BC, both in the estimation of the elasticity of R&D and in calculating the value marginal product for the ROR calculation, which follows in Section 5.

[6] This conceptual separation may not hold entirely in reality; it was noted, for instance, that range and forage research could be viewed as either maintenance or improvement.

[7] If less were spent on maintenance research, then the horizontal axis would move downwards, corresponding to some level of productivity decline and the segment BD would begin from where AB meets the axis.

If the RORs for maintenance and health R&D are to be estimated separately, the second requirement is a dependent variable, other than production, or productivity, that can be explained by the health maintenance expenditures.[8] In this case, a series on cattle deaths is available, but it is not ideal, partly because the other livestock are not covered and also because the brief survey in Section 2.1 showed that not all diseases are fatal (many diseases, including foot and mouth and lumpy skin disease reduce the productivity of animals rather than killing them). This is taken into account in the empirical model, which is developed in the next section.

3. The model: a livestock supply function and a disease prevention function

At the national level, it is possible to construct an MFP index, which is the ratio of aggregate output to an aggregate of all inputs. At the sector level, it is not possible to determine what inputs were allocated to animal production, so the basic model uses the supply response function, which is the basis of the economic surplus approach to determining the ROR.[9] The attraction is that only the input prices are needed, and these are not activity-specific, but the model needs adapting to allow for the long response lags involved with animals.

3.1. Livestock supply function

Output is taken to be a function of own price, the prices of substitutes and complements, input prices, technology and the weather. The preferred functional form is linear in logarithms (except for the weather), so that the coefficients are elasticities. Suppliers will not have reached an equilibrium position, since adjustment is a slow process, so following Nerlove (1958), a dynamic approach is taken, based on lagged adjustments and expectations. Following Wickens and Greenfield (1973), who dealt with similar problems of slow adjustment and long lags in modelling tree crops such as coffee, a very unrestrictive distributed lag model is used, which allows for lagged prices, lags on the dependent variable and long lags for the process by which research produces new technology. The estimated equation is a simple livestock supply function in which R&D expenditures generate the technology that shifts the supply curve outwards over time.

Thus, the improvements research model is specified as

$$\begin{aligned}\mathrm{LOUT}_t = \alpha_0 &+ \sum_{i=1}^{p}\phi_i \mathrm{LOUT}_{t-i} + \sum_{i=0}^{q}\beta_{1i}\mathrm{LRPLIVE}_{t-i} \\ &+ \sum_{i=0}^{s}\beta_{2i}\mathrm{LRPHORT}_{t-i} + \sum_{i=0}^{t}\beta_{3}\mathrm{LRPMAIZE} \\ &+ \sum_{i=0}^{r}\beta_{4i}\mathrm{LRPDIPS}_{t-i} + \sum_{i=0}^{s}\beta_{5i}\mathrm{LHEALTH}_{t-i} \\ &+ \sum_{i=0}^{t}\beta_{6i}\mathrm{LRD}_{t-i} + \delta W_t + u_t \qquad (1)\end{aligned}$$

where LOUT is the Divisia aggregate of livestock outputs, LRPLIVE the Divisia aggregate real livestock price index, LRPHORT the real price of horticultural products, LRPMAIZE the real price of maize, LRPDIPS the real price of dips and vaccines, LHEALTH the animal health expenditures of the Department of Agriculture (DOA), LRD the real R&D expenditures of the SAARC, W the rainfall index and u the error term. Horticulture and crops are the alternatives to livestock at the enterprise level, but the maize price was used rather than a crop aggregate because maize is used as feed and, is thus, also a key input, along with dips and vaccines. Thus, output is explained by its own lagged value, own price, prices of substitutes, input prices and government expenditures on livestock health. The DOA health programmes should have fairly immediate effects, reducing the production losses caused by diseases like foot and mouth, lumpy skin disease, and the erosive diseases, whereas the R&D expenditures shift the function over the longer run. The production data used are from 1947 to 1994 while the R&D series is from 1927, to allow for the long lags between R&D expenditures and their

[8] This is the case in any attempt to decompose the process whereby R&D affects productivity. For example, Thirtle et al. (1998a) were able to separate basic and applied research and diffusion because the dependent variables available were publications, trial plot yields and farm yields, respectively.

[9] This model was used extensively in investigating the South African R&D system. Several references can be found in Thirtle et al. (1998b), which reviews the results.

impacts. The length of the lag was allowed to vary for each variable and was determined using a combination of t-tests, the Akaike information criterion (AIC) and the Schwartz criterion (SC).

Two models were fitted to investigate the propositions in Section 2.

Model 1: In Model 1, the conventional approach is followed, with output being explained as in Eq. (1), where the R&D expenditures are the total of health and improvements research. This is, of course, incorrect, but would be estimated if all that were available were total R&D and the output or productivity gain that it is supposed to explain. The same model is also estimated with the R&D variable as improvement research only, so it very simply estimates the return to improvements research and ignores health maintenance.

Model 2: This is a two-equation model, which exploits the data fully. The first equation is again Eq. (1), from above, but the R&D variable is improvements R&D only. Then, in a second equation, cattle deaths are explained by the DOA health expenditures and health maintenance R&D only.[10] This second equation is the disease prevention function presented below.

3.2. The disease prevention function

The equation used to explain cattle losses from disease is basically a production function, rather than a supply response model. The variables expected to affect deaths are the DOA animal health service expenditures on dips and vaccines, the quality of vaccines and dips, animal health R&D and the weather, since in wet years, diseases are usually more prevalent than in dry years. Thus, the disease prevention function is

$$\begin{aligned}\mathrm{LDISEASE} &= \lambda_0 + \sum_{i=1}^{g} \gamma_i \mathrm{LDISEASE}_{t-i} \\ &+ \sum_{i=0}^{k} \delta_{1i} \mathrm{LRPDIPS}_{t-i} + \sum_{i=0}^{h} \delta_{2i} \mathrm{LHEALTH}_{t-i} \\ &+ \sum_{i=0}^{j} \delta_{3i} \mathrm{LRD}_{t-i} + \varphi W + u_t \qquad (2)\end{aligned}$$

[10] The two equations are not independent and the seemingly unrelated regression model would be used, except that the time periods differ and too much data is ignored if this is done.

where LDISEASE is the number of cattle deaths as a percentage of the total cattle population, LRPDIPS the real price of dips and vaccines, which is included in the hope of adjusting for the considerable quality change over the period, LHEALTH the animal health expenditures of the DOA and W is rainfall. As before, all these variables are in logarithms except for the weather.

4. Time series properties, estimation and results

Prior to estimation of the equations, the time series properties of the variables were examined to avoid spurious regressions (Granger and Newbold, 1974). The Dickey–Fuller test (Dickey and Fuller, 1981) and Johansen (1988) procedures were used. The results indicated that all variables are integrated of order one, except for the weather, which is stationary, and further tests suggested that the variables in both Eqs. (1) and (2) are co-integrated. A common approach taken when co-integration exists is to use the error correction model (ECM), which is a valid representation (Engle and Granger, 1987). The ECM, however, is a simple re-parameterisation of the autoregressive distributed lag model (Pesaran and Shin, 1995). Thus, this more general distributed lag representation was retained for both the supply response and disease prevention functions. The AIC and SC used to determine the length of the lags in Eq. (1) indicated long lags for the livestock price variable and R&D expenditures.

The large number of lagged variables causes collinearity problems, so although the sum of the coefficients of these lagged variable provide unbiased estimates of the elasticity, the lag structure is modelled by imposing an Almon polynomially distributed lag (PDL). The polynomial form is popular due to its empirical simplicity and it is a smooth and feasible form. However, the specification imposes restrictions, the validity of which has been questioned, particularly, the end point restrictions (Hallam, 1990). To test these restrictions, the AIC and SC are used to determine not only the lag length, but also the degree of the PDL in the model. The structure of these lag relationships was determined by examining a range of PDL models. A similar approach was taken in estimating the animal health model in Eq. (2).

Table 2
Results for the estimated models

Variables	Livestock supply equations, 1947–1994		Animal health equations, 1920–1983
	Model 1: conventional	Model 2: animal improvements R&D only	Model 2: animal health R&D only
Constant	2.386 (3.30)	2.53 (3.73)	12.804 (10.28)
$LOUT_{t-1}$	0.436 (3.05)	0.420 (2.93)	–
LRPLIVE	0.030 (2.84)	0.028 (2.24)	–
$LRPLIVE_{t-1}$	0.055 (2.84)	0.046 (2.24)	–
$LRPLIVE_{t-2}$	0.066 (2.84)	0.056 (2.24)	–
$LRPLIVE_{t-3}$	0.066 (2.84)	0.056 (2.24)	–
$LRPLIVE_{t-4}$	0.055 (2.84)	0.046 (2.24)	–
$LRPLIVE_{t-5}$	0.033 (2.84)	0.028 (2.24)	–
Sum (LRPLIVE)	0.306	0.262	–
LRPHORT	−0.236 (−1.89)	−0.221 (−1.95)	–
LRPDIPS	−0.141 (−1.25)	−0.130 (−1.14)	NS
LRPMAIZE	−0.199 (−2.97)	−0.205 (−3.15)	
W	NS	NS	NS
LDISEASE	–	–	NS
LHEALTH	0.072 (0.91)	–	−0.3498 (−3.36)
LRD	0.0042 (1.99)	0.0034 (2.11)	−0.1437 (−2.93)
LRD_{t-1}	0.0078 (1.99)	0.0063 (2.11)	−0.1935 (−3.09)
LRD_{t-2}	0.0109 (1.99)	0.0087 (2.11)	−0.1800 (−3.37)
LRD_{t-3}	0.0134 (1.99)	0.0107 (2.11)	−0.1297 (−3.82)
LRD_{t-4}	0.0153 (1.99)	0.0121 (2.11)	−0.0643 (−2.59)
LRD_{t-5}	0.0167 (1.99)	0.0131 (2.11)	−0.0014 (−0.03)
LRD_{t-6}	0.0176 (1.99)	0.0136 (2.11)	0.0462 (0.81)
LRD_{t-7}	0.0179 (1.99)	0.0136 (2.11)	0.0698 (1.06)
LRD_{t-8}	0.0176 (1.99)	0.0131 (2.11)	0.0655 (1.03)
LRD_{t-9}	0.0167 (1.99)	0.0121 (2.11)	0.0335 (0.66)
LRD_{t-10}	0.0153 (1.99)	0.0107 (2.11)	−0.0213 (−0.74)
LRD_{t-11}	0.0134 (1.99)	0.0087 (2.11)	−0.0897 (−5.22)
LRD_{t-12}	0.0109 (1.99)	0.0063 (2.11)	−0.1579 (−3.94)
LRD_{t-13}	0.0078 (1.99)	0.0034 (2.11)	−0.2078 (−3.30)
LRD_{t-14}	0.0042 (1.99)		−0.2170 (−3.02)
LRD_{t-15}	–		−0.1582 (−2.88)
Sum (LRD)	0.190	0.136	−1.349
R^2 (adjusted)	0.981	0.985	0.938
F-statistic	421.7	427.2	122.50
Log likelihood	85.19	85.45	36.77
Durbin's h-statistic	−3.73	−3.57	
MIRR (%)	18	27	>35

The results for the statistically preferred estimates of Eqs. (1) and (2) are reported in Table 2. The first column reports the conventional model. The independent variables in this supply response function explain 98% of the variance in output. The one lagged value of the dependent variable is sufficient to overcome serial correlation, as indicated by the reported value of the Durbin h-statistic.

The slow response to price of animal output is demonstrated by the five significant coefficients on the own price term. Farmers react slowly to prices, as it usually takes several years to build up a livestock herd. The sum of these elasticities is 0.306, indicating that the response to price is positive, as it should be, with a 1% price increase generating a 0.306% total response. The elasticity on the price of horticulture and fruit may be interpreted as the short run supply response, and the negative sign shows that these activities are substitutes for animal production. The short run elasticity for dips, vaccines and sprays, which are an input, is negative as it should be, but significantly different from zero only at low confidence levels. The maize price elasticity is negative and highly significant, which it should be, as maize is both an input, as feed, and a substitute in production. The DOA animal health expenditures have a positive sign, which is correct, but the t-statistic shows that the effect on output is not significant. R&D expenditures are modelled with a second degree PDL and the effects persist over 14 years. The sum of the lagged R&D coefficients is 0.19 which is more than double the coefficient of 0.09 derived by Khatri et al. (1996) for their livestock supply equation in a profit function model (this approach led to the low ROR for livestock research reported by van Zyl (1996)).

When this model is estimated with just the improvements research expenditures (not shown), the changes are not great, with the same explanatory power and no time series problems, but there are lower t- and F-statistics, indicating that this model is statistically inferior. The own price elasticity increases to 0.429, but the short run price elasticities for the other variables change very little. The DOA health expenditures are again insignificant and improvement in R&D has a lower total elasticity.

Model 2 has the advantage of allowing separate PDLs to be fitted to the two R&D variables. The results for the improvements equation, without the DOA health expenditures that were found to be insignificant and with only improvements R&D, are reported in the second column of Table 2. The F-statistic suggests a slightly improved fit and there are no statistical problems or unexpected results. The short run price elasticities are all low, the largest being the own price elasticity of 0.262. However, the coefficient on the lagged dependent variable is the adjustment elasticity and it can be shown that the long run elasticities can be calculated by dividing the short run elasticities by one minus the adjustment elasticity. This gives a long run own price elasticity of 0.45, while the equivalent result for the horticulture and fruit price is 0.36. For the price of dips, sprays and vaccines the long run elasticity is 0.22, and for the price of maize it is

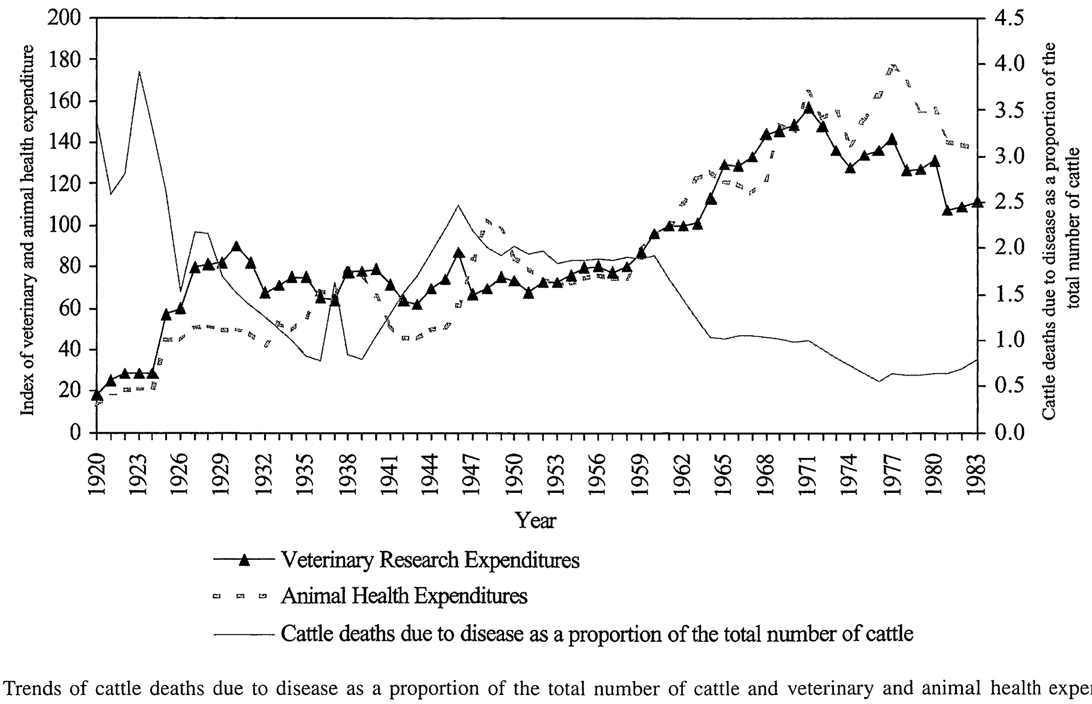

Fig. 2. Trends of cattle deaths due to disease as a proportion of the total number of cattle and veterinary and animal health expenditures.

0.35. Only the price of dips and sprays is insignificant and the 13 years of lag terms on R&D sum to 0.136.

Thus, nothing is lost in the improvement equation and the last column, which reports the animal health results, shows the gains. The Durbin Watson statistic shows that no lagged value is needed since there is no serial correlation. The price of dips, the weather and the lagged dependent variable are all insignificant. The DOA health expenditures and the SAARC health maintenance research both have negative coefficients, indicating that they reduce cattle deaths. These variables alone explain 94% of the variance in the dependent variable. The negative correlation of these variables is easily seen in Fig. 2, but the lag lengths between expenditures and cattle deaths are much harder to determine.[11]

The statistical tests of the lag structure lead to rejection of the simple second degree PDL in favour of a fourth degree PDL with the first end point restricted to equal zero and a lag of up to 15 years. The *t*-statistic show why a function with three turning points was selected by the AIC and SC tests. Two peak effects are identified; the first from 0 to 4 lags and the second from 11 to 15 lags. The coefficients in between are not significant. The first peak may represent near market research on vaccines, which soon reduce disease loss, while the longer lag would be needed for more basic R&D, e.g. to develop new vaccines.

5. Rates of return

Having estimated the elasticities for the effects of R&D expenditures on the value of output, these can be easily converted into value marginal products.[12] First, since elasticities are ratios of marginal to average values, they must be multiplied by the averages of output value and R&D to leave a marginal product in value terms. The value marginal product is thus

$$\mathrm{VMP}_{\mathrm{R\&D}_{t-i}} = \beta_i \left[\frac{\overline{\text{output}}}{\overline{\text{R\&D}}} \right] \tag{3}$$

where the bars on output and R&D indicate averages. It is this apparently innocuous transformation that leads to errors, since if total R&D expenditures, rather than just improvement R&D expenditures are used, the result is the value average product and this will be less than the value marginal product (see Fig. 1). Second, the lags are taken into account by discounting the benefits. Solving for r in Eq. (4) yields the marginal internal rate of return (MIRR) to research:

$$\sum_{i=1}^{n} \frac{\mathrm{VMP}_{t-i}}{(1+r)^i} - 1 = 0 \tag{4}$$

where i is the lag on R&D.

Note that for livestock there is limited data on net output measures, such as net farm income. The value used in the study is the gross value of output, without the value of inputs being netted out. Netting out could only be done if gross and net margin information that is representative of the whole country and consistent over the period were available. Net returns calculated in this way would be marginally lower. For the Model 2, the decline in the number of cattle deaths due to disease as a proportion of the total cattle population was converted into a gain (the livestock saved) and then multiplied by price to put it in value terms.

The results of these calculations are reported in the last row of Table 2. In the conventional model, the MIRR to the sum of all the R&D expenditures is 18%, rather than van Zyl's (1996) figure of 0–5%. Thus, the greater flexibility of the two-stage approach results in a higher ROR than the profit function result that was reported in Table 1. This is usually true and the results of ROR estimates for the SAARC system, reported in Thirtle et al. (1998b) showed that the two-stage aggregate result was far higher than the profit function outcome. Nevertheless, this MIRR for animals is still lower than for any of the other commodities in the SAARC system, except for ornamental flowers.[13]

[11] The cattle deaths index shows a peak after the First World War, caused by a serious anthrax outbreak, and another peak after the Second World War. These costs of neglecting animal health measures during the conflicts is in itself clear evidence of the need for livestock health expenditures.

[12] The conversions and discounting procedures are fully described in Thirtle and Bottomley (1989). This case is very simple, so the error in the ROR calculation (discussed in Section 2) is more obvious.

[13] In these cases, the RORs were low because the projects took an inordinately long time to produce saleable results.

Thus, animal research still appears to be a relatively poor investment.

In the second version of Model 1 (not shown) the R&D series is only the improvement research conducted at the Animal Improvements Institute and the Animal Products and Animal Nutrition Institute. Although the R&D elasticity is lower, so are the expenditures, and the lag is shorter. The last two effects dominate and increase the MIRR to 23%, but, as stated above, model is poor statistically. This return to improvements expenditures corresponds to the correct measure shown in Fig. 1and is preferable to the 18% figure for the conventional model. Thus, provided that improvements expenditures can be separated from maintenance R&D, a reasonably correct estimate can be obtained. However, the improvements equation in Model 2 is preferred and combines the shorter lag with a higher elasticity, which together result in a higher MIRR of 27%. In this case, the cattle death series allows the returns to health expenditure to be estimated as well.

Thus, the remaining expenditures, for the Range and Forage Institute, the Onderstepoort Veterinary Institute and the Onderstepoort Institute for Exotic Diseases are classified as health maintenance research and form the R&D series in the cattle deaths equation. This is equivalent to assuming that Onderstepoort spends all its funds on cattle disease prevention research. As this is not true, the resulting MIRR of 35% is clearly a lower bound.

Note that, cattle, including dairying, accounted on average for about 50% of the value of the output of the animal sector during this period. Therefore, if the deaths of other animals are similarly affected by health R&D, the MIRR would increase to about 70%. Even without this adjustment, just taking the cattle losses that would have occurred into account raises the average return on animal research to just over 30%, which is very similar to the return on crops and suggests that research resources have not been misallocated.

6. Conclusions

This study examines the returns to livestock research in South Africa using a methodology that differentiates between animal health and animal production research. If these components of livestock research are considered separately the returns to livestock research increase from 18 to 27% for animal improvements research, and to at least 35% for animal health research. Thus, livestock research is just as productive as crop research, but studies that do not account for the losses that would occur in the absence of health maintenance research fail to recognise this.

This is perhaps particularly obvious for the case of animal production in a hostile environment such as South Africa, but it is not a special case. The vast majority of the large number of ROR studies that have been published do not make any allowance for maintenance research and this must lead to a downward bias in the ROR results. This is not a matter of lack of effort or understanding on the part of other researchers. It is only possible to model maintenance research separately if R&D expenditures can be decomposed and a suitable dependent variable, such as the series for cattle deaths due to disease that is used in this study, is available.

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