Assessing the Benefits of Virginia Tech Agricultural Programs: Studies in Feeder Cattle Certification and Small Grains Breeding

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ABSTRACT

This thesis consists of two research papers, each of which studies the benefits from a different College of Agriculture and Life Sciences (CALS) program. These analyses provide necessary information to allocate resources efficiently among programs.

The first paper studies the Virginia Quality Assured feeder cattle certification program and its effects on feeder cattle prices and profitability. No significant effect on price from VQA certification is found. However, enterprise budgets indicate that VQA cattle allow higher farm profits due to their lower sale weight, which allows for faster turnover and lower prices.

The second paper studies the benefits to producers from wheat and barley breeding conducted by Virginia Tech researchers. Variety trial data are combined with acreage estimates constructed from royalty data to estimate gains from replacement of old varieties with new ones. The study finds that the program generated benefits to producers of over $119 million between 2000 and 2018.

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GENERAL AUDIENCE ABSTRACT

This thesis contains two papers that assessed the benefits of two agricultural research and extension programs at Virginia Tech.

The first paper studies the Virginia Quality Assured certification program. This program certifies cattle that have been raised following practices that are designed to result in cattle that will grow faster and stay healthier in a feedlot. Statistical analysis of cattle sold through a Virginia telephone auction show that VQA certified cattle do not receive higher prices than uncertified cattle, but the analysis also finds that certified and uncertified cattle have important physical differences, including lighter weights for certified cattle. These lighter weights make it possible for farmers to sell more VQA cattle in a year because they spend less time gaining weight before being sold, giving producers of VQA cattle the opportunity for higher profits per year.

The second paper studies the benefits to farmers from wheat and barley breeding by Virginia Tech researchers. Field trials are used to compare the yields of old and new varieties, and acreage estimates are used to show how newer varieties replace older ones in farmers' fields. The study finds that economic benefits to farmers from new varieties released by the program total $119 million from 2000 to 2018.

DEDICATION

This thesis is dedicated to my parents, without whom none of this would have been possible, and to my high school agriculture teacher Eric Stogdale, without whom I never would have considered a career in agricultural economics.

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Table of Contents

Chapter I: Introduction

This thesis describes and measures benefits generated by two programs in the College of Agriculture and Life Sciences at Virginia Tech. This research is part of a multi-year series of impact assessment research studies of College programs intended to help the College effectively allocate resources. This research provides a nuanced picture of the benefits of College programs, and how those benefits are created, the people to whom they accrue, and factors enhancing or impeding their success. The first study suggests that the Virginia Quality Assured feeder cattle program does not lead to a statistically significant increase in price for certified cattle. However, because certified cattle have lower sale weights, the program may yield benefits to producers by allowing them to produce more cattle in a year, leading to higher annual profits. The second paper studies the small grains breeding program at Virginia Tech. This program is found to generate $119 million in benefits to Virginia and other states from 2000 to 2018.

Land-grant universities have the public benefit at the core of their identity. When the land-grant university system was established by the Morrill Act of 1862 and historically Black land-grant universities were established by the Morrill Act of 1890, their core mission was to make knowledge accessible to the general public via education. The Hatch Act of 1887 expanded this mission to include agricultural research, and the Smith-Lever Act of 1914 created the extension system required to connect the public with this new knowledge that was being created on their behalf. Although the purview of land-grant universities has expanded beyond their agricultural and mechanical roots and their relationship with the public (specifically in terms of funding) has evolved, these institutions still define themselves in terms of their mission to improve public well-being.

Universities, like any other human enterprise, operate under conditions of scarcity, facing fundamental questions of how to allocate resources. The money and labor available to a university are finite; universities question which programs deserve more or less money and labor, which deserve none at all, and how to increase the pool of resources available. If all universities were solely beholden to a profit motive in the same way that economic thought describes most businesses, this would be a simple mathematical question of profit maximization based on program revenues and costs. For public programs, however, where funding support or program revenues are not always directly linked to the benefits of the program, the resource allocation question is more complicated.

In order to allocate resources effectively and to increase the resource pool available (either by strategic application of existing resources or by appeals to outside sources such as the public, grants, or legislators), universities must be able to effectively evaluate and understand the programs at hand. Applied economic analysis of these programs and their impacts is a useful tool for evaluation, particularly where optimal allocation of scarce resources is a major concern.

Two programs are studied. The Virginia Quality Assured feeder cattle certification program focuses on shaping the way people think and act. This program uses education in an attempt to change the way feeder cattle producers raise their animals, using a certification program to change perceptions and market behavior of feeder cattle buyers. These practices are intended to produce cattle that will stay healthier and gain weight faster during finishing, which should increase the price feedlot operators are willing to pay for them.

This study departs from prior research in the way it defines benefits. Most studies focus only on the price effects of traits or certifications; if a certification increases the price received for an animal, it is considered successful. However, this assumption is not necessarily consistent with economic theory. Producers usually maximize utility by maximizing profit, not by maximizing price, and an increase in price does not necessarily translate into an increase in profits. In fact, in the case of preconditioning programs like VQA, practices used to increase prices, like vaccinations or better nutrition at certain growth stages, may also increase costs. In these cases, using price increases as the estimate of benefits to farmers risks overestimating benefits, and depending on the costs of participation, certified cattle could even be less profitable in some cases than uncertified cattle. Thus, profit itself is used to estimate benefits from the VQA program.

This study focuses on specific cattle characteristics and using enterprise budgets to model producer profitability. VQA certification and other feeder cattle characteristics were regressed on price to find the price premiums or discounts associated with each characteristic. Certification was found to have a positive, but not statistically significant, effect on price. Other cattle and lot characteristics were found to have important and statistically significant effects on price. The most important factor was the average weight of a lot of cattle, with lighter cattle receiving higher prices. *t*-tests were used to evaluate differences in physical characteristics between the two groups. The most dramatic difference was that of weight, with certified cattle being sold at much lighter weights than uncertified cattle. An enterprise budget comparing the certified and uncertified cattle found that, at similar rates of weight gain, this lower weight required VQA cattle to stay on the farm for shorter periods prior to sale, possibly even allowing producers of VQA cattle to sell more cattle in a year due to reduced pasture requirements.

The inclusion of enterprise budgets shifts the analysis from price per hundredweight to profit per head to profit per year for entire farms. Not only does this approach do more to consider farmers, it also presents more accurate information. Instead of presenting higher prices as benefits for the program, which fails to account for increased costs, putting benefits in terms of farm profits provides a measure that is directly relevant to farmers.

The second program studied here is Virginia Tech's small grains breeding program. Rather than changing the behavior or perceptions of individuals, this program produces new agricultural technologies in the form of improved wheat and barley varieties. The study finds that public and exclusive varieties released by the program were responsible for $119 million in benefits to farmers from 2000 to 2018, most of which came from public varieties. However, exclusive varieties (see definition below) were responsible for most of the $10.4 million in royalty payments received for wheat and barley varieties over the same period. Although benefits are the primary focus of the analysis, the study also acknowledges that royalties and other revenues can be important considerations when allocating resources to programs.

Little work has been done to analyze the benefits of small grains breeding programs within the United States. Additionally, as copyright laws governing plant germplasm have changed over the past few decades, the number of breeders working in the public sector has declined, as has the scope of the programs. This paper adopts a flexible framework from international study of plant breeding programs to show the importance of the Virginia Tech breeding program. This study uses field trial data and royalty reports by variety to estimate both yield gains and adoption for varieties released by the program. By comparing changes in varietal adoption and average yields over time, gains in production attributable to the program were estimated.

The paper focuses on two types of varieties released by the program: public and exclusive. Public varieties are released by the University in partnership with the Virginia Crop Improvement Association and are available at a lower cost to growers than private varieties.

Exclusive varieties are developed at Virginia Tech and then licensed to a private entity, who distributes the seed and makes royalty payments to the University. Exclusive varieties exhibit lower yield gains, so they generate lower benefits than public varieties, but they generate higher royalties, providing more funding support for the breeding program. Both public and exclusive varieties are marketed all over the United States, and some are marketed in Canada.

Although public varieties provide greater benefits to farmers, revenues from exclusive varieties can be an important source of support for work on both public and exclusive varieties. In this way, the paper illustrates the fine line that programs must walk between producing public benefits and securing funding support. Although breeders at land-grant universities are part of an enterprise intended to benefit the public, it would be naïve to think of them as being free from considerations of funding and revenue; indeed, the resources available to them influence the impact that they can have.

The thesis is structured as follows. Chapter 2 presents the study of the VQA program, focusing on direct price effects and producer profitability. Chapter 3 presents the study of small grains breeding at Virginia Tech, with a focus on the relationship between public and exclusively licensed varieties. Chapter 4 concludes the thesis by describing the main implications of this research and suggesting avenues for future study.

Chapter II: Beef and the Bottom Line: The Effect of Value-Added Certification on Feeder Cattle Profitability

Abstract

Data from 1,422 feeder cattle teleauction lots were used to assess the impacts on profitability of the Virginia Quality Assured (VQA) feeder cattle program. The analysis finds higher profits for VQA cattle due to their faster turnover and lower feed costs; however, certification does not have a significant effect on price. Our analysis suggests that the cost side should be studied alongside the price effects studied in previous literature.

JEL Classifications: Q13, Q12, M31

Introduction

Value-added certifications have become a ubiquitous part of today's agricultural markets. Consumers use and interpret these certifications on trips to the grocery store. A carrot bearing a USDA Certified Organic label is priced higher than a carrot without such a label, even if both carrots are otherwise identical, were grown using identical practices, and were picked within inches of each other. The use of consumer-oriented product certification is familiar to most people. Because high-quality price data is often widely available in the United States, studies on certification programs in a domestic context often rely on certification premiums to discuss the benefits of these programs (Spalding and Sexton 2019).

The role of value-added certification is less clear lower in the value chain. Because additional inputs must be added and additional risk must be assumed to turn an intermediate input into a finished product, the value of certification for these intermediate inputs is uncertain. Sometimes the certification has value that is easily transmitted down the value chain, as with organic certification, and sometimes the story is more complicated. In the feeder cattle industry, where buyers representing feedlot operators must interpret large amounts of information to make decisions quickly about the expected profitability of a large group of cattle, transmission of certification value is indirect. While feedlot operators seek cattle with characteristics that will maximize profit, feeder cattle producers do the same, leading to a complex relationship between cost and quality in feeder cattle markets.

We analyze the Virginia Quality Assured (VQA) feeder cattle certification to assess the value it adds for feeder cattle producers. Regression analysis is used to determine the effect of VQA certification and other lot characteristics on feeder cattle prices in the Virginia Cattlemen's Association Tel-O-Auction. Certified cattle receive higher prices than uncertified cattle, but the role of the certification itself is unclear as other lot factors also affect prices. There is clear evidence of physical differences between certified and uncertified feeder cattle, and these physical differences create significant price effects.

We use these physical differences to construct enterprise budgets comparing the profitability of certified and uncertified cattle. Although their lower sale weight makes VQA cattle less profitable on a per-head basis, their higher price per hundredweight and faster turnover make them 77.7% more profitable on an annual per-acre basis. This increased profitability depends on production practices rather than on certification status, but increased profitability is a strong incentive for producer participation in the VQA program.

Previous research on value-added characteristics and certifications in feeder cattle markets have shown that these practices can carry statistically significant price premiums. However, these studies fail to analyze the profitability of such practices, even though profitability is generally of greater importance to producers than price.

This study focuses on producer profitability in addition to prices received by feeder cattle producers. It combines regression analysis and enterprise budgets to assess the benefits of feeder cattle certification, even where identification of specific producers is not possible.

Background

In an era of increased scrutiny of public funds used for agricultural extension (Coppess et al. 2018), programs such as VQA need evidence of their economic benefits, even though increased extension funding has been shown to improve both farmer net returns and the number of farmers retained in the industry (Goetz and Davlasheridze 2017). For public investment in the VQA program to be considered socially beneficial, evidence is needed that the value it provides exceeds its costs. This study aims to provide policymakers with a comprehensive estimate of program benefits to be compared with program expenditures.

The value of farmgate sales of cattle and calves was nearly $700 million in Virginia in 2017 (USDA NASS 2019), and feeder cattle form an important segment of that market. Buyers in feeder cattle markets look for animals that will provide the largest profit margin. Characteristics that buyers seek are those that will maximize feedlot performance, meaning that the market value of feeder cattle is tied to the expected value of weight gained in the feedlot. Steers are generally preferred to heifers in a feedlot, as they are thought to gain muscle faster (Rutherford 2009). Lighter animals are also preferred because their marginal weight gain per unit of feed will be greater than heavier animals with similar genetics (Rutherford 2009).

Prior research on the impact of feeder cattle certifications and value-added characteristics has focused on price premia resulting from certification. Schroeder et al. (1988) examined the value of various feeder cattle characteristics. They noted that, because feeder cattle are an intermediate input in the production of fat cattle, prices for feeder cattle characteristics were based on their expected value to feedlot operators (Schroeder et al. 1988). Turner, McKissick, and Dykes (1993) applied the same conceptual framework to feeder cattle teleauctions and prices in Georgia. They found higher prices for cattle that had undergone health treatments or weaning, which are fundamental practices in most modern value-added preconditioning programs such as VQA, but did not find a significant effect for preconditioning itself (Turner, McKissick and Dykes 1993). In a study of value-added practices in calf sales, Zimmerman et al. (2012) found that preconditioning and health programs (similar to VQA protocols) were associated with premiums of $3 to $5 per cwt when controlling for other factors, but traditional price determinants such as weight and frame size remained major influencing factors. Williams et al.

(2012), in a study of premiums from the Oklahoma Quality Beef Network (OQBN) state feeder cattle certification program, found that certified cattle received an average of $6/cwt more than their uncertified counterparts without controlling for other factors. They also noted that lighter cattle received higher premiums for OQBN certification, as well as higher prices overall.

Williams et al. (2014a, 2014b) have discussed the appropriateness of using propensity score matching to study participation in feeder cattle certification programs (Williams et al. 2014a) and net returns to value-added practices that make up many preconditioning programs (Williams et al. 2014b). However, this approach works better when certification status is randomly distributed and lots are generally marketed by one producer, making identification easier.

Research on certification programs internationally, where reliable price data may be more difficult to obtain from a central source, uses producer surveys to study the effects of certification on household income. This is evident in recent research on value-added and fair trade certifications dealing with black pepper (Parvathi and Waibel 2015) and coffee production (Astuti et al. 2015; Jena and Grote 2017). This approaches the issue of profitability more directly as a survey can measure inputs and their costs, but producer surveys are generally more time- and resource-intensive to conduct than studies using market data. This makes them less attractive to researchers working in the United States, where market data is relatively easy to obtain.

The VQA Program

The VQA program combines producer education and verification of best management practices with the intention of improving the quality of Virginia feeder cattle. For cattle to be eligible for VQA certification, producers must participate in the Beef Quality Assurance (BQA) program (Greiner, McKinnon and Hall 2003), a beef producer certification program that focuses on the proper handling and husbandry of beef cattle. Specific topics include proper vaccination, optimal feeding and watering, and transportation of livestock, among others (Osborne and Hockenberry 2010).

Following training, participants become eligible for VQA certification. Although the BQA certification is a prerequisite for entry into the program, it certifies the producers, whereas the VQA certification focuses on the characteristics of the cattle. Cattle can be certified at the Gold Tag or Purple Tag levels, signified by ear tags of the corresponding color. A Gold Tag certified animal must have received a panel of vaccines at least two weeks prior to the sale date, have been owned by the seller for at least 60 days, and weigh at least 400 pounds.[1] Purple Tag certified cattle must meet the requirements of the Gold Tag program and be sired by bulls expected to pass on above-average yearling weight characteristics. Cattle in both programs may also have a “W” on their ear tag, signifying that they have been weaned for at least 30 days and are trained to eat from feed and water troughs prior to the sale. All standards must be certified by a registered third party, usually veterinarians or Virginia Cooperative Extension agents (McKinnon 1998). The intended result is an animal that, due to better handling and genetics, will remain healthier and gain weight faster at the feedlot. If this expectation of better health and increased weight gain is held by buyers as well, then VQA certification would be expected to result in higher sale prices for feeder cattle.

[1] Most cattle sales use the hundredweight (cwt) as a unit of weight somewhat interchangeably with pounds. For instance, prices will often be listed in terms of dollars per cwt, whereas average weights are often listed in pounds. Both appear in this paper.

Model, Methods, and Data

Conceptual Model

Feeder cattle producers are assumed to maximize expected profit across their operation. They choose the bundle of characteristics possessed by the cattle, how long the cattle should be fed, and how many cattle should be produced (determined by the number of batches produced and the number of cattle in a batch). For each animal i, expected profit $E(\pi_i)$ is determined as follows:

$$\textbf{(1)}\ \boldsymbol{E(\pi_i) = E(P_i(w_i(f), H_i))w_i(f) - E(C_i(f, H_i))}$$

where P_i is the price received per pound as a function of the weight and characteristics of the animal, w_i is the weight of the animal in pounds as a function of time on feed, H_i is a selection of characteristics possessed by the animal (such as VQA certification or sex of the animal) and C_i is the cost of producing the animal as a function of time on feed and its characteristics. The first term is the expected revenue for the animal. Producers choose the final weight of the animal by varying the amount of time on feed (f), and they also choose the animals' characteristics by changing production practices or pursuing value-added certifications. The cattle included in the dataset represent a mix of calves being sold as feeder cattle (generally weighing around 400–599 lbs.) and stocker cattle (above 600 lbs.). Stocker cattle are generally fed on pasture prior to sale (referred to as "backgrounding" or "stockering") to allow them to gain weight cheaply prior to entering the feedlot.

Annual farm profits may be specified as

$$\textbf{(2)}\ \boldsymbol{\pi_j = \textstyle\sum_1^q \pi_i}\ \ s.t.\ \ \boldsymbol{q = nb};\ \boldsymbol{n \leq (\tfrac{A}{s})};\ \ \boldsymbol{b \leq \tfrac{D}{f}}$$

where π_y is the farm's annual profit, q is the number of head produced in that year, n is the number of cattle in a batch, b is the number of batches produced in a year, A is the total acreage available to the farm, and s represents acres required per animal. D is the number of days in the production season, and f is the number of days on feed from equation 1. This equation introduces n and b as new choice variables, while A, s, and D are given. The total number of head produced in a year (q) is dependent on the stocking rate of the animals, the time animals spend on feed, and the length of the growing season. The acreage constraint shows that a farm cannot produce more cattle in a year than their space allows. To produce more cattle, farms can expand (increase A by renting or buying more land) or reduce the acreage requirement per head (s), such as by using more intensive (but more expensive) grazing practices. The batch constraint shows that producers cannot replace the current batch of animals with a new batch if there is not sufficient time left in the season.

Keeping cattle on feed for a longer period entails an opportunity cost of replacing them with newer, younger animals (Burt 1993). This opportunity cost influences the producer's selection of an optimal sale weight. If producers keep an animal on feed for too long, they will run out of time to replace it with a new animal. In Virginia, producers can produce up to two batches of animals, i.e., $b \in \{1,2\}$. We assume that producers will choose how many batches to produce at the beginning of the year, influencing their choice of f. Although producers may sell cattle slightly earlier or later to take advantage of short-term price movements, f will primarily be based on the number of batches produced, which will itself be based on the long-term price expectations of producers. Because all Virginia cattle producers are subject to a similar length of grazing season, most farmers have the same ability to produce up to two batches.[2]

Feeder cattle prices are determined by their expected profitability in a feedlot operation. Prices for feeder cattle and other intermediate inputs are the sum of the marginal values of each input's characteristics to the buyer (Ladd and Martin 1976). This allows us to explicitly estimate the price term in equation 1. Following Schroeder et al. (1988),

$$(3)\ \boldsymbol{P_{kt}} = \sum_{t} \boldsymbol{V_{klt} H_{klt}} + \sum_{h} \boldsymbol{R_{ht} M_{ht}}$$

where P reflects market prices for the kth lot at time t and is a function of characteristics (H) and market forces (M) subject to the values of those characteristics (V) and the price effects of those market forces (R), where l refers to each specific characteristic and h refers to the influence of the market. The coefficients in the model provide the value of each characteristic, from physical attributes (including weight) to certifications. In this specification, VQA certification would be included as a characteristic and its premium would be included as a value. Feeder cattle producers will pursue certification for a given feeder if it increases expected profit. However, feeder cattle producers may also pursue attributes normally associated with VQA-certified cattle, such as vaccination or weaning, without actually certifying the cattle.

Data Description

In most in-person livestock markets, buyers rely heavily on visual assessment to infer the quality of the animals in the lot. Animal size, condition, and lot uniformity can be assessed rapidly, with

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[2] One possible exception to this is that cow-calf producers may find it more difficult to produce a second batch of feeder cattle compared to producers who simply purchase their calves for stocking, as cow-calf producers would need to continue to pasture their brood cows.

buyers making quick decisions about bidding. In a teleauction setting, bills of sale containing a variety of information about each lot are published ahead of the sale so that buyers can make decisions in advance about which lots to bid on. This information provides the lot characteristics included in vector H in equation 3. A description of variables is presented in Table 1, and summary statistics are presented in Table 2.

The data are obtained from the bills of sale for the Virginia Cattlemen's Association (VCA) Tel-O-Auction from January 2013 to August 2019. The lots included in this dataset cover a geographical area representing most of Virginia's beef-producing regions, which are concentrated in the western part of the state. Fourteen of the 28 stockyards in Virginia are involved in these sales as administrative entities (Virginia Market News Service n.d.), and the dataset also contains a small number of lots from sales in Pocahontas County, West Virginia, and Boone, North Carolina. The majority of the lots were sold in southwest Virginia, with 43.53% sold via the Tri-State Livestock Market in Abingdon, VA and another 26.16% sold via the Pulaski Livestock Market in Dublin, VA (Table 3). Sales of cattle and calves in Virginia totaled 825,758 head in 2017 (National Agricultural Statistics Service 2020), so although the dataset covers a large area, it represents a small proportion of total Virginia cattle sales (Table 4, columns 5 and 6).

Market and time fixed effects, represented in vector M in equation 3, are included to account for differences across time and space. The price of corn is included to control for changes in input prices (USDA NASS 2020).

Various ownership structures are present in the data. In some cases, cattle are sold by single farms or individuals, with the name of the seller listed on the bill of sale. Some sellers consign several lots of cattle a month, some sell only once a year, and some sell more sporadically. In other cases, cattle in the dataset were consigned to local and regional feeder cattle associations, such as the Dublin Feeder Cattle Association, which generally sell large, commingled lots of VQA-certified cattle. Additionally, some producers may produce only feeder cattle (as in a stocker operation), while some may also produce calves (as in a cow-calf operation). However, because of the commingling of lots, we are not able to effectively identify these producers in the data.

Empirical Procedures

Following the framework adapted from Schroeder et al. (1988) as shown in equation 3, regression analysis is used to estimate mean prices and weights for VQA-certified and uncertified cattle. Based on equations 1–3 in the Conceptual Model, the natural log of price is regressed on lot characteristics, including fixed effects for market location, month, and year. Using the variables listed in Table 1, the regression model is estimated as follows:

$$(4)\, ln(P)_k = \beta_0 + \beta_1 VQA_k + \beta_2 LOGWT_k + \beta_3 LOGHD_k + \beta_4 HEIFER_k + \beta_5 NATURAL_k + \beta_6 HOME_k + \beta_7 FRAME_k + \beta_8 MUSCLE_k + \beta_9 FLESH_k + \beta_{10} PCTBLK_k + \beta_{11} LOGCORN_k + \mu_{1t} + \mu_{2t} + \nu_h + \epsilon_k$$

where μ_{1t} *and* μ_{2t} are month and year fixed effects, respectively, ν_h are market fixed effects for each lot, and ϵ_j is the error term. Average weight, number of head in the lot, and corn price are included as natural logs so that the coefficients may be interpreted as elasticities.

An enterprise budget is used to estimate the costs for producing certified and uncertified cattle. Per-head costs of production are:

$$(5)\, E(C_{VQA}) = FEED(f) + CALF + INT(f) + LABOR(f) + LAND(f) + DLOSS + VC + FC$$

Cost is based on the major categories in a feeder cattle budget.[3] The major costs are feed, including pasture and hay (*FEED*), calf purchases (*CALF*), interest accrued on calf purchases (*INT*), labor (*LABOR*), death loss (*DLOSS*), other variable costs (*VC*), and fixed costs (*FC*). Of these, feed costs, interest expenses, and labor vary based on the time animals spend on the farm. We assume that *CALF*, *DLOSS*, *VC*, and *FC* are the same for both VQA and non-VQA cattle. Cost advantage for calf purchases is more likely to be determined on a producer-by-producer basis than categorically for certified and uncertified cattle, although the data at hand do not provide any indication one way or the other. We also assume that cost does not vary between Purple Tag and Gold Tag VQA certification. Although calves used to produce Purple Tag cattle may cost more due to their improved genetics, the bills of sale used to construct the dataset generally do not indicate Gold or Purple Tag certification specifically, so we do not include these differences here. Additionally, veterinary and medical costs do not differ based on VQA status because the budget assumes a VQA-compliant vaccine panel for all cattle, certified and uncertified (Griffith and Bowling 2020).

The age of the animals in the dataset is not recorded in any consistent manner. While it is possible to directly measure differences in weight between certified and uncertified cattle, it is not possible to measure differences in age. It is, however, feasible to estimate the number of days on feed (*f*) based on differences in sale weight and assumptions of average daily gains. This process is described in greater detail in the "Differences in Cost and Profitability for VQA-Certified and Uncertified Cattle" portion of the results section. When combined with other

[3] Developed using the University of Tennessee's Stocker/Backgrounding Budget for 2020 (Griffith and Bowling 2020).

descriptive statistics and figures, we feel that these estimates are sufficient to make statements about likely differences in the number of cattle that can be produced by a farm in a given year.

Results

A comparison of the mean prices of VQA certified and noncertified cattle by year, shown in Table 4, suggests that certified cattle consistently command higher prices than uncertified cattle. However, the temporal variability in the price premium for certified cattle is high, ranging from less than $1 per hundredweight in 2017 to over $20 in 2015. This variability is in line with the results from previous VQA research (Greiner et al. 2003). When examining the effect of certification on logged prices and controlling only for month and year effects, VQA certification has a large and statistically significant effect, raising prices by roughly 6.7% for certified cattle (Table 5, column 1). A premium of about $11 per cwt is roughly double that found by Williams et al. (2012) and Zimmerman et al. (2012).

Because VQA certification entails education intended to change producer behavior and required practices intended to change the physical characteristics of the cattle, certified and uncertified cattle generally do not have identical characteristics. Table 5, columns 3 and 4 show the effects of VQA certification on price when controlling for physical attributes and non-VQA certifications while including fixed effects for market and time. In column 3, VQA certification has a small and nonsignificant effect on price. Physical attributes such as weight, frame size, and flesh score play a larger role and once these factors are accounted for, while VQA participation has a negligible effect. The impact of average weight of a lot of cattle on price received is large, negative, and highly significant. The results suggest that a 1% increase in weight per head (roughly 7.4 pounds at the mean) decreases the price received for a lot by 0.19%. Because marginal weight gain per unit of feed drops as animals gain weight, this outcome is consistent with expectations (Rutherford 2009).

A 1% increase in the price per bushel of corn decreases feeder cattle prices by 0.74% (Table 5, column 3). This price effect is statistically significant at the 1% level. This result is expected because an increase in corn price decreases the profit margins of feedlot operators (ceteris paribus).

The suggestion of Greiner et al. (2003) that VQA certification price effects vary over time is examined by adding an interaction term between VQA certification and year. Results are presented in Table 5, column 4. The coefficient for certification shows a highly significant premium of 3.2% in the base year 2013. The interaction effects have negative signs, with differing magnitudes and degrees of significance, suggesting the net effect varies over time. The interaction effect in 2017, when the VQA cattle price premium was very small, was particularly large, with a negative coefficient that is highly significant and almost double the magnitude of the VQA premium of in the base year. The combination of the main effect (shown for the base year) and the interaction effects for the other years shows that even though VQA cattle received higher prices every year, the net effect of VQA certification itself varied from year to year and sometimes even had a negative effect.

Estimates of premiums associated with VQA certification based on regression analysis do not necessarily imply higher profitability of VQA-certified cattle. To analyze the profitability of certified versus uncertified cattle, price and weight information is necessary to compare revenues and costs of the two groups using enterprise budgets. Certified cattle are generally sold at a significantly lower weight, with a mean weight of 677 lbs. per animal for lots of certified cattle and a mean weight of 848 lbs. for lots of uncertified cattle. A t-test confirms that this difference is highly significant (Table 2). As an additional robustness check, we regressed logged weight on VQA certification, sex, breed, and corn price (Table 6). This regression shows that certified cattle are 20.6% lighter than uncertified cattle, which is highly significant and within a rounding error of the t-test results. Another t-test shows that a highly significant difference in average price for certified and uncertified cattle is also evident, with certified cattle receiving an average price of $169.11/cwt and uncertified cattle receiving an average price of $161.59/cwt (Table 2).

Because VQA is an extension program, there is likely to be some bias in terms of farmer participation. Farmers who place less value on extension education in general are less likely to participate in BQA training, and therefore less likely to participate in VQA. Conversely, because extension education programs are often bundled or marketed together, producers involved in VQA may have greater exposure to extension programs beyond VQA. This selection effect might lead to a bias due to unobserved factors affecting participation in the program that may also affect price received. If this problem is significant, it would most likely lead to an overestimation of the effect of participation on price received.

The selection bias could be controlled for if we had information on individual farmers and factors affecting program participation. However, feeder cattle associations market commingled lots of VQA cattle from different producers, so identification of participating farmers and gathering information on their attributes is impossible. Given that detailed information on farmer participation and eligibility for the VQA program was not available, we focus on identifiable physical differences between certified and uncertified cattle. However, additional information on the farmers themselves would improve the assessment of the program's success. Without this information our sense is that selection imparts a positive bias on the estimated price impact.

Differences in Cost and Profitability for VQA-Certified and Uncertified Cattle

A comparison of costs of production for VQA and uncertified cattle is presented in Table 7. Using the price and weight information from the regression analysis and cost information from the budget, it is straightforward to estimate the differences in revenue per head, cost per head, and overall profitability for producers of certified and uncertified cattle. We assume that calves used to produce certified and uncertified cattle are purchased at the same weight. However, because uncertified cattle are sold at a heavier final weight, they remain on the farm over twice as long as VQA cattle. Our estimates of time spent on the farm are based on the differences between sale weight (677 and 848 lbs. for certified and uncertified cattle, respectively) and purchase weight (504 lbs. for both groups), divided by the average daily gain of the animals. Because heavier cattle gain weight more slowly, average daily gain for uncertified cattle will be lower.

Estimates of difference in revenue per head can be taken from the first term of equation 1, $E(P_i)w$. Recall that P_i refers here to the price received for an individual animal, and w refers to the weight of the animal. Because differences in price and weight for VQA cattle and uncertified cattle were estimated empirically, the difference in revenue per head between the two groups is estimated as

$$(6)(Pw)_{VQA} - (Pw)_{non} = P_{VQA}w_{VQA} - P_{non}w_{non}$$

As shown in the t-test of price, certified cattle are sold at an average price of $1.69/lb., while uncertified cattle are sold at an average price of $1.61/lb. (Table 2). Also, VQA cattle are sold at a weight of 677 lbs., while uncertified cattle are sold at a weight of 847 lbs. Thus, each head of VQA cattle sold brings, on average, $1144.13 in revenue, while, on average, each head of uncertified cattle sold brings in $1363.67. Thus, the change in revenue per head from certification (equation 6) is –$219.54.

Because certified cattle are sold at a lighter weight, they will be on pasture for a shorter time and will consume less feed, accrue lower interest expenses, require less labor, and use less land on an annual per-head basis. Thus, the difference in cost between certified and uncertified cattle is:

$$(7) C_{VQA} - C_{non} = FEED_{VQA} + INT_{VQA} + LABOR_{VQA} + LAND_{VQA} - (FEED_{non} + INT_{non} + LABOR_{non} + LAND_{non})$$

The sum of these cost reductions is shown above in equation 7, with a total cost reduction of $200.23 per head for certified cattle compared to uncertified cattle (Table 8).

Finally, the effect of VQA certification on per-head profitability is:

$$(8)\ \pi_{VQA} - \pi_{non} = (Pq_{VQA} - Pq_{non}) - (C_{VQA} - C_{non})$$

$$\pi_{VQA} - \pi_{non} = -219.54 - (-200.27)$$

$$\pi_{VQA} - \pi_{non} = -19.27$$

On a per-head basis, VQA cattle are less profitable than uncertified cattle, because the revenue effect of lighter sale weights outweighs the increase in profits from higher prices received and lower feed, labor, and interest costs. However, the lighter sale weight of VQA cattle also means that they spend less than half as much time on the farm, making it possible to produce two batches of cattle per year where only one batch of heavier cattle is possible. The distribution of lots in the data by month and certification status suggests that this is the case, with most uncertified cattle in the dataset being marketed in the summer months, while VQA cattle are marketed in the summer and again in the winter months (Figure 1). Although uncertified cattle could be sold at a lighter weight, for the lots in our dataset, this is emphatically not the case (Table 2). Land costs are already bid into per-head profits, but the ability to produce an additional batch of cattle has a marked effect on firm profitability.

This increase in the number of head produced leads to higher firm profits for producers of VQA cattle. By producing two batches per year, producers of certified cattle can spread their fixed costs over more animals and earn profits that are 74.6% higher per head per day than for a single batch of heavier cattle (Table 7, net return/head/day). Because certified cattle are on feed for a shorter time, they also use less than half as much pasture per head. Combined with higher prices received, this higher stocking density increases their returns per acre by 77.7% (Table 7, net return/acre) and making them attractive to producers for whom land is a constraint. Reducing the time and land needed to produce an animal can allow greater stocking densities, allow for replacement with fresh animals, or even allow the expansion of other farm operations (such as adding more cow-calf pairs for farms who produce both calves and feeder cattle). Although VQA cattle have lower revenue per head, their faster turnover and higher stocking density allow operations producing VQA cattle to earn greater total revenues for the operation than those producing uncertified cattle (Table 7, land rent).

Conclusions

The analysis suggests that the VQA program does not have a large price effect, but it has a positive impact on producer profitability by allowing production of a greater number of smaller, higher-priced feeder cattle. These cattle have been handled properly and will gain weight faster in a feedlot setting due to their smaller size. Cattle marketed through the VQA program are fed for a shorter time prior to sale, command higher prices per hundredweight, and increase producer profits. The increase in profitability may be the main incentive for participation in the program.

Although prior work on value-added feeder cattle programs suggest that certification programs should increase the price received for feeder cattle (Williams et al. 2012; Zimmerman et al. 2012), our analysis does not suggest a consistently high premium to certification once controlling for other factors. Price premiums for VQA certification vary over time, as do profits per acre, but this analysis suggests that profits per acre provide a stronger and more consistent motivation for producers seek VQA certification than do price premia.

We conclude that the VQA program adds value to Virginia's feeder cattle industry not by simply raising prices, but by increasing producer profits and reducing the demands of feeder cattle on land and time. Prior studies have judged feeder cattle certification programs solely on their ability to command price premiums, but we find that there are important differences in the regimes used to produce VQA and noncertified cattle. This difference in regimes also leads to differences in profitability with regard to important production constraints (in this case, time on feed and land available).

These findings have important implications for work in the United States and elsewhere. In the United States, these findings encourage researchers to focus on the profitability (rather than price) of new practices before suggesting their adoption to producers. This is as true for feeder cattle as it is in other contexts, such as organic certification (Spalding and Sexton 2019). For international work, this study highlights the importance of profitability relative to major production constraints. Although time and land used are still important considerations in the United States, they can be even more crucial in contexts where land markets may function imperfectly (or not at all) or where time for off-farm employment is an important part of family income. Thus, international research should look for certifications that allow not just for increased profits, but also for judicious use of important resources. Certification literature should be driven by the issues that matter most to the potential users—in this case, farmers.

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Tables and Figures

Table 1: Description of variables.

Variable	Description
Price	Price of the lot, per hundredweight (cwt).
Logp	Log of price.
Month	Month in which the lot was sold (1-12). Included as a fixed effect.
Year	Year in which the lot was sold (13-19). Included as a fixed effect.
Numhead	Number of head contained in the lot.
Loghd	Natural log of numhead.
Avgwt	Average weight of the cattle in the lot (in pounds).
Logwt	Natural log of avgwt.
Frame	Weighted average of the frame score of the cattle contained in the lot. Large=0, medium=1, small=2.
Muscle	Weighted average of the USDA muscle scores of the cattle in the lot.
Flesh	Flesh scores of the cattle in the lot. Reflected in .5 increments.
Pctblk	Percentage of black or "black baldie" (black with white face) cattle in the lot. Continuous variable between 0 and 1.
Heifer	1 if the lot is a lot of heifers, 0 if steers. No bull calf lots included in the dataset. No mixed lots sold in the VCA Tel-O-Auction.
Vqacert	1 if the lot contains all VQA-certified cattle.
Natural	1 if lot contains all natural cattle per USDA definition.
Home	1 if all cattle in the lot were home raised.
Mkt	Index variable created by assigning each of the markets a number (1-16). Included as a fixed effect.
Cornprice	US monthly corn prices corresponding to the sale date, $/bushel (USDA NASS 2020).

Table 2: Summary statistics of variables, including comparison of means by VQA certification status.

	Mean	Standard Deviation	Mean (VQA)	Std Dev (VQA)	Mean (Non-VQA)	Std Dev (Non-VQA)	t
Numhead	63.63	14.53	67.36	15.13	57.85	11.35	-12.71
Avgwt	744.10	137.99	677.15	110.72	849.64	103.22	29.43
Frame	.64	.15	.61	.15	.67	.15	7.44
Muscle	1.15	.18	1.20	.20	1.08	.11	-12.75
Vqacert	.61	.49	-	-	-	-	-
Heifer	.35	.48	.39	.49	.27	.45	-4.69
Flesh	4.96	.33	4.90	.35	5.05	.28	8.19
Pctblk	.93	.07	.93	.11	.93	.04	-0.96
Natural	.05	.21	.06	.17	.03	.24	-2.78
Home	.43	.50	.52	.50	.31	.46	-7.91
Price	166.17	39.84	169.11	42.64	161.59	34.07	-3.50
Cornprice	3.96	.94	-	-	-	-	-
N	1422	-	867	-	555	-	-

Table 3: Distribution of lots by market.

Market Name	Frequency	Percentage
Abingdon	619	43.5
Alleghany	21	1.5
Boone (NC)	10	0.7
Lewisburg (WV)	5	0.4
Lynchburg	77	5.4
Monterey	1	0.1
Narrows	57	4.0
Pocahontas (WV)	9	0.6
Pulaski	372	26.2
Radiant	13	0.9
Roanoke	44	3.1
Rockingham	6	0.4
Springlake	26	1.8
Southside	60	4.2
Staunton	49	3.5
Wythe	53	3.7
Total	**1422**	**100**

Table 4: Mean prices ($/cwt) and number of head sold by year and VQA certification status.

Year	Price (Certified)	Price (Uncertified)	P(diff ≠ 0)	# Head Sold (Certified)	# Head Sold (Uncertified)	P(diff ≠ 0)	# Lots Sold (Certified)	# Lots Sold (Uncertified)
2013	150.30	140.06	.000	7,563	5,949	.000	118	104
2014	218.53	200.92	.000	11,339	7,842	.000	163	130
2015	208.26	188.08	.000	11,318	6,284	.000	162	110
2016	140.93	130.78	.000	13,905	5,527	.000	208	98
2017	135.87	135.40	.800	9,502	3,195	.000	141	55
2018	148.39	140.33	.003	3,325	1,735	.002	53	32
2019	143.60	137.53	.079	1,384	1,630	.169	21	27
Total	**169.11**	**161.58**	**-**	**58,336**	**32,162**	**-**	**866**	**556**

Table 5: Effects of lot characteristics on logged price per cwt.

Lnprice	**(1)**	**(2)**	**(3)**	**(4)**
Vqacert	.0684***	.0674***	.0148	.0320***
	(.006)	(.008)	(.012)	(.012)
Logwt	-	-	-.1910***	-.1926***
			(.070)	(.071)
Loghd	-	-	.0593***	.0597***
			(.013)	(.013)
Heifer	-	-	-.0891***	-.0891***
			(.007)	(.007)
Natural	-	-	.0398***	.0346***
			(.011)	(.011)
Home	-	-	-.0061	-.0050
			(.006)	(.007)
Frame	-	-	.0590***	.0558**
			(.021)	(.022)
Muscle	-	-	.1269***	.1199***
			(.041)	(.042)
Flesh	-	-	-.0347***	-.0363***
			(.010)	(.010)
Pctblk	-	-	.0599**	.0624**
			(.030)	(.029)
Logcorn	-	-	-.7380***	-.7489***
			(.032)	(.032)
Market FE	No	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Month	Yes	Yes	Yes	Yes
Year*Vqacert	No	No	No	Yes
Intercept	4.9511	4.9576	7.3003	7.3366
R^2	0.7404	0.7467	0.8552	0.8573
N	1422	1422	1422	1422

Notes: Robust standard errors in parentheses. Market fixed effect refers to the market location, while year and month fixed effects refer to the sale date. Year*Vqacert is an interaction effect to discern differences in VQA premiums over time. "No" means the fixed effect was not included, while "Yes" means the fixed effect was included.

Table 6: Effects of lot characteristics on logged weight.

Logwt	
Vqacert	-.2057***
	(.010)
Heifer	-.0692***
	(.009)
Pctblk	-.2102***
	(.045)
Logcorn	-.0643
	(.065)
Market FE	Yes
Year	Yes
Month	Yes
Year*Vqacert	No
Intercept	7.0219
R^2	0.4169
N	1422

Notes: Robust standard errors in parentheses. Market fixed effect refers to the market location, while year and month fixed effects refer to the sale date. Year*Vqacert is an interaction effect to discern differences in VQA premiums over time. “No” means the fixed effect was not included, while “Yes” means the fixed effect was included.

Table 7: Enterprise budget comparing profits of VQA-certified and uncertified feeder cattle

Item	Unit	Quantity (VQA)	Quantity (Non-VQA)	Price	$/Head (VQA)	$/Head (Non-VQA)
Revenues						
Feeder Cattle	lb	677	---	$1.69	$1144.13	---
Feeder Cattle	lb	---	847	$1.61	---	$1363.67
Total Revenue					**$1144.13**	**$1363.67**
Variable Expenses						
Calf Purchase	lb	504	504	$1.52	$766.08	$766.08
Pasture Production	acre	0.37	0.82	$119.28	$44.13	$97.81
Hay Production	acre	0.17	0.37	$179.32	$30.48	$66.35
Supplemental Feed	lb	333.35	735.35	$0.11	$36.67	$80.89
Salt & Mineral	lb	16.59	36.78	$0.35	$5.81	$12.87
Vet & Med	head	1	1	$15.50	$15.50	$15.50
Death Loss	%	3%	3%	$766.9	$23.01	$23.01
Other Expenses	head	1	1	$1.00	$1.00	$1.00
Labor	hours	2.5	4.8	$10.00	$25.00	$48.00
Calf Purchase Interest	APR	1.35%	2.97%	$766.08	$10.37	$22.73
Other Interest	APR	1.35%	2.97%	$181.60	$2.46	$10.25
Marketing	head	1	1	$24.86	$24.86	$24.86
Land Rent	acre	0.54	1.19	$25.00	$13.50	$29.75
Total Variable Expenses					**$998.87**	**$1199.10**
Return over Variable Exp.					**$145.26**	**$164.57**
Fixed Expenses						
Facilities & Equipment	head	1	1	$11.67	$11.67	$11.67
Pasture & Hay Machinery	head	1	1	$48.33	$48.33	$48.33
Miscellaneous Overhead	head	1	1	$4.77	$4.77	$4.77
Total Fixed Expenses					**$64.77**	**$64.77**
Total Expenses					**$1063.64**	**$1263.87**
Net Return to Management					**$80.49**	**$99.80**
Net Return/Head/Day					$0.97	$0.55
Net Return/Acre					$149.04	$83.86

	VQA	**Non-VQA**
Average Daily Gain	2.1	1.9
Days Stockered	82.38	180.53
Acres Required	0.54	1.19

Table 8: Cost differences by VQA certification status, as described in equation 7.

Item	**VQA**	**Non-VQA**	**Difference (VQA-Non)**
Pasture Production	$44.13	$97.81	-$53.68
Hay Production	$30.48	$66.35	-$35.87
Supplemental Feed	$36.67	$80.89	-$44.22
Salt & Mineral	$5.81	$12.87	-$7.06
Total Feed	**$117.09**	**$257.92**	**-$140.83**
Labor	$25.00	$48.00	-$23.00
Total Labor	**$25.00**	**$48.00**	**-$23.00**
Calf Purchase Interest	$10.37	$22.73	-$12.36
Other Interest	$2.46	$10.25	-$7.79
Total Interest Costs	**$12.83**	**$32.98**	**-$20.15**
Land Rent	$13.50	$29.75	-$16.25
Total Land	**$13.50**	**$29.75**	**-$16.25**
Total Cost Difference			**$200.23**

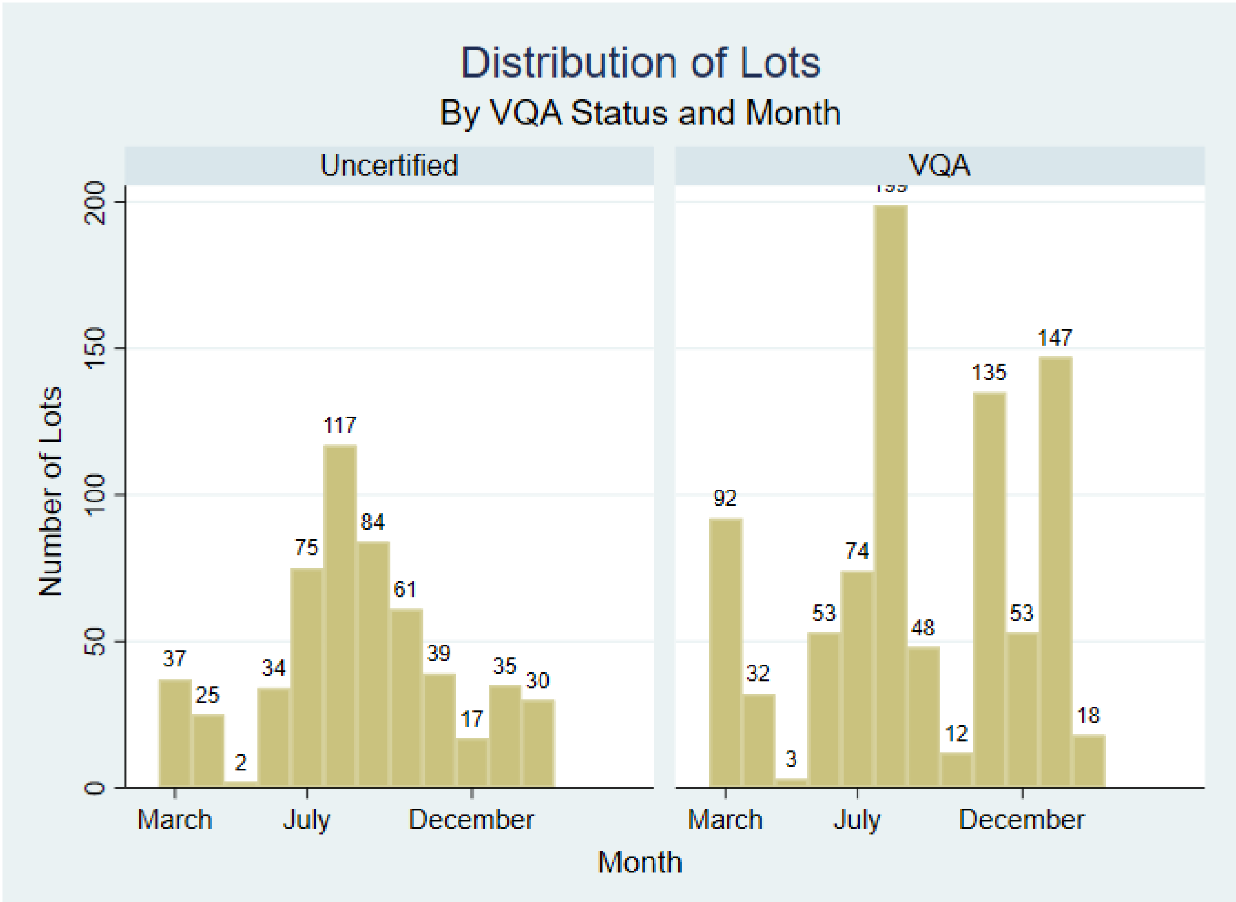

Figure 1: Distribution of VCA Tel-O-Auction sale lots by VQA certification status and month. Source: VCA Tel-O-Auction bills of sale.

Chapter III: Outstanding in the Field: Impacts of University Small Grains Breeding in Virginia

Abstract

New production from public and exclusive varieties released by the small grains breeding program at Virginia Tech generated benefits in excess of $119 million from 2000 to 2018. Public varieties were responsible for $101.8 million in benefits. Benefits to other states formed roughly two thirds of benefits from public varieties, suggesting that the program has significant geographic reach. Exclusive varieties developed by Virginia Tech but marketed by private companies were responsible for the remaining $17.4 million in benefits. The program was found to have a significant impact on Virginia and out-of-state, with many of these benefits due to collaboration with public and private partners.

JEL Classifications: Q16, O31, O32

Introduction

Since the mid-20th century, public breeding of new crop varieties has declined as changes in technology and intellectual property laws governing germplasm development induced a shift to private plant breeding. This decline has been particularly dramatic since 1990 (Shelton and Tracy 2017). Although most improved germplasm in the United States in the early 20th century was produced by the USDA or public universities, public plant breeding programs now must work harder to justify their existence as more and more breeding is conducted in the private sector. This study examines the impacts from 2000-2018 of a university-run small grains breeding program at Virginia Tech (VT) that produces both public and exclusive (university-developed but privately licensed) varieties. It provides information to public officials, university administrators, and stakeholders in the program, illustrating the importance of university research to the modern plant breeding industry and the benefits this research provides to farmers.

This study uses data from field trials conducted around Virginia from 1991 to 2018 to estimate yield changes associated with specific varieties. It combines these estimates with acreage data to estimate benefits from yield increases attributable to the breeding program. Because both practice and study of university breeding programs are dominated by public varieties, this study contributes to the literature by incorporating benefits from exclusive varieties in addition to public varieties. It also compares the differences between the two in terms of the marketing process, benefits generated, and royalties collected.

The study shows the economic importance of yield improvements from the program, but also underscores the benefits of collaboration, both between universities and between the public and private sector. The varieties released by this program generate significant benefits within Virginia and even larger spillover benefits to other states or regions. The breeding programs also provide benefits from impartially running trials of private varieties or varieties developed by public entities in other states. This research cross-pollination is something that public breeding programs are better positioned to provide than breeders who only work with proprietary germplasm.

This study also acknowledges the potential importance of royalty payments (especially to program administrators) in addition to benefits at a time when public breeding programs overall were shrinking. Shelton and Tracy (2017) note that researchers found a marked decline in the number of public sector breeders and breeder-hours worked in the 1990s, including a loss of 108 breeders from state agricultural experiment stations from 1994-2001. In 2015, their research found that 57% of breeders surveyed were skeptical that their university would replace them if they retired or otherwise left their job (Shelton and Tracy 2017). While the Virginia Tech breeding program provides evidence that these programs can generate significant benefits to farmers, strong royalty generation may make these already valuable programs even more attractive to administrators, given their ability to be at least partially self-supporting.

Background

Although corn and soybeans are the dominant field crops in Virginia, wheat and barley remain important, with 210,000 acres of wheat and 30,000 acres of barley planted in 2017 compared to 500,000 acres of corn and 600,000 acres of soybeans (National Agricultural Statistics Service 2020). Because in the state winters are relatively warm, most wheat production is soft red winter (SRW) wheat, with the two main uses being as a cover crop or production of pastry and biscuit flour. Barley is grown primarily for livestock feed, although farmers increasingly grow malting barley following the rapid growth of the craft beer industry in Virginia.

Variety improvement in general, and in small grains specifically, falls into two categories: yield improvement and quality improvement. Yield improvement may refer to increasing yields directly by adoption or improvement of traits such as dwarfism or leaf angle, or it may refer to maintaining yields in the face of disease or pest pressures by breeding for resistance (Brennan and Murray 1995). Quality improvement entails selecting for different traits depending on the preferences of buyers, processors, and end consumers. For wheat, end use is determined by which of the six classes of US wheat a variety belongs to, with each class being grown in a different area of the United States (US Wheat Associates n.d.). As a result, wheat quality is improved by within-class breeding for desired traits. For instance, wheat classes used for bread baking would be bred with other wheats in their class for higher protein or gluten content. For barley, certain varieties are considered sufficiently high quality to be appropriate for malting, but these varieties must also be managed and handled to conform to other quality standards including protein content, moisture, and germination rate (MacLeod n.d.).

Although substantial research has been conducted on the impact of new releases of a single variety, studies focusing on the impact of a state- or national-level breeding program are rarer, in part due to increased scope of the data required. Pardey et al. (2004), in their study of the economic benefits from the Brazilian Agricultural Research Corporation, develop an approach that allows for estimation of national or regional breeding program benefits using breeding trial data. Their approach, which uses changes in proportional acreage grown in each variety to account for adoption and disadoption of varieties, is flexible in that it allows for the estimation of predicted yields even when data are incomplete across locations or time. The framework also allows for estimation of benefits for multiple crops under a single program (Pardey et al. 2004). The approach has been applied to other breeding programs, such as in a study of the impacts of South Africa's national cultivar trials (Dlamini, Magingxa and Liebenberg 2015).

Noguiera et al. (2015), in their analysis of the welfare impacts of wheat breeding in Washington state, provide an example of impact analysis in a United States-focused setting and for small grains research. That study focuses on wheat and provides a detailed analysis of producer and consumer surplus created by the breeding program and disaggregates impacts by each of the five wheat classes in the program (Nogueira et al. 2015). Studies on the impact of barley breeding in the United States could not be found, although a study of barley breeding in Syria suggests that the benefits from such programs can be high (Mustafa, Grando and Ceccarelli 2006).

Public and Private Grains Breeding

From the nineteenth to the mid-to-late twentieth century, most new crop varieties in the United States came from public breeding programs run by universities or the USDA. Patenting new asexually propagated crop varieties first became legal in 1930 with the passage of the Plant Patent Act (Shelton and Tracy 2017). Intellectual property protections for plant breeders were dramatically strengthened by the Plant Variety Protection Act of 1970, which protected new crop varieties produced from seed (Klotz-Ingram and Day-Rubenstein 1999). The Bayh-Dole Act of 1980 further cemented the role of intellectual protections in the germplasm industry by allowing universities to patent technologies resulting from federally funded research. This in turn allowed for universities to transfer intellectual property rights from these technologies to private partners, as in the case of exclusive varieties released by Virginia Tech (Graff et al. 2003). These lega l changes dramatically increased the incentives for private participation in plant breeding, causing the funding and manpower of private breeders to swell while the public sector dwindled (Shelton and Tracy 2017). As a result, public breeding programs are faced with the question of what they should be doing given the rapid evolution of opportunities for the private sector.

Public and private plant breeding programs are not direct substitutes. The most fundamental difference is that universities produce a public good through their collaboration with other breeding organizations, while private breeders produce licensed varieties and are not likely to collaborate. Universities generally (though not always) share their germplasm with other universities and public programs (Shelton and Tracy 2017), while private breeders rarely share proprietary germplasm with anyone. This comparison is not meant to disparage private programs, but to highlight that public and private breeders respond to fundamentally different incentives. Although both are primarily interested in improving varieties on the market, private breeders are more likely to safeguard their successes from others in an attempt to maximize the profits they can collect from improved varieties. This may entail forgoing potential varietal improvements from collaboration as well as some reduction of access to some proprietary varieties to farmers based on financial or geographic barriers. Public breeding programs, because they do not respond to an explicit profit incentive, are more likely to collaborate in the service of further varietal improvement. They are also more likely to balance royalties (which support their programs) with emphasizing broad access for the varieties they produce. In short, private breeders are considered successful if they can maximize rents from their intellectual property, while universities are considered successful if they can maximize benefits to the public from their programs, leading them to act in different ways.

Small Grains Breeding and Distribution at Virginia Tech

The university-run breeding program in Virginia is supported by the Commonwealth of Virginia, USDA grants, the Virginia Crop Improvement Association (VCIA), and royalties. Roughly three quarters of royalties collected by the program are from exclusive crop varieties (those that are developed by VT and licensed to private companies), with the remainder coming from public varieties released by the program (Santantonio and Hardiman 2021). Breeding objectives have changed over time based on producer priorities and grant objectives, but they generally include disease resistance and quality improvement, especially for specialty varieties such as malting barley and bread wheat (USDA National Institute of Food and Agriculture n.d.). Varieties with highly specialized end uses (with bread wheat being the most prominent example) or specific geographic adaptations are somewhat more likely to be licensed as exclusive varieties so that they may meet specific client needs. Since 1990, the program has released 12 public wheat varieties and 11 public barley varieties. It has also licensed and released one exclusive barley variety and 67 exclusive wheat varieties.

The program is conducted via annual agronomic field trials at agricultural experiment stations around the state. The role of these trials is twofold. The first objective is to compare yields of different varieties in order to provide information to producers on how well different lines are adapted to area-specific production conditions. The second objective, and the one that is of greater concern to us here, is to generate experimental germplasm that can be crossed and/or linebred to contribute to development of public and exclusive experimental varieties released by Virginia Tech. Although improved lines (especially public ones) may be used as parents for later lines, much of the experimental germplasm created by the program turns over from year to year. Most germplasm used in these experiments is from Virginia Tech, but a small but significant portion is from other universities or produced in direct collaboration with other universities, evidence of substantial inter-university collaboration.

The role played by exclusive varieties in the program is an important one (Santantonio and Hardiman 2021). Licensing some varieties for exclusive release provides two key advantages. First, licensing a variety privately allows the variety to have increased marketing support that private entities can provide but that Virginia Tech cannot. As a result, although these varieties are marketed for less time by the private sector, they generally enjoy greater uptake by farmers compared to what they would have if the University opted to market them as part of a larger public portfolio (Thomason 2020). Because the reach of varieties produced by the program is larger as a result of private marketing, benefits from yield improvement generated by Virginia Tech germplasm are larger than they would be in the absence of exclusive varieties. Second, royalties from exclusive varieties provide revenue to fund further breeding, meaning that royalties from exclusive varieties fund the release of exclusive and public varieties.

Higher royalties from exclusive varieties might incentivize breeders to emphasize exclusive releases over public ones, either for their own benefit or in order to expand the program. However, royalties from these varieties are divided among the programs themselves, administrative partners like VCIA, and university administration, meaning that breeders and their programs do not reap the full benefits of these increased royalties. Thus, incentives to maximize royalties are more muted than they may appear.

Distribution of seeds and administration of royalties from public varieties are in partnership with VCIA, which acts as the seed certification agency in Virginia. Varieties are generally marketed within Virginia under the administration of VCIA and in other states with the cooperation of their seed certification agencies. VCIA is also responsible for the production of "Foundation" seed, which is distributed to select farmers for production of certified seed. Certified seed is sold to farmers wishing to produce a given variety (Thomason 2021a). Royalties are collected based on certified seed production and split between VT and VCIA, with smaller royalties collected for out-of-state production (Hardiman 2021).[4] The process of creation, administration, and distribution of public varieties is shown in Figure 1. Exclusive varieties are produced and distributed by the entity to which it is licensed, and royalties are paid to Virginia Tech Intellectual Properties (VTIP), with payments disbursed to VCIA, other administrative funds within Virginia Tech, and the breeding program itself. The process by which exclusive varieties are created, licensed, and distributed is shown in Figure 2.

[4] For Callao, Nomini, Pamunkey Price, Starling, and Thoroughbred barley, VCIA collects only 50% of royalties for out-of-state acreage. The same is true for Jackson, Madison, and Wakefield wheat. For Dan, Eve, Doyce, Atlantic, and Secretariat barley, VCIA collects 70% of royalties for out-of-state acreage. The same is true for McCormick, Pocahontas, Roane, Sisson, Jamestown, Merl, and Hilliard wheat.

Model, Methods, and Data

Conceptual Model

It is assumed that farmers choose to plant the bundle of crop varieties that maximizes expected utility. In general, expected utility increases as farm profits increase, although farmers may also derive utility from traits such as environmental impacts or labor requirements. Varietal adoption may also be impacted by barriers such as incomplete information on the part of farmers or unequal availability across locations. In addition to changes in mean expected utility, the variance of expected utility and the risk imposed by increased variance also play important roles in farmer choices. As a result, farmers may be reluctant to adopt new varieties quickly because of the perceived risks of doing so, but the risk of using older varieties also rises as pest and disease resistance degrades. Farmers may plant only one or a mix of varieties depending on their preferences (Useche, Barham and Foltz 2013). As varieties age, they become more susceptible to insect pests and diseases (Brennan and Murray 1995), so farmers are constantly adopting new varieties for the increased resistance and to take advantage of other new traits.

We assess benefits to farmers from the VT breeding program following the methods used by Pardey et al. (2004). The approach allows for trial data that do not compare all varieties in all locations in all years, as is the case for the VT program, where new varieties were released over time. It also allows us to easily account for adoption and disadoption of varieties by farmers over time.

We follow the example of Pardey et al. (2004) and find proportional yield gains from research (k) and apply those gains to the value of total production in Virginia (PQ)

to find total benefits from research (B), giving total benefits from small grains research in a given year:

$$\textbf{(1) } B_t = k_t P_t Q_t$$

It is assumed that inputs are held constant across varieties in an experimental setting and that differences between varieties in a specific place at a specific time are therefore the result of varietal differences and differences in environment rather than management. This allows regression of experimental yields on variables reflecting variety, trial location, time, and weather. We estimate experimental yields for observation i of variety j in each year t and test site s as follows:

$$\textbf{(2) } Y_{ijst} = \alpha_0 + \sum_{j=1}^{J} \alpha_j DV_j + \beta x_i + \sum_{s=1}^{S} \delta_S DS_s + \sum_{t=1}^{T} \gamma_t DT_t + \phi_s W_{st} + \varepsilon_{ijst}$$

where Y_{ijst} is the experimental yield for variety j at site s in year t summed over all i observations; DV_j is a vector of variety dummy variables; x_i is a vector of management practices applied to an observation in a given year; DS_s is a vector of trial site dummy variables identifying each site; DT_t is a vector of dummy variables identifying each year; W_{st} is an index of weather for site s in year t; and ε_{ijst} is the model residual.

Using the parameters estimated by the model in equation 2, we can calculate fitted values of experimental yields for each variety at each site in each year as:

$$\textbf{(3) } \widehat{Y}_{jst} = \alpha_0 + \widehat{\alpha_J} + \widehat{\delta_S} + \widehat{\gamma}_t$$

In equation 3, the effects of management ($\widehat{\beta}$) and weather variations ($\widehat{\phi_s} W_{st}$) on yield are netted out as we are interested in expected yields net of management and weather. Experimental yield performance indices are constructed for each variety using the fitted values for all locations for each year given the actual adoption patterns of each variety in that year as:

$$(4)\ \boldsymbol{Y^{a}_{st}} = \sum_{j=1}^{J} \boldsymbol{\widehat{Y}_{jst}\pi_{jt}}$$

where π_{jt} represents adoption across the study area (which includes Virginia as well as other states where these varieties are grown) as a proportion of total area A cultivated in variety j ($\pi_{jt} = \frac{A_{jt}}{A_t}$). Fitted values are summed across J—the set of all varieties—because the yield indices are calculated using a weighted average of fitted yields and proportional acreage across all varieties within the region and year. Although π_{jt} contains acreage both inside and outside Virginia, trial data for these varieties is available only from the Virginia trials, so the same fitted values of yield are used for both in-state and out-of-state acreage. Actual yield is compared to a counterfactual of composite yields given adoption patterns of varieties in the base year, which shows what yield would be if no new varieties had been released and farmers were still using only varieties available in the base year. The counterfactual takes the form

$$(5)\ \boldsymbol{Y^{b}_{st}} = \sum_{j=1}^{J} \boldsymbol{\widehat{Y_{jst}}\pi_{jb}}$$

The counterfactual is the same as the actual yield index except that proportional acreage for each variety is set equal to the proportional acreage in the base year, π_{jb}. Only varieties available in the base year are used to calculate the counterfactual yield index and their proportions of total yields are fixed, while the actual yield index allows proportional acreage to change as new varieties are made available. While yields change over time for the counterfactual yield index, the varieties used do not. In this way, the counterfactual allows us to show what yields would have been in the absence of improved varieties from the program, while the actual yield index shows the gains from new varieties released by the program by accounting for adoption of more effective varieties over time.

Proportional yield gains attributable to varietal improvement (k_t) are obtained by comparing actual yield and adoption (in terms of acres planted) to projected yield and adoption rates in the absence of crop improvement research ($k_t = (\frac{Y_{st}^a - Y_{st}^b}{Y_{st}^a})$). Because the same fitted values of yield are used for both in-state and out-of-state acreage, this study assumes that k_t is the same for both groups as well. In reality, different varieties are likely to be better adapted to some states than they are to Virginia and worse adapted in others. Using the same k_t splits the difference between the two while allowing us to have some estimate of out-of-state benefits in the absence of trial data for these areas. Because out-of-state acreage is such a large portion of total acreage planted to Virginia Tech varieties, out-of-state benefits are likewise an important portion of the benefits of the overall program.

k_t is then combined with estimates of the value of production for acres planted using Virginia Tech varieties in a given year (Pardey et al. 2004) to find total benefits for that year as B_t where:

$$\textbf{(6)}\ \boldsymbol{B_t = k_t P_t (\textstyle\sum_{j=1}^{J} \widehat{Y}_{jst} \pi_{jt})}$$

For equation 6, we have substituted the production of varieties released by the program (expected yield multiplied by acreage summed across all varieties) for Q in equation 1. These varieties are sold in many markets inside and outside Virginia, and seed sold by private entities cannot always be disaggregated by geographic location. Thus, k_t is estimated explicitly from yield and acreage data, because aggregate supply measures for a single market cannot be used accurately in this case.

Finally, total benefits from the program are estimated by summing benefits in all years as follows:

$$(7)\ \boldsymbol{B} = \sum_{t=1}^{T} \boldsymbol{B_t}$$

Because Virginia is a small producer of wheat and barley and VT varieties are small proportions of out-of-state areas, we assume that increased production from the program will not impact market prices.

Description of data used to evaluate yields

Experimental data are obtained from field trials conducted by Virginia Tech breeders from 1991 to 2018 (Table 1). These data cover nine test sites across the state and include over a thousand varieties, and more than 20,000 observations for barley and 67,000 observations for wheat. Barley yields in the trials averaged 101.56 bushels per acre with a standard deviation of 27.02, while wheat yields averaged 74.95 bushels per acre with a standard deviation of 17.77. Summary statistics of yield and selected other variables are shown in Table 2.

Varieties included in the trial may be public, private, exclusive, or experimental lines. The dataset also identifies public, exclusive, and experimental lines by source. Many of the lines tested in Virginia are experimental lines from other universities, privately developed germplasm from seed companies, or public varieties from the USDA or other universities. Privately developed varieties are included in these trials to compare yields, but their inclusion does not indicate that Virginia Tech can use them to develop experimental germplasm. The distribution of germplasm by origin is summarized in Figure 3. The barley trials include relatively more public germplasm (13.18% of all observations) with no exclusive varieties and very few private varieties (0.24% of all observations). The wheat trials are more diverse, with total observations consisting of 6.32% public germplasm, 5.30% exclusive germplasm, and 19.53% private germplasm. The remainder of the germplasm for each crop consists of experimental germplasm from Virginia Tech or other universities.

Area planted by year to each variety is estimated for public varieties released by the program since 1990 based on acreage data from 2000-2018 and is used to estimate the proportion of total area cultivated in a given variety (π_{jt}). For public varieties, acreage estimates can be separated between Virginia and out-of-state acreage. Acreage data for public varieties is constructed based on royalty receipts by state provided by VCIA, which are used to estimate units of certified seed sold using the royalty rate per unit of seed. The units of seed sold allows new certified seed acreage to be estimated. We assume that new certified seed acreage accounts for roughly 60 percent of total acreage, while saved seed accounts for roughly 40 percent based on estimates from industry experts contacted by program personnel (Thomason 2021b). Public variety royalties paid by seed producers based in Virginia are counted towards Virginia acreage, whereas royalties paid by universities and crop improvement organizations in other states are counted toward out-of-state acreage. Historical data for wheat and barley production and prices in Virginia (for Virginia acreage) and the United States (for acreage in other states) are used to construct the value of production estimates for each year (National Agricultural Statistics Service 2020). As noted above, these value of production estimates are then reported as in-state or out-of-state so that readers may compare the impact of public varieties in Virginia with their impact in other states.

For exclusive varieties, royalty receipts from Virginia Tech Intellectual Properties are used to estimate acreage using royalty rates per unit as above. However, because licensees for exclusive varieties generally operate in more than one state and royalties are generally paid by one or a small number of multi-state licensees, acreage estimates could not be separated by state for these varieties. As a result, US prices were used for these varieties.

Weather data used in the regression are historical data compiled by the National Climatic Data Center (National Climatic Data Center n.d.). Total precipitation and mean temperature by month were collected for each test site from 1991 to 2018. Data were taken from historical records for the National Weather Service station in the ZIP code nearest to the test site. In cases where the nearest weather station lacked complete records, the next closest station with complete records was used. In cases where data from neither of the two closest stations were complete, data from the less complete station was used to fill in the series for the more complete station. The data were then annualized and used to construct deviations from mean for each location by year.

Empirical Procedures

Yield is regressed on variety, year, location, management practices, and weather to provide fitted values for each variety in each location and year. The regression model for both wheat and barley is estimated as follows:

$$\textbf{(8)}\ \boldsymbol{Y_{ijst} = \alpha_0 + \sum_{i=1}^{I} \alpha_1 LINECODE_j + \beta_2 NOTILL_i + \beta_3 TREATED_i + \sum_{s=1}^{S} \delta_4 LOCCODE_s + \sum_{t=1}^{T} \gamma_5 YEAR_t + \phi_6 TEMPDEV_{st} + \phi_7 PRECDEV_{st} + \varepsilon_{ijst}}$$

where the regressors are listed in Table 5.

Although the regression model described in equation 8 was used to calculate fitted values for both public and exclusive varieties, the actual and counterfactual yield indices (Y_{st}^{a} and Y_{st}^{b}) were calculated separately for each type of variety. This separate calculation was done to preserve the ability to report in-state and out-of-state benefits separately for public varieties, where it is possible to separate the two, as opposed to exclusive varieties, where such disaggregation is impossible.

Results

Total acreage planted in public wheat and barley varieties released by the program from 2000 to 2018 is shown in Figure 4. Out-of-state acreage is a significant portion of total acreage for both crops, with out-of-state acreage being particularly dominant in the wheat program. Total acreage planted in exclusive wheat varieties released by the program from 2004 to 2018 is shown in Figure 5. Exclusive varieties analyzed here are planted on slightly less acreage (296,227 acres per year on average) than the public varieties (a combined 383,696 acres per year on average). However, this lower acreage is likely due to the lack of exclusive barley varieties produced by the program and the lack of acreage or yield information leading to the omission of some exclusive wheat varieties.

The regression equations described in equation 6 were fitted for both wheat and barley. A post-estimation Breusch-Pagan test on the regressions failed to reject the null hypothesis of homoskedasticity in both cases. As a result, normal standard errors were used.

The means of the fitted values of yield generated by this regression were combined with the acreage data to generate actual composite yields (Y_{st}^{a}) and counterfactual yields (Y_{st}^{b}). The composite and counterfactual yields for public wheat and barley varieties from 2000 to 2018 are shown in Figure 6. Although barley yields are higher than wheat yields throughout the study period, composite wheat yields experienced greater improvements over counterfactual wheat yields. Exclusive composite and counterfactual yields from 2004 to 2018 are shown in Figure 7. There is little difference in exclusive composite and counterfactual yields until 2012. Even in 2018, the difference between the two is relatively small.

Yield gains for public and exclusive varieties over the course of the study period are shown in Figure 8. These yield gains can be thought of as being representations of the relative differences between the composite and counterfactual yield lines from Figures 6 and 7. Thus, public wheat varieties have the highest yield gains due to their greater difference in composite and counterfactual yields, with gains of 6.96% per year on average compared to 3.40% per year on average for public barley varieties. Because their composite and counterfactual yields were late to diverge, exclusive varieties see the lowest yield gains, with average gains of 1.96% per year.

Benefits from public varieties produced by the program, in terms of new production attributable to research conducted by the program, are shown in Figure 9. Benefits from public varieties totaled over $101 million from 2000 to 2018, with average annual benefits of more than $5.3 million. Benefits to other states were an important part of the benefits from public varieties, with total out-of-state benefits being roughly twice the size of in-state benefits. This difference in benefits is primarily due to the higher out-of-state than in-state acreage for these varieties. However, the fact that wheat and barley prices are generally lower in Virginia than in the rest of the United States also plays a role. When considering the potential impacts of jointly released varieties for which royalty data were unavailable, out-of-state benefits are likely higher than estimated here. Because the fitted yields from Virginia were used to calculate the yield increases to construct the out-of-state benefits, the actual benefits to other states may be higher or lower than what is presented here.

Total benefits to farmers from new production attributable to exclusive wheat varieties[5] released by Virginia Tech from 2004-2018 were also calculated. Benefits to farmers from the exclusive wheat varieties studied here, shown in Figure 10, were $17.3 million from 2004 to 2018, in 2018 dollars. These benefits are dramatically lower than those for public varieties, which may be due to several factors. First, the yield gains are much smaller for exclusive varieties than for public varieties. Second, the exclusive varieties studied here occupied a lower acreage than the public varieties (when taken together). Finally, due to a lack of yield and acreage information, 35 of the 68 exclusive wheat and barley varieties released during the study period were omitted from the analysis. Because of this last factor, benefits to farmers from the program's exclusive releases are likely to be higher than what is captured here.

Total benefits from public and exclusive varieties studied here are shown in Figure 11. Benefits to farmers over the study period total over $119 million, with average benefits of over $6.5 million per year. The majority of these benefits are from public varieties, which yield benefits averaging $5.4 million per year, while benefits from exclusive varieties total $1.2 million per year.

[5] Exclusive varieties that were omitted from the variety trials were not included in this analysis. Amaze 10, the only exclusive barley variety licensed by VT during the study period, was omitted for this reason, meaning that all exclusive varieties analyzed here are wheat varieties. Exclusive varieties were also omitted if royalty rates per unit were unavailable for the variety, making it impossible to estimate acres planted in the variety from royalty data. Benefits were estimated for 33 exclusive wheat varieties in total.

When it comes to royalties, however, exclusive varieties have a clear advantage. Total royalties from the program, shown in Figure 12, total $10.4 million over the study period. Despite covering less time, exclusive varieties account for the lion's share of royalties collected ($7.3 million).[6] Although private varieties account for a larger share of benefits to farmers, exclusive varieties provide the financial support that is necessary to keep the program thriving.

Conclusions

The Virginia Tech small grains breeding program is an example of what can be achieved by well-managed university plant breeding programs. New production from public and exclusive varieties released by the program yields substantial benefits. The role of privately marketed exclusive varieties, the presence of non-VT germplasm in the trials, the release of jointly developed varieties with other states, and the role of benefits from VT varieties to other states all suggest that collaboration is an important feature of university breeding programs. As seen here, collaboration can provide additional funding (via royalty revenues), marketing support, and the genetic material needed for program success. On a societal level, however, this collaboration helps universities fill a role that the private sector has a limited incentive to fill. Because private companies are unlikely to share germplasm among themselves, they are unlikely to realize the genetic gains that can result from such cooperation, nor are they likely to host broad trials with varieties from all sources to compare performance head-to-head for the benefit of farmers.

[6] Because fitted yield values and per-unit royalty rates are not needed to calculate aggregate royalties, this estimate reflects all exclusive varieties for which royalty data is available, not just those for which benefits to farmers were calculated.

This study provides evidence that the small grains breeding program at Virginia Tech has generated significant benefits from improved crop varieties. Universities are well positioned to share the benefits of their work among institutions and states, and the Virginia Tech program illustrates that universities can generate substantial gains for farmers by working with both the public and private sectors.

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Tables and Figures

Table 1: Description of variables used in regression and other analysis.

Variable	**Description**
Linecode	Factor variable denoting each individual released variety or (unreleased) experimental line.
Notill	1 if the observation was planted using no-till practices.
Treated	1 if any management treatment such as pesticide or herbicide was applied to the observation
Loccode	Factor variable denoting each trial location.
Year	Year of trial (1991-2018). Included as a factor variable.
VT	Dummy variable where 1 denotes varieties originating at Virginia Tech.
Private	Dummy variable where 1 denotes a variety that was both developed and licensed by the private sector.
Public	Dummy variable where 1 denotes a public variety.
Exclusive	Dummy variable where 1 denotes a variety developed by a university and licensed by the private sector.
Tempdev	Deviations of annual mean temperature from mean of all annual temperatures from 1991 to 2018 for the test location.
Precdev	Deviations of annual mean precipitation from mean of all annual precipitation from 1991 to 2018 for the test location.

Source: Temperature and precipitation data are taken from National Climatic Data Center historical data. All other data are from Virginia Tech wheat and barley field trials.

Table 2: Summary statistics of selected variables.

	Mean (Barley)	Std Dev (Barley)	Mean (Wheat)	Std Dev (Wheat)
Yield	101.506	26.099	74.946	17.767
Notill	.005	.070	.055	.228
Treated	.004	.061	.052	.222
VT	.717	.451	.440	.496
Private	.002	.049	.195	.396
Public	.132	.338	.063	.243
Exclusive	0	0	.053	.224
N	20263	-	67221	-

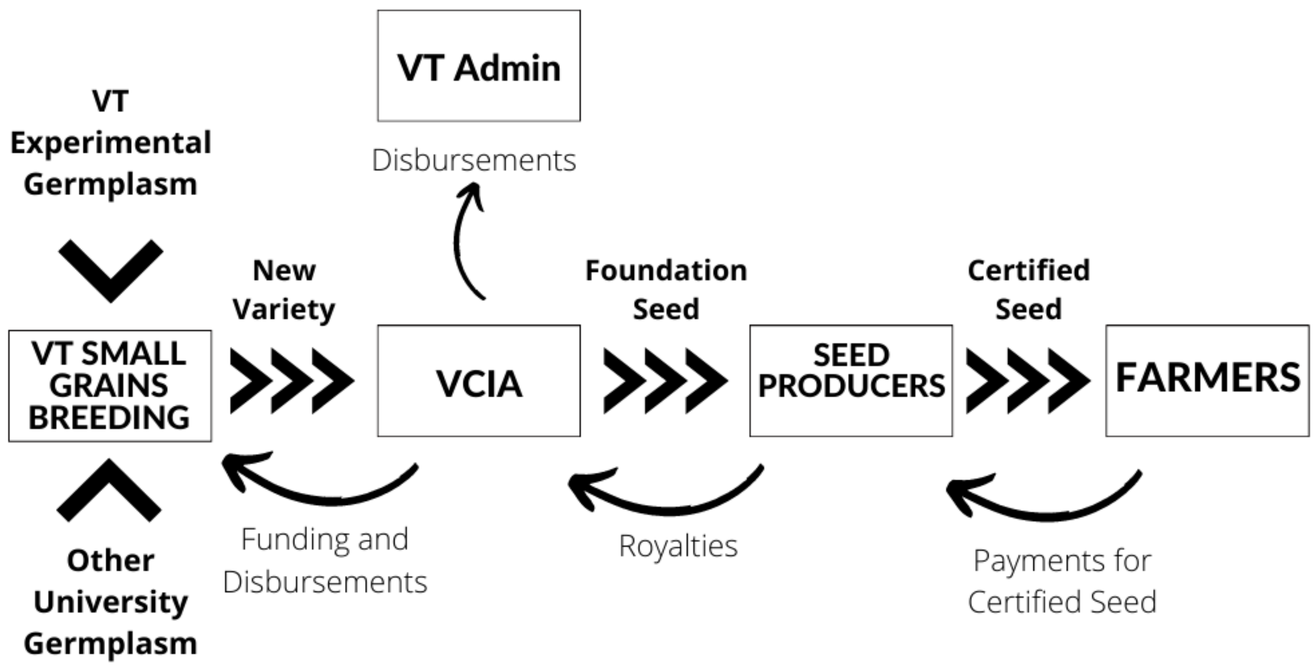


Figure 1: Flowchart describing the creation, licensing, and distribution of public varieties created by the Virginia Tech small grains breeding program and the movement of revenues, royalties, and funding from these varieties.

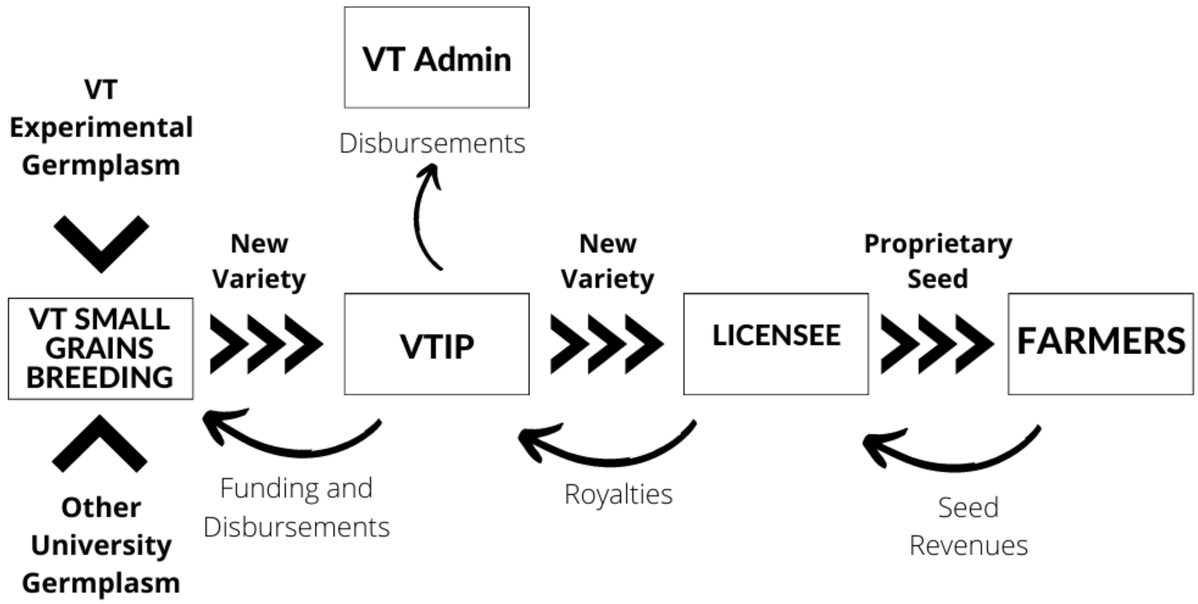


Figure 2: Flowchart describing the creation, licensing, and distribution of exclusive varieties created by the Virginia Tech small grains breeding program and the movement of revenues, royalties, and funding from these varieties.

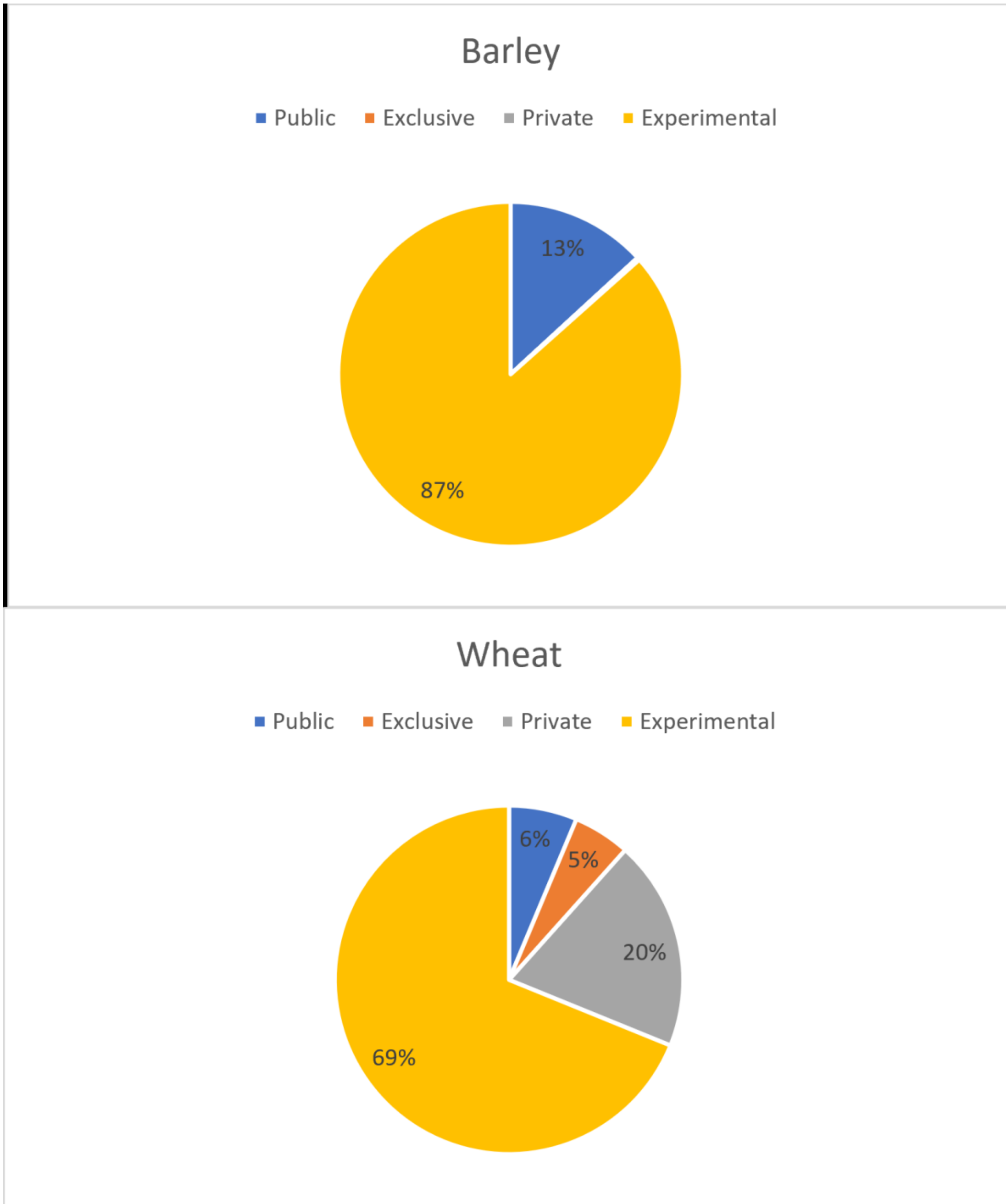
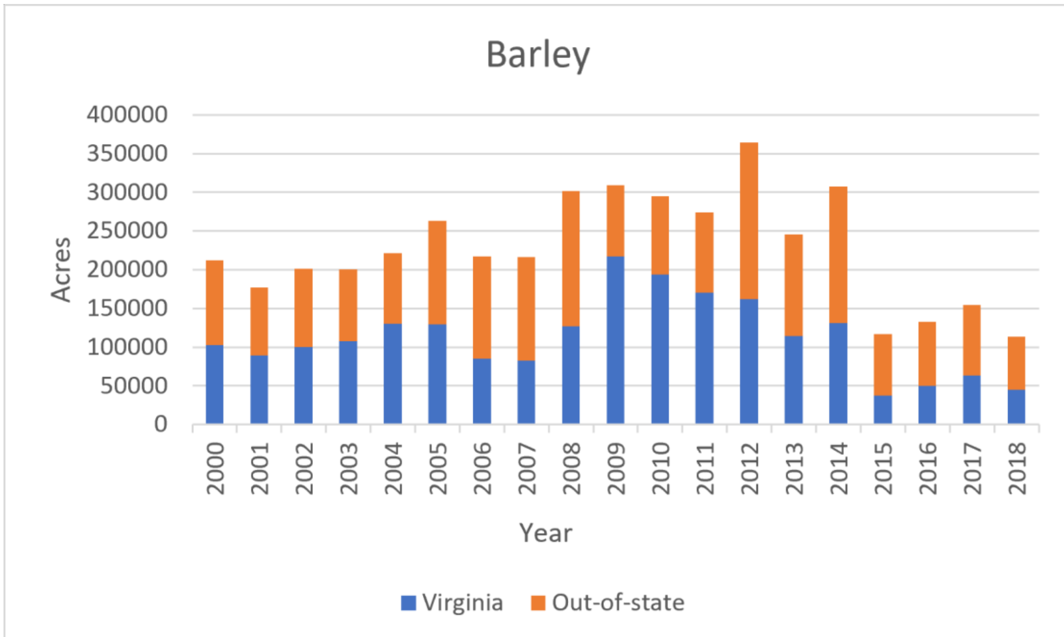


Figure 3: Distribution of germplasm used in wheat and barley field trials by origin. Source: Virginia Tech wheat and barley field trial data.



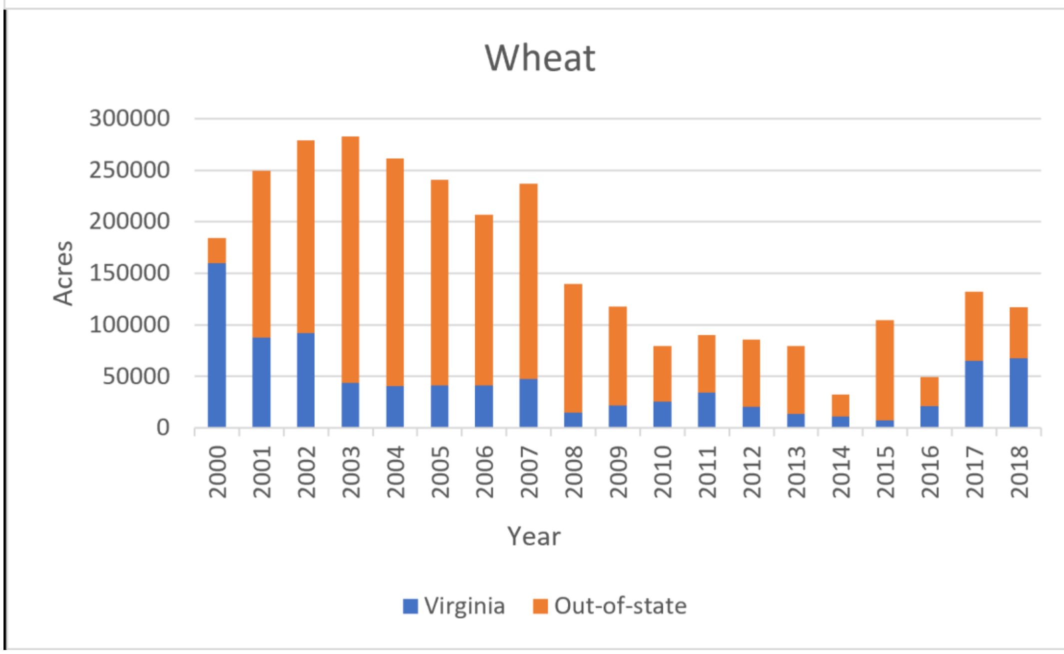


Figure 4: Acres planted of public wheat and barley varieties, 2000-2018. Source: Virginia Crop Improvement Association and Virginia Tech Intellectual Properties royalty reports.

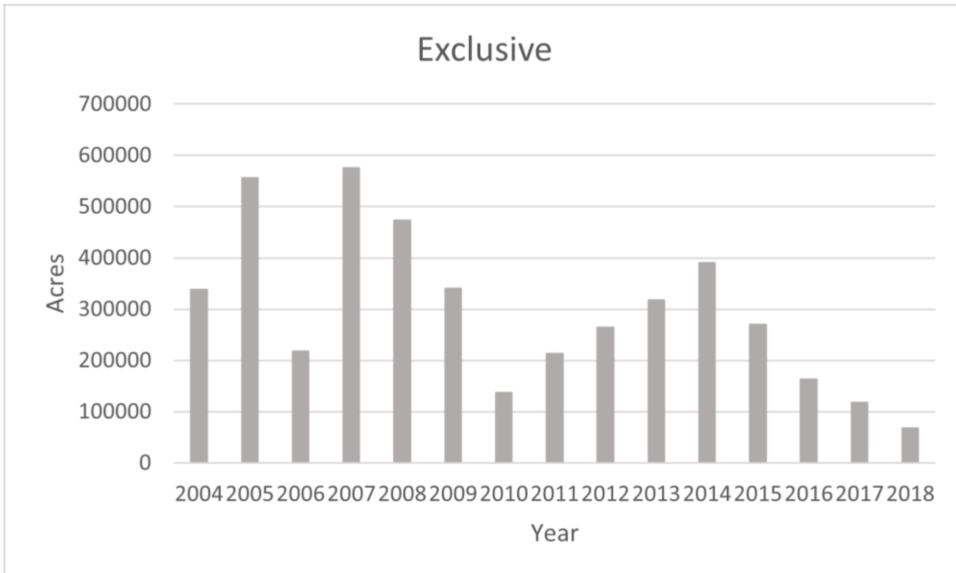


Figure 5: Acres planted of exclusive wheat varieties, 2004-2018.
Source: Virginia Crop Improvement Association and Virginia Tech Intellectual Properties royalty reports.

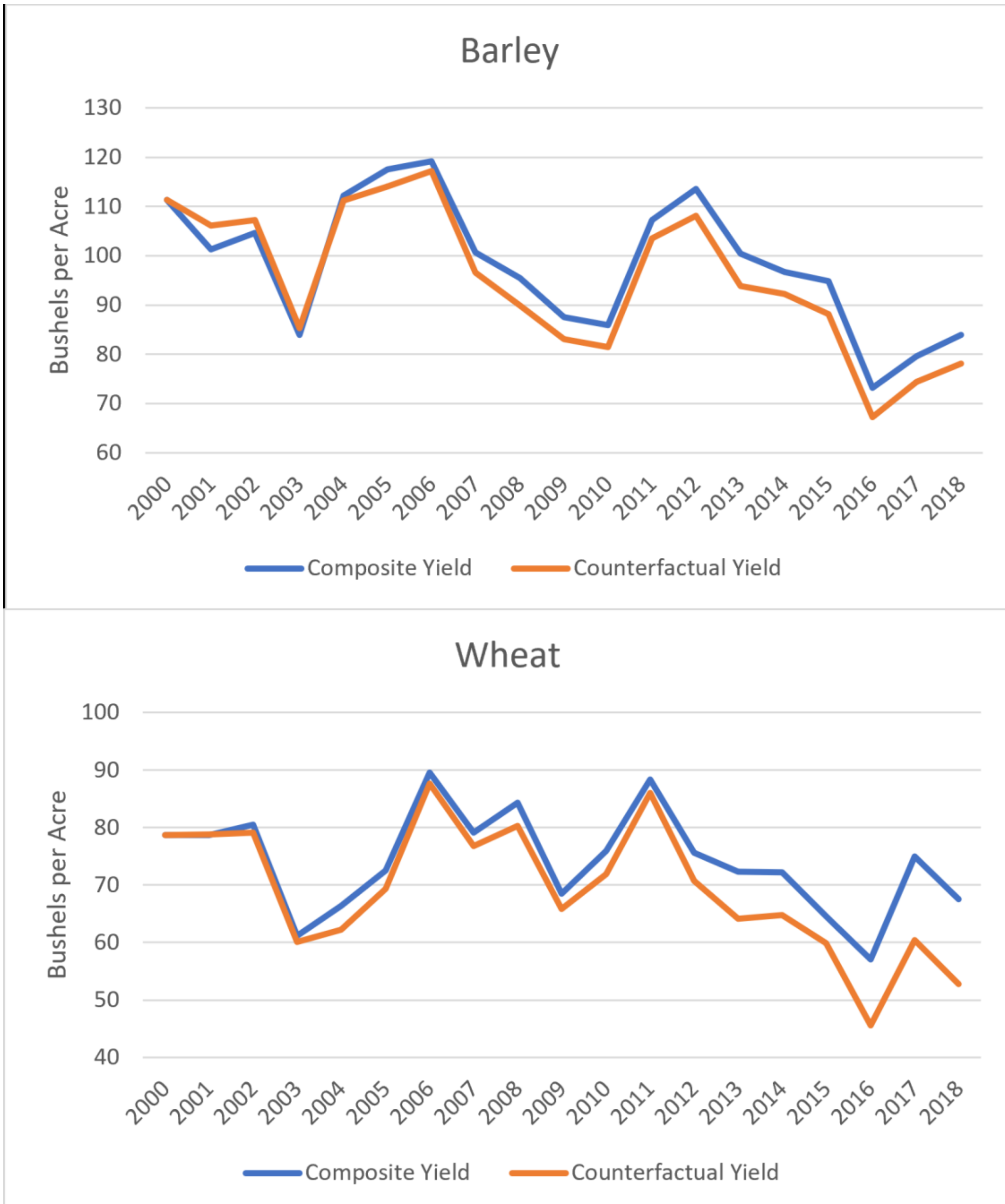


Figure 6: Composite and counterfactual yields by year for public wheat and barley varieties, 1991-2018.
Source: Virginia Tech wheat and barley field trial data fitted values.

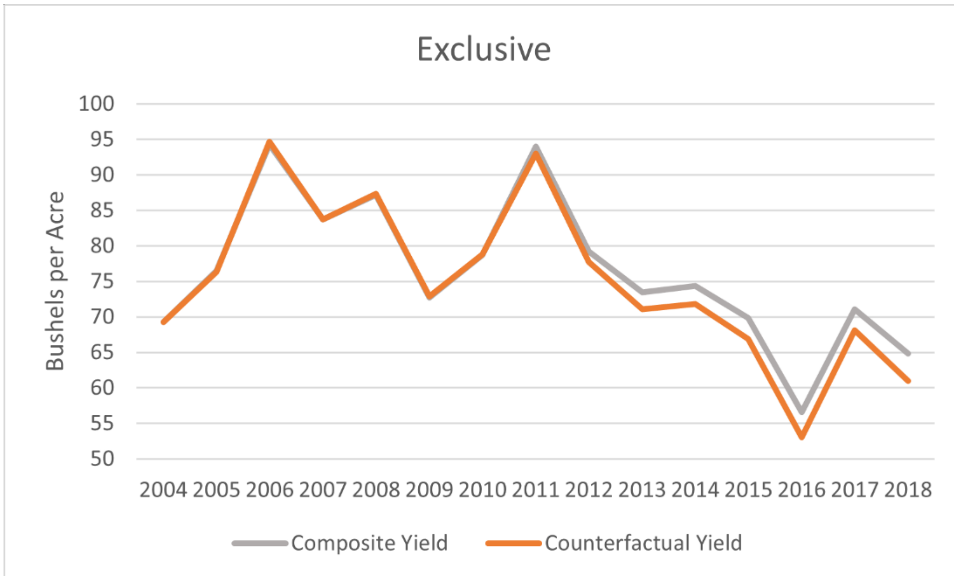


Figure 7: Composite and counterfactual yields by year for exclusive wheat varieties, 2004-2018.
Source: Virginia Tech wheat and barley field trial data fitted values.

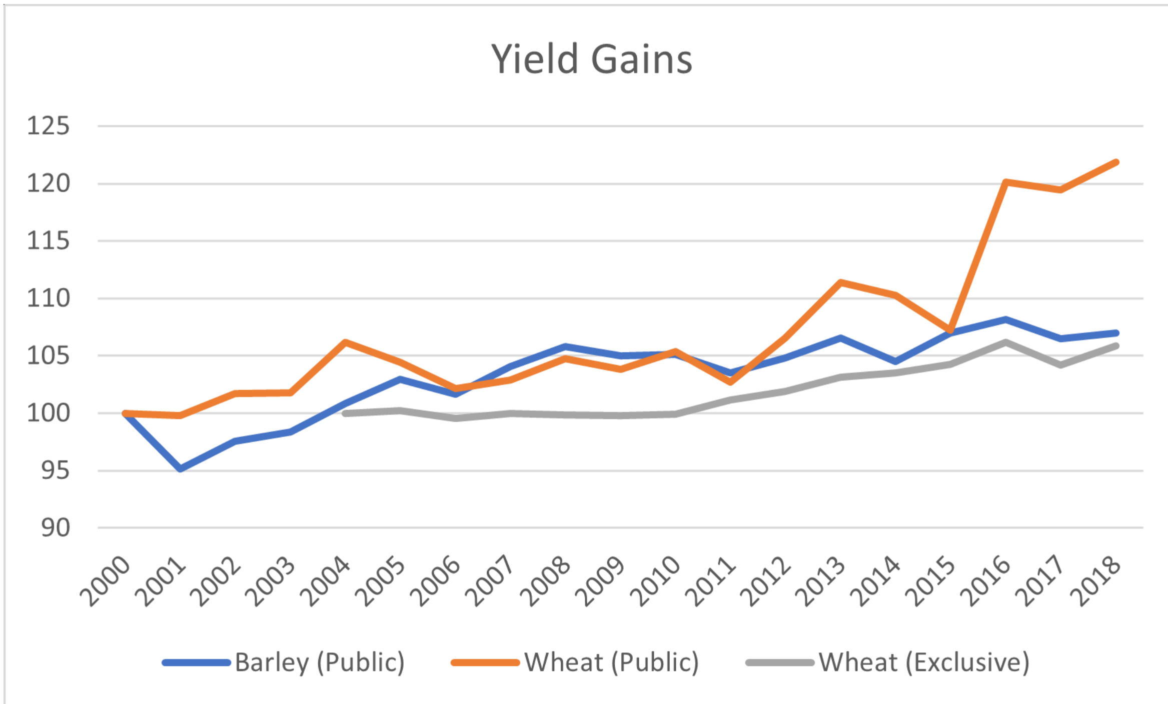
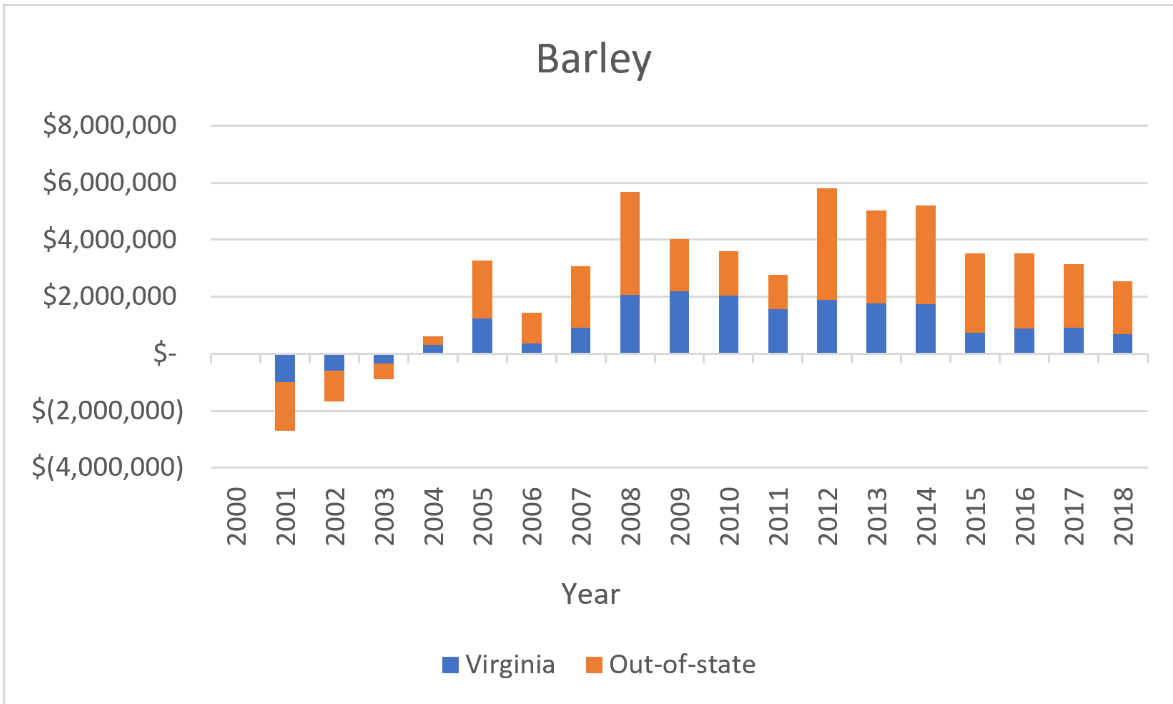


Figure 8: Wheat and barley yield gains (k_t) relative to base, public and exclusive, 2000-2018.
Note: 100 denotes value in base year (2000 for public varieties and 2004 for exclusive varieties).
Source: Virginia Tech wheat and barley field trial data fitted values.



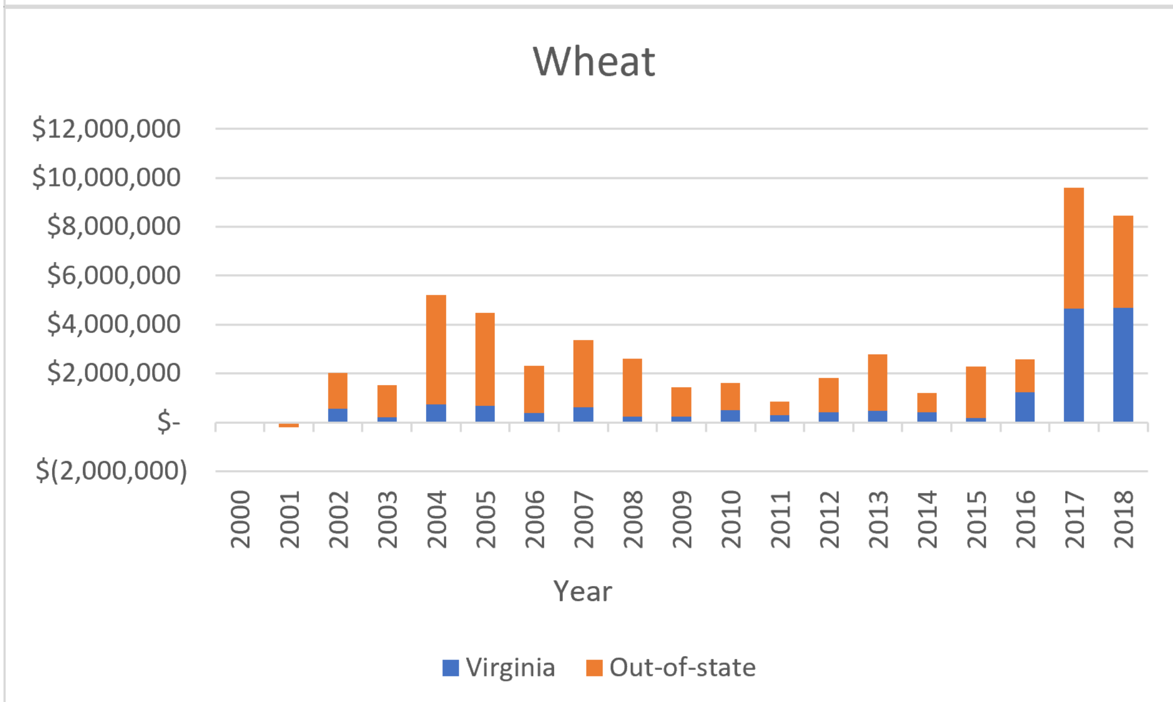


Figure 9: Public wheat and barley variety production attributable to VT research by location and year, in 2018 dollars, 2000-2018
Source: Virginia Tech wheat and barley field trial data, Virginia Crop Improvement Association royalty reports, and Virginia Tech Intellectual Properties royalty reports.

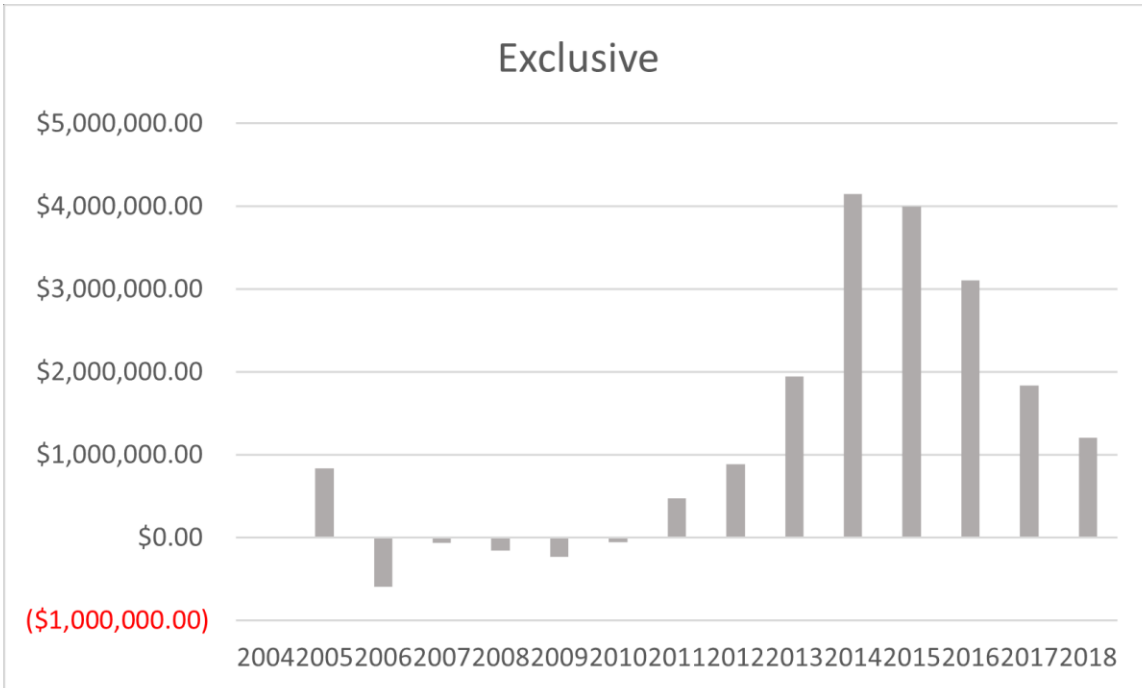


Figure 10: Exclusive wheat variety production attributable to VT research by location and year, in 2018 dollars, 2004-2018
Source: Virginia Tech wheat and barley field trial data, Virginia Crop Improvement Association royalty reports, and Virginia Tech Intellectual Properties royalty reports.

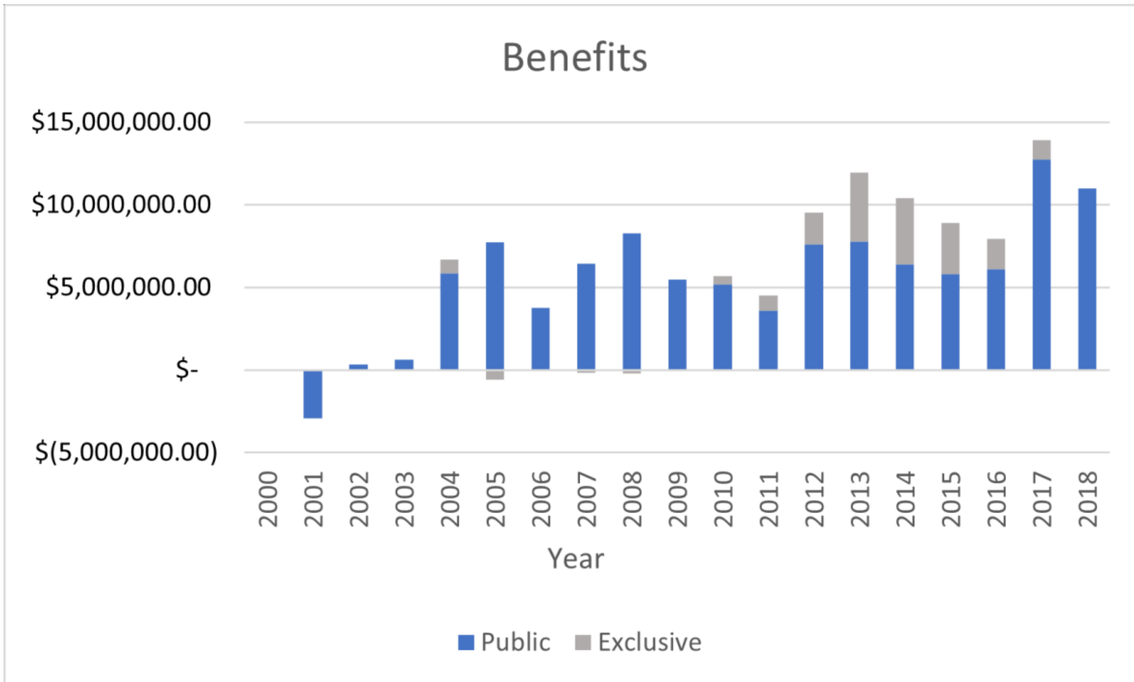


Figure 11: Total program benefits from public and exclusive varieties by year, in 2018 dollars, 2001-2018.
Source: Virginia Tech wheat and barley field trial data, Virginia Crop Improvement Association royalty reports, and Virginia Tech Intellectual Properties royalty reports.

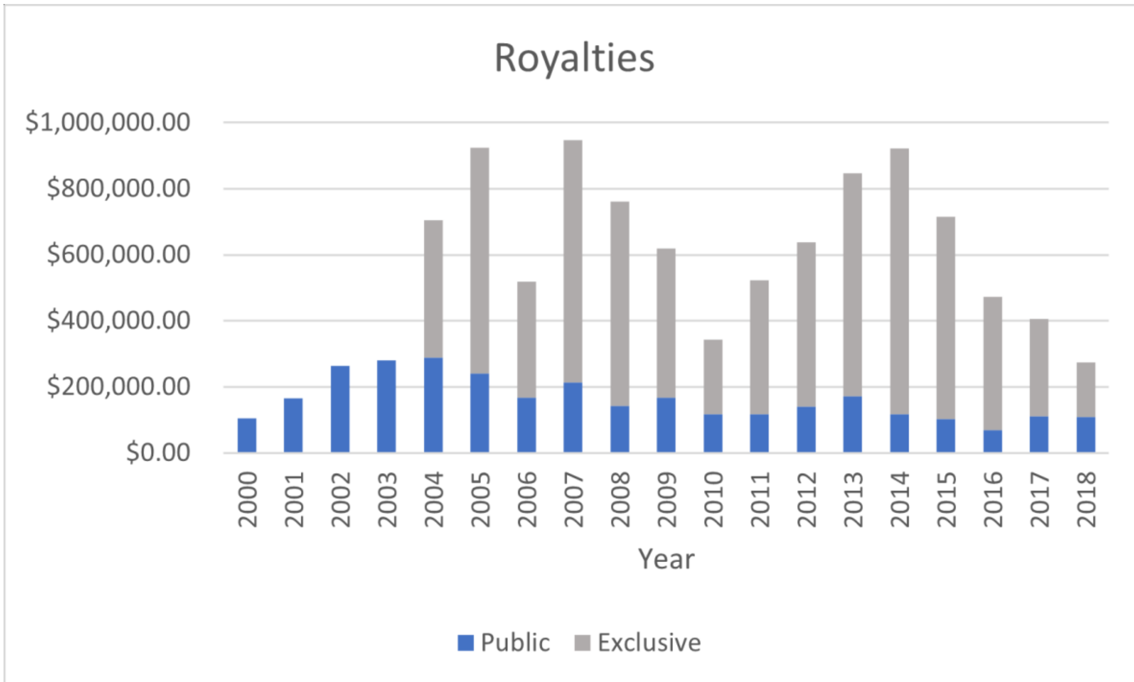


Figure 12: Public and exclusive variety royalty payments by year, 2000-2018. Source: Virginia Crop Improvement Association and Virginia Tech Intellectual Properties royalty reports.

Chapter IV: Conclusion

Broadly, this thesis finds that the College of Agriculture and Life Sciences programs studied here yield significant benefits. However, the shape those benefits take may be complex (as in the case of the VQA program) and the sources of support for those benefits may be nuanced (as in the case of small grains breeding).

The work presented here also suggests that there is plenty of research yet to be done on impact assessment of public agricultural programs within the United States. In the case of small grains breeding, impact assessment is common when releasing a new variety internationally, where researchers wish to know more about the effects of specific interventions and funding organizations wish to know the impact of the money they spend. Storied careers and Nobel Prizes have been founded on such research. In the United States, however, relatively little research is done on the impact of varietal research, even though improved varieties from public programs were a major early step in the agricultural growth of the United States and even though the very public programs responsible for these varieties are in clear decline. There is a story here to be told about the benefits of such research, and substantial benefits to farmers stand to be lost if this story is not told.

In the case of feeder cattle certification research, the story has been told for a long time, but the focus continues to shift. Many of the fundamental theoretical and empirical frameworks used decades ago are still relevant today, but the discussion continues to center around price, which is of great interest to economists, rather than profits, which are the main concern of farmers. Although established techniques continue to be useful in the analysis of these programs, there is potential for feeder cattle research to become even more relevant by shifting to a farmer-centric focus and incorporating methods that complement this focus.

For land-grant universities and the people who run them, impact assessment remains a critical tool, both for resource allocation and nuanced understanding of the programs they oversee. Good impact assessment can combine the hands-on knowledge of program implementers with (relatively) unbiased empirical analysis in a single concise, readable package. When administrators are informed, they are better positioned to allocate people, funds, and other support in a way that better serves both the university and the public.

In order to conduct the best research possible, two things are absolutely imperative: good data and strong working relationships between program implementers and impact assessment researchers. The first charge is in the hands of implementers and the university itself. Records should be kept as accurately and consistently as possible, and program implementers should either keep copies of such records themselves or know with which partner organizations they can be found. If a researcher shows up to study a program that administrators consider important but finds that adequate records have not been kept, they cannot then conjure accurate results out of thin air.

The second charge—strong relationships—falls on both researchers and implementers, although it is arguably the role of researchers to reach out first. Impact assessment researchers are not subject matter experts on the programs they study. Even if they happen to have an intimate understanding of the commodity or subject at hand, they cannot understand the program itself as well as the people who work with it every day. Thus, impact assessment can only be truly successful when both researchers and implementers are invested in producing a high-quality, accurate assessment of the program. This thesis serves as an example: without extensive help and advice from the people in charge of VQA and small grains breeding at Virginia Tech, both of these papers would have been simply impossible. However, with the commitment of researchers, implementers, and administrators, impact assessment can be a tool for the improvement of both university programs and the public benefit.

Appendix A: Beef and the Bottom Line Stata Code

Cleaning and Transformations

```
gen logp=ln(price)
egen mkt=group (mktname)
gen logwt= ln(avgwt)
gen loghd= ln(numhead)
gen totwt= (numhead*avgwt)/100
gen range= maxwt-minwt
gen corn=0
replace corn =[price] if year==[year] & month==[month]
```

Summary t-*tests* (Table 2)*:*

```
ttest numhead, by (vqacert)
ttest avgwt, by (vqacert)
ttest frame, by (vqacert)
ttest muscle, by (vqacert)
ttest heifer, by (vqacert)
ttest flesh, by (vqacert)
ttest pctblk, by (vqacert)
ttest natural, by (vqacert)
ttest home, by (vqacert)
ttest price, by (vqacert)
ttest logp, by (vqacert)
ttest logwt, by(vqacert)
ttest loghd, by(vqacert)
```

Lots by Market (Table 3)*:*

```
tab mkt
```

Price and Head by Certification Status and Year (Table 4)*:*

```
bys year: ttest price, by (vqacert)
bys year: ttest numhead, by (vqacert)
```

Regression 1 (Table 5)*:*

```
regress logp i.vqacert i.month i.year, robust
```

Regression 2 (Table 5)*:*

```
regress logp i.vqacert i.month i.year i.mkt, robust
```

Regression 3 (Table 5)*:*

```
regress logp logwt loghd i.mkt i.vqacert i.heifer i.natural i.home i.month i.year frame muscle
flesh pctblk logcorn, robust
```

Regression 4 (Table 5)*:*

```
regress logp logwt loghd i.mkt i.vqacert i.heifer i.natural i.home i.month i.year i.year#i.vqacert
frame muscle flesh pctblk logcorn, robust
```

Regression 5 (Table 6)*:*
regress logwt i.vqacert i.heifer pctblk logcorn i.month i.year i.mkt, robust

Histogram (Figure 1)*:*
histogram month, discrete frequency addlabel ytitle(Number of Lots) xtitle(Month) by(, title(Distribution of Lots subtitle(By VQA Status and Month)) by(vqacert)

Appendix B: Outstanding in the Field R Code

Location Cleaning and Transformations

```
wheattrials$loccode[which(wheattrials$loccode==[old location code])]=[new location code]

wheattrials$loccode_2 <- 0
wheattrials$loccode_2[which(wheattrials$loccode==[old location code])]=[new location code]
```

Line cleaning

```
wheattrials$linecode[which(wheattrials$linecode==[old line code])]=[new line code]
```

Origin variable coding

```
wheattrials$public <- 0
wheattrials$public[which(wheattrials$linecode==[line code])]=1

wheattrials$exclusive <-  0
wheattrials$exclusive[which(wheattrials$linecode==[line code])]=1

wheattrials$private <-  0
wheattrials$private[which(wheattrials$linecode==[line code])]=1

wheattrials$vt <- 0
wheattrials$vt[which(wheattrials$linecode==[line code])]=1
```

Appendix C: Outstanding in the Field Stata Code

Cleaning and Transformation

```
destring yield, replace force
destring tstwt, replace force
gen treated = 0
replace treated =1 if trt=="yes"
gen notill = 0
replace notill =1 if loccode_2==4
replace loccode_2=7 if loccode_2==4
```

Weather Codes

```
gen precdev= 0
replace precdev=[precipitation deviation from mean] if year ==[year] & loccode_2==[location code]
gen tempdev=0
replace tempdev=[temperature deviation from mean] if year==[year] & loccode_2==[location code]
```

Summary Statistics (Table 2)*:*

```
summarize yield notill treated vt private public exclusive
```

Regression:

```
regress yield i.linecode i.notill i.treated i.year i.loccode_2 tempdev precdev
estat hettest
rvfplot
```

Fitted Values:

```
predict pred_yield
tabstat pred_yield, by (linecode)
```

Yields by year:

```
egen yldyr= mean (pred_yield), by (linecode year)
```