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Abstract

This study estimates the proportion of dry bean yield increase in South African Agricultural Research Council (ARC) released dry bean cultivars that are attributable to genetic improvements through the ARC breeding program. Using data from 32 test plots across South Africa, the study quantifies the yield and yield variance evolution attributable to the breeding program. In addition, this study calculates the economic benefits to small landholder's attributed to the ARC dry bean breeding program. Results indicated that by releasing modern dry bean cultivars, the ARC dry bean breeding program increased average producer yield by 11.42 kg/ha annually. During the period of 1972 to 2014, the ARC Breeding Program contributed 489.36 kg/ha cumulatively (11.42*42) to dry bean yields solely from genetic improvements, which is equivalent to a 23.15% (489.36/1130.78) increase in producer yields. The benefits associated only with the genetic gains from the breeding program are estimated to be 701.4 million Rand (46.8 million USD) from 1992-2014. Using historic ARC breeding costs the benefit cost ratio was estimated to be 5.67:1. Like every other country in the world South Africa continuously has to battle for agricultural

R&D funds to support programs like ARC whose role is to help small scale producers in Africa. As such, we find the annual genetic gain attributed to the ARC Breeding Program has increased, and the returns to the breeding program continue to play a large role for dry bean farmers and consumers in combating food insecurity.

Key Words: dry beans, breeding program, cost benefit.

Introduction

Dry beans (*Phaseolus vulgaris L.*) are the most highly consumed whole-food legume globally and their increased production is central to ensuring food security for many poor households in Africa and Latin America (Siddiq and Uebersax, 2012; Ron et al., 2015). Dry beans are a great source of protein, contain complex carbohydrates, soluble and insoluble dietary fibers, and have no cholesterol; all of which are important in Sub-Saharan Africa where micronutrient and protein deficiencies are prevalent (DOAFF, 2012). Dry beans, often called the “meat of the poor”, provide micronutrients to over 300 million people in the tropics, and in many areas are the second-most-important source of calories following maize (CGIAR, 2016). Given the large population growth rates in Sub-Saharan Africa, increases in dry bean yields will need to at least equal or surpass that of population growth in order to ensure food and micronutrient security. Breeding programs focused on increasing yields, reducing the cost of production, and maximizing the overall productivity of bean production can help meet the growing demand for food and micro-nutrients in Sub-Saharan Africa. Indeed, the scientific literature is rich on how genetic gains are affected by cereal breeding programs, and especially for their impact on increasing yields (Fischer and Wall, 1976; Feyerherm et al., 1984; Waddington et al., 1986; Brennan, 1989a; Holland and Bingham, 1994; Traxler et al., 1995; Gollin, 2006; Barkley et al., 2008; Nalley et al., 2008; Nalley and

Barkley, 2010); however, the research is sparse on quantifying those same genetic gains caused by bean breeding programs specifically. Accordingly, this kind of void in the research is critical to address given that over 200 million people in Sub-Saharan Africa depend on the common bean as their staple crop, and women, who are the main bean growers, need the surplus grain to sell in local markets (CGIAR, 2016).

Dry beans production in South Africa is conducted by smallholder farmers on farms of less than one hectare in size, and typically the seeds these farmers are able to obtain are of low quality and come from miscellaneous varieties. In terms of consumption in South Africa, in 2010 dry beans accounted for about 80% of total caloric supply provided by Pulses, and an estimated daily per capita caloric supply of 25Kcal (FAOSTAT, 2014).

Although beans have significant nutritional and agronomic value (since they fix nitrogen in the soil in areas where producers cannot afford to purchase external inputs), public funding for bean breeding in Africa has been continuously plagued by inadequate government funding, low numbers of qualified scientific staff, and high turnover of skilled staff due to few professional incentives. These problems combined with civil strife, droughts/floods, and political instability have hindered ongoing bean research for prolonged periods of time (Buruchara et al., 2011). That being said, since the 1980s dry bean yields in South Africa have increased from 984kg/ha in 1972, which was the initial year of the Agricultural Research Council (ARC) breeding program, to 1200/ha in 2013 (see Figure 1) (FAO, 2015). Such a yield increase equates to a 116.17% increase from 1972 to 2014, or a 3.71% increase per year. However, until now these gains have not been disentangled between agronomic and genetic gains, which would aid in understanding the difference between general trends in better agricultural production and those brought about through publically-supported genetic breeding programs.

The growth in South Africa's dry bean production is partially attributable to past investments in dry bean research, specifically the national dry bean breeding program. In South Africa, the ARC is a government institution that conducts agricultural research, develops human capital, and fosters innovation to support and develop the agricultural sector. As a part of its activities, the ARC's Grain Crops Institute has conducted dry bean breeding since the 1970s. Specifically, the dry bean ARC breeding program focuses on two major breeding components: yield enhancement and disease resistance/maintenance (bacterial and fungal). Since the 1970s, the ARC Breeding Program has released 21 varieties of dry beans that are resistant to diseases such as bacterial brown spot [P. syringae pv. Syringae (Pss)], halo blight [Pseudomonas savastanoi pv. Phaseolicola (Psp)], and bacterial blight [Xanthomonas axonopodis pv. phaseoli (Xap)] (See Appendix Table A1). As shown in Figure 1, the slope coefficient on the fitted trend line indicates that since 1972—the first release year of varieties by the ARC— dry bean yields have grown by an average of 11.38kg/ha, which suggests that the program has provided a significant contribution to expanding the capacity of dry bean farmers to increase production.

Like many public breeding institutions (any of the CGIAR centers for example), securing adequate funding to increase variety yields and address ever-evolving diseases is a consistent struggle. With this in mind, funding for the ARC is derived from a number of sources: the South Africa Parliamentary Grant (68%); external income (revenue derived from project contracts, research and development contracts, sale of farm products, and royalty income) (30%); and Other Income (interest received from short-term investments) (2%) (ARC, 2014a). It is estimated that the ARC's outdated infrastructure, capital replacement, and maintenance costs required a capital injection of over R480 million in 2014 (ARC, 2014a). These investments in infrastructure and capital equipment enabled the ARC to continue effectively conducting agricultural research, developing human capital, and fostering innovation to support and develop the agricultural sector; thereby positively contributing to the sustainable growth of the agriculture sector and the economy in South Africa.

In the financial year of 2013-2014, the ARC has managed to perform its functions with the allocated resources, mainly through cost containment and the reprioritization of projects. However, this strategy is not sustainable as it adversely affects the ARC's ability to deliver solutions for ever-changing agriculture development and economic growth (ARC, 2014a). Moreover, though the ARC's bean varieties are growing in popularity (42.43% annually since 1992 (CEC, 2015; FAO, 2015)), its funding has not increased proportionally. Given the fact that the bean breeding program at ARC is publically funded and competes for that funding against other agricultural research programs, an academic study is necessary to illustrate the economic impacts of the ARC Breeding Program, both from a per hectare and an aggregate standpoint. Therefore, this type of study may better inform the government and the taxpayers of South Africa about the ARC Breeding Program's net benefits to consumers and producers. Furthermore, showing the program benefits to its constituents is of upmost importance in maintaining and increasing funding levels.

While most breeding programs typically focus on yield enhancement, targeting a reduction in yield variability in low-income countries may be equally beneficial to both producers and consumers, as it generally reduces price instability within markets (Nalley and Barkley, 2010). Correspondingly, Gollin (2006) highlights three ways for improving yield stability; the first is breeding for improved disease or pest resistance in modern varieties. As increased hectares are planted with these modern varieties, ceteris paribus, yield stability should increase. The second method for improving yield stability is by replacing traditional varieties with higher-yielding modern varieties, which in effect could have lower relative yield variability. Finally, the third way to improve yield stability is by diffusing multiple varieties that differ in their susceptibilities to disease and resistance to pests. Critics of modern varieties have suggested that the yields of these varieties, although higher, vary more across growing seasons than traditional varieties in low-income countries, thereby exposing consumers and producers to greater risks.

To explain further, Timmer (1998) states that food security is a function of many short-term dimensions, and specifically discusses food price stability as one of these factors. Yield stability (or variance reduction) benefits food producers because it reduces the risks they incur in production from season-to-season. This risk reduction leads producers to increase investments in new technologies that are designed to increase overall productivity. Timmer (1998) also found that consumers benefit from stable food prices because they do not face the risk of sudden and sometimes sharp reductions in real income as a result of price shocks. This benefit accrues disproportionately to the poor since they spend a larger portion of their budget on food. Thus, the benefits to the consumer from price stabilization have a significant equity dimension, which can play an important role in poverty alleviation. Ideally, the ARC would like to increase yield and decrease yield variability for the purpose of creating more price stability, which could consequently eliminate some of the factors of consumers' food insecurity.

In light of this, the main objective of this study was to determine the proportion of yield increases of ARC-released dry bean varieties attributable to genetic enhancements and not agronomic management changes between 1982 and 2014, using data from 32 test plots across South Africa. The second aim was to determine whether modern dry bean varieties released by ARC have influenced yield variability in the same time period. In addition to quantifying the evolution of the yields and yield variance from the release of ARC varieties, the third objective of this study was to calculate the economic benefits of the ARC dry bean-breeding program for local South African bean producers.

Prior research on the impacts of bean research (Evenson, 2003; Kalyebara et al., 2008; Larochelle et al., 2016; Johnson, Pachico and Wortman, 2003) tended to look at total (genetic and agronomic) gains and has not disentangled the two. The problem with analyzing total gains is that often a large portion of yield gains is attributed to management practices, thus "inflating" the impact of breeding programs. Furthermore, genetic gains are fluid and should be estimated yearly on the basis of variety and location; while best management practices often provide benefits (such as obtaining a skill or input package) that are uneven. In fact, the Consultative Group in Agricultural Research (CGIAR) stated that through their breeding efforts in low-income countries, high growth rates from varietal/genetic improvement were realized in all crops except beans, suggesting that gains may be a result of management practices as well as genetic enhancements.

For these aforementioned reasons, this study aims to quantify only the genetic gains associated with dry bean research in South Africa. This study is relevant for this reason: if the discounted net benefits of the ARC bean program exceed the costs, then the overall returns from the research would justify public investment in the research. To illustrate, the justification of agricultural research in other low/middle-income countries is an ongoing struggle; so, the more information given to governments, private donors, and public breeders on the impact of breeding, the better each institution is at making informed investment decisions. Moreover, the ARC, whose germplasm is released to help poor producers and consumers, will need to ensure that their modern lines enhance yield potential and lower yield variance to help feed a growing population of consumers. This enhancement will also help small bean producers smooth out revenue streams across time.

Methodology and Data

Data

Dry bean yield data were collected from the ARC dry beans trials, which are conducted annually throughout the dry beans production regions of South Africa—Free State, North West, KwaZulu Natal, Mpumalanga, and Limpopo—from 1982 to 2014. The trials, 2,927 in total, used for this study were conducted on farms located in commercial farmer localities within each region and were cultivated simultaneously with the farming operations of the implementing farmers. Additionally, farmers provided a small portion of land for the purposes of these trials. Regarding planting, the seeds were planted by hand or with planters—recommended spacing for the trials was 750 mm between rows and 75 mm within rows, resulting in about 170,000 seeds/ha. Enough seed for four rows of five meters per plot was supplied for each farmer, and the middle two rows were harvested, leaving the last plant at the end of each row to eliminate any border effects.

The bean ARC Breeding Program concentrates on two main dry bean types: small white canning (SWC) and red speckled (RS). The SWC bean varieties are used for canning purposes and have canning attributes such as: (1) low moisture content of approximately 8% or less, (2) low levels of splitting, not higher than 9%, and (3) a water uptake of an 80% maximum. SWC cultivars have determinate growth (Growth habit I: flowers at the ends of branches, which stops stem growth after flowering). In addition, SWC have upright growth and are usually higher yielding than RS (ARC, 2014b). Comparatively, households throughout South Africa mainly use the RS cultivars to make a variety of dry bean soups, stews, salads, etc. The RS cultivars are relatively softer than SWC and cook in a short period of time (ARC, 2014b). Red speckled cultivars have indeterminate growth and have few short and upright branches. They grow after flowering and are almost always inclined to lodging; hence, they have lower yields than determinate growth cultivars. About 61% of the observations in the dataset are for the red speckled sugar bean type with the remaining 38.74% being for small white canning beans. Cultural practices vary somewhat across production locations, but overall, the trials are conducted under conditions for high yield. Nitrogen, Phosphorus, and Potassium fertilizers are applied to the fields at an average annual rate of 42.30 kg/ha, 22.34 kg/ha, and 18.43 kg/ha, respectively. The average yield by variety and location are presented on Table A2 in the Appendix.

Optimally, weather data (temperature, relative humidity, solar radiation, and vapor pressure deficit) would enter the model, but these data were not available for this dataset.[1] Tack et al. (2015) suggest that in settings where localized weather outcomes are unavailable, common weather shocks across locations can be controlled using trial-year fixed effects. The authors suggest a minimum of 10 years of data before the mean yield estimate reflects a "typical" weather year. This suggestion is similar to the claim made in Lobell et al. (2009) that one must conduct experiments over many years to ensure that the mean yield estimate reflects a typical range of weather variation. As a caveat to this claim, localized weather outcomes could be controlled for if the time series dimension of the data is small. Thus, while actual weather observations are preferred, some of the scientific literature suggests that year and location fixed effects can simulate a "typical" growing year if the dataset is large enough.

Conceptual Framework

The methodology used to calculate the economic benefits of the ARC Breeding Program followed extensive literature on the economic impacts of agricultural research, as summarized by Huffman and Evenson (2006) and Alston et al. (1995). Previous evaluations of agricultural breeding programs are exemplified in the literature (Brennan, 1984; Brennan, 1989a; Barkley et al., 2008; Traxler et al., 1995; Nalley et al., 2008; Maredia et al., 2010). Brennan (1989b) evaluated the impacts of breeding programs at different stages in their lives, which further extended the applications of this type of analysis. With this in mind, our first step in evaluating the economic impact of the ARC Breeding Program was to measure the

[1] Yearly precipitation (total) was available for some years, but was left out of the model due to its non-continuous nature.

proportion of yield increases attributable to genetic improvements, holding all other factors such as agronomic, management practices, and weather constant.

The use of relative yield performance data from test plots implicitly assumes that actual producer yields are equivalent to test plot yields in the trials. Annual changes in relative yields are measured with performance test data, which represent ideal management and agronomic conditions, instead of actual dry bean yield performance. Although a gap between experimental and actual yields exists, Brennan (1984) states that the only reliable sources of relative yields are variety trials. Thus, the absolute yield/yield variance could be higher/lower on test plots and the relative difference should be the same between test plots and producers' fields. The genetic contribution of the ARC Breeding Program was measured by quantifying the increase in yields attributable to genetic enhancements for the period of 1982 to 2014. Subsequently, the yield changes were measured for all varieties released by the ARC Breeding Program. Salmon (1951) reported that tests over many location-years are necessary to accurately detect differences in variety yields. With this in mind, the yield data were aggregated over all locations and years to develop a yield ratio for each variety.

Following Feyerherm et al. (1984), the relative yield ratios were derived by calculating the mean yield ratio between the first released variety (Bonus, released in 1972) and the subsequent varieties, over all location-years. For ease of interpretation, the yield differences were also calculated by subtracting the mean yield (kg/ha) of each variety from that of Bonus. The yield ratio and yield differential provide comparisons of variety performance (Table 1). This table shows that since the release of Bonus in 1972, yields have improved with every newly released variety. The only exception to this are Stomberg, Kranskop, and Teebus RCR2, released in 1990, 1993, and 2005 respectively. The average yield improvement since Bonus is 12.90%. Also, comparing the average annual yields of ARC's varieties to those reported by FAO (2015) from 1972 to 2012 shows an average yield difference of 823.61 kg/ha, equivalent to a 64% yield enhancement annually. While the Feyerherm et. al. (1984) method allows for the estimation of relative yield differences, it does not account for differences in breeding objectives; that is, whether a variety is bred for resistance to a fungus such as the bean common mosaic necrosis virus, or bred for not only maximum yield but yield stability as well. Therefore, to incorporate this objective of yield stability, the Just and Pope (1979) method was applied.

The Just-Pope production function offers flexibility in describing a stochastic technological process that might exhibit changes in the mean and the probability distribution of output. This method provides a straightforward procedure for testing the effects of increased yield on yield stability.[2] Specifically, the Just-Pope production function allows the inputs to affect both the mean and variance of the outputs. The production function is as follows:

$$Y_i = f(\boldsymbol{X}_i, \beta) + h(\boldsymbol{X}, \alpha)\varepsilon_i \qquad (1)$$

where Y_i is yield of the i^{th} variety, $\mathbf{X}_i$ are explanatory variables, β and α are parameter vectors, and ε_i is the customary error term with a mean of zero. The first term—$f(\boldsymbol{X}_i, \beta)$—on the right-hand side of Equation (1) captures other factors affecting the mean output, while the

[2] Another approach to estimation is the Generalized Method of Moments. Although this estimation strategy has its advantages, it requires instruments that are orthogonal to the error term ε_i that we were unable to find.

second term—$h(\boldsymbol{X}, \alpha)\varepsilon_i$—captures factors affecting the output variance (σ_i^2). Since the basis of the Just-Pope production function is that the error term (ε_i) depends on some or all of the explanatory variables, it can be viewed as a multiplicative heteroscedasticity model, which can be estimated using a three-stage procedure. If output variance (σ_i^2) is an exponential function of K explanatory variables, the general model with heteroscedastic errors can be written as:

$$Y_i = X_i'\beta + e_i, \quad (i = 1, 2, \dots, N) \tag{2}$$

$$E(e_i^2) = \sigma_i^2 = exp[X_i'\alpha], \tag{3}$$

where $X_i' = (x_{1i}, x_{2i}, \dots, x_{ki})$ is a row vector of observations on the K independent variables. The vector $\alpha = (\alpha_{1i}, \alpha_{2i}, \dots, \alpha_{ki})$ is of the dimension ($K \times 1$) and represents the unknown coefficients. $E(e_i)$ = 0 and $E(e_i \cdot e_j)$ = 0 for $i \neq j$. Equation (3) is rewritten as:

$$\ln \sigma_i^2 = X_i'\alpha \tag{4}$$

where σ_i^2 is unknown, but the marginal effects of the explanatory variables on the variance of production, using the least squares residuals from Equation (2), can be estimated such that:

$$\ln \hat{e}_i^2 = X_i'\hat{\alpha} + \mu_i \tag{5}$$

where $\hat{e}_i$ are predicted values of e_i from the least squares estimation of Equation (2). The error terms μ_i are calculated by solving Equation (4) and (5) for μ_i. The output variance (σ_i^2) is calculated from the estimation of Equation (5), which provides estimates of:

$$\mu_i \cdot \mu_i = \ln(\hat{e}_i^2 / \sigma_i^2) \tag{6}$$

The predicted values from Equation (5) are used as weights for estimating generalized least squares coefficients for the mean output in Equation (2). That is, the estimates from Equation (5) can be viewed as the effects of the independent variables on yield variability (σ_i^2). The predicted values from Equation (5) are then used as weights when re-estimating Equation (2). Lastly, the results from the re-estimation of Equation (2) with the weights from the error terms of Equation (5) provide the effects of the independent variables on yield.

An advantage of the Just-Pope production function is its correction of multiplicative heteroscedasticity, which is important for varietal traits because of the variations in both of the species (red speckled vs white canning) and in the breeding goals (yield, drought resistance, disease resistance, etc.) across varieties. Notably, the error terms across varieties may be heteroscedastic in nature and as such need to be accounted for since varieties are intended to be grown throughout heterogeneous areas and are specifically bred for resistance to different pathogens and adaptation to various agronomic conditions.

Empirical Model Specification

The mean and variance of yield are specified as a function of the release year (RLYR) of each variety, which can be interpreted as the "vintage" of a breeding technology (Arrow, 1962; Traxler et. al., 1995; Nalley et al., 2008). The coefficient on the RLYR captures the progression of the breeding technology across time and is the main parameter for measuring the impact (yield and yield variance) of the breeding program. However, a distinction exists between RLYR, which varies from 1972 to 2012, and the trial date, which varies from 1990 to 2014. Each variety has a single RLYR, the date that the variety was released to the public for planting, and each one embodies the breeding technology for that specific year. In the estimated multiple regression model, the coefficient on RLYR only captures the effect of dry bean seed technology at the specific year of release. A typical life cycle of a variety is one of relatively higher yields than previously released varieties in the early years of adoption, and then the eventual replacement with yet higher-yielding releases (Nalley et al., 2008).

RLYR is not a time trend variable, but is modeled similarly to the way that Arrow's (1962) growth model showed the embodied technology (Traxler et al., 1995). Specifically, Arrow (1962) assigned "serial numbers" of ordinal magnitude to the embodied technology in capital. In this model, the variable RLYR represents the embodied technology for a given year of release by the breeding program. In addition to the RLYR, the mean and variance of yield were also modeled as a function of whether variety *i* was a red speckled variety (RS), in a particular location ($\boldsymbol{Loc}$), and for a specific growing year ($\boldsymbol{Year}$). Subsequently, the location variables entered the models as dummies: Free State, North West, KwaZulu Natal, Mpumalanga, and Limpopo, with Gauteng acting as the control location. Likewise, growing years were also modeled as dummies with 1981 as the control. The growing year and location fixed effects account for differences in agro-climatic potential and farm structure across time and locations, respectively. Therefore, the estimated models for yield (Y_i) in kg/ha and the log variance of yield ($\hat{e}_i^2$) are:

$$Y_i = \beta_1 RLYR_i + \beta_2 RS + \boldsymbol{\beta_3 Loc_i} + \boldsymbol{\beta_4 Year_t} + e_i \quad (7)$$

$$\ln \hat{e}_i^2 = \delta_1 RLYR_i + \delta_2 Rs + \boldsymbol{\delta_2 Loc_i} + \boldsymbol{\delta_3 Year_t} + \mu_i \quad (8)$$

Results

The results from the Just-Pope model, including the effects on yield and on yield variance as well as the OLS estimates, are shown in Table 2. Additionally, Table 3 presents the coefficients of fixed effects for each growing year included in the models in Table 2. The magnitude of the coefficient of determination (R^2) shows that 23% (6%) of the variation in mean yield (yield variance) is explained by the independent variables in the model. Furthermore, the variable RLYR is the focus in this study, since it captures the "vintage" of each variety, or the level of technology that characterizes each bean variety. The results from the Just-Pope model (Table 2) indicate that from 1982 to 2014, the ARC bean breeding program significantly ($P<0.01$) increased annual average dry bean yields by 11.42 kg/ha, which is equivalent to 1.03% annually (11.42/1130.78, where 1130.78 kg/ha is the average yield for dry beans over the time period under investigation (FAO, 2015)). During the period of 1972 to 2014, the ARC Breeding Program contributed 489.36 kg/ha cumulatively (11.42*42) to dry bean yields, which is equivalent to a 23.15% (489.36/1130.78) increase in producer yields attributed to genetic enhancement from the program.

The aforementioned estimates are in line with the work of Singh et al. (2007) who found that seventy-five years of breeding dry beans in the Western US was associated with a 0.65% gain in yield annually. For similar studies on wheat and rice, Barkley et al. (2008) and Nalley et al. (2008) showed that wheat-breeding programs in Mexico and rice-breeding programs in the US increased yields by 0.46% and 0.42%, respectively. With regard to yield variance, the model shows that, from 1982 to 2014, the varieties released by the ARC Breeding Program experienced no significant ($P>0.05$) change in annual yield variance. Notably, the fact that yield variance does not increase is of importance because it asserts that the yields of ARC-released bean varieties have increased without increasing the risk associated with the yield variance.

Table 4 presents the estimates of the genetic and economic benefits of the ARC Breeding Program for dry bean producers in South Africa, assuming a perfectly elastic demand for dry beans. This is a realistic assumption given that South Africa produces a small portion of the global dry bean supply (FAO, 2015), and the yield increase is a relatively small shift in the total domestic supply, let alone the world supply. Thus, the increased South African dry bean production as a result of genetic improvement does not influence the global price of dry beans. To illustrate, the genetic gains on Table 4 are calculated from the results (RLYR) of the regression model on Table 2. An important feature of the calculation of the genetic gains associated with a breeding program is to take into account the cumulative effects of the program over the entire period. That is, the yield gains attributable to the breeding program in 2014 are those observed in that year and the previous year (2013). Therefore, the genetic gains for 2014 would be the sum of the year-specific genetic gain from 1972–2014. Specifically, the annual and cumulative genetic gains for the ARC Breeding Program are listed in Table 4. Dry bean producers in South Africa received an average annual economic benefit of R 326.25 million (in 2014 terms) from the breeding program during the 1992–2014 period. This benefit is a function of several exogenous factors (acreage, price, adoption rate, etc.) and the endogenous factor of genetic gains attributed to the breeding program. The average economic benefits that South African producers have received this decade (2004–2014) are estimated at R 27.35 million (in 2014 terms) annually.

The benefit cost ratio was estimated to be 5.67:1, using an annual average interest rate on savings of 3.65% (from 2000 to 2012 retrieved from IMF (2015)) as a proxy for a discount rate to calculate the discounted cost and benefits, while also accounting for the 12-year lag between the initial cross and release year. That is, for each South African Rand of public funds invested in the ARC Breeding Program, there are R 5.67 in benefits. Similarly, the calculated benefits for every Rand invested in the ARC Breeding Program are R 9.48 and R 3.16, respectively, using the same assumptions as above, but with minimum and maximum discount rates of 1.27% and 6.46% for the same period.

In the literature, the internal rate of return (IRR) to investments is a measure to gauge research effectiveness. To illustrate, the returns-to-research literature is replete with studies that have assessed both the aggregate investments in agricultural research and the various components of the agricultural system. Researchers have used different methodological approaches to show that the internal rate of return, for the most part, is high for the investments made. The IRR is computed as the discount rate resulting in a value of zero for the net present value. See Alston et al. (2000) and Evenson (2001) for inventories and a meta-analysis of IRRs specifically derived from agricultural research studies. In addition, previous studies estimating the IRR on the expenditures of various components of the ARC, regardless of methodology or the level of aggregation, have shown that the IRRs on investments in research in the production improvement of animals and cereal (maize, sorghum, and wheat) range between 11%-16% and 28%-63%, respectively, per annum (Thirtle et al., 1998). Similarly, Dlamini et al. (2015) showed that the IRR for the ongoing ARC national variety trials for sorghum, sunflower, soybeans and dry beans is 16% per annum. Even more, in the US, Nalley et al. (2008) showed that investments in rice-breeding research is associated with an IRR of 30.9%. As for the analysis of the ARC Breeding Program in this study, the estimated IRR is 12.51%.

According to Hurley et al. (2014), the IRRs reported by a vast majority of studies are perceived by policy-makers to be implausibly high. As such, to obtain more credible rate of return estimates, Hurley et al. (2014) developed the modified internal rate of return (MIRR). The MIRR is interpreted as the annual compounding interest rate paid by an investment and is directly related to the benefit–cost ratio. Hurley et al. (2014) compared the IRR that was reported by 372 separate studies from 1958 to 2011, to each of their counterpart recalibrated MIRR. They showed that MIRR produces a more modest rate of return as compared to those of the IRR (median of 9.8% vs 39% per year). In light of this, computing MIRR for the ARC Breeding Program indicates an 8.92% return in investments. While the calculated IRR and MIRR may seem low relative to the IRRs calculated for other components of the ARC and elsewhere, this is partly due to small area that is sown to beans in South Africa relative to other crops.

The results illustrated above are most likely conservative in that they don’t account for maintenance breeding. Maintenance breeding generally results in pathogen resistance for a crop specimen. Therefore, the most tangible outcome of a breeding program of any type is increased yield. Economists and policy-makers tend to undervalue the productivity losses that can be avoided by utilizing informative agricultural research. Accordingly, the substantial economic benefit that accrues from avoided yield losses through resistance to those pathogens is often forgotten in the cost-benefit analysis of such breeding programs. Previous studies (Marasas et al. 2003) on breeding programs have estimated that the economic impact of a research program’s breeding efforts for pathogen resistance (maintenance breeding) can be as great, if not greater than the impact of increased yields. Previous research (Strass, 1999 and Strauss and Killian, 1996) in South Africa has shown that bean yields can increase by 1.4 to 6.8 times that of an unsprayed rust (caused by Uromy-I ces appendiculatus) susceptible variety when controlled via fungicide or through genetic resistance. Thus, there are large economic gains associated with the ARC bean-breeding program, which do not necessarily increase yield, but maintain yield at its ceiling via pathogen resistance. Notably, this study did not account for the economic impact of the maintenance breeding of the ARC bean-breeding program, nor did it account for the increases in input costs (fungicides, pesticides, insecticides, etc.) that producers would have to incur if the breeding program did not continuously breed for biotic and abiotic stresses.

Conclusion and Implications

South African dry bean farmers who adopted the ARC Breeding Program’s varieties during the period from 1992 to 2014, experienced a yield gain approximately equal to 13%, which can be solely attributed to the genetic advancement from the breeding program. These estimates result in South African dry bean farmers receiving an average annual economic benefit amounting to approximately R 326.25 million (in 2014 terms) for the same period. The benefit-cost-ratio and the IRR provide evidence that the economic rate of return from the ARC Breeding Program is relatively high, although assessing these measures further is difficult without comparable values for other public investments (the opportunity cost of funds).

The most tangible improvements of the ARC Breeding Program are the increased yields, but the substantial economic benefits are also evident in the yield losses avoided through resistance breeding, or ‘‘maintenance breeding.’’ Even though there was no statistical evidence to support the claim that the downward trend in yield variability is attributable to the ARC Breeding Program, there is none to disprove it either. However, this study only valued yield increases and did not attempt to quantify the value of the maintenance breeding, or to monetize the value of decreased yield variability; thus, the benefits estimated to producers in this study are on the conservative side. In other words, without the breeding program, dry bean yields could have remained at their low values in the 1980s, or worse, could have deteriorated and become more unstable as pathogens such as blast and sheath blight may have drastically reduced yield while increasing yield variation as they overcame earlier resistance genes. Furthermore, climate models suggest that by the 2020’s some 3.8 million ha of land suitable for bean production in Africa would benefit from a better drought tolerance package, and 7.2 million ha would benefit from heat tolerance (Buruchara et al., 2011). This observation implies the need for continuous funding in bean breeding for a crop that provides micronutrients to over 300 million people in the tropics.

Holding all other factors constant, the annual genetic gain attributed to the ARC Breeding Program has increased, and the returns to the breeding program continue to play a large role for dry bean farmers in increasing dry bean yields. Given the estimates found in this research, the benefits of the bean-breeding program outweigh the costs by a large multiple, demonstrating that investments in the ARC Breeding Program have provided large and sustained economic benefits to dry bean farmers and consumers in South Africa.

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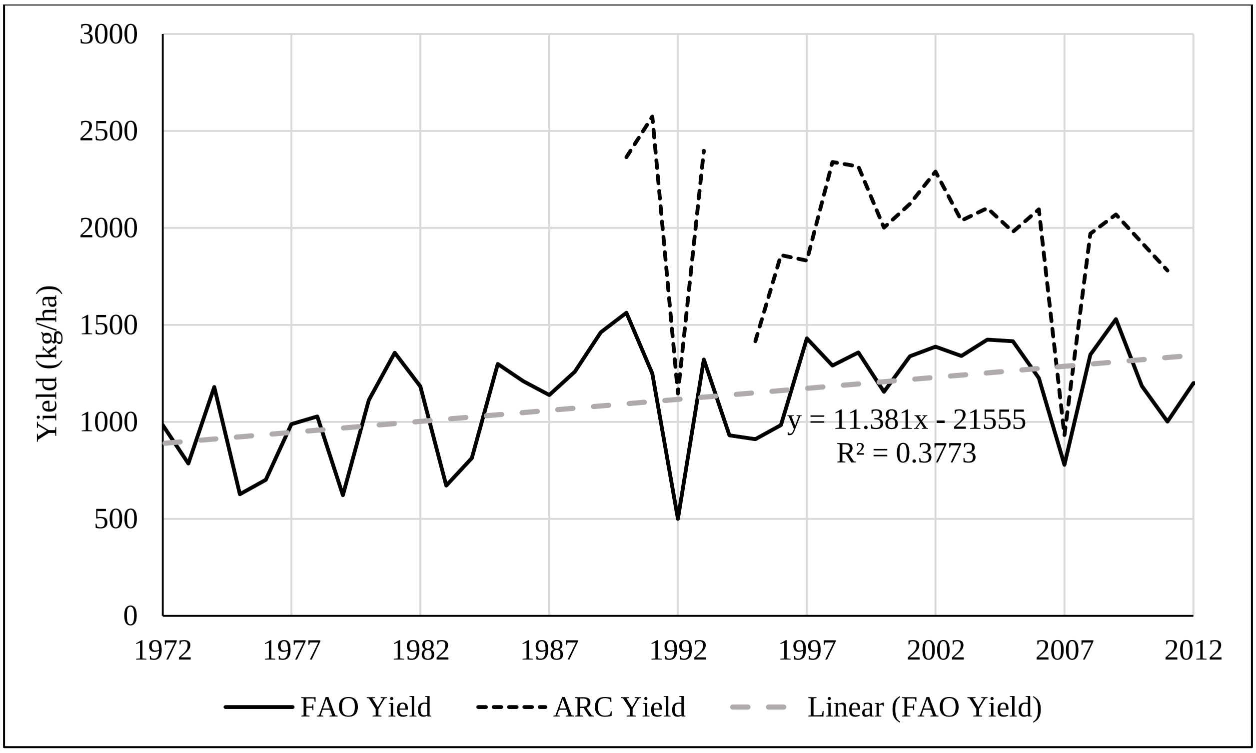
Figures and Tables



Constructed using data retrieved from FAO (2015) and data provided by ARC

Figure 1: Historical dry bean yields (kg/ha) in South Africa

Table 1: Relative yield advantages of ARC's varieties, (1972-2012)

Variety	Average Yield (kg/ha)	Yield Ratio [a]	Yield Difference (kg/ha) [b]	Year Released to Public	Number of Observations	Red Speckled
Bonus	1882.53	-	-	1972	439	Yes
Teebus	2039.64	1.08	157.10	1976	411	No
Kamberg	2351.85	1.25	469.32	1982	230	No
Helderberg	2240.37	1.19	357.84	1990	155	No
Stomberg	1699.50	0.90	-183.04	1990	196	Yes
Kranskop	1874.18	1.00	-8.35	1993	114	Yes
Jenny	1981.14	1.05	98.60	1995	260	Yes
OPS GH1	2441.18	1.30	558.65	1996	51	Yes
OPS RS1	2012.47	1.07	129.94	1996	208	Yes
OPS-KW 1	2014.87	1.07	132.34	1997	157	No
OPS-RS 3	2073.73	1.10	191.19	1999	51	Yes
OPS RS 4	2219.13	1.18	336.60	2001	135	Yes
RS 5	1981.55	1.05	99.02	2002	132	Yes
Teebus RR1	2228.20	1.18	345.67	2002	102	No
Kranskop HR1	2140.92	1.14	258.39	2003	96	Yes
Teebus RCR2	1799.68	0.96	-82.85	2005	53	No
Sederberg	1949.86	1.04	67.32	2006	55	Yes
RS6	2260.00	1.20	377.47	2008	41	No
Tygerberg	2619.75	1.39	737.22	2010	4	Yes
Kamiesberg	2194.71	1.17	312.18	2011	24	Yes
RS 7	2383.79	1.27	501.26	2012	14	Yes

[a] Mean values of the ratio of the yield of each variety to the yield of the control variety (Bonus) for all location years. A larger value indicates a higher yield relative to the control variety.

[b] Calculated by subtracting the mean yield of each variety from the mean yield of the control variety.

Constructed using data provided by ARC.

Table 2: Regression results from OLS and Just Pope production functions

Variable	OLS Yield Model	Just Pope Yield	Just Pope Variance
Intercept	-20787.00 (3486.00)**	-21262.00 (3525.45)***	11.63 (8.39)
RLYR	11.42 (1.74)**	11.65 (1.76)***	0.00 (0.00)
Red Speckled	-155.45 (34.89)**	-156.76 (35.26)***	0.04 (0.08)
Free State	109.59 (48.08)*	111.40 (48.86)*	-0.26 (0.12)*
KwaZulu-Natal	208.41 (47.44)***	204.87 (47.61)***	0.39 (0.11)**
Mpumalanga	262.53 (48.86)**	263.49 (49.42)***	0.05 (0.12)
Limpopo	503.16 (151.03)**	516.82 (144.71)**	0.98 (0.36)**
Adj. R^2	0.23	0.23	0.06

Significance levels: *p<0.1 ** p<0.05, ***p<0.0.

T-statistic are in parenthesis.

Table 3: Year fixed effects regression results from OLS and Just Pope production function

Year	OLS Yield Model	Just Pope Variance	Just Pope Yield	Year	OLS Yield Model	Just Pope Variance	Just Pope Yield
1982	2935.03 (228.89)**	0.36 (0.55)	2954.98 (224.32)***	1999	-13.40 (131.01)	-0.42 (0.32)	1.48 (129.36)
1983	2886.18 (237.25)**	0.67 (0.57)	2903.43 (230.39)***	2000	79.90 (129.50)	-0.41 (0.31)	93.42 (127.71)
1984	-411.75 (198.93)*	-0.63 (0.48)	-392.60 (199.86)*	2001	348.83 (133.74)**	-0.41 (0.32)	367.22 (131.96)**
1985	576.04 (187.49)**	-0.34 (0.45)	590.09 (187.11)**	2002	205.50 (123.95)	-0.56 (0.30)	221.15 (122.31)
1986	198.91 (161.29)	-0.23 (0.39)	212.43 (160.12)	2003	-72.83 (142.52)	-0.59 (0.34)	-54.79 (141.64)
1987	-95.80 (175.17)	-0.98 (0.42)*	-79.25 (176.86)	2004	302.82 (134.47)*	-0.59 (0.32)	326.00 (133.32)*
1988	59.95 (170.06)	-0.69 (0.41)	73.72 (170.52)	2005	79.35 (124.35)	-0.57 (0.30)	99.08 (122.79)
1989	422.92 (166.02)*	-0.24 (0.40)	435.16 (164.43)**	2006	-86.29 (132.38)	-0.33 (0.32)	-75.42 (130.91)
1990	440.13 (161.68)**	0.39 (0.39)	451.46 (158.23)**	2007	-1018.36 (133.31)**	-1.76 (0.32)***	-1002.70 (134.62)***
1991	727.97 (195.03)**	-0.80 (0.47)	745.87 (197.11)**	2008	-71.10 (139.71)	-0.83 (0.34)*	-59.42 (139.27)
1992	-694.85 (162.70)***	-0.79 (0.39)*	-672.10 (163.10)***	2009	-47.12 (167.92)	-0.37 (0.40)	-39.57 (166.98)
1993	258.25 (131.32)*	-0.48 (0.32)	269.76 (129.80)*	2010	4.85 (154.28)	-1.22 (0.37)**	26.60 (155.81)
1995	-611.21 (139.26)**	-0.94 (0.34)**	-593.89 (138.87)***	2011	-256.01 (144.57)	0.10 (0.35)	-232.76 (141.43)
1996	165.09 (133.40)	-0.07 (0.32)	174.28 (131.23)	2013	408.10 (140.62)**	0.45 (0.34)	435.40 (136.54)**
1997	-198.14 (135.86)	-1.41 (0.33)***	-180.23 (136.29)				
1998	48.52 (133.70)	-0.52 (0.32)	60.94 (132.38)				

Significance levels: *p<0.1 ** p<0.05, ***p<0.0.

T-statistic are in parenthesis.

Table 4: Per hectare cumulative genetic gains associated to the *ARC dry beans breeding program*, (1972-2012)

Year	Cumulative genetic gain (kg/ha)	Hectares of Beans in South Africa	Adoption rates (%)	Additional Production (kg)	Real price (R/kg) (2014 = 100)	Additional Gains (R/year)
1992	233.03	53,594	4.60	574,488	7.20	4,136,831
1993	244.68	46,888	6.10	699,822	6.36	4,447,699
1994	256.33	54,500	8.03	1,121,789	6.09	6,837,255
1995	267.98	59,052	3.20	506,395	7.69	3,893,424
1996	279.63	56,431	7.41	1,169,294	6.83	7,991,257
1997	291.28	47,000	8.40	1,149,989	6.77	7,789,147
1998	302.94	38,805	9.45	1,110,886	7.17	7,961,207
1999	314.59	64,800	18.77	3,826,762	7.51	28,744,495
2000	326.24	71,800	14.18	3,321,125	7.04	23,384,359
2001	337.89	77,950	12.87	3,389,502	5.79	19,625,374
2002	349.54	44,900	14.10	2,212,547	8.59	19,000,444
2003	361.19	51,010	20.56	3,787,752	7.62	28,860,206
2004	372.84	56,200	7.23	1,513,912	6.25	9,460,996
2005	384.49	49,300	9.09	1,723,064	5.37	9,246,879
2006	396.15	54,880	4.27	928,320	7.28	6,758,188
2007	407.80	50,725	35.78	7,401,284	9.91	73,373,670
2008	419.45	43,800	30.00	5,511,559	10.26	56,528,963
2009	431.10	43,800	29.30	5,532,483	8.27	45,733,008
2010	442.75	44,100	23.70	4,627,508	8.01	37,087,298
2011	454.40	41,900	29.20	5,559,530	8.03	44,629,571
2012	466.05	39,750	30.70	5,687,378	11.46	65,175,438
2013	477.71	43,550	28.70	5,970,773	12.79	76,362,139
2014	489.36	55,820	35.90	9,806,413	12.58	123,324,068

Constructed using data provided by ARC and release year estimate from Table 2.

Appendix

Table A1: Characteristics of the most important varieties released by ARC-Grain Crops Institute

Variety	% Yield Increase	Bean common mosaic necrosis virus	Rust	Angular leaf spot disease	Halo blight disease	Common bacterial blight
Large seeded (red speckled sugar)						
Bonus (SA) (standard)	0	S	S	S	S	S
Kranskop	5-8	R	I	S	S	S
Kranskop-HR 1	14-26	R	I	I-S	R	S
OPS-RS 1	12	R	I	S	S	S
Werna*	27*	R	R-I	R	S	R
OPS-RS 2	0-5	R	I	S	S	S
OPS-RS 4	22-27	R	I	I	S	S
OPS-RS 5	7	S	I	S	S	S
OPS-RS 6	18	R	I	S	S	S
Jenny	11-16	R	I	S	S	S
Sederberg	14-24	R	R	R	S	S
Tygerberg*	33*	R	R	R	S	S
Small seeded (small white canning and carioca)						
Teebus (standard)	0	R	S	R-I	I	S
Kamberg**	<25**	R	R	R	I	S
Helderberg**	<29**	R	R	R	I	S
OPS-KW 1	11-17	R	R	R	I	S
Teebus-RR 1	19-30	R	R	R-I	I	S
Teebus-RCR 2	20	R	R	R-I	I	R
CAR-2008	21*	R	R	R	I	I

I-S – Intermediate susceptible; R-I – Intermediate resistant; S– Susceptible; I – Intermediate

Constructed using data provided by ARC.

Table A2: Average yield by variety and location

Variety	Bean type	Year Released to Public	Average Yield (kg/ha)					Yield Ratio [a]					Number of Observations				
			FS	NW	KZN	MP	LP	FS	NW	KZN	MP	LP	FS	NW	KZN	MP	LP
Bonus	Red speckled	1972	1989.50	1963.74	1500.26	2087.19	1524.50	-	-	-	-	-	111	113	107	104	4
Teebus	Small white canning	1976	2066.75	2101.28	1719.83	2288.00	2262.25	1.04	1.07	1.15	1.10	1.48	101	110	104	92	4
Kamberg	Small white canning	1982	2121.93	2576.61	2079.26	2580.81	2301.00	1.07	1.31	1.39	1.24	1.51	55	67	53	53	2
Helderberg	Small white canning	1990	1924.54	2399.06	2278.06	2282.56	-	0.97	1.22	1.52	1.09	-	28	32	54	41	0
Stomberg	Red speckled	1990	1799.46	1830.23	1455.78	1851.02	-	0.90	0.93	0.97	0.89	-	37	44	68	47	0
Kranskop	Red speckled	1993	1837.92	1434.65	2342.78	1709.79	2027.20	0.92	0.73	1.56	0.82	1.33	37	17	27	28	5
jenny	Red speckled	1995	1902.66	1795.84	2162.56	1933.86	2944.67	0.96	0.91	1.44	0.93	1.93	61	55	82	59	3
OPS GH1	Red speckled	1996	2242.44	2520.62	2515.40	2413.69	-	1.13	1.28	1.68	1.16	-	9	13	15	13	0
OPS RS1	Red speckled	1996	1942.44	1753.51	2248.13	2019.82	2949.00	0.98	0.89	1.50	0.97	1.93	50	47	61	49	1
OPS-KW 1	Small white canning	1997	1818.08	1829.17	2551.82	2126.90	-	0.91	0.93	1.70	1.02	-	38	35	44	40	0
OPS-RS 3	Red speckled	1999	1995.00	2429.56	1903.76	2150.38	-	1.00	1.24	1.27	1.03	-	8	9	21	13	0
OPS RS 4	Red speckled	2001	2103.78	1593.93	2868.05	2055.07	2655.00	1.06	0.81	1.91	0.98	1.74	37	29	40	27	2
RS 5	Red speckled	2002	1917.25	1368.71	2451.14	1823.26	3350.20	0.96	0.70	1.63	0.87	2.20	36	28	36	27	5
Teebus RR1	Small white canning	2002	2169.36	1554.81	2984.74	1986.08	2814.50	1.09	0.79	1.99	0.95	1.85	28	21	27	24	2
Kranskop HR1	Red speckled	2003	2136.30	1507.94	2539.74	2022.85	2760.67	1.07	0.77	1.69	0.97	1.81	30	16	27	20	3
Teebus	Small	200	178	147	244	162	-	0.	0.	1.	0.	-	1	1	10	1	0

RCR2	white canning	5	8.76	2.00	7.20	0.67		90	75	63	78		7	1		5	
Sederberg	Red speckled	2006	1833.39	1337.70	2491.21	1945.00	2296.00	0.92	0.68	1.66	0.93	1.51	18	10	14	11	2
RS 6	Small white canning	2008	2147.73	1522.67	2516.88	2069.40	3094.00	1.08	0.78	1.68	0.99	2.03	11	6	16	5	3
Tygerberg	Red speckled	2010	2212.50	-	3027.00	-	-	1.11	-	2.02	-	-	2	0	2	0	0
Kamiesberg	Red speckled	2011	2130.50	1009.75	2545.67	2018.00	2764.00	1.07	0.51	1.70	0.97	1.81	4	4	12	2	2
RS 7	Red speckled	2012	2284.50	1196.50	2735.00	3273.00	1258.00	1.15	0.61	1.82	1.57	0.83	2	2	8	1	1

Location; FS = Free State; NW = North West; KZN = KwaZulu Natal; MP = Mpumalanga; LP = Limpopo

[a] Mean values of the ratio of the yield of each variety to the yield of the control variety (Bonus) for all location years. A larger value indicates a higher yield relative to the control variety

Constructed using data provided by ARC.