Does research and development (R&D) investment lead to economic growth? Evidence from the South African peach and nectarine industry

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Abstract

The agricultural research programmes in Africa have experienced waning state financial allocations. Efforts to change these funding trends have been fettered by the limited evidence of research investment benefits and the long lags associated with these returns. In a bid to provide such information, this article seeks to calculate the benefits of investments in the Agricultural Research Council's peach and nectarine research programme – one of Africa's successful and oldest research programmes. It uses the supply response function to model South Africa's peach and nectarine industry and estimates the effect of deciduous fruit prices, production costs, research investment and weather on production. A lag distribution of Research and Development (R&D) investment is estimated using the polynomial distribution function and the derived elasticities are used to calculate the marginal internal rate of return. The study's results reveal that investment in the peach and nectarine programme is associated with a marginal internal rate of return of 55.9%. This means that every R100 invested yields a R55.9 increase in value in the peach and nectarine industry. In light of these findings, it is concluded that R&D investment is worthwhile and recommends that the funding allocated to this programme be increased.

KEY WORDS: R&D investment, supply response function

JEL Classification: O1, O2, O3, O4, O5

1. Introduction

According to Pardey *et al*. (2016), research-enabled growth in agriculture has been critical to the overall economic growth prospects Sub-Saharan Africa (SSA). Several studies have shown that the benefits of Research and Development (R&D) investments in the region have been substantial and have encouraged long term economic growth (Alston *et al*., 2002). However, notwithstanding the economic development importance placed on agricultural R&D investments, state allocations to agricultural R&D have been waning.

For South Africa's agricultural research parastatal, the Agricultural Research Council (ARC), state investment has decreased from 100% to below 50% of total R&D funding received between 1992 and 2000 (Liebenberg and Kirsten, 2006). Limited evidence of research investment benefits as well as a past culture of government over-spending on agriculture, have led to an increase in the level of caution exercised in financial resource allocation in the industry. Consequently, great emphasis has been placed on the calculations of the financial benefits of agricultural R&D investment as a way of improving resource allocation, accountability and overall priority setting. Therefore, there is great impetus for the research organisation to provide evidence of how productively it has used past investment as a justification for continual funding not only at the aggregate agricultural level but also at the individual crop level (Thirtle *et al*., 1998).

The ARC's peach and nectarine research programme has had past successes which have indicated research organisation's efficient use of money. Since its inception in 1937, the programme has bred 96 cultivars which have been extensively used in the local industry. The use of these cultivars has resulted in farmers reaping higher yields and the expansion of the industry's production area, which used to be restricted to the Western Cape Province. According to Pieterse (2013), ARC–bred peach and nectarine cultivars contributed 100% of canning fruit volumes, 100% of the fresh nectarine exports and 55% of dried peach exports in 2012. These cultivars have also enabled industry stakeholders to explore new lucrative marketing windows and to increase the production capacity in the canning sector (Smith *et al*., 2012).

Whilst these reports may be viewed as compelling evidence for the programme's efficient use of financial resources, they do not provide a measure that allows for comparison between the peach and nectarine research programme with other programmes with which it "competes" for scarce funds. Lack of such information has fettered the programme's ability to motivate for an increase in research funding as it does not avail information that is useful during priority setting or allocation decisions between different crops. Therefore, the aim of this study is to calculate the marginal internal rate of return for the ARC's peach and nectarine research programme. This calculation will be instrumental as it will give comprehensive estimate of the whole programme. The available information is incomplete because it makes no mention of the benefits of other basic and adaptive research disciplines which are included in the programme whose outputs are not as easily quantified as those of the breeding discipline. Hence, filling this empirical gap in knowledge will further provide a more convincing argument for increasing research investment. It will further provide motivation for the funding of multi-disciplinary research programmes as opposed to single discipline projects which are favoured by the current R&D funding policies.

The remainder of the paper is structured as follows: Section 2 gives a background of R&D funding in Africa while Section 3 reviews evidence from past studies which investigated the impact agricultural R&D funding. Section 4 discusses the theoretical framework used to explain the effect of R&D in the peach and nectarine industry. Section 5 gives the data sources and explains the method used to analyse the data. Section 6 presents and discusses the results, and the study is concluded in Section 7. Recommendations are made in this last section.

2. Background on Research and Development in Africa

Formalised agricultural research in Africa dates as far back as the early 1900s where colonial governments established research infrastructure and organised local and regional research systems (Walker and Alwang, 2015). Political independence in the 1950s and 1960s saw African countries inherit the running and financing of these research systems and this ushered in a period of various developments. According to Pardey *et al*. (1995), African research institutions experienced a six-fold increase in research centre numbers, an almost fivefold increase in African researcher numbers and significant increase in overall educational levels of research stuff between 1961 and 1991. Ill-advisedly, these changes were not matched with increases in research funding as government research expenditure allocations decreased from 91% in 1961 to 85.6% in 1991 (Pardey *et al*., 1997). As a result of the thin spread of funds, the agricultural research’s efficiency and effectiveness were negativity impacted. The commencement of structural adjustment programmes in the late 1980s further curtailed government investment spending and eroded the past achievements.

The 1990s were marked with significant increases in R&D investments by donor organisations (e.g. The Bill and Melinda Gate Foundation). Market liberalisation adopted during this period also brought better fortunes as this motivated for significant increases in private sector investment (Beintema and Stads, 2011). However, this investment growth was substantially volatile due to retraction of government funding which simultaneously occurred and the large proportion of short-term funding extended by the ad hoc donors (Stads and Beinteima, 2015). At the turn of the 21st century most research programmes continued to experience fluctuating, inconsistent and fragile investments (Alene, 2011). The worst trends were reported in francophone, West African and Central African countries (Alene, 2011). For SSA as a whole, national investments in food and agricultural R&D dropped from 6.1% to 3.9% between 1980 and 2011 (Pardey *et al*., 2016).

There is no consensus on the single cause of the diminishing agricultural R&D funds. Walker and Alwang (2015) claim the dwindling support from SSA governments has been caused by shifts in attention of public sector spending to social sectors and negative perceptions associated with returns to agricultural research investments. Pardey *et al*. (1995) attribute the negative trend to the pervasion weak link that exists between research and the African production needs. Pardey *et al.* (1995) add that there is also a general lack of research capacity congruency across countries that limits the effectiveness of regional research. Pardey *et al*., (2016) report that the limited evidence of research investment benefits and the long lags associated with past investment returns has fettered efforts to motivate for domestic political support in reversing this trend.

Similar to the rest of Africa, the earliest organised and publicly supported R&D programmes in South Africa rested with a range of research activities funded by and largely carried out by the colonial governments (Liebenberg and Pardey, 2011). Coupled with the work done in Departments of Agriculture of the former Boer Republics, South Africa spearheaded Africa's research excellence from as early as the 1910s. By 1961, South Africa had 740 full time equivalent (fte) researchers while other countries had between 100 and 400 ftes (Pardey *et al*., 1995). Thirtle *et al*. (1998) report that South Africa managed to develop a research system that was sufficiently advanced and comparable with best in the global research system.

It is in South Africa that the first deciduous fruit research station was established. This station was later incorporated as a research programme in the Agricultural Research Council's Infruitec-Nietvoorbij institute (ARC-Infruitec-Nietvoorbij). The research program was started in 1937, houses the peach and nectarine research programme which is arguably the most successful research programmes in Africa. The peach and nectarine research programme was ranked 7th in the world, based on the number of cultivars released between 1990 and 1996 (Byrne, 2005). It accounted for two thirds of the stone fruit cultivars bred at the ARC-Infruitec-Nietvoorbij institute between 1996 and 2012 (Smith *et al*., 2012). In 2012, ARC-bred peach and nectarine cultivars accounted for 100% of canning fruit volumes, 100% of the fresh nectarine exports and 55% of dried peach exports (Pieterse, 2013). This multidisciplinary programme carries out research in five disciplines. These are the: Soil Technology and

Irrigation, Biotechnology and Pathology, Post–Harvest Technology, Horticulture; and Plant Improvement, and Soil Technology and Irrigation disciplines.

South Africa's R&D funding is relatively more diversified than other African countries and this has significantly contributed to the stability of its research system as reflected in its relatively higher human capital endowments. For example, the country had fewer than 3 ftes per million whereas other countries like Guinea have over 57 ftes per million dollars spent in R&D expenditures during the 1961 (Walker and Alwang, 2015). The peach and nectarine research programme receives its core funding from the state through a competitive allocation process. Similar to the rest of Africa, funding from this source has been decreasing. In its place, the private sector, through producer organisations levies, has filled the gap through project specific funding which is allocated on a competitive basis as well. Private sector funding commenced in 1992 after policy reforms were enacted to end the industry's state dependence for R&D investment. Such reforms have provided reason for the government to continuously withdraw its financial commitment to agricultural R&D.

The research program also raises funds through the sale of its research texts (e.g. technical bulletins) and royalties acquired from the sale of cultivars and rootstock licenses. Although success has been registered in raising funds using royalties because approximately a tenth of the annual funding is generated this way, this fundraising method has its limitations (Tsvakirai, 2015). Royalty collection system has often been proven to be too closely linked to the market thus lending itself to the fluctuations of commodity prices thus jeopardizing consistency in funding levels. Such dependence on commodity tax revenues has had a negative impact on the R&D investments in some African countries like Mauritius (Walker and Alwang, 2015).

3. Past Rate of Return studies and methods

Agricultural Science administrators have been interested in measures of the economic benefit from agricultural R&D investment for a long time (Alston *et al*., 2002a). The interest of some economists has been driven by the belief the global phase of sustained growth has ended and has ushered in a phase of general fiscal restraint (Alston *et al*., 2002b). Therefore, they hold a sceptical view of the social benefits of investments in Science and this has resulted in an increase in research which justifies R&D funding. Others believe the heightened fear of future food insecurity due to Climate Change, population growth and resource scarcity calls for close monitoring of R&D funding and investment returns as there exists close a relationship between investment and agricultural productivity which could portend to future of food production (Pardey *et al*., 2016).

Numerous studies have been conducted on impacts of agricultural research globally. However, impact assessment of agricultural research in SSA is still sparse (Maredia and Raitzer, 2006). Most evaluations have been carried out at multi-country and multi-regional levels. An assessment done by Walker and Alwang (2015) revealed that there was little correlation between the returns to investment evaluations and the value of agricultural output. The study reports that Nigeria which contributed 36.1% to SSA's 2014 agricultural output value accounted for just 4.3% of the region's studies, whereas Zambia which contributed less than 1% of the value of output constituted 11.4% of the reports. Additionally, of the 48 countries in the region merely five (Kenya, South Africa, Uganda, Zambia, and Zimbabwe) accounted for 42.8% of the published reports (Walker and Alwang, 2015).

The largely positive returns that have been calculated for the region have been acquired using mostly econometric methods. Masters *et al.* (1998) reported that 75% of the SSA studies reviewed applied econometric modelling. This study showed SSA investment had annual returns of over 20%. Fuglie and Rada (2013) used Total Factor Production method and found that the use of modern technologies was associated with a 45–82% return to investment. A benefit-cost ratio calculated by Kristjanson *et al*., (2002) resulted in returns of between 50% and 103% for cowpea adoption in West Africa. Applied research has been generally reported higher returns than basic research (Hurley *et al.*, 2016).

There is a marked focus on cereal crops evaluations in SSA as these take up about 56% of the total studies available (Walker and Alwang, 2015). For South Africa, just five evaluations were conducted on cereal crop investments of the 19 studies reported by Liebenberg and Kirsten (2006). A review of South Africa's Rate Of Return (ROR) studies showed that the return to investments of public sector agricultural R&D was at least 40% (Khatri *et al.,* 1996). When analysing the gains from research according for the different ARC research institutes, it was found that the Wine Institute and the Fruit Technology institutes had higher ROR estimates of 40-60% and 78%, respectively. On the other hand, the Animal Production Improvements institute and Range and Forage institute had estimates of 11% to 16%, respectively (Thirtle *et al.*, 1998).

South Africa’s ROR investigations which were conducted at national level have utilised two-stage decomposition, profit function and TFP models (Liebenberg and Kirsten, 2006). Due to input use appropriability challenges, studies that have be conducted at crop level often use partial productivity methods (Beintema and Stads, 2011). For South African studies these have included the: supply response function, error correction model, economic surplus model and production function (Nieuwoudt and Niewoudt, 2004). Different from the other techniques, the profit function has been applied on both aggregate and research programme levels (Van Zyl, 1996; Khatri *et al.*, 1996).

This paper used the supply response function to evaluate the returns to investments in the peach and nectarine research programme. The method has been used in South Africa to evaluate the deciduous fruit and sweet potato research programmes (Thirtle *et al.*, 1998). The main advantages of using this method are its simplicity, flexibility and accuracy of measurement. According to Alston *et al*. (1998), another strength of the method is its ability to incorporate price variables which enables the capturing the effects of opportunity cost of producing the specified agricultural crop. In addition, the model also captures the research effects on changes in quality which are reflected in prices (Hall *et al*., 2010). These are important aspects firstly, because land suitable for deciduous fruit production in South Africa is limited therefore, production of peaches and nectarines is associated with high opportunity cost. Secondly, the research programme under study has been reported to have an effect on fruit quality in addition to R&D’s effect on output quantity that would be normally captured by other *ex–post* methods.

The theoretical framework for the supply response function is discussed below.

4. Theoretical framework

Micro-economic theory states that market supply is mainly determined by a commodity’s own price, the price of substitute goods, the price of inputs as well as technology, weather and other related factors such as infrastructure (Garnett *et al*., 2014). Consequently, a supply response function describes the extent to which the supply changes relative to variations in economic and non-economic factors (Rao, 1989). According to the theory of the firm, changes in a commodity’s own price induces the movement along the supply schedule while changes in all other variables shifts the supply curve (Kapuya, 2010). This supply curve is represented as follows:

$$Q_t^e = b_o + b_1 P_t^e + b_2 W_t + U_t \quad (1)$$

Where Q_t^e is desired level of output, P_t^e is a vector of expected level of prices, W_t represents the set on non-price factors, *b*'s are parameters and U_t accounts for unobserved random factors with zero expected value.

For the agricultural sector, the supply of an agricultural commodity does not have an instantaneous response to any of these changes due to biological lags, barriers to entry and exit, imperfect market knowledge and risk (Muchapondwa, 2009). Additionally, there is often a relationship between the production levels and market prices between successive years thus production behaviour of agricultural producers diverts from what the theory of firm stipulates.

One model which captures the partial adjustments to output resulting from changes in market prices experienced in the agricultural sector is the Nerlovian supply response. This model postulates the following hypothesis,

$$Q_t – Q_{t-1} = \gamma (Q_t^e – Q_{t-1}), O< \gamma <1 \quad (2)$$

Where γ is known as the coefficient of adjustment, $Q_t - Q_{t-1}$ is the actual change in output and $Q_t^e - Q_{t-1}$ is the desired change in output.

According to equation 2 the actual change in output in any given time period *t* is some fraction *γ* of the desired change for the period. Typically, γ is expected to lie between 1 and 0 indicating two extremes since adjustment to the desired output is likely to be constrained by various lags. Specification of a model that explains how price expectations are formed based on the differences between actual and past prices assumes:

$$P_t^e - P_{t-1} = \beta (P_{t-1} - P_{t-1}), O < \beta <1 \quad (3)$$

Where *β* is adaptive expectations coefficient.

Equation 3 states that expectations are revised each period by a fraction *β* of the gap between the current value of prices and its previous expected value. This means that expectations about the price level are revised by farmers by a fraction of *β* due to factors that affect the price level observed in the current period and what its anticipated value had been in the previous period.

As expectations are seldom fully realised, there is usually a gap between the actual and expected level of prices because of constraints in public policies and non-policy variables.

In order to use the Nerlovian model for estimation, it is necessary to transform the three equations into the reduced form. In the reduced form, the partial adjustment variable Q_t^e which is associated with the desired output and the adaptive expectation variable P_t^e which is associated with price expectation are transformed into distributed lag structures in the form of past level of output and the previous expected price level. This is consistent with the Nerlovian model which is based on price expectation and output adjustment. The entire process necessary to arrive at the reduced form equation is shown below. There are two constants in the equation, γ and β. γ is referred to as the Nerlovian coefficient of adjustment. By imposing a restriction that $\beta = 1$ and substituting equations (5) and (6) into equation (4), a reduced form equation is derived as follows:

$$Q_t^e = b_0 + b_1 P_t^e + b_2 W_t + u_t \quad (4)$$

$$Q_t = Q_{t-1} + \gamma(Q^e_t - Q_{t-1})\ 0 < \gamma < 1 \quad (5)$$

$$P_t^e = P_{t-1} + \beta\ (P_{t-1} - P_{t-1}) 0 < \beta < 1 \quad (6)$$

$$Q_t = Q_{t-1} + \gamma Q_t^e - \gamma Q_{t-1} \quad (7)$$

$$P_t = P_{t-1} + \beta P_{t-1} - \beta P_{t-1} \quad (8)$$

Substitute equation (8) into equation (4) where $\beta = 1$:

$$Q_t^e = b_o + b_1 P_{t-1} + b_2 W_t + U_t \quad (7)$$

$$Q_t = Q_{t-1} + \gamma Q_t^e - \gamma Q_{t-1} \quad (8)$$

Substitute equation (8) into equation (7):

$$Q_t = Q_{t-1} + \gamma b_o + \gamma b_1 P_{t-1} + \gamma b_2 W_t + \gamma U_t - \gamma Q_{t-1} \quad (9)$$

Collect like terms:

$$Q_t = \gamma b_o + \gamma b_1 P_{t-1} + \gamma b_2 W_t + (1 - \gamma)\ Q_{t-1} + \gamma U_t$$

The equation becomes:

$$Q_t = a_o + a_1 P_{t-1} + a_2\ W_t + a_3\ Q_{t-1} + U_t \quad (10)$$

Where

$a_0 = \gamma b_o$

$a_1 = \gamma b_1$

$a_2 = \gamma b_2$

$a_3 = 1 - \gamma$

$U_t = \gamma U_t$

Equation (10) provides the reduced form of the Nerlovian model. It states that the current level of agricultural output Q_t is determine by the autonomous output a_o, the previous expected level of prices, P_{t-1}, a set of non-price variables W_t, the past level of output Q_{t-1} and on the disturbance term U_t.

5. Data and analytic method

5.1 The empirical estimation

The Ordinary Least Squares technique was used to estimate the parameters of the supply response function for South Africa's peach and nectarine industry. Agricultural production output measured in tonnes was used as the dependent variable as it was viewed as a suitable indicator of peach and nectarine supply. Other variables, such as acreage were disregarded because the supply of perennial crops can be easily altered by any of the exploratory variables while the area under production remained constant (Shoko *et al*., 2016; Utuk, 2014). This is the case especially for industries with high input use such as the South African peach and nectarine industry which has experienced an increase in supply despite a general downward trend in the area under production since 1978 (Tsvakirai, 2015). Independent variables that influenced supply included: market prices of peaches and nectarines and competing crops, the price of production inputs, weather and R&D investments.

Save for the weather variable, all variables were differenced once to make them stationary as they had a unit root. The explanatory variables (except for the weather variable and R&D investment) were lagged individually to determine the time delay effect of these variables on production response. The lag with the most significant effect on the dependent variable was selected using the t–statistic criteria. The variables which showed the weakest statistical relationships were progressively dropped individually until the variables with the highest levels of statistically significant relationships with the peach and nectarine fruit supply remained. The combination of lagged explanatory variables showing the highest significant levels was selected using the F–statistic criteria. After this variable selection process was complete the prices of packaging material, apricots, table and dried grapes, weather and R&D investment showed significant relationships with the dependent variable. The supply of peaches and nectarines was modelled as follows:

$$lnQ_{t} = \beta_{0} + ln\beta_{1}X_{j(t-i)} + ln\beta_{2}P_{j(t-i)} + ln\beta_{3}P_{r(t-i)} + ln\beta_{4}W_{t} + \sum_{i=1}^{n}\beta_{5}lnR\&D_{t-i} + u_{t} \qquad (11)$$

Where: Q_t represents the total tonnage of peach and nectarine produced in the industry, $X_{i(t-i)}$ represented lagged price of packing material; $P_{j(t-i)}$ represents the lagged average price of the different deciduous fruits; W represents a computed weather index, $R\&D_{(t-i)}$ represents the investment in the ARC peach and nectarine research programme, u_t which represents all other uncontrolled factors, and n is the maximum lag of research investment that affects yield.

Most studies using the supply response function use the calculated the expectation and adjustment coefficients to estimate the short run and long run elasticities. This study diverts from loosely defining the effect of R&D investment as a short run or long run effect and further investigates the R&D investment lag distribution. There often exists a relationship between R&D investment levels of successive years therefore, when examining the R&D lag structure the problem of collinearity is confronted. In order to capture lagged effects of R&D on supply, while avoiding collinearity, an Almon Polynomial Lag Distribution (PDL) is used. Past studies that have applied the PDL include: Evenson (1967), Doyle and Ridout (1985), Thirtle and Bottomely (1989), and Townsend and Van Zyl (1998).

A function of order 2 with no “far end”, “near end” or “both end” constraints was used to calculate the elasticities of the R&D variable in this study. A function of order 2 implies that a second order degree polynomial was estimated to fit the lag distribution of R&D. This assumption is in line with economic theory as a review of ROR studies done by Hall *et al.*, (2010) reported that most studies showed that R&D investment provided a continuous stream of benefits which peaked at some point in time and decreased thereafter. The lack of “far end”, “near end” or “both end” restrictions means that the study did not predetermine the start and end periods for investment benefit generation.

The elasticities obtained from the PDL function were used to calculate the corresponding marginal product values. As done by Thirtle and Bottomley (1989), each lagged coefficient, β_i is the output elasticity of *R&D* for that year:

$$\beta_i = \frac{\partial \ln OUTPUT_t}{\partial \ln R\&D_{t-i}} = \frac{\partial OUTPUT_t}{\partial R\&D_{t-i}} \cdot \frac{R\&D_{t-i}}{OUTPUT_t} \tag{3.2}$$

Thus, the marginal physical product of *R&D* is the elasticity multiplied by the average physical product:

$$MPP_{t-i} = \frac{\partial OUTPUT_t}{\partial R\&D_t} = \beta_i \frac{OUTPUT_t}{R\&D_{t-i}} \tag{3.3}$$

Replacing $Yield/R\&D_{t-i}$ by its geometric mean, and changing from continuous to discrete approximations, gives:

$$\frac{\Delta OUTPUT_t}{\Delta R\&D_{t-i}} = \beta_i \frac{\overline{YIELD}}{\overline{R\&D}_{t-i}} \tag{3.4}$$

Then multiplying by the increase in the value of the output and dividing by the change in quantity converts from output quantity to output value. Thus, the value marginal product of research investment in period *t–i* can then be written as:

$$VMP_{t-i} = \frac{\Delta VALUE_t}{\Delta R\&D_{t-i}} = \beta_i \frac{\overline{OUTPUT}}{\overline{R\&D}_{t-i}} \cdot \frac{\Delta VALUE_t}{\Delta OUTPUT_t} \tag{3.5}$$

Where: $OUTPUT/R\&D_{t-i}$ is an average and $\Delta VALUE_t/\Delta OUTPUT_t$ is calculated as the average of the last five years minus the average for the first five years, for both variables. Thus, these are constants, but β_i varies over the lag period, giving a series of marginal returns resulting from a unit change in research expenditure. The value of output, $\Delta VALUE_t/\Delta OUTPUT_t$ is the geometric mean calculated using the value of output relative to chosen base year. Similarly, $YIELD/R\&D_{t-j}$ is a constant–price geometric average. The Marginal Rate of Return (MIRR) is calculated from:

$$\sum_{i=1}^{n} \frac{VMP_{t-i}}{(1+r)^i} - 1 = 0 \tag{3.6}$$

Where: *n* is obtained by solving for *r* to get the MIRR.

5.2 Data Sources

The study made use of annual data spanning recorded between 1971 and 2012 as this was the time period for which data was available. R&D data were defined as the research costs comprising of labour, maintenance and overhead costs. The data for research expenditure in peach and nectarines research was estimated from the Western Province's allocation to the ARC's deciduous fruit research institute for the years before 1992. Data for the years after 1991 were acquired from ARC's annual reports and financial reports. The data on agricultural output and all the deciduous fruit prices were acquired from the Abstracts of Agricultural Statistics published is by the South Africa's Department of Agriculture, Forestry and Fisheries. The study made use of average market prices for individual deciduous fruits were calculated from data acquired from this source as well. All prices and the R&D investment were adjusted for inflation using a deflator calculated relative to South Africa's 2010 Gross Domestic Product.

A weather index was computed using data collected from South Africa's Weather Services. Calculation of this index was done using rainfall and temperature data from peach and nectarine production areas. Deciduous fruit conventional input cost indexes were used as proxies for the cost of peaches and nectarines convention inputs. Conventional inputs considered were fertiliser and packing material because these were found to be the highest production cost drivers. These input indexes which were acquired from the South Africa's Department of Agriculture, Forestry and Fisheries' input cost monitor data. Here the assumption was made that the average input price of the deciduous fruit industry would serve as an adequate proxy for the price for peach and nectarine inputs.

6. Analysis, results and discussion

6.1. Regression analysis results

The regression analysis was run using Eviews 8 software. The results in Table 1 show that the prices of grapes and apricots were negatively related to the dependent variable. This result is in line with prior expectations as table and dried grapes, and apricots are fruits which act as competitor goods of peaches and nectarines. As expected, the price of packaging material was negatively related to peach and nectarine output because higher production costs discourage increases in production volumes. "Weather" was positively related to production output. The small coefficient on this variable is an expected result as it shows the limited effects that result from the use of ARC–bred well-adapted cultivars. The coefficient for the "constant" term was negatively related to the dependent variable. This implies that the absence of market incentives and R&D investment is most likely to decrease peach and nectarine industry supply or production volumes.

The model showed that "Weather" had an immediate (short–run) effect on the quantity of peach and nectarine produced. That is, a change in weather had an effect in the same year of production. The prices of grapes, packaging material and apricots were found to have lagged (long–run) effects which were significant after 17, 16 and 4 years respectively. The long lag lengths are in line with economic theory as perennial crop farmers are reluctant to switch to the production of different fruits due to the high costs associated with switching, long break-even lags associated with fruit farming, and the risk–averse nature of farmers. The unresponsiveness of peach and nectarine production output volumes to their own prices is attributed to the high input specificity of the processed fruit market, which consumes about 80% of the annual production (Siphugu, 2009). This market uses specific cultivars grown under specific production conditions and South Africa has a limited production area that can provide these production conditions. Thus, assuming there is no change in the policy environment or technology for example cultivars, it would not be possible for the industry to respond to a price movement since production levels are dictated by the availability of resources i.e. land.

The model suggests that, in the long run, every 10% increase in the price of grapes causes the peach and nectarine industry's output to decrease by 4%, *ceteris paribus*. As shown in Table 1, every 10% increase in the price of packaging material, will cause the industry's output to decrease by 6%, *ceteris paribus*. Holding all things constant, a 10% increase in the price of apricots leads to a 0.6% decrease in the peach and nectarine industry's output. As the coefficients of the price variables are less than 1, this implies that peach and nectarine supply is price inelastic. This means the industry's supply does not significantly respond to market incentives. As shown by the magnitude of the packaging material's coefficient, the cost of production has a bigger influence on the industry's output than deciduous fruit prices.

Table 1: Supply response regression results

Variable	Coefficients	Standard error	t–statistic
Constant	–4.958356	1.225062	–4.047432
Weather Index	0.061426	0.011245	5.462659
Packaging material$_{(t-16)}$	–0.57976	1.036323	10.20895
Price of apricots$_{(t-4)}$	–0.062676	0.271420	3.915241
Price of table and dried grapes$_{(t-17)}$	–0.380973	0.163389	8.452033
R&D	0.31400	0.16974	1.84993
R&D$_{t-1}$	0.44739	0.23668	1.89030
R&D$_{t-2}$	0.57056	0.30859	1.84891
R&D$_{t-3}$	0.68351	0.37756	1.81031
R&D$_{t-4}$	0.78623	0.44098	1.78291
R&D$_{t-5}$	0.87874	0.49781	1.76522
R&D$_{t-6}$	0.96103	0.54755	1.75513
R&D$_{t-7}$	1.03309	0.58997	1.75110
R&D$_{t-8}$	1.09494	0.62492	1.75212
R&D$_{t-9}$	1.14656	0.65233	1.75763
R&D$_{t-10}$	1.18796	0.67217	1.76737
R&D$_{t-11}$	1.21915	0.68441	1.78131
R&D$_{t-12}$	1.24011	0.68907	1.79967
R&D$_{t-13}$	1.25085	0.68618	1.82291
R&D$_{t-14}$	1.25137	0.67579	1.85171
R&D$_{t-15}$	1.24167	0.65797	1.88712
R&D$_{t-16}$	1.22175	0.63285	1.93057
R&D$_{t-17}$	1.19161	0.60059	1.98407
R&D$_{t-18}$	1.15125	0.56148	2.05039
R&D$_{t-19}$	1.10067	0.51595	2.13330
R&D$_{t-20}$	1.03987	0.46473	2.23757
R&D$_{t-21}$	0.96885	0.40912	2.36814
Adjusted R–squared	0.925570		
F–statistic	30.53400		
F–statistic p–value	0.000002		
Akaike Information Criterion (AIC)	–0.100243		
Durbin–Watson statistic	2.136780		

Source: Eviews output

As shown in Table 1, the adjusted R squared value shows that 93% of the variation in supply of peach and nectarine is explained by the explanatory variables included in the model. According to Gujarati and Porter (2009), adjusted R squared values closer to 100% are more desirable than values closer to 0. A value of this magnitude does not come as a surprise as Carter (1999) who used the supply response model to calculate the rate of return for deciduous fruits had R squared vales ranging from 85% to 95%. Similarly, Townsend and Van Zyl (1998) had values above 74% while Nieuwoudt and Nieuwoudt (2004) had an R squared values of 87%. The model's F–statistic p–value was 0.000002. Such a low p–value shows that the joint interaction of the explanatory variables has a very significant effect on peach and nectarine supply. The AIC value of –0.1 is sufficiently low to confirm that the model has an adequately high goodness-of-fit with respect to the number of parameters included in it. The Durbin-Watson statistic value of 2.13 is sufficiently close to 2. Hence, it can be concluded that the model is free of serial correlation.

6.2. R&D lag distribution

The coefficients of the research investment terms for the regression model are shown in Figure 1 below.

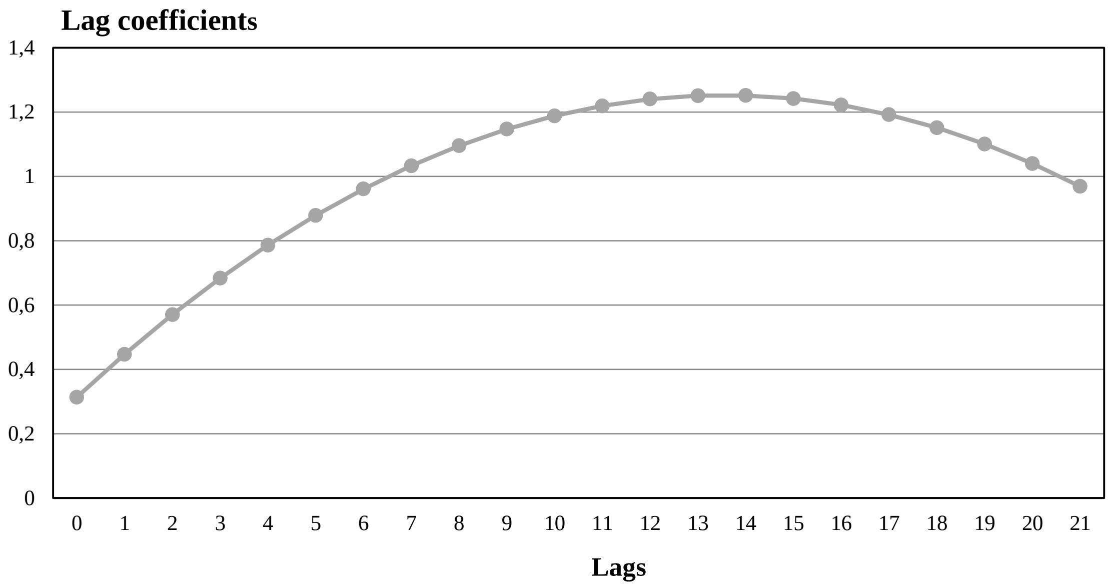

Figure 1: Distribution of R&D effects on peach and nectarine production.

Source: Author's calculations

Figure 1 shows that the coefficients for the research investment terms range from 0.31 to 1.25. As shown, the returns to research are initiated immediately, i.e. in the initial year of investment. These returns increase gradually and reach a peak and then start to decrease. This initial impact of research is due to the agronomic and maintenance research that influences the quality of the existing crops (Townsend and Van Zyl, 1998). An example of such a project that is conducted in the programme is the breeding of sterile fruit flies which reduces the pest's populations and reduces postharvest losses. This programme is problem-oriented and adaptive in nature. Its R&D investment thus has positive effects that materialise in the same year in the form of reduced postharvest losses (Townsend and Van Zyl, 1998). The use of pest traps which are baited with extracted pheromones is another example of a project in the Biotechnology and Pathology discipline which forms part of the research program. Thirtle *et al.*, (1998) also attribute the quick effect of some of ARC's research to the targeted extension programme which is conducted in the Horticultural discipline.

The research lag distribution shows an increasing effect of research investment because other research disciplines with research lags begin to yield dividends. Examples of this type of research are conducted in the Postharvest Technology discipline, and Plant Improvement discipline which take time to be completed. According to Walker and Alwang (2015), the lag in cultivar development is decreasing due to the incorporation of biotechnology in advanced breeding techniques. However, a significant amount time still elapses before the developed technologies are adopted (Nhemachena *et al*., 2016), especial due to the programme's reliance on conventional breeding methods. As there is an overlap between the realisations of short to long term research, the peak represents the combined effect of the different types of research. The slow rate of decrease in the magnitude of R&D investment coefficients after the peak in year 13 represents the wearing of effects of short term and medium-term effects research.

As the coefficients of the research investment terms are greater than one from year seven to year twenty, this means peach and nectarine supply is inelastic from year zero to year six, and is elastic from year seven to year twenty. This implies that the investment in research starts to cause a significant increase in the quantity of peach and nectarines produced in the industry seven years after investment. In year twenty-one research investment continues to have a positive influence however the supply is inelastic (unresponsive to R&D investment). This result emphasises the need of continuous investment in research as the benefits of research tend to decay with time. The full decay period could not be determined in this study owing to data limitations.

6.3. Validation of the model

To further ensure the consistency and reliability of the model used in the analysis, four diagnostic tests were conducted. These tested the model for normality of the error terms, autocorrelation in the error terms, autoregressive conditional heteroscedasticity of the error terms and heteroscedasticity. The results of these tests were favourable as they showed that the model was free of autocorrelation, heteroscedasticity and autoregressive conditional heteroscedasticity problems. These tests were run because the supply response function is known to yield biased and inefficient estimates if there is auto-correlation of the error terms in the model and if the model also has a stochastic lagged dependant variable (Kapuya, 2010). As the estimated peach and nectarine supply response model in this study did not use a stochastic dependent variable and is free of auto-correlation (as shown below); the results acquired from this study can be used with confidence as they appear to be reliable and robust.

The results from the diagnostic tests are summarised in Table 2 below.

Table 2: Results from diagnostic tests

Test	Null hypothesis (H_0)	Test Statistic and degrees of freedom	P–Value	Conclusion
Jarque–Bera	Normality	**JB (2) =** 10.74	0.005	Residuals are normally distributed
Breusch–Godfrey LM	No second order correlation in the residuals	**nR^2(2) =** 0.87	0.81	No second order correlation in the residuals
ARCH LM	No 1st order autoregressive conditional heteroscedasticity	**nR^2(1) =** 0.02	0.91	No 1st order autoregressive conditional heteroscedasticity
White	No heteroscedasticity	**nR^2 =** 2.75	0.98	No heteroscedasticity

Source: Author's calculations

6.4. Rate of Return

The MIRR of peach and nectarine research programme was found to be 55.9%. This means that every R100 invested yields a R55.9 increase in value in the industry. This rate of return is relatively high; however, it lies within the expectations as it falls within the range of rate of return findings calculated at research programme level reported by Liebenberg and Kirsten

(2006). Also, according to expectation, it is lower than the rate of return calculated at institutional level which was reported to be 78% by Thirtle *et al.* (1998).

As the MIRR is this high, it can be concluded that investment in agricultural research is worthwhile. This justifies for an increase in research funding. According to Kaliba *et al*. (2007), when a high rate of return of this magnitude is associated with inelastic supply responsiveness, it is an indication of potential underinvestment in R&D. Thus, industry stakeholders from both the public and private sector should increase the funding for the ARC's peach and nectarine research programme.

7. Conclusion and recommendation

The aim of this article was to calculate the rate of return of the ARC's peach and nectarine research programme. This paper makes a unique contribution to the literature of ROR to agricultural research investment as it combines supply response modelling with R&D lag distribution estimation. The results of the study show that investment in the ARC's peach and nectarine research programme has been efficient in its use of financial resources. An MIRR of 55.9% was calculated. This result implies that every R100 that was invested, effect a R55.9 increase in value in the industry. The R&D lag distribution showed that the benefits from R&D investment are spread over about 21 years with 14 years of significant supply response. These high returns make a case for an increment in research funding for ARC peach and nectarine research programme and it is recommended that industry stakeholders renew their commitment and increase their financial allocations in this programme. As the benefits of R&D investment were found to wear away with time, it is recommended that careful planning which provides a consistent investment stream be made to ensure continuity in benefit generation.

The R&D lag distribution also revealed that there was no lead in the lag distribution of R&D investment, and that the investment had long lag effect. This shows that the research programme adequately responds to industry's problems, and the effects of research continue to have a positive effect several years after investment. The continuous distribution of research benefits was made possible by the multi-disciplinary nature of the peach and nectarine research programme. This evidence suggests that investment in a comprehensive programme would be more beneficial than single discipline projects as it will address immediate needs, yield faster returns and have longer lasting benefits. This gives reason for revisions of the current project specific funding model applied by the private sector.

The unresponsiveness of the industry's production to market incentives (prices) shows the necessity for continuous investment in innovation as these growth stimulators have not been found to significantly inspire advances in supply. The study provides evidence that today's R&D investment can indeed have an effect on future production. As shown, today's peach and nectarine production is still benefiting from the research investments made 20 years ago. Therefore, today's investment in R&D can secure the future of the agricultural industry and set a frontier for food production.

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List of references

Alene, A. D., Y. Yigezu, J. Ndjeunga, R. Labarta, R Andrade, A. Diagne, R Muthoni, F. Simtowe, and T. Walker. 2011. "Measuring the effectiveness of agricultural R&D in Sub-Saharan Africa from the perspectives of varietal output and adoption: Initial Results from the Diffusion of Improved Varieties in Africa Project." Paper presented at the ASTI/IFPRI-FARA, Accra, December 5–7.

Alston, J. M., G. W. Norton and P. G. Pardey. 1998. Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Washington: CAB International.

Alston, J. M., M. C. Marra, P. G. Pardey, and T. J. Watt. 2002a. "Research returns redux: a meta-analysis of the returns to agricultural R&D." *The Australian Journal of Resource Economics* 44 (2): 185-215.

Alston, J. M., P. G. Pardey, and V. H. Smith. 2002b. "Financing agricultural R&D in rich countries: What's happening and why." *The Australian Journal of Agricultural and Resource Economics* 42 (1): 51-82.

Anandajayasekeram, P., D. Martella, and M. Rukuni. 1996. A training manual on R&D evaluation and impact assessment of investments in agricultural and natural sciences research. SACCAR: Botswana.

Askari, H., and J. T. Cummings. 1977. "Estimating agricultural supply response with the Nerlove model: Survey." *International Economic Review* 18 (2): 257–92.

Carter, J. 1999. "Estimating the economic rate of return in the South African deciduous fruit industry." Master's diss., University of Stellenbosch.

Dlamini, T. S., and F. G. Liebenberg. 2015. "The aggregate economic benefits of the national cultivar trials for maize in South Africa with specific reference to the highveld region." *Agrekon* 54 (3): 43–61. DOI: 10.1080/03031853.2015.1085228

Doyle, C. J., and M. S. Ridout. 1985. "The impact of scientific research on UK agricultural productivity." *Research Policy* no.14: 109-116.

Evenson, R. E. 1967. "The contribution of agricultural research to production." *Journal of Farm Economics* no. 49: 1415-1425.

Fuglie, K.O., and N. E. Rada. 2013. "Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa." US Department of Agriculture, Economic Research Service, February 2013.

Garnett, A. M., P. E. Lewis, and A. P. Obrian. 2014. *Micro Economics*. Third ed. Melbourne: Pearson.

Gujarati, D., and D. Porter. 2009. *Basic econometrics*. 6th ed. New York: McGraw–Hill, Inc.

Hall, B. H., J. Mairesse and P. Mohnen. 2010. "Measuring the returns to R&D." In Handbook of the Economics of Innovation edited by Hall, B. H., and N. Rosenberg. 1033–1082 New York: Elsevier.

Hurley, T. M., P. G. Pardey, X. Rao, and R. S. Andrade. 2016. "Returns to food and agricultural R&D investments worldwide, 1958-2015." *International Science and Technology Practice and Policy (INSTEPP)*, August 2016. St. Paul, Mini: International Science & Technology Practice & Policy centre,

Kaliba, A., S. Fox, and D. Norman. 2007. "Economic returns from livestock research and development in Tanzania" In *Impact of Science on African Agriculture and Food Security*, edited by Anandajayasekeram, M., S. Sabu, F. G. Liebenberg, and C. L. Keswani. Pretoria: CAB International printers.

Kapuya, T. 2011. "Modelling the impact of the "Fast Track" land reform policy on Zimbabwe's maize sector." Master's Diss. University of Pretoria.

Khatri, Y., C. Thirtle, and J. Van Zyl. 1996. "Public research and development as a Source of Productivity Change in South African Agriculture." *South African Journal of Science* no. 92: 143-50.

Kristjanson, P., S. Tarawali, I. Okike, B. B. Singh, P. K. Thornton, et al. 2002. "Genetically Improved Dual-purpose Cowpea: Assessment of Adoption and Impact in the Dry Savannah of West Africa." Impact Assessment Series No. 9, International Livestock Research Institute, Nairobi.

Leaver, R. 2003. "Measuring the supply response function of tobacco in Zimbabwe." *Agrekon* 43(1):113-131.

Liebenberg, F. and J. F. Kirsten. 2006. "South Africa: Coping with structural changes." In Agricultural R&D in the Developing World: Too little too late? edited by Pardey, P. G., M. Julian, N. Alston, and R. Piggott, Washington D.C: International Food Policy Research Institute.

Liebenberg, F. and P. Pardey. 2011. "South African agricultural R&D: Policies and public institutions, 1880–2007." *Agrekon* 50 (1): 1-15, DOI:10.1080/03031853.2011.56268

Lyname, J., N. Beintema, and I. Annor-Prepong. 2012. "Agricultural R&D Investing in Africa's future. Analysing trends, challenges and opportunities." *Agricultural Science and Technology Indicators (ASTI)* ASTI/IFPRI-FARA Conference outputs. Accessed on 19 December 2017 http://www.asti.cgiar.org/2011conf

Marasas, C. N., J. C. Anandajayasekeram, M. Coetzee, D. Martella, B. J. Pieterse, and C. J. Van Rooyen. 1998. "The future of wildflower research and development in South Africa–The Lachenalia case study." *Agrekon* 37 (4): 588–601.

Maredia, M. K. and D. Raitzer. 2006. "CGIAR and NARS Partner Research in Sub-Saharan Africa: Evidence of Impact to Date." Commissioned Paper, CGIAR Science Council Secretariat: Rome.

Muchapondwa, E. 2009. Supply response of Zimbabwean agriculture: 1970–1999. Accessed 05 October 2016 http://econrsa.org/papers/w_papers/wp90.pdf

Nerlove, M. 1958. *The dynamics of supply: estimation of farmers' response to price*. Baltimore: Johns Hopkins.

Nhemachema, C., F. G. Liebenberg, and J. F. Kirsten. 2016. The evolving landscape of plant breeders' rights. *South African Journal of Science* 112 (3): 1-8. doi.org/10.17159/sajs.2016/20150164

Nieuwoudt, W. L., and T.W. Nieuwoudt. 2004. "The rate of return on R&D in South African sugar industry, 1925–2001." *Agrekon* 43 (3): 265–275.

Pardey, P. G., R. S. Andrade, T. M. Hurley, and F. G. Liebenberg. 2016. "Returns to food and agricultural R&D investments in Sub-Saharan Africa, 1975–2014." *Food Policy* no.65: 1-8. DOI.org/10.1016/j.foodpol.2016.09.009

Pardey, P., J. Roseboom, and N. M. Beintema. 1995. "Investments in African agricultural research. International Food Policy Research Institute (IFPRI)." Environment and Production Technology Division discussion paper No 14.

Pieterse, W. M. 2013. "The South African peach breeding programme: Introducing molecular techniques." *Acta Horticulture* 976 (13): 445–448.

Rao, J. M. 1989. Agricultural supply response: A survey. *Journal of Agricultural Economics* 30 (3): 1-22.

Shoko, R. R., P. Chaminuka and A. Belete. 2016. Estimating the supply response of maize in South Africa: A Nerlovian partial adjustment model approach. *Agrekon* 55 (3): 237-253. DOI: 10.1080/03031853.2016.1203802

Smith, W. J. C., C. Bester, J. P. Human, L. Kotze, W. M. Pieterse, and K. Tobutt. 2012. "The Agricultural Research Council's tree–fruit breeding programs–Where we are going and how we will get there!" Paper presented at the annual HORTGRO Symposium, November 6–9.

Stads, G., and Beintema, N. 2015. "Agricultural R&D Expenditure in Africa: An Analysis of Growth and Volatility." *The European Journal of Development Research* 27 (3): 391–406.

Thirtle, C and P. Bottomley. 1989. "The rate of return to public sector agricultural R&D in the UK, 1965–80." *Applied Economics* no. 21: 1063–1086.

Thirtle, C., R. F. Townsend, J. Amandi, A. Lusigi and J. Van Zyl. 1998. "The rate of return on expenditures of the South African Agricultural Research Council (ARC)." *Agrekon* 37(4): 612–622.

Townsend, R and J. Van Zyl. 1998. "Estimation of the rate of return to wine and grape research technology development expenditure in South Africa." *Agrekon* 37(2): 189–210.

Tsvakirai, C. Z. 2015. "An economic evaluation of South Africa's peach and nectarine research." MSc Agricultural Economics thesis summary, Agricultural Research Council. Available online: http://www.arc.agric.za. [Accessed 01/09/2017]

Utuk, I. O. 2014. "Aggregate Agricultural Output Supply Response in Akwa Ibom State of Nigeria: An Application of the Nerlovian Adjustment Model." *Journal of Agriculture and Veterinary Science* 7(9): 22-33.

Van Zyl, J. 1996. Returns to research on crops, horticulture and livestock in South Africa. Department of sustainable practices, Agricultural Research Council Internal research study. Pretoria.