Seed Potato Certification and Potato Virus Y: An Economic Assessment

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This thesis of Jeremy Rosenman, submitted for the degree of Master of Science with a Major in Applied Economics and titled "Seed Potato Certification and Potato Virus Y: An Economic Assessment," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

"The Optimal Tolerance for PVY in Certified Seed Potatoes" proposes a new standard for seed potato certification based on the results of post-harvest laboratory tests rather than field inspections. We model the commercial and seed potato markets and evaluate the legitimacy of our model using historical potato production data. We then use our model to find the optimal standard for seed potato certification in terms of post-harvest test results.

"Estimating the Economic Impact of In-Season PVY Spread" models the spread of PVY from infected seed stock to uninfected plants during the growing season. Using these models, we developed a tool that allows commercial potato growers to estimate the in-season spread of PVY based on seed-bourn infection level. The tool also estimates the profit/loss due to seed potato quality vs. a baseline of 2% seed-borne PVY.

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DEDICATION

To my incredible parents, Robby & Pam, for all their support.

To Katie, for inspiring me.

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INTRODUCTION

The commercial potato crop is grown not from seeds but from pieces of potatoes harvested during the previous season that are known as seed potatoes. A form of vegetative propagation, this method is vulnerable to the emergence of diseases over successive generations due to both a lack of genetic diversity and the ability of a pathogen to survive within seed potatoes from one season to the next. Failure to manage seed potato crops and remove infected seed potatoes from the market can lead to decreased yields or even crop failure among commercial producers.

In an effort to mitigate the impact of tuber-borne diseases commercial potatoes are now almost exclusively grown from certified seed potatoes. To be certified, seed potatoes must be produced in accordance with standards set by state-level certification agencies and pass a number of inspections during and after the growing season. Certified seed potatoes are produced under a limited generation system that regularly removes old seed lines and introduces new genetic material into the market that is disease free.

We investigate seed potato certification with a focus on Potato Virus Y (PVY), an economically relevant pathogen that can reduce overall yield and cause damage to tubers, rendering them unmarketable. A seed-borne/aphid-transmitted disease, PVY is a significant concern to commercial potato producers; failure to manage PVY over successive years can lead to crop losses nearing 100% in extreme cases.

The first chapter "The Optimal Tolerance for PVY in Certified Seed Potatoes" models the commercial and seed potato industry in Idaho and proposes a new certification standard regarding PVY based on laboratory test results rather than the current method, which relies on visual field inspections. The second chapter "Estimating the Economic Impact of In-Season PVY Spread" uses experimental data to model the in-season spread of PVY within commercial potato fields. Using these models we developed a tool for commercial growers to estimate the in-season spread of PVY and communicate the economic value of high-quality of seed potatoes.

CHAPTER 1: THE OPTIMAL TOLERANCE FOR PVY IN CERTIFIED SEED POTATOES

Introduction

Vegetativly propagated crops such as potatoes are susceptible to the accumulation of viral and bacterial pathogens over the course of successive generations, a process known as degeneration. Major potato producing states have developed seed potato certification programs to provide commercial growers with seed potatoes of both higher quality and less quality variation. Certified seed potatoes must be produced in accordance with certification agency standards and meet prescribed tolerances for economically important potato diseases and parasites. Seed potatoes are produced via a limited generation system, with inspection tolerances increasing for older generations.

Among the potato diseases managed through seed certification programs is Potato Virus Y (PVY), one of the most economically serious pathogens faced by commercial potato producers. With regards to PVY, certification of a seed lot is based on field inspections which look for foliar mosaic, a common symptom of the virus. For a seed lot to be eligible for re-certification, which allows the seed to be re-planted for the production of a successive seed generation, it must pass a winter grow-out test. For this a sample of tubers from the seed lot are planted, grown, and then laboratory tested for the presence of PVY. The results of these post-harvest tests do not influence the certification status of a seed lot and are not shared with the buyers of certified seed.

The certified seed potatoes used by commercial growers are generally four field-grown generations removed from the laboratory produced microtubers used to begin seed lines. As such the certified seed potato lines used by commercial growers must have met both field inspection and winter grow-out test tolerances for PVY over several successive years. Field inspections are less reliable than the grow-out testing; the appearance of foliar mosaic in infected plants varies across both potato variety and virus strains. As such we feel that whether a seed lot meets the re-certification standard to be a more accurate and reliable measure of seed potato quality.

Using a model of the Idaho potato industry (commercial and seed potatoes) we seek to estimate the economically optimal standard based on post-harvest test results. This is not necessarily the complete absence of seed-borne PVY (0% infection rate) since infection level and seed potato price are inversely related. The optimal certification standard will be the point at which the marginal benefit of increasing seed potato quality is overtaken by the increase in the marginal cost of seed potatoes faced by commercial growers.

Previous Academic Work

Academic literature regarding the economics of seed potatoes and seed potato certification systems is extremely limited. Contemporary work on the subject primarily focuses on potato production in Africa, where seed potato quality is low (Fuglie, 2007, Gildemacher et al. 2009). Within much of the developing world certification systems are lacking or nonexistent (Hirpa et al. 2010, Gildemacher et al. 2010); this makes such research of limited use when addressing seed potatoes in North America, which has well-developed seed potato certification systems and some of the highest quality seed potatoes in the world (Frost et al, 2013).

If we ignore the potatoes and focus on the minimum quality standards implemented by seed potato certification systems a large swath of economic research become applicable to our study. We begin of course with Akerlof's seminal 1978 paper "The Market for Lemons". Commercial potato producers face the same issue of asymmetric information when determining the quality of seed potatoes as that of the car buyer in the article; this article finally provided economic justification for a system implemented in the early 1900's. Derivative works including, Ronnen (1991), and Garella & Petrakis (2008) further investigate the problem; consistently finding that minimum quality standards are effective at mitigating the social cost imposed by asymmetric information on markets. Leland (1979) discusses both the use of minimum quality standards within markets and how these standards are likely to be too high when set by the profession or industry which they regulate and may serve as a barrier to entry.

Theoretical Model

This section describes the theoretical model we use to determine the optimal standards for seed potato certification. We will assume that both the certified seed potato market and the commercial potato market are perfectly competitive. The standard for seed potato certification *S*, will determine the quantity of certified seed potatoes produced and the quality of those seed potatoes in terms of the commercial yield they produce.

We let $f(S)$ be the fraction of seed potatoes entered for certification that are certified under the standard. If the standard increases (becomes stricter) the fraction certified will decrease so $f' < 0$. We assume concavity, so $f'' < 0$. If Q_0 equals the quantity of seed potatoes entered for certification then $Q_C = f(S)Q_0$ is the quantity of seed potatoes that are certified.

We let $g(S)$ be the ratio between quantity of commercial potatoes sold (Q_P) and the quantity certified seed potatoes planted, (Q_S). We assume a closed market (which implies $Q_S = Q_C$) so that

$g(S) = Q_P/Q_C$. As yield will increase under a stricter standard $g' > 0$. We assume diminishing returns so $g'' < 0$. The objective function for commercial potato growers is therefore given by,

$$\pi_P = P_P g(S) Q_C - P_C Q_C - c_P(Q_C) \quad (1)$$

Where P_P is the price for commercial potatoes received by producers, P_C is the price of certified seed potatoes, and $c_P(Q_C)$ is the cost of growing commercial potatoes except for the price of certified seed potatoes. The first order condition with respect to Q_C is given by,

$$\frac{d\pi_P}{dQ_C} = P_P g(S) - P_C - c_P^{\prime(Q_C)} = 0 \quad (2)$$

Under the assumption of a perfectly competitive commercial potato market, potato growers make zero economic profit and are price takers. The market price for seed potatoes is therefore given by,

$$P_C = P_P g(S) - \frac{c_P(f(S)Q_0)}{f(S)Q_0} \quad (3)$$

From this equation we see that the market price for certified seed potatoes depends on the market price of commercial potatoes, the certification standard, and the average cost besides seed of growing commercial potatoes. Given the market price for certified seed potatoes the objective function for certified seed potato growers is given by,

$$\pi_{SP} = P_P g(S) f(S) Q_0 - c_P(f(S)Q_0) - c_{SP}(Q_0) \quad (4)$$

Where $c_{SP}(Q_0)$ is the cost of growing certified seed potatoes. If certified seed growers optimize with respect to the certification standard the first order condition is given by,

$$\frac{d\pi_{SP}}{dS} = P_P\big((g'(S)f(S) + g(S)f'(S)\big) - c_P'(f(S)Q_0)f'(S) = 0 \quad (5)$$

Using equation (2) this can be reduced to,

$$f(S) = \frac{-P_C f\prime(S)}{P_P g'(S)} \quad (6)$$

If the certified seed potato growers are optimizing in a competitive market this equation should hold. If standards are too strict the possibility exists that seed potato growers are exerting market power by limiting quantity produced to increase the price of certified seed potatoes.

Data & Analysis

Data for the analysis was drawn from numerous sources. Production data for Idaho comes from the USDA National Agricultural Statistical Service. Seed certification data for Idaho was provided by the Idaho Crop Improvement Association. Post-harvest testing results from numerous states was provided by Cornell University. Production costs for commercial and seed growers were estimated using Idaho AgBiz bi-annual crop budgets produced by University of Idaho Extension. Data regarding the impact of seed-borne PVY infection on commercial yield comes from experimental data generated by the University of Idaho from 2010 – 2012. The price received by commercial potato producers was estimated using the Grower Return Index published by North American Potato Market News, additional estimates come from Idaho AgBiz budgets and the NASS Annual Potato Summery. Details on the derivation of the variables is presented in Appendix. Data was analyzed for production years 2002 – 2015; this time frame was dictated by the availability of Idaho certification data.

$f(S)$, the fraction of seed potatoes entered for certification that are certified under a given standard. We estimated $f(S)$ using two sets of post-harvest test results; one covering Idaho from 2008 – 2015, the other covering numerous states, including Idaho, from 2009 – 2015. Visual analysis of this data suggests $f(S)$ has a logarithmic form. See Appendix for specifics.

$f(S^*)$, the fraction of seed potatoes entered for certification that are certified under the current standard S^*. This is computed using two sets of certification data for the State of Idaho; one is overall state certification results covering the years 2002 – 2015, the other is plot-level certification results covering the years 2010 – 2015. Certification of seed lots is based on in-season field inspections, not the post-harvest testing results that are used to compute $f(S)$ above. As only plots that pass in-season inspection are evaluated with the post-harvest grow-out testing we know from the data used to compute $f(S)$ that ~80% of plots that are certified under in-season inspections also meet the current 2% infection standard for post-harvest testing.

Q_S, the quantity of certified seed potatoes planted by commercial growers. We estimate this quantity with seed use estimates from the Idaho AgBiz budgets and the estimated commercial acreage derived from NASS production data. As noted in the discussion of the model we assume this is equal to Q_C as well.

Q_0, the quantity of certified seed entered for certification. This is calculated using the equation $Q_0 = \frac{Q_C}{f(S^*)}$ since no data is available regarding the quantity of potatoes produced by plots that fail certification. This method of estimating Q_0 requires us to assume there is no difference in physical tuber yield per acre between seed plots of the same generation that are certified and those that are not.

Q_P, the quantity of commercial potatoes sold. NASS production data lumps seed and commercial potato sales together so this quantity is estimated; see Appendix for methodology.

$g(S^*)$, the per-unit commercial yield of certified seed potatoes. This is calculated using the equation $g(S) = \frac{Q_P}{Q_C}$.

$g'(S)$, the marginal change in commercial yield of certified seed potatoes in regards to the standard S. Calculated from U Idaho experimental data.

P_P, the price per cwt of potatoes that is received by commercial producers. We use estimates from several sources for this value: the NASS Annual Potato Summery, Idaho AgBiz budgets, and the NAPMS Grower Return Index (GRI). With the GRI data we found an annual average price and an average price from August to March of each growing season (the period before which sprout inhibitor is applied to stored potatoes). We also find a weighted GRI for each growing season using monthly farm marketing shares from the Annual Potato Summery.

P_C, the price per cwt for certified G3 seed potatoes paid by commercial producers (and received by seed potato producers). This value come from Idaho AgBiz budgets. The AgBiz budgets list the price per cwt of seed and the cutting cost per cwt separately under the more general "Seed" budget category; we include cutting cost when calculating P_C except where noted.

$c_P(Q_C)$, the cost per cwt of certified seed planted of growing commercial potatoes besides the cost of certified seed. Bi-annual Idaho AgBiz production and storage budgets were used to estimate these costs. Potato production budgets are available for odd-numbered years, even years use the following year's budget data (so 2014 uses 2015 budget values). Operating cost, total cash cost, and total cost were estimated. Costs are per cwt of certified seed planted for consistency in units.

The overall cost of growing commercial potatoes is a combination of production costs and on-farm storage cost. Not all production is stored on-farm, so storage costs are not paid by all producers. This required the estimation of $c_P(Q_C)$ for various shares of total state production being stored on-farm; we estimate for a range between 30% and 70% with the assumption that storage rates are constant across all budget regions.

$c_{SP}(Q_0)$, the cost per cwt of certified G2 seed potatoes planted of growing certified seed potatoes. This data comes from Idaho AgBiz production budgets; even years similarly use the following year's budget data and the same three different cost levels as $c_P(Q_C)$ were calculated.

Results

In the discussion of the results we focus on estimates that are calculated using the Total Cash Cost estimate of $c_P(Q_C)$. Estimates of Total Cash Cost include operating expenses, land rent, insurance, fees, and interest payments. It excludes capital depreciation and other costs that do not impact short term cash flow.

The analysis of equation (1) supports our assumption that the commercial potato market is competitive. Table 1.1 summarizes the estimated profit per cwt from the 60 permutations we calculated. When we calculate profits with $c_P(Q_C)$ equal to total cash cost we find mean profits are zero when on-farm storage levels range between about 40% and 60%, depending on the estimate of $P_P$used.

Table 1.1: Estimated Profit of Commercial Producers per cwt

P_P	$c_P(Q_C)$	Mean π_P per cwt for given share of Q_P stored on-farm				
		30%	**40%**	**50%**	**60%**	**70%**
Composite Budget	Operating Cost	$1.87	$1.80	$1.74	$1.68	$1.61
	Total Cash Cost	$0.14	**$0.03**	-$0.07	-$0.18	-$0.28
	Total Cost	-$0.33	-$0.43	-$0.54	-$0.64	-$0.75
Annual Summery	Operating Cost	$2.04	$1.98	$1.91	$1.85	$1.79
	Total Cash Cost	$0.31	$0.21	$0.10	**$0.00**	-$0.11
	Total Cost	-$0.15	-$0.26	-$0.36	-$0.47	-$0.57
Average GRI	Operating Cost	$1.95	$1.89	$1.82	$1.76	$1.70
	Total Cash Cost	$0.22	$0.12	**$0.01**	-$0.09	-$0.20
	Total Cost	-$0.24	-$0.34	-$0.45	-$0.56	-$0.66
Weighted GRI	Operating Cost	$1.81	$1.75	$1.68	$1.62	$1.56
	Total Cash Cost	$0.09	**-$0.02**	-$0.13	-$0.23	-$0.34
	Total Cost	-$0.38	-$0.48	-$0.59	-$0.69	-$0.80

We must consider whether the range of 40% - 60% accurately reflects the share of commercial production that is stored on-farm. The commercial Idaho potato crop is generally harvested in September and October; for our period of investigation an average of 22% of total farm sales occur during these two months. If we assume this share of sales is not stored on farm (going directly from field to the market) than we must account for the storage of 78% of commercial production. To have the share of commercial production stored on farm fall into the 40% - 60% range would require at least 18% of total commercial production, or 23% of the production that is stored, to be stored somewhere other than where it is grown.

The analysis of equation (3) suggests the estimates for P_C from the Idaho AgBiz budgets are reasonable when we use the total cash cost $c_P(Q_C)$ values in the estiamtion. Comparing prices estimated by equation (2) and the composite budget estimate of P_C we see agreement between the two when the on-farm storage share is between 40% - 60%, again depending on the value of P_P used. The estimates of P_C in Table 1.2 assume that all possible rents are captured by certified seed potato producers.

Table 1.2: Estimated Price of Certified Seed Potatoes per cwt

P_P	$c_P(Q_C)$	**Mean P_C per cwt for given share of Q_P stored on-farm** vs mean composite budget price of $12.65/cwt				
		30%	**40%**	**50%**	**60%**	**70%**
Composite Budget	Operating Cost	$45.30	$44.20	$43.09	$41.99	$40.89
		$32.65	$31.55	$30.44	$29.34	$28.24
	Total Cash Cost	$15.09	**$13.25**	$11.40	$9.56	$7.71
		$2.44	**$0.60**	-$1.25	-$3.09	-$4.94
	Total Cost	$6.98	$5.13	$3.28	$1.43	-$0.42
		-$5.67	-$7.52	-$9.37	-$11.22	-$13.07
Annual Summery	Operating Cost	$48.61	$47.51	$46.40	$45.30	$44.20
		$35.96	$34.86	$33.75	$32.65	$31.55
	Total Cash Cost	$18.41	$16.56	$14.72	**$12.87**	$11.03
		$5.76	$3.91	$2.07	**$0.22**	-$1.62
	Total Cost	$10.30	$8.45	$6.60	$4.75	$2.90
		-$2.35	-$4.20	-$6.05	-$7.90	-$9.75
Average GRI	Operating Cost	$47.63	$46.52	$45.42	$44.32	$43.22
		$34.98	$33.87	$32.77	$31.67	$30.57
	Total Cash Cost	$17.43	$15.58	$13.74	**$11.89**	$10.05
		$4.78	$2.93	$1.09	**-$0.76**	-$2.60
	Total Cost	$9.32	$7.47	$5.62	$3.77	$1.92
		-$3.33	-$5.18	-$7.03	-$8.88	-$10.73
Weighted GRI	Operating Cost	$45.17	$44.07	$42.96	$41.86	$40.76
		$34.25	$33.15	$32.04	$30.94	$29.84
	Total Cash Cost	$14.97	**$13.12**	$11.28	$9.43	$7.59
		$2.32	**$0.47**	-$1.37	-$3.22	-$5.06
	Total Cost	$6.86	$5.01	$3.16	$1.31	-$0.54
		-$4.06	-$5.91	-$7.76	-$9.61	-$11.46

The evaluation of equation (4) suggests that the market for certified seed potatoes is not perfectly competitive when we use the Total Cash Cost estimate of $c_P(Q_C)$. For most estimates (9 of 12) seed producers realize a profit margin > 5% for the composite budget seed price. Table 1.3 summarizes the estimated profit per cwt realized by seed potato producers for the various permutations we analyzed.

Table 1.3: Estimated Profit of Certified Seed Potato Producers per cwt

P_P	$c_{SP}(Q_C)$	Mean π_{SP} per cwt for indicated $f(S^*)$ & Q_0 Source		
		State	County (Acres)	County (Plots)
Composite Budget	Operating Cost	\$33.64	\$32.05	\$30.45
	Total Cash Cost	\$2.41	\$0.80	-\$0.83
	Total Cost	-\$5.90	-\$7.51	-\$9.14
Annual Summery	Operating Cost	\$36.52	\$34.93	\$33.31
	Total Cash Cost	\$5.29	\$3.68	\$2.03
	Total Cost	-\$3.02	-\$4.64	-\$6.28
Average GRI	Operating Cost	\$35.08	\$33.53	\$32.02
	Total Cash Cost	\$3.85	\$2.28	\$0.74
	Total Cost	-\$4.47	-\$6.04	-\$7.58
Weighted GRI	Operating Cost	\$32.78	\$31.26	\$29.77
	Total Cash Cost	\$1.55	\$0.01	-\$1.51
	Total Cost	-\$6.76	-\$8.31	-\$9.82

Solving equation (6) gives us estimates for the optimal value of S, the certification standard (tolerance) for PVY based on laboratory tests. These estimates, summarized in Table 1.4, suggest that the recertification standard of 2% is too strict; we estimate the optimal standard if using the post-harvest test for certification is between 3.5% to 6.8%, depending on the specific permutation of equation (6).

If we drop models 2 & 4, which estimate the optimal S using a subset of the data, we get a tighter bunching of estimates. For estimates with $P_C = seed\ cost$ the optimal S ranges between 3.5% and 5.0%, with a mean of 4.0%. For estimates where $P_C = seed\ cost + cutting\ cost$ the optimal S ranges between 4.0% and 5.7% mean of 4.6%.

Table 1.4: Estimated Optimal Value for S

P_C	P_P	Optimal Value for S by Model						
		1	2	3	4	5	6	Mean
Composite Budget Seed Cost	Composite Budget	5.0%	4.0%	3.6%	4.0%	3.7%	4.4%	4.1%
	Annual Summery	4.9%	3.9%	3.5%	3.9%	3.6%	4.3%	4.0%
	Average GRI	4.9%	3.9%	3.5%	3.9%	3.6%	4.3%	4.0%
	Weighted GRI	5.0%	4.0%	3.6%	4.0%	3.7%	4.4%	4.1%
Composite Budget Seed Cost + Cutting Cost	Composite Budget	5.7%	4.5%	4.1%	4.6%	4.2%	5.0%	4.7%
	Annual Summery	5.6%	4.4%	4.0%	4.5%	4.1%	4.9%	4.6%
	Average GRI	5.6%	4.4%	4.0%	4.5%	4.2%	4.9%	4.6%
	Weighted GRI	5.7%	4.5%	4.1%	4.6%	4.2%	5.0%	4.7%

Conclusions

From the evaluation of our model, specifically equation (6), we believe that if basing certification on post-harvest laboratory test results the standard should be significantly higher than the recertification standard of 2%. Depending on our value for $c_P(Q_C)$ the optimal S is around 4% or 4.5%. The Idaho AgBiz budget includes seed cutting cost as part of the cost of the "Seed" input. We treat this as such when calculating $c_P(Q_C)$ so the estimates which include cutting cost as part of P_C are likely more accurate. Humanity uses a base-10 numeric system; outside of numbers that end in zero those we like best end in 5. Based on our results we would recommend that the certification standard be 4.5%, conveniently close to the 4.6% average of the seed and cutting cost estimate from models using the full dataset.

This recommendation is limited by our model, which assumes the Idaho potato industry operates as a closed economy. In reality this is not the case, only around 30% of the potatoes planted by commercial Idaho growers are Idaho grown. Gathering data on the price and quality of the certified seed potatoes planted within Idaho yet grown outside of it would allow us to improve our recommendation. As the total quantity of certified seed potatoes produced by Idaho seed growers is similar to the total quantity planted by Idaho commercial growers we believe our results hold water despite this.

Our model treats the PVY infection level of a commercial potato field as unchanged during the growing season; this is inaccurate as a seed-borne PVY infection is spread to uninfected plants throughout the growing season. Further development of the model to consider the in-season spread of PVY will provide a better estimation of the optimal standard.

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CHAPTER 2: ESTIMATING THE ECONOMIC IMPACT OF IN-SEASON PVY SPREAD

Introduction

Potato Virus Y (PVY) is among the most serious plant diseases faced by commercial potato growers. Primarily introduced into commercial fields through the use of infected seed potatoes, PVY decreases physical tuber yield and tuber quality and may present foliar mosaic symptoms. Some varieties of PVY can also cause potato tuber necrotic ringspot disease (PTNRD) which can render production unmarketable. Seed-borne PVY can spread to uninfected plants during the growing season, further impacting production. Understanding the relationship between seed-borne PVY and in-season PVY spread during the growing season will help commercial growers manage the impact of the virus and make more informed purchase decisions of certified seed potatoes.

Aphid Transmission of PVY

Infected seed potatoes serve as the main reservoir for PVY in commercial potato fields, though some weed species may play a contributory role (Warren et al., 2005). The virus is spread through mechanical transmission (sap inoculation) and aphid vectors (Nolte et al., 2010). Sap inoculation has been found capable of infecting plants across rows in some varieties (Hane & Hamm, 1999) but is viewed as a slow, inefficient method of viral spread. The aphid vector is the primary concern since it spreads PVY far more efficiently and potentially over a much larger area (Nolte et al., 2010). The ability to spread PVY and other pathogens make aphids a larger threat to commercial growers than defoliators or tuber pests (Radcliffe & Ragsdale, 2002).

The aphid vector can be subdivided into two groups, colonizing aphids and non-colonizing aphids. Colonizing aphids live and reproduce on potato plants and are the most efficient vectors of PVY ("Information on Aphid Vectors", n.d.). Non-colonizing aphids prefer hosts other than potato plants; while moving through potato fields in search of a preferred host theses aphids will taste the sap of the potato plants they come in contact with, potentially spreading the virus from infected to uninfected plants (Schramm et al., 2011).

Aphid transmission of PVY is non-persistent; aphids that probe an infected plant and acquire the virus lose the ability to transmit it after just a few probes of uninfected plants (Difonzo et al., 1997; Schramm et al., 2011). Because it is transmitted non-persistently there is no incubation period within the aphid vector, the virus can be transmitted almost immediately after it is picked up from an infected plant (Warren et al., 2005). Transmission of the virus occurs in a matter of seconds (Halbert et al., 2003). While non-colonizing aphids are much less efficient vectors than colonizing aphids they cannot be effectively managed with pesticides (Radcliffe, 1982). The ineffectiveness of insecticides, the nature of non-persistent viral transmission, and their vast numbers in potato producing areas may make non-colonizing aphids the major vector for PVY transmission in commercial potato fields (Halbert et al., 2003).

PVY & Seed Potato Certification

Given the difficulties in combating PVY transmission through aphid vectors, commercial producer's best method of managing PVY is through the use of certified seed. Certified seed potatoes are seed potatoes that are produced, inspected, graded, and handled in accordance with the regulations of a seed certification agency (Bohl et al, 1992). By using certified seed, commercial producers obtain seed of both higher average quality and less variation in quality than they would from non-certified seed stock (Carlson & Main, 1976).

Certified seed potatoes are produced under a limited generation system, in which seed growers are limited in the number of times they may replant a given seed line to produce certified seed. All seed potato lines originate from laboratory tested parental stock; the specific terminology for how many generations a given seed lot is removed from this parental stock differs depending on certification agency (summarized in Table 2.1). Commercial growers primarily purchase seed 4 – 7 generations removed from the laboratory stock (Bohl et al, 1992).

For seed lots to be certified they must pass two visual inspections during the growing season, which are conducted by the state seed certification agency. The allowable level for well-defined foliar mosaic (a visual symptom of PVY) varies by generation; field inspection standards for Idaho are summarized in Table 2.2. Following the harvest of seed lots that pass both field inspections, tuber samples are grown over the winter and laboratory tested for PVY. Seed lots that test above 2% PVY in post-harvest testing are not eligible to be re-certified the following year. Having passed both field inspections these seed lots may still be sold as certified seed if they pass shipping point inspections, which do not screen for PVY.

Table 2.1: Limited Generation Certified Seed Potatoes – Field Planting Equivalency Table[a]

Certification Agency	Year in Field[b,c]							
	1	2	3	4	5	6	7	8
Alaska	G1	G2	G3	G4	G5	G6	G7	G8
California	G1	G2	G3	G4	G5	--	--	--
Colorado	G1	G2	G3	G4	G5	G6	--	--
Idaho	N	G1	G2	G3	G4	G5	G6	--
Maine[f]	FY1	FY2	FY3	FY4	FY5	--	--	--
Michigan[f]	FY1	FY2	FY3	FY4	FY5	FY6	--	--
Minnesota	G1	G2	G3	G4	G5	G6	C	--
Montana	N	G1	G2	G3	G4	G5	--	--
Nebraska/Wyoming	N	G1	G2	G3	G4	G5	--	--
Nevada	N	G1	G2	G3	G4	G5	--	--
New York[d]	(U)G1	U(G2)	U(G3)	G4	G5	G6	--	--
North Dakota	N	G1	G2	G3	G4	G5	C	--
Oregon	N	G1	G2	G3	G4	G5	--	--
Utah	N(G1)	G2	G3	G4	G5	G6	--	--
Washington	N	G1	G2	G3	G4	G5	--	--
Wisconsin[e]	FY1	FY2	FY3	FY4	FY5	FY6	C	--
Canada	PE	E1	E2	E3	E4	F	C	--

Source: Certification Section of the Potato Association of America, revised 12/2017

[a] The purpose of this table is to express equivalency of terms used by carious certification agencies for seed potatoes harvested from a series of successive field plantings. For specific criteria relating to disease tolerances and other requirements the reader is referred to the certification regulations of the agency in question.

[b] The first field planting utilizes laboratory-tested stocks which may be tissue-cultured plantets, greenhouse-produced minitubers, stem cuttings, or line selections. Contact agencies for details as to types of stocks planted in their programs.

[c] Terms used by agency for seed potatoes for a particular year in the field: C = certified, E = elite, F = foundation, G = Generation, N = nuclear, PE = pre-elite.

[d] If lots originate at Cornell-Uihein Farm, the first three generations (G!-G3) are also designated by a (U) to denote source.

[e,f] FY = Foundation Year (Wisconsin), FY = Field Year (Michigan; Maine).

Table 2.2: Field Inspection Tolerances for Well Defined Mosaic

Inspection	Seed Lot Generation					
	Nuclear	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5/6
1st	0.00	0.00	0.50	1.00	1.50	2.00
2nd	0.00	0.00	0.25	0.50	0.75	1.00

Source: Idaho Crop Improvement Association Potato Standards

For seed lots to be certified they must pass two visual inspections during the growing season, which are conducted by the state seed certification agency. The allowable level for well-defined foliar mosaic (a visual symptom of PVY) varies by generation; field inspection standards for Idaho are summarized in Table 2. Following the harvest of seed lots that pass both field inspections, tuber samples are grown over the winter and laboratory tested for PVY. Seed lots that test above 2% PVY in post-harvest testing are not eligible to be re-certified the following year. Having passed both field inspections these seed lots may still be sold as certified seed if they pass shipping point inspections, which do not screen for PVY.

Seed-Borne PVY Infection Levels of Idaho Grown Certified Seed Potatoes

The foliar mosaic symptoms looked for during field inspections are commonly seen in varieties including the Red Norland and Russet Burbank (Nolte et al, 2010). Other varieties such as Russet Norkotah and Shepody display mild or no foliar mosaic symptoms when infected with PVY, complicating the production of high quality certified seed due to the reliance on visual inspection in the certification process (Nolte et al, 2004). As such there is potential for certified seed potatoes to carry higher levels of PVY than the field inspections indicate. Based on post-harvest testing results from 2008 – 2015 an average of 15% of seed potato lots, representing nearly 20% of seed potato acreage, tested above the 2% re-certification threshold (Table 2.3a-b).

Table 2.3a: Post Harvest Testing Results – Share of Plots with Indicated PVY Infection Level

Year	**Tested PVY Infection Level**									
	Not Tested	0%	>0%, ≤0.5%	>0.5%, ≤1.0%	>1.0%, ≤1.5%	>1.5%, ≤2.0%	>2.0%, ≤5.0%	>5.0%, ≤10.0%	>10.0%	>2.0%
2008	0.34%	41.11%	11.58%	12.42%	9.06%	6.88%	11.91%	4.70%	2.01%	18.62%
2009	2.93%	48.54%	13.10%	11.71%	5.55%	4.01%	10.17%	2.31%	1.69%	14.18%
2010	2.20%	59.47%	13.36%	9.99%	4.99%	2.64%	3.52%	2.35%	1.47%	7.34%
2011	3.97%	47.82%	10.90%	10.64%	7.44%	2.18%	8.97%	4.23%	3.85%	17.05%
2012	5.75%	58.41%	9.62%	8.19%	3.98%	2.32%	4.76%	2.99%	3.98%	11.73%
2013	8.41%	50.16%	8.41%	7.15%	5.26%	4.10%	8.52%	2.63%	5.36%	16.51%
2014	6.30%	46.41%	7.93%	9.46%	6.52%	3.70%	10.22%	4.02%	5.43%	19.67%
2015	4.94%	48.74%	10.29%	7.88%	6.30%	3.15%	10.29%	3.99%	4.41%	18.70%
Mean	**4.36%**	**50.08%**	**10.65%**	**9.68%**	**6.14%**	**3.62%**	**8.55%**	**3.40%**	**3.53%**	**15.47%**

Table 2.3b: Post Harvest Testing Results – Share of Acres with Indicated PVY Infection Level

Year	**Tested PVY Infection Level**									
	Not Tested	0%	>0%, ≤0.5%	>0.5%, ≤1.0%	>1.0%, ≤1.5%	>1.5%, ≤2.0%	>2.0%, ≤5.0%	>5.0%, ≤10.0%	>10.0%	>2.0%
2008	0.45%	33.24%	12.73%	13.03%	8.25%	8.11%	16.12%	5.77%	2.30%	24.19%
2009	0.65%	38.95%	16.96%	13.04%	8.56%	5.05%	11.85%	3.42%	1.50%	16.78%
2010	1.32%	47.83%	17.45%	14.25%	6.36%	2.93%	4.30%	3.50%	2.07%	9.87%
2011	1.62%	40.16%	16.38%	14.84%	6.33%	3.27%	11.22%	3.13%	3.05%	17.40%
2012	2.61%	47.51%	13.78%	13.71%	5.56%	4.39%	6.90%	3.87%	1.66%	12.44%
2013	2.26%	36.97%	14.50%	11.07%	7.04%	6.99%	12.92%	3.14%	5.11%	21.16%
2014	2.88%	30.10%	11.10%	12.18%	10.80%	6.87%	15.05%	4.65%	6.38%	26.08%
2015	2.14%	33.35%	14.26%	12.26%	6.97%	3.55%	13.93%	5.69%	7.86%	27.49%
Mean	**1.74%**	**38.51%**	**14.64%**	**13.05%**	**7.48%**	**5.15%**	**11.54%**	**4.15%**	**3.74%**	**19.43%**

From this data it is clear that a significant share of certified seed potatoes have a PVY level above the threshold and will not be eligible for recertification. These seed potatoes are still certified (having passed both field inspections and contingent on passing a shipping point inspection) and can therefore be sold to commercial growers as certified seed potatoes. Commercial growers primarily buy seed potatoes in their 4th to 7th field year (G3 – G6 in Idaho) so we must consider how the variance in PVY infection is distributed across the various seed potato generations. We have plot-level data from 2010 – 2015 (Table 2.4a-b) that breaks down both certified plots and certified acreage by generation; we can use this data to estimate the upper and lower bound for the average PVY infection level of certified Idaho seed potatoes that are planted by commercial producers.

Table 2.4a: Certified Plots by Generation

Year	nuclear	G1	G2	G3	G4	G5	G6
2015	197	150	132	314	56	5	0
2014	198	107	173	337	61	9	0
2013	192	216	120	339	70	5	2
2012	212	94	102	396	45	15	4
2011	106	79	125	345	80	8	5
2010	86	88	118	312	59	9	0

Table 2.4b: Certified Acres by Generation

Year	nuclear	G1	G2	G3	G4	G5	G6
2015	93.877	851.23	5885.49	22232.889	2312.92	28.2	0
2014	92.9409	546.688	5878.384	22575.068	2846.428	439.95	0
2013	59.165	619.87	4710.09	24760.62	2726.05	210	0.2
2012	130.806	508.541	4510.49	26719.4903	2484.17	105.8	2.3
2011	45.3117	488.609	5443.3	24303.677	3507.03	52.93	46.65
2010	47.95	472	5541.72	21026.1	2768.7	191	0

We can estimate the lower bound for PVY infection level by assuming that all G3 and later seed has the lowest infection rate possible. We also assume that any seed lots that were not tested are G3 or later and are free of PVY. To estimate the upper bound for PVY infection level we assume that all G3 and later seed has the worst infection rate possible, including that seed lots that were not tested are G3 or later and tested above 10% PVY. We also assume that yield per acre is constant across all G3 and later seed plots. These two approaches give us the best case and worst-case scenarios respectively for the seed-borne PVY level of G3 and later certified seed potatoes produced in Idaho. Working with the acreage and plot data we can calculate new PVY infection distributions for G3 and later certified seed potatoes (Table 2.5a-b) and use these to estimate the seed-borne PVY levels encountered by commercial growers.

Table 2.5a: Estimated PVY Distribution G3 and Later Certified Seed Potatoes (Plot Data)

Year	% PVY															
	0%		>0%, ≤0.5%		>0.5%, ≤1.0%		>1.0%, ≤1.5%		>1.5%, ≤2.0%		>2.0%, ≤5.0%		>5.0%, ≤10.0%		>10.0%	
	L	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**
2010	100%	7.7%	0.0%	30.4%	0.0%	22.7%	0.0%	11.4%	0.0%	6.0%	0.0%	8.0%	0.0%	5.4%	0.0%	8.4%
2011	100%	0.0%	0.0%	10.2%	0.0%	23.1%	0.0%	16.2%	0.0%	4.7%	0.0%	19.5%	0.0%	9.2%	0.0%	17.0%
2012	100%	5.6%	0.0%	21.8%	0.0%	18.6%	0.0%	9.0%	0.0%	5.3%	0.0%	10.8%	0.0%	6.8%	0.0%	22.1%
2013	100%	5.9%	0.0%	15.9%	0.0%	13.5%	0.0%	9.9%	0.0%	7.7%	0.0%	16.1%	0.0%	5.0%	0.0%	26.0%
2014	90.0%	8.5%	10.0%	13.6%	0.0%	16.1%	0.0%	11.1%	0.0%	6.3%	0.0%	17.4%	0.0%	6.9%	0.0%	20.0%
2015	94.9%	9.3%	5.1%	18.2%	0.0%	13.9%	0.0%	11.1%	0.0%	5.6%	0.0%	18.2%	0.0%	7.1%	0.0%	16.5%

Table 2.5b: Estimated PVY Distribution G3 and Later Certified Seed Potatoes (Acreage Data)

Year	% PVY															
	0%		>0%, ≤0.5%		>0.5%, ≤1.0%		>1.0%, ≤1.5%		>1.5%, ≤2.0%		>2.0%, ≤5.0%		>5.0%, ≤10.0%		>10.0%	
	L	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**
2010	62.8%	33.3%	22.3%	22.3%	14.9%	18.2%	0.0%	8.1%	0.0%	3.7%	0.0%	5.5%	0.0%	4.5%	0.0%	4.3%
2011	52.3%	25.1%	20.5%	20.5%	18.6%	18.6%	8.0%	7.9%	0.6%	4.1%	0.0%	14.0%	0.0%	3.9%	0.0%	5.9%
2012	59.9%	37.3%	16.5%	16.5%	16.4%	16.4%	7.3%	6.6%	0.0%	5.2%	0.0%	8.2%	0.0%	4.6%	0.0%	5.1%
2013	46.1%	25.9%	17.0%	17.0%	13.0%	13.0%	6.5%	8.3%	8.2%	8.2%	9.1%	15.2%	0.0%	3.7%	0.0%	8.7%
2014	40.0%	15.1%	13.5%	13.5%	14.8%	14.8%	8.6%	13.1%	8.3%	8.3%	14.8%	18.3%	0.0%	5.6%	0.0%	11.2%
2015	44.5%	16.5%	17.9%	17.9%	15.4%	15.4%	13.5%	8.7%	4.4%	4.4%	4.4%	17.5%	0.0%	7.1%	0.0%	12.5%

Using these skewed distributions, as well as a flat distribution across generations, we can calculate a weighted average PVY infection level. For each bounded range (0% < PVY% ≤ 0.5%, 2% < PVY% ≤ 5.0%, etc.) we use the midpoint value (0.25% and 3.5% for the mentioned ranges). For plots/acres that test above 10% we use a PVY infection level of 15%. These estimates are summarized in Table 2.6.

Table 2.6: Estimated PVY Levels for G3 and Later Certified Seed Potatoes

Year	Plot Data			Acreage Data		
	Lower Bound	Weighted Mean	Upper Bound	Lower Bound	Weighted Mean	Upper Bound
2010	0.000%	0.737%	1.887%	0.179%	1.004%	1.506%
2011	0.000%	1.446%	3.516%	0.345%	1.374%	1.964%
2012	0.000%	1.164%	3.824%	0.271%	1.065%	1.713%
2013	0.000%	1.512%	6.294%	0.638%	1.783%	2.534%
2014	0.000%	1.711%	5.778%	0.835%	2.207%	3.304%
2015	0.000%	1.540%	5.194%	0.500%	2.371%	3.439%
Mean	**0.000%**	**1.323%**	**4.415%**	**0.461%**	**1.634%**	**2.410%**

The true PVY level for G3 & later certified seed potatoes is unlikely to be near the boundaries; given the distribution of plots and acres above this would require unrealistic mathematical gymnastics, especially at the lower boundary. It is reasonable to think that later generations of seed potatoes have a higher mean infection rate than younger generations, as the limited generation certification program is specifically designed to combat the emergence of diseases in vegetativly propagated crops over time.

Of the two sets of estimates, those based on acreage data are almost certainly more accurate due to variation in average plot size across generations (Table 2.7). Combining this and the expectation of a higher PVY level in later generations suggest the actual level in G3 and later certified seed potatoes is a bit above the acreage data weighted average, likely close to the 2% recertification standard.

Table 2.7: Mean Plot Size by Generation

Year	nuclear	G1	G2	G3	G4	G5	G6
2010	0.56	5.36	46.96	67.39	46.93	21.22	NA
2011	0.43	6.18	43.55	70.45	43.84	6.62	9.33
2012	0.62	5.41	44.22	67.47	55.20	7.05	0.58
2013	0.31	2.87	39.25	73.04	38.94	42.00	0.10
2014	0.47	5.11	33.98	66.99	46.66	48.88	NA
2015	0.48	5.67	44.59	70.81	41.30	5.64	NA
6-Year Mean	**0.48**	**5.10**	**42.09**	**69.36**	**45.48**	**21.90**	**3.34**

Relationship Between Seed-Borne PVY & In-Season PVY Spread

The prevalence of PVY in certified seed potatoes and the near inevitability of aphids appearing in a commercial field means the in-season spread of PVY is a challenge faced by most if not all commercial potato growers. Evaluating the connection between seed-borne PVY and in-season PVY spread was done with the use of experimental data produced by University of Idaho Extension.

Test plots were planted near the Teton Seed Management Area of southeastern Idaho during the 2010, 2011, & 2012 growing seasons. Third generation seed potatoes were harvested the previous season and screened using an Enzyme-linked immunosorbent assay (ELISA) to determine PVY infection status. Infected and uninfected seed potatoes were then separate and stored under identical conditions in the same storage facility until being planted. At planting time, clean and infected seed potatoes were blended to achieve the desired level of seed-borne PVY infection and planted in commercial potato fields.

The experiment was conducted using both Russet Burbank and Russet Norkotah potatoes. For Russet Burbank there were five treatments for 2010-2011 and four in 2012 with varying target levels of in-season PVY spread. For Russet Norkotah potatoes five treatments were used all three years of the experiment. Each treatment had a different target level of in-season PVY spread; there were four replications of each treatment for a total of 20 plots per variety each year except for 2012 when there were 16 plots of Russet Burbank. Seed-borne PVY levels varied within treatment groups as well as across them. After harvest the plants from each test plot were again screened using ELISA to determine the end-of season PVY infection rate for each plot. Treatment targets and observed levels of in-season PVY transmission are summarized in Table 2.8. Seed borne, post-harvest, and in-season PVY levels for each test plot are summarized in Table 2.9a-b. We observe a higher rate of in-season PVY transmission in Russet Norkotah potatoes than in Russet Burbank; there is also significant variation in mean in-season PVY spread across the three years of data (Table 2.10).

Table 2.8: Treatment Target In-Season PVY Transmission Levels by Variety

Variety	Year	Treatment 1 0% Target	Treatment 2 5% Target	Treatment 3 10% Target	Treatment 4 25% Target	Treatment 5 50% Target
Russet Burbank	2010	4.4%	10.2%	16.3%	30.2%	51.3%
	2011	12.0%	13.8%	13.1%	30.9%	49.7%
	2012	6.9%	10.8%	17.2%	30.5%	--
Russet Norkotah	2010	1.9%	7.7%	8.1%	26.3%	50%
	2011	8.2%	14.7%	22.0%	31.5%	58.3%
	2012	1.3%	8.2%	14.5%	29.3%	51.3%

Table 2.9a: Russet Burbank Test Plot Data

2010			2011			2012		
Seed-Borne PVY %	Post-Harvest PVY %	In-Season PVY%	Seed-Borne PVY %	Post-Harvest PVY %	In-Season PVY%	Seed-Borne PVY %	Post-Harvest PVY %	In-Season PVY%
0	2.5	2.5	2.5	7.5	5	5	5	0
5	7.5	2.5	7.5	17.5	10	5	5	0
5	12.5	7.5	10	35	25	5.1	5.1	0
5	5	0	10	22.5	12.5	5.1	5.1	0
7.5	10	2.5	12.5	20	7.5	10.3	15.4	5.1
7.9	7.9	0	12.5	32.5	20	12.5	15	2.5
12.5	7.5	-5	12.5	32.5	20	12.5	12.5	0
12.8	20.5	7.7	15	27.5	12.5	15	15	0
15	15	0	17.5	30	12.5	15.4	23.1	7.7
15	17.5	2.5	17.5	32.5	15	17.5	25	7.5
17.5	17.5	0	17.5	32.5	15	17.9	26.6	8.7
20	22.5	2.5	20.5	59	38.5	18.4	21.1	2.7
27.5	40	12.5	25	42.5	17.5	26.8	34.2	7.4
30	30	0	30	50	20	27	29.7	2.7
30.8	35.9	5.1	32.5	57.5	25	30.6	33.3	2.7
32.5	37.5	5	35.9	60	24.1	37.5	45	7.5
50	55	5	45	65	20			
51.3	61.5	10.2	48.7	77.5	28.8			
51.3	51.3	0	52.5	77.5	25			
52.5	57.5	5	52.5	77.5	25			

Table 2.9b: Russet Norkotah Test Plot Data

2010			2011			2012		
Seed-Borne PVY %	Post-Harvest PVY %	In-Season PVY%	Seed-Borne PVY %	Post-Harvest PVY %	In-Season PVY%	Seed-Borne PVY %	Post-Harvest PVY %	In-Season PVY%
0	0	0	2.4	61.9	59.5	0	0	0
2.5	15	12.5	2.6	33.3	30.7	0	8	8
2.5	10	7.5	9.8	46.3	36.5	2.6	5.1	2.5
2.5	10	7.5	10	67.5	57.5	2.6	5.1	2.5
5	17.5	12.5	10.5	81.6	71.1	5	7.5	2.5
5	20	15	15	85	70	7.5	10	2.5
7.5	22.5	15	20	75	55	7.5	10	2.5
7.5	17.5	10	20	60	40	10	12.5	2.5
7.5	32.5	25	20	65	45	12.8	15.4	2.6
7.7	23.1	15.4	21.1	84.2	63.1	15	17.5	2.5
10	25	15	22.5	80	57.5	15	25	10
13.2	18.4	5.2	23.1	92.3	69.2	17.9	28.2	10.3
25	40	15	25	80.5	55.5	25.6	30.8	5.2
25	35	10	32.5	92.5	60	27.5	35	7.5
25	40	15	35	92.5	57.5	28.2	35.9	7.7
30	55	25	35.9	92.5	56.6	35.9	43.6	7.7
47.5	75	27.5	52.5	97.6	45.1	50	55	5
48.8	61	12.2	52.5	92.5	40	51.3	59	7.7
51.3	66.7	15.4	60.5	97.4	36.9	51.3	56.4	5.1
52.5	60	7.5	67.5	97.5	30	52.5	62.5	10

Table 2.10: Observed In-Season PVY Spread by Variety & Year

Potato Variety	**Mean In-Season PVY Spread %**		
	2010	2011	2012
Russet Burbank	3.3%	18.9%	3.4%
Russet Norkotah	13.4%	51.8%	5.2%

The data gleaned from these test plots was evaluated using both ordinary least squares (OLS) and quantile regression. The aim of quantile regression is to estimate a conditional quantile of the dependent variable, rather than the conditional mean estimated by OLS. Quantile regression is useful in evaluating data with a skewed conditional distribution (Koenker & Hallock, 2001), making it a valuable tool for dealing with the heteroscedasticity often seen is ecological data (Cade & Noon, 2003). The use of quantile regression in addition to OLS analysis gives us a more complete picture of the relationship between Seed-Borne PVY and Post-Harvest PVY levels.

Quantile regression is a generalization of Least Absolute Deviations (LAD), which is equivalent to quantile regression at the median (50th percentile). Whereas OLS minimizes the sum of the squared residuals, LAD minimizes the sum of the absolute value of the residuals. Since the residuals are not squared, LAD is more robust against outliers than OLS. Expanding on LAD, quantile regression imposes an asymmetric penalty on the absolute value of residuals ($|e_i|$), with the asymmetry increasing as the quantile approaches 0 or 1. The quantile regression estimator for the quantile q minimizes the objective function:

$$Q(\beta_q) = \sum_{i:y_i \geq x_i'\beta}^{N} q\left|y_i - x_i'\beta_q\right| + \sum_{i:y_i < x_i'\beta}^{N} (1-q)\left|y_i - x_i'\beta_q\right|, \qquad q \in (0,1)$$

For both varieties of potatoes, we see a much higher rate of in-season PVY spread in 2011 than in 2010 or 2012. As 2011 appears to be an outlier we evaluated the combined 2010 & 2012 data with OLS in addition to individual years and the entire period of investigation. The limited number of observations prevented us from evaluating individual years with quantile regression; all quantile regression models used the entire three years' worth of data. The models for PVY transmission during the growing season for the two varieties are summarized in Table 2.11a-b.

Table 2.11a: Models Generated Using OLS

Variety	Model	Intercept Coefficient	Intercept σ	Seed PVY Coefficient	Seed PVY% σ	R^2	Adjusted R^2
Russet Burbank	3 Year	3.968	2.042	**1.233**	0.079	0.820	0.816
	2010	1.637	1.483	**1.073**	0.053	0.958	0.956
	2011	**11.932**	2.796	**1.294**	0.099	0.905	0.900
	2012	0.238	1.426	**1.194**	0.075	0.947	0.944
	2010/12	1.514	0.996	**1.092**	0.041	0.955	0.954
Russet Norkotah	3 Year	19.850	4.494	**1.164**	0.156	0.489	0.481
	2010	**11.287**	2.152	**1.113**	0.083	0.909	0.904
	2011	**59.214**	4.836	**0.726**	0.149	0.570	0.546
	2012	**3.347**	0.948	**1.089**	0.034	0.982	0.981
	2010/12	**7.582**	1.547	**1.087**	0.058	0.903	0.900

Bold entireties are significant at a 95% confidence level

Table 2.11b: Models Generated Using Quantile Regression

Variety	Model	Intercept Coefficient	Intercept σ	Seed PVY Coefficient	Seed PVY% σ	Pseudo R^2
Russet Burbank	10th Percentile	0	2.153	**1.000**	0.083	0.616
	25th Percentile	-0.556	1.370	**1.111**	0.053	0.622
	50th Percentile	2.500	2.922	**1.183**	0.113	0.583
	75th Percentile	**7.500**	3.434	**1.333**	0.132	0.615
	90th Percentile	16.961	8.542	**1.243**	0.329	0.575
Russet Norkotah	10th Percentile	1.020	0.766	**1.123**	0.027	0.496
	25th Percentile	2.109	2.059	**1.150**	0.072	0.454
	50th Percentile	8.00	6.858	**1.280**	0.238	0.373
	75th Percentile	**34.526**	11.140	**1.201**	0.387	0.195
	90th Percentile	**59.647**	5.182	**0.939**	0.180	0.154

Bold entireties are significant at a 95% confidence level

Tables 2.11a and 2.11b show results for different data sets and estimation approaches, with estimates statistically significant with a p-value<0.05 in bold. For all models (both OLS and quantile) the Seed PVY Coefficient is significant. Each estimated equation can be used to predict the end of season infection rate of a commercial field from the infection rate of the seed potatoes used to plant the field. For example, using the Russet Burbank 3-year OLS estimate, a commercial field of Russet Burbank potatoes planted with seed that had a PVY infection level of 3% will have an infection level of 7.337% come harvest time.

For Russet Burbank, OLS analysis of the 2011 data produce results that differ radically from those using the data from either of the other two years. The 3-year OLS model has an intercept just under 4 and a Seed PVY Coefficient of 1.123. The models generated using 2010, 2012 and combined 2010/2012 data are of similar magnitudes, especially for the Seed PVY Coefficient. OLS using only 2011 data gives remarkably different estimates, especially for the intercept. Furthermore, only for the 2011 model is the intercept significantly different from zero.

The Russet Burbank quantile models have coefficients with similar magnitudes to the OLS models (excluding the 2012 model), save for the intercept coefficient of the 90th percentile model. As many data points at or above the 90th percentile are outliers it is reasonable that a model base on the 90th percentile of a data set will be an outlier as well.

For Russet Norkotah potatoes, OLS analysis of the 2011 data again produces results that differ radically from those using data from either 2010 & 2012. The 3-year OLS model has an intercept just under 20 and a Seed PVY Coefficient of 1.164. Again, the models generated using 2010, 2012, and 2010/2012 data are of similar magnitude, especially the Seed PVY Coefficient. The model generated only from 2012 data is again an outlier with a much higher intercept coefficient and the only Seed PVY coefficient among all OLS models that is less than 1 (0.726). The intercept coefficient is significant for all Russet Norkotah OLS models except of the model created using all three years of data.

The Russet Norkotah 10th percentile, 25th percentile, and 50th percentile quantile regression models have coefficients similar to the 2010, 2012, and 2010/2012 OLS models. The 75th and 90th percentile models have intercept coefficients more in line with the 2012 OLS model; the Seed PVY coefficients for these models are less consistent with the 75th percentile model's coefficient similar to the 2010, 2012, & 20101/2012 OLS models and the 90th quantile model having a coefficient 0f 0.939, near the midpoint of the 2010/2012 and 2011 OLS models

Application of Research - Estimating the Economic Impact of Seed Quality

In-season PVY spread is an issue of real concern for commercial farms, with the potential to have a significant impact on profits. As academic journals are a rather poor method of disseminating the results of research to commercial potato growers we developed an interactive tool that estimates the economic impact of seed-borne PVY on their operations.

We use the 2% PVY threshold for seed lot recertification as our baseline; certified seed with a PVY level below this will add positive economic value, certified seed with a PVY level above this has a negative economic value. Despite the basis of our argument being that certified seed potatoes are a heterogeneous good we assume that price does not vary with quality; since buyers cannot distinguish between seed potatoes of varying quality, variations in quality should not impact the price that seed potato producers are able to charge.

User Input

To use the estimation tool a user selects the potato variety and the seed-borne PVY infection level. They have the choice of using default production values (which approximate the average commercial potato farm in Idaho) or enter custom values for seed price per cwt, planting density (seed used per acre), and total acreage planted; these values are used to estimate the total seed cost for a farming operation.

The user then choses to use or not use our default model; regardless of variety the default is to use the quantile regression model for the 50th quantile. If users chose not to use the default model they are given the choice of available models for the selected potato variety. When building the tool, we chose to omit the Russet Norkotah 2011 linear model and the 75th & 90th quantile models due to the extremely high intercept coefficients. We felt the inclusion of these rather extreme models would detract from our efforts to translate the academic research into a useable tool for potato growers.

User Input		
Potato Variety	Russet Norkotah	
Seed-Borne PVY%	3.00%	
Use Default Production Values (1)	(●) Yes	( ) No
	Default	Custom Values
Seed Price ($/cwt)	$15.00	
Planting Density (cwt/acre)	21.7	
Total Acreage Planted	500	
Total Seed Cost	**$162,750.00**	
Use Default Model (2)	( ) Yes	(●) No
Default Model		
Select Custom Model	3 Yr Norkotah	

Figure 2.1: User Input

Estimated In-Season PVY Spread and Yield Impact

From the user inputs the tool estimates the end of season PVY level and calculates in-season PVY spread during the growing season. Using estimates for yield impact per acre per percentage point of PVY infection the tool then estimates the yield loss per acre due to PVY.

Estimated PVY Emergence and Yield Impact	
Estimated End of Season PVY Infection Rate	14.63%
Estimated PVY Emergence %	11.63%
Modeled Yield Impact per % of PVY Infection	1.174
Estimated per Acre Yield Impact of PVY (cwt)	17.17

Figure 2.2: In-Season PVY Spread and Total Yield Impact of PVY

Seed Performance Comparison

The estimated in-season PVY spread and yield impact from the user input needs some context to be of use to commercial potato growers. We therefore compare the performance of seed matching the user input with five different benchmarks of seed-borne PVY: clean seed (0% seed-borne PVY), the

2010-2015 tested mean (1.63%), the current recertification standard (2%), "bad seed" (5%), and "very bad seed" (10%). End of season PVY level, in-season PVY transmission, and per acre yield impact are estimated using the user-selected model for each of these seed-borne PVY levels.

Seed Performance Comparison						
	User Input	Clean Seed	2010 - 2015 Tested Mean	**Recertification Standard**	Band Seed	Very Bad Seed
Seed-Borne PVY Infection %	**3.00%**	0	1.63%	**2.00%**	5.00%	10.00%
Estimated EOS PVY Infection %	**14.63%**	11.29%	13.11%	**13.51%**	16.85%	22.42%
Estimated PVY Emergence %	**11.63%**	11.29%	11.47%	**11.51%**	11.85%	12.42%
Estimated per Acre Yield Impact (cwt)	**17.17**	13.25	15.39	**15.86**	19.78	26.32

Figure 2.3: Seed Performance Comparison

Economic Impact Comparison

We calculate the economic impact of seed potato quality by comparing the user-input against seed potatoes that meet the recertification standard of 2% seed-borne PVY. For completeness we also compare the other benchmarks used in the seed performance comparison (0%, 1.63%, 5%, & 10%) to the 2% recertification standard. We chose the 2% recertification standard as the baseline because a post-harvest test result above this threshold results in termination of the seed line.

We first calculate the PVY yield impact vs. that expected from seed potatoes with a seed-borne PVY level of 2%. If the yield impact is higher than that of a 2% PVY level it will have a negative impact on revenue compared with our baseline; if it is lower, it will have a positive impact on revenue compared with the baseline. We calculate the revenue impact per acre by finding the difference in yield impact between the recertification standard and the user input (or other benchmarks) and multiplying it by the appropriate price received by commercial producers for their output (Table 2.12).

Table 2.12: Grower Return per cwt by Variety and Market

Potato Variety	Fresh Market Return per cwt	Process Market Return per cwt
Russet Burbank	$8.21	$7.21
Russet Norkotah	$8.96	NA

Knowing the revenue impact of seed quality tells commercial potato producers whether they should be satisfied or unsatisfied with the price paid for certified seed. However, it does not tell them how satisfied or unsatisfied they should be with the price paid for certified seed. We accomplish this by calculating the revenue impact per cwt of seed by dividing the revenue impact per acre by the quantity of seed potatoes planted per acre.

The revenue loss or gain from seed quality can be offset by adjusting the price commercial growers pay for their seed potatoes. Adding the revenue impact per cwt of seed to the price paid per cwt of seed gives us the Indifference Seed Price. Commercial growers should be indifferent between paying the user input price for seed with a 2% PVY level and the indifference seed price for seed potatoes with the user input seed-borne PVY level because profits will be the same under both scenarios.

Economic Impact Comparison vs Recertification Standard						
	User Input	Clean Seed	2010 - 2015 Tested Mean	**Recertification Standard**	Band Seed	Very Bad Seed
Yield Impact Per Acre vs Rectification Standard	**108.24%**	83.53%	96.99%	**NA**	124.71%	165.89%
Revenue Impact of Seed Quality (Fresh Market)	**-$11.71**	$23.41	$4.28	**NA**	-$35.12	-$93.65
Revenue Impact of Seed Quality (Processed Market)	**NA**	NA	NA	**NA**	NA	NA
Revenue Impact Per Cwt of Seed (Fresh Market)	**-$0.54**	$1.08	$0.20	**NA**	-$1.62	-$4.32
Revenue Impact per Cwt of Seed (Processed Market)	**NA**	NA	NA	**NA**	NA	NA
Indifference Seed Price (Fresh Market)	**$14.46**	$16.08	$15.20	**NA**	$13.38	$10.68
Indifference Seed Price (Process Market)	**NA**	NA	NA	**NA**	NA	NA

Figure 2.4: Economic Impact Comparison

Total Economic Impact of Seed Quality

The final component calculates the overall economic impact of seed quality for a farming operation assuming prices are not adjusted to the indifference seed price. This is found through multiplying the per acre revenue impact by the number of acres planted. We chose to include this component as we felt it would be the most effective means to communicate the impact of seed potato quality to commercial growers.

Total Economic Impact of Seed Quality	
Total Revenue Impact of Seed (Fresh Market)	-$6,120.50
Total Revenue Impact of Seed (Process Market)	NA

Figure 2.5: Total Economic Impact of Seed Quality

Potential Applications

Through use of the PVY Economic Impact Estimator both commercial potato growers and certified seed potato producers will be more able to understand the value of high quality seed. As high-quality seed is valuable to both parties this information should encourage a market response towards higher seed quality (lower seed-borne PVY levels).

To get the most out of the tool commercial producers should try various scenarios to get a range of possible outcomes. The default production values approximate the average Idaho commercial potato farm; producers whose operation differ significantly from these defaults, especially in regard to seed price and planting density, should not use them. Commercial producers with more specific information on the quality of seed they use may prefer a different model than the default.

The tool can also be of use to Idaho's seed potato certification agency, the Idaho Crop Improvement Association. By aggregating results for all commercial and seed potato producers within Idaho, policy makers can use this tool to develop seed potato certification standards that improve economic outcomes for both commercial and seed potato producers.

User Input

Potato Variety	Russet Norkotah	
Seed-Borne PVY%	3.00%	
Use Default Production Values	(1) ◉ Yes	○ No
	Default	Custom Values
Seed Price ($/cwt)	$15.00	
Planting Density (cwt/acre)	21.7	
Total Acreage Planted	500	
Total Seed Cost	**$162,750.00**	
Use Default Model	(2) ○ Yes	◉ No
Default Model		
Select Custom Model	3 Yr Norkotah	

Estimated PVY Emergence and Yield Impact

Estimated End of Season PVY Infection Rate	23.34%
Estimated PVY Emergence %	20.34%
Modeled Yield Impact per % of PVY Infection	1.174
Estimated per Acre Yield Impact of PVY (cwt)	27.40

Total Economic Impact of Seed Quality

Total Revenue Impact of Seed (Fresh Market)	-$6,120.50
Total Revenue Impact of Seed (Process Market)	NA

Seed Performance Comparison

	User Input	Clean Seed	2010 - 2015 Tested Mean	**Recertification Standard**	Band Seed	Very Bad Seed
Seed-Borne PVY Infection %	**3.00%**	0	1.63%	**2.00%**	5.00%	10.00%
Estimated EOS PVY Infection %	**23.34%**	19.85%	21.75%	**22.18%**	25.67%	31.49%
Estimated PVY Emergence %	**20.34%**	19.85%	20.12%	**20.18%**	20.67%	21.49%
Estimated per Acre Yield Impact (cwt)	**27.40**	23.30	25.54	**26.04**	30.13	36.97

Economic Impact Comparison vs Recertification Standard

	User Input	Clean Seed	2010 - 2015 Tested Mean	**Recertification Standard**	Band Seed	Very Bad Seed
Yield Impact Per Acre vs Rectification Standard	**105.25%**	89.51%	98.08%	**NA**	115.74%	141.98%
Revenue Impact of Seed Quality (Fresh Market)	**-$12.24**	$24.48	$4.48	**NA**	-$36.72	-$97.93
Revenue Impact of Seed Quality (Processed Market)	**NA**	NA	NA	**NA**	NA	NA
Revenue Impact Per Cwt of Seed (Fresh Market)	**-$0.56**	$1.13	$0.21	**NA**	-$1.69	-$4.51
Revenue Impact per Cwt of Seed (Processed Market)	**NA**	NA	NA	**NA**	NA	NA
Indifference Seed Price (Fresh Market)	**$14.44**	$16.13	$15.21	**NA**	$13.31	$10.49
Indifference Seed Price (Process Market)	**NA**	NA	NA	**NA**	NA	NA

Figure 2.6: PVY Economic Impact Estimator

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APPENDIX: DERIVATION OF VARIABLES

What follows is an overview of the derivation of the variables needed to evaluate the theoretical model from Chapter 1: The Optimal Tolerance for PVY in Certified Seed Potatoes.

$f(S)$

$f(S)$, the share of potatoes entered for certification that are certified under the standard S, is estimated using two data sets of post-harvest tests results that were compiled by researchers at Cornell University. The first data set (Table A.1) contains post-harvest test results for Idaho from 2008 – 2015 showing the share of certified acres and certified plots that tested at various PVY infection levels.

Table A.1: Idaho Post-Harvest Test Results (2008 – 2015)

Year	% of Certified Acres Testing at Indicated PVY Level								
	No Test	**0**	**>0, ≤0.5**	**>0.5, ≤1**	**>1, ≤1.5**	**>1.5, ≤2**	**>2, ≤5**	**>5.0, ≤10**	**>10**
2015	2.14%	33.35%	14.26%	12.26%	6.97%	3.55%	13.93%	5.69%	7.86%
2014	2.88%	30.10%	11.10%	12.18%	10.80%	6.87%	15.05%	4.65%	6.38%
2013	2.26%	36.97%	14.50%	11.07%	7.04%	6.99%	12.92%	3.14%	5.11%
2012	2.61%	47.51%	13.78%	13.71%	5.56%	4.39%	6.90%	3.87%	1.66%
2011	1.62%	40.16%	16.38%	14.84%	6.33%	3.27%	11.22%	3.13%	3.05%
2010	1.32%	47.83%	17.45%	14.25%	6.36%	2.93%	4.30%	3.50%	2.07%
2009	0.65%	38.95%	16.96%	13.04%	8.56%	5.05%	11.85%	3.42%	1.50%
2008	0.45%	33.24%	12.73%	13.03%	8.25%	8.11%	16.12%	5.77%	2.30%
Year	**% of Certified Plots Testing at Indicated PVY Level**								
	No Test	**0**	**>0, ≤0.5**	**>0.5, ≤1**	**>1, ≤1.5**	**>1.5, ≤2**	**>2, ≤5**	**>5.0, ≤10**	**>10**
2015	4.94%	48.74%	10.29%	7.88%	6.30%	3.15%	10.29%	3.99%	4.41%
2014	6.30%	46.41%	7.93%	9.46%	6.52%	3.70%	10.22%	4.02%	5.43%
2013	8.41%	50.16%	8.41%	7.15%	5.26%	4.10%	8.52%	2.63%	5.36%
2012	5.75%	58.41%	9.62%	8.19%	3.98%	2.32%	4.76%	2.99%	3.98%
2011	3.97%	47.82%	10.90%	10.64%	7.44%	2.18%	8.97%	4.23%	3.85%
2010	2.20%	59.47%	13.36%	9.99%	4.99%	2.64%	3.52%	2.35%	1.47%
2009	2.93%	48.54%	13.10%	11.71%	5.55%	4.01%	10.17%	2.31%	1.69%
2008	0.34%	41.11%	11.58%	12.42%	9.06%	6.88%	11.91%	4.70%	2.01%

Using this data, we found the share of certified acres/plots that were tested from each year that would be certified under various values of S (Table A.2); We used this data to estimate f(S).

Table A.2: Share of Tested Specimens at or below Indicated PVY %

Year	% of Tested Certified Acres Meeting Selected Standards						
	0%	≤0.5%	≤1%	≤1.5%	≤2%	≤5%	≤10%
2015	34.08%	48.65%	61.17%	68.29%	71.91%	86.15%	91.97%
2014	30.99%	42.42%	54.95%	66.08%	73.15%	88.64%	93.43%
2013	37.82%	52.66%	63.99%	71.19%	78.35%	91.57%	94.78%
2012	48.78%	62.93%	77.01%	82.72%	87.23%	94.32%	98.29%
2011	40.82%	57.47%	72.56%	78.99%	82.31%	93.71%	96.90%
2010	48.47%	66.15%	80.59%	87.03%	90.00%	94.36%	97.91%
2009	39.20%	56.28%	69.40%	78.02%	83.11%	95.04%	98.49%
2008	33.39%	46.18%	59.27%	67.55%	75.70%	91.89%	97.69%
Year	**% of Tested Certified Plots Meeting Selected Standards**						
	0%	**≤0.5%**	**≤1%**	**≤1.5%**	**≤2%**	**≤5%**	**≤10%**
2015	51.27%	62.10%	70.39%	77.02%	80.33%	91.16%	95.36%
2014	49.54%	58.00%	68.10%	75.06%	79.00%	89.91%	94.20%
2013	54.76%	63.95%	71.76%	77.50%	81.97%	91.27%	94.14%
2012	61.97%	72.18%	80.87%	85.09%	87.56%	92.61%	95.77%
2011	49.80%	61.15%	72.23%	79.97%	82.24%	91.59%	95.99%
2010	60.81%	74.47%	84.68%	89.79%	92.49%	96.10%	98.50%
2009	50.00%	63.49%	75.56%	81.27%	85.40%	95.87%	98.25%
2008	41.25%	52.86%	65.32%	74.41%	81.31%	93.27%	97.98%

The first step in estimating $f(S)$ from this data was to determine its functional from; plotting the data (Figures A.1 & A.2) suggested $f(S)$ to be logarithmic; we rearranged the data to be usable by STATA and ran an OLS regression with the share of acres/plots certified as the depended variable and the log of the standard S as the independent variable. We expressed S as a decimal (1% ≈ .01) and dropped all observations for which $S = 0$ as $\ln(0)$ is undefined.

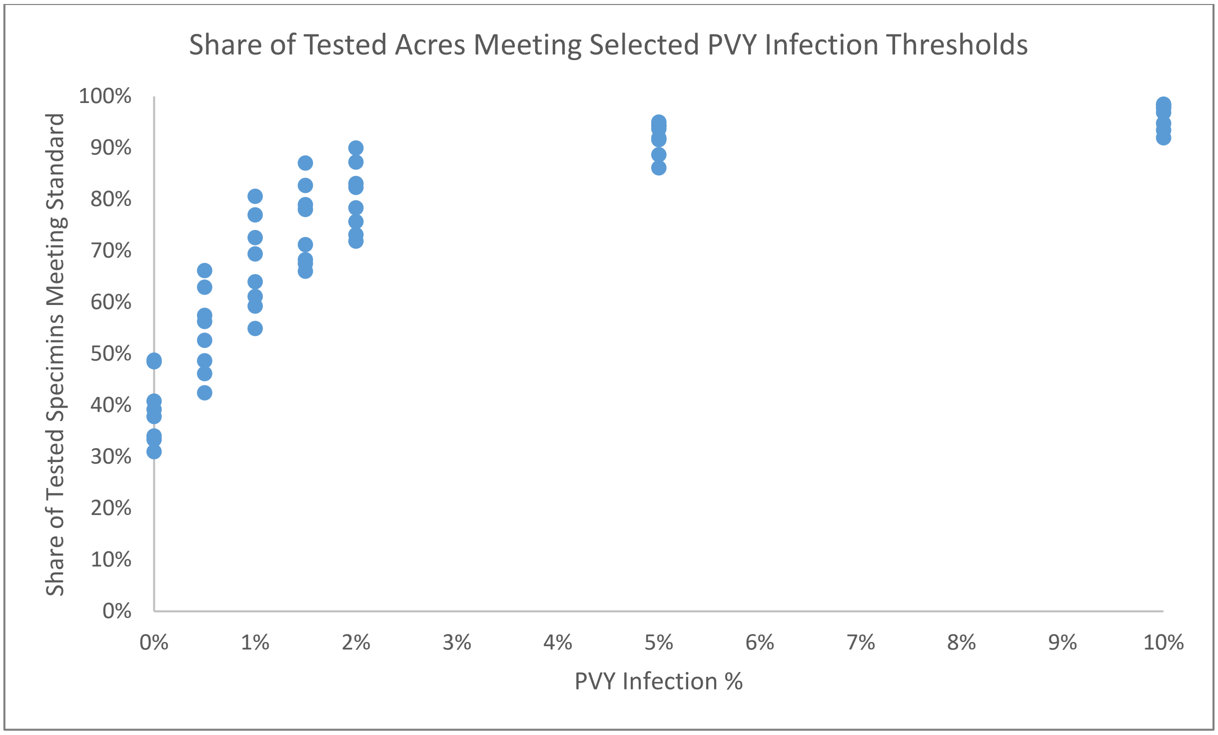

Figure A.1: Share of Tested Acres Meeting Selected PVY Infection Thresholds

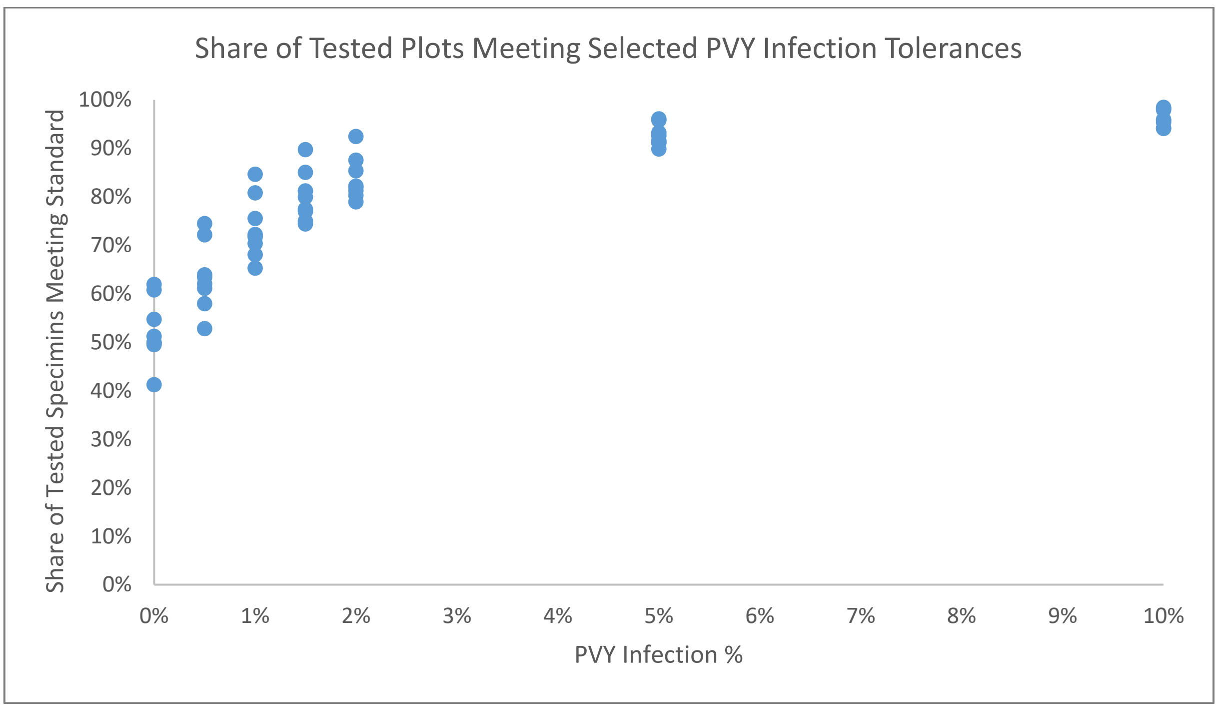

Figure A.2: Share of Tested Plots Meeting Selected PVY Infection Tolerances

For both the acreage data and plot data we modeled the entire data set (with S values of 0.5%, 1%, 1.5%, 2%, 5%, and 10%) and for values of $S \leq 2\%$, which is the current standard. With both acreage and plot data this resulted in the first four models in Table A.3 below.

We were provided with a second set of data covering 7 states from 2009 – 2015, though most of the states only had data from 2009 – 2012. We followed the same process described above but this time with plot data not just from Idaho but from Colorado, Maine, Michigan, Minnesota, Montana, and New York as well (the data for Idaho did not match the data referenced above). This data set was also less precise, with infection thresholds of 0%, 2%, 5%, and 10%; Main data from 2012 – 2014 only reported at the 0%, 2% and 5% levels.

We again used STATA to run OLS regressions with the share of plots certified as the depended variable and the log of the standard S as the independent variable, dropping observations for which $S = 0$. We developed four models from this data set, one using data from all seven states, one using all data from all states except NY, one using data from Colorado, Idaho, & Montana, and a final one using only data from Idaho. These are models 5 – 8 in Table A.3. We constructed one final model for S by combining the Idaho-specific data with the Idaho observations from the multi-state data. This resulted in model 9. All models have a form of: $f(S) = a + b\ln(S)$, where a is the Intercept and b is the Coefficient.

Table A.3: Models of f(S)

Model #	Data Set	Model Name	Intercept	s.e.	Coefficient	s.e	R^2	Adj. R^2	Observations
1	Idaho	Acres	0.673	0.0124	0.1413	0.0101	0.8101	0.806	
2	Idaho	Acres ($S \leq 2\%$)	0.6725	0.0138	0.1888	0.026	0.6368	0.6246	
3	Idaho	Plots	0.7376	0.0092	0.1097	0.0075	0.8218	0.818	
4	Idaho	Plots ($S \leq 2\%$)	0.7374	0.0103	0.1474	0.0194	0.659	0.6476	
5	Multi	All States	0.7557	0.0202	0.0974	0.0123	0.4081	0.4016	
6	Multi	No NY	0.7239	0.0199	0.1101	0.0121	0.512	0.5059	
7	Multi	West	0.7355	0.0322	0.1003	0.0193	0.404	0.3891	
8	Multi	Idaho Only	0.6786	0.0322	0.1163	0.0193	0.657	0.639	
9	Both	Blended ID	0.7304	0.0097	0.1018	0.007	0.758	0.7544	

$\boldsymbol{f(S^*)}$

$f(S^*)$, the share of seed potatoes entered for certification that are certified under the current standard, was calculated using two data sets from the Idaho Crop Improvement Association. The first set of data (Table A.4) documents the number of acres entered for certification, the number of acres certified, and the quantity of certified seed potatoes of all generations produced each year from 2002 – 2015. From this data we can find a yearly value for $f(S^*)$ simply by dividing the number of acres certified by the number of acres entered for certification.

Table A.4: Idaho Seed Potato Certification Data 2002 – 2015

Year	Acres Planted	Acres Certified	Quantity Certified (cwt)
2015	33,334	33,108	7,330,000
2014	32,545	32,366	7,760,000
2013	33,579	33,115	7,500,000
2012	36,153	35,073	7,470,000
2011	34,435	34,039	6,710,000
2010	30,461	30,461	6,480,000
2009	31,950	31,900	6,510,000
2008	30,953	30,832	6,390,000
2007	31,529	31,405	6,890,000
2006	32,393	31,863	6,520,000
2005	31,626	30,969	6,400,000
2004	36,650	36,646	6,600,000
2003	40,363	40,235	7,100,000
2002	41,032	40,780	7,200,000

The second data set (a small piece of which is reproduced in Table A.5) contains data on individual seed plots for 2010 – 2015. This data includes the generation of the seed plot, the county in which the seed plot is located, the number of acres within the seed plot, and the number of acres within the seed plot that are certified.

Table A.5: Idaho Seed Potato Certification Plot Data (Fragment)

2015 Seed Potato Lot Certification Results			
Class	**Acres Applied**	**Acres Accepted**	**County**
G4	3	3	Ada
PVX G1		9.4	Bannock
G4	160	160	Bannock
PVX G1	33.4	33.4	Bannock
PVX G2	28.3	28.3	Bannock

In calculating $f(S^*)$ from this data we first had to decide how to deal with some anomalies that occurred amongst the approximately 5200 lines of data. These anomalies took two forms, either the number of acres certified was greater than the number of acres entered for certification or only some of the acres in a plot were recorded as being certified. The first type of anomaly can be further divided into three subtypes: entries with a blank value for the quantity of acres entered for certification, entries with a large difference between the two values, and entries that appear to be different due to rounding (such as 0.445 acres entered for certification and 0.45 acres certified).

In the case of the first type of anomaly, we dropped entries with a blank value or a large difference between the two values. For entries where the difference appeared to be due to rounding we chose to use the more precise value (continuing from above the 0.45 acres certified would be changed to 0.445 acres certified). These edits were made to avoid nonsensical values of $f(S^*) > 1$. Entries with the second type of anomaly, where only a fraction of a plots acreage was recorded as certified, were also dropped since the certification of a plot is all-or-nothing.

Having made these adjustments to the data we can then calculate $f(S^*)$ for both acres and plots for 2010 – 2015 (Table A.6). To make this data useable for analyzing Equation 4 we use the 2010 – 2015 average for the years 2002 – 2009.

Table A.6: Estimates of f(S^*), the Share of Seed Potatoes Certified under Current Standard

Year	$f(S^*)$ – State	$f(S^*)$ – County (acres)	$f(S^*)$ – County (plots)
2015	0.9932	0.9402	0.9095
2014	0.9945	0.9843	0.9537
2013	0.9862	0.9855	0.9926
2012	0.9701	0.9805	0.9677
2011	0.9885	0.9808	0.9627
2010	1.0000	0.9877	0.9882
2009	0.9984	0.9765 **	0.9624 **
2008	0.9961	0.9765 **	0.9624 **
2007	0.9961	0.9765 **	0.9624 **
2006	0.9836	0.9765 **	0.9624 **
2005	0.9792	0.9765 **	0.9624 **
2004	0.9999	0.9765 **	0.9624 **
2003	0.9968	0.9765 **	0.9624 **
2002	0.9939	0.9765 **	0.9624 **

** 2010 – 2015 average

Q_P

USDA Idaho production data (Table A.7) combines commercial and seed sales into a single total so we must estimate Q_P, the quantity of commercial potatoes that are sold. At the national level the USDA does report commercial and seed sales separately (Table A.8), as well as the fate of production that is not sold. At the national level around 25% of production used where grown is commercial rather than seed. Given that Idaho produces almost 30% of the nation's potatoes we feel it is reasonable to assume that the use of production where it is grown is similar to that of the nation as a whole. Under this assumption we can use national use to estimate use within Idaho.

Table A.7: Idaho Potato Production 2002 – 2015

Year	Acres Planted	Acres Harvested	Production (cwt)	Total Used as Seed (cwt)	Used Where Grown (cwt)	Shrink and Loss (cwt)	Total Sold (cwt)
2015	323,000	322,000	130,400,000	8,060,000	1,089,000	8,420,000	120,891,000
2014	321,000	320,000	132,880,000	7,703,000	890,000	8,630,000	123,360,000
2013	317,000	316,000	131,131,000	7,545,000	1,166,000	8,525,000	121,440,000
2012	345,000	344,000	141,820,000	7,481,000	1,540,000	9,550,000	130,730,000
2011	320,000	319,000	128,760,000	7,935,000	925,000	8,000,000	119,835,000
2010	295,000	294,000	112,970,000	7,584,000	878,000	7,100,000	104,992,000
2009	320,000	319,000	132,500,000	6,844,000	1,000,000	9,200,000	122,300,000
2008	305,000	304,000	116,475,000	7,520,000	908,000	7,150,000	108,417,000
2007	350,000	349,000	130,010,000	6,930,000	945,000	8,700,000	120,365,000
2006	335,000	334,000	128,915,000	7,875,000	1,188,000	8,200,000	119,527,000
2005	325,000	323,000	118,288,000	7,370,000	1,230,000	7,800,000	109,258,000
2004	355,000	353,000	131,970,000	7,260,000	1,250,000	10,902,000	119,818,000
2003	360,000	358,000	123,180,000	7,810,000	1,463,000	8,900,000	112,817,000
2002	375,000	373,000	133,385,000	7,920,000	1,440,000	8,650,000	123,295,000

Table A.8: US Potato Production & Use 2002 – 2015 (1000 cwt)

Year	Total Production	Fresh Sales	Processing Sales	Feed Sales	Seed Sales	Seed Used Where Grown	Other Used Where Grown	Shrink & Loss
2015	441,205	110,960	272,538	919	25,648	3,765	866	26,509
2014	442,170	107,344	280,330	768	22,774	3,343	849	26,762
2013	434,652	106,930	273,506	1,251	22,431	3,215	1,108	26,211
2012	462,766	118,535	283,220	4,080	23,706	3,286	1,583	28,356
2011	429,647	102,655	272,407	825	21,863	3,012	1,130	27,755
2010	404,273	107,407	246,442	593	20,621	3,002	1,218	24,990
2009	431,318	115,083	255,826	6,533	20,219	3,346	1,189	29,122
2008	415,055	109,351	253,424	803	20,900	3,315	823	26,438
2007	444,875	110,860	276,892	1,160	22,297	2,986	1,119	29,561
2006	441,348	101,383	280,044	1,660	23,671	3,503	1,235	29,852
2005	423,926	120,372	245,991	1,999	22,254	3,595	1,196	28,519
2004	456,041	130,418	258,562	1,942	22,915	3,601	1,195	37,408
2003	457,814	133,143	257,226	2,005	24,603	4,000	1,543	35,294
2002	458,171	131,889	262,706	3,044	24,005	4,144	1,478	30,905

For each year of our analysis we used the below process (Figure A.3) to estimate the commercial sales for that year. We assumed that Idaho saw the same percentage of seed used where it was grown as the US. Subtracting this amount from the total used for seed gives us an estimate of the quantity of seed sold if we assume that all seed produced is either used where it is grown or sold. Subtracting estimated seed sales from the total sold gives us a yearly estimate for commercial sales.

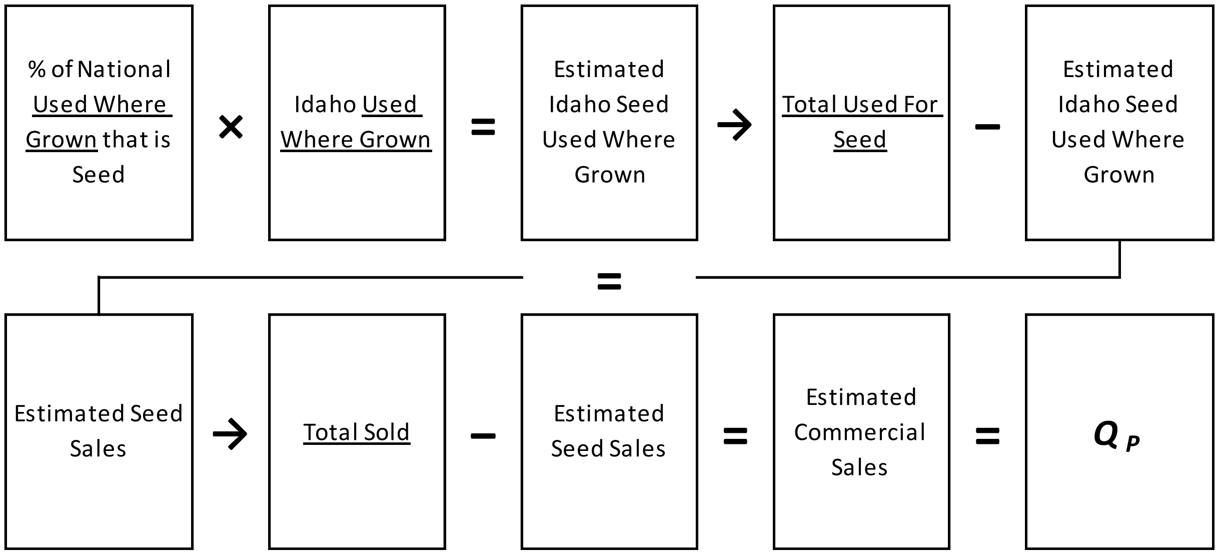

Figure A.3: Process for Estimating Q_P

Composite Budget

In order to evaluate Idaho potato production, we must estimate the production function for the state. Idaho AgBiz produces four different commercial potato production budgets for Idaho in odd-numbered years: one each for the states southcentral and southwest agricultural districts and two for the southeast agricultural district; one for the northern region and one for the south (Table A.9 a-d). For our analysis we used the budget from the following year for even-numbered years: 2003 budget data for 2002, 2005 budget data for 2004, and so on. These budgets estimate the production function and input costs for commercial growers within the indicated geographical area. To evaluate the equations of our theoretical model we needed to derive a state-wide budget covering all commercial production from the regional ones. We accomplish this by creating a composite budget that is a weighted average of the four commercial production budgets.

Table A.9a: Southcentral Agricultural District Production Budget

Year	Yield per acre (cwt)	price received per cwt	cwt seed used per acre	seed cost per cwt	cutting cost per cwt	seeding cost per acre	operating cost per acre less seed	ownership cost per acre (cash)	ownership cost per acre (non-cash)
2015	470	$7.25	23	$12.65	$1.70	$330.05	$1,901.99	$884.56	$188.10
2014	470	$7.25	23	$12.65	$1.70	$330.05	$1,901.99	$884.56	$188.10
2013	455	$7.00	23	$12.50	$1.65	$325.45	$1,907.60	$876.12	$179.99
2012	455	$7.00	23	$12.50	$1.65	$325.45	$1,907.60	$876.12	$179.99
2011	460	$6.88	23	$13.63	$1.83	$355.35	$1,740.95	$829.09	$189.50
2010	460	$6.88	23	$13.63	$1.83	$355.35	$1,740.95	$829.09	$189.50
2009	465	$6.75	23	$14.75	$2.00	$385.25	$1,574.30	$782.05	$199.00
2008	465	$6.75	23	$14.75	$2.00	$385.25	$1,574.30	$782.05	$199.00
2007	450	$5.50	23	$10.20	$1.90	$278.30	$1,611.10	$625.18	$172.77
2006	450	$5.50	23	$10.20	$1.90	$278.30	$1,611.10	$625.18	$172.77
2005	430	$4.90	23	$7.55	$1.55	$209.30	$1,148.88	$515.75	$142.95
2004	430	$4.90	23	$7.55	$1.55	$209.30	$1,148.88	$515.75	$142.95
2003	430	$4.90	23	$8.65	$1.65	$236.90	$1,004.94	$463.25	$108.55
2002	430	$4.90	23	$8.65	$1.65	$236.90	$1,004.94	$463.25	$108.55

Table A.9b: Southeast Agricultural District (North Region) Production Budget

Year	Yield per acre (cwt)	price received per cwt	cwt seed used per acre	seed cost per cwt	cutting cost per cwt	seeding cost per acre	operating cost per acre less seed	ownership cost per acre (cash)	ownership cost per acre (non-cash)
2015	360	$7.00	21	$11.60	$1.70	$279.30	$1,274.07	$648.08	$169.59
2014	360	$7.00	21	$11.60	$1.70	$279.30	$1,274.07	$648.08	$169.59
2013	350	$7.25	21	$11.40	$1.65	$274.05	$1,287.66	$633.74	$164.39
2012	350	$7.25	21	$11.40	$1.65	$274.05	$1,287.66	$633.74	$164.39
2011	360	$7.75	21	$12.95	$1.60	$305.55	$1,186.52	$570.23	$192.30
2010	360	$7.75	21	$12.95	$1.60	$305.55	$1,186.52	$570.23	$192.30
2009	335	$6.75	21	$13.65	$2.00	$328.65	$1,065.59	$535.25	$208.00
2008	335	$6.75	21	$13.65	$2.00	$328.65	$1,065.59	$535.25	$208.00
2007	335	$5.50	20	$8.95	$1.90	$217.00	$844.38	$423.08	$171.81
2006	335	$5.50	20	$8.95	$1.90	$217.00	$844.38	$423.08	$171.81
2005	320	$4.90	20	$6.40	$1.55	$159.00	$730.38	$352.84	$142.32
2004	320	$4.90	20	$6.40	$1.55	$159.00	$730.38	$352.84	$142.32
2003	315	$4.70	20	$7.55	$1.65	$184.00	$627.73	$314.99	$118.89
2002	315	$4.70	20	$7.55	$1.65	$184.00	$627.73	$314.99	$118.89

Table A.9c: Southeast Agricultural District (South Region) Production Budget

Year	Yield per acre (cwt)	price received per cwt	cwt seed used per acre	seed cost per cwt	cutting cost per cwt	seeding cost per acre	operating cost per acre less seed	ownership cost per acre (cash)	ownership cost per acre (non-cash)
2015	425	$7.25	21	$12.10	$1.70	$289.80	$1,708.84	$764.37	$171.94
2014	425	$7.25	21	$12.10	$1.70	$289.80	$1,708.84	$764.37	$171.94
2013	415	$7.25	21	$11.95	$1.65	$285.60	$1,690.02	$718.79	$167.13
2012	415	$7.25	21	$11.95	$1.65	$285.60	$1,690.02	$718.79	$167.13
2011	410	$7.75	21	$13.50	$1.60	$317.10	$1,535.37	$635.11	$186.15
2010	410	$7.75	21	$13.50	$1.60	$317.10	$1,535.37	$635.11	$186.15
2009	395	$6.75	21	$14.20	$2.00	$340.20	$1,363.32	$600.20	$208.00
2008	395	$6.75	21	$14.20	$2.00	$340.20	$1,363.32	$600.20	$208.00
2007	385	$5.50	21	$9.30	$1.90	$235.20	$1,131.98	$477.10	$185.48
2006	385	$5.50	21	$9.30	$1.90	$235.20	$1,131.98	$477.10	$185.48
2005	380	$4.90	21	$6.75	$1.55	$174.30	$983.40	$405.63	$153.66
2004	380	$4.90	21	$6.75	$1.55	$174.30	$983.40	$405.63	$153.66
2003	360	$4.90	21	$7.90	$1.65	$200.55	$830.04	$396.45	$127.98
2002	360	$4.90	21	$7.90	$1.65	$200.55	$830.04	$396.45	$127.98

Table A.9d: Southwest Agricultural District Production Budget

Year	Yield per acre (cwt)	price received per cwt	cwt seed used per acre	seed cost per cwt	cutting cost per cwt	seeding cost per acre	operating cost per acre less seed	ownership cost per acre (cash)	ownership cost per acre (non-cash)
2015	530	$7.25	24	$12.10	$1.70	$331.20	$2,105.73	$1,026.51	$217.09
2014	530	$7.25	24	$12.10	$1.70	$331.20	$2,105.73	$1,026.51	$217.09
2013	530	$7.50	24	$13.00	$1.65	$351.60	$2,202.95	$1,021.43	$194.20
2012	530	$7.50	24	$13.00	$1.65	$351.60	$2,202.95	$1,021.43	$194.20
2011	530	$7.00	24	$14.55	$1.60	$387.60	$1,964.83	$976.56	$246.00
2010	530	$7.00	24	$14.55	$1.60	$387.60	$1,964.83	$976.56	$246.00
2009	530	$6.75	24	$15.50	$2.00	$420.00	$1,752.84	$896.70	$274.00
2008	530	$6.75	24	$15.50	$2.00	$420.00	$1,752.84	$896.70	$274.00
2007	505	$5.20	23	$10.75	$1.90	$290.95	$1,586.47	$752.65	$274.74
2006	505	$5.20	23	$10.75	$1.90	$290.95	$1,586.47	$752.65	$274.74
2005	500	$4.75	23	$8.00	$1.55	$219.65	$1,353.42	$596.88	$297.18
2004	500	$4.75	23	$8.00	$1.55	$219.65	$1,353.42	$596.88	$297.18
2003	480	$4.65	23	$9.35	$1.65	$253.00	$1,160.91	$558.48	$245.34
2002	480	$4.65	23	$9.35	$1.65	$253.00	$1,160.91	$558.48	$245.34

We first use NASS production data to find the total acreage planted within each budget area. For the southcentral and southwest agricultural districts, each of which has a single budget for all commercial production, this was a trivial task of simply downloading planting data for each agricultural region. For the southeast agricultural district, it is more complicated; there are two production budgets (north & south) that collectively cover only five of the sixteen counties within the district. We therefore had to decide which budget(s) to use for production from the eleven other counties within the SE district.

Based on geography we placed Jefferson County into the north region along with Bonneville and Madison counties. Idaho AgBiz releases a bi-annual budget for seed potato production in Caribou, Fremont, and Teton counties; we therefore placed these counties into a "seed" area. The remaining counties within the southeastern agricultural district account for less than 5% of annual potato production; we placed this production into a fourth group we called "Other Counties."

We retrieved 2002 – 2015 data from NASS at the county level for the Southeastern Ag district and organized it into these groups (Table A.10). Beginning in 2011 some counties within the three regions (North, South, & Seed) do not report individual data; rather their acreage is reported as "Other" and included with the Other Counties group. For years with missing county data we will have to estimate the total acreage planted in each budget region. We again used STATA to run OLS regressions with regional acreage planted as the response variable and total SE district acreage planted & year as the explanatory variables (Table A.11). For the North region we had full data from 2002 – 2011, for the South region full data from 2002 – 2010, and for the Seed region full data from 2002 – 2012.

Table A.10: Southeastern Ag District Potato Acreage Planted by County

Year	Southeastern Ag District North Region			Southeastern Ag District South Region with fumigation			Southeastern Ag District Seed Region			Southeastern Ag District Other Counties						Total
	Bonneville	Madison	Jefferson	Bannock	Bingham	Power	Caribou	Fremont	Teton	Butte	Custer	Franklin	Lemhi	Oneida	Other	
2015	*0*	28,200	*0*	*0*	61,200	*0*	*0*	*0*	*0*	0	0	0	0	0	130,600	**220,000**
2014	23,000	29,300	*0*	4,500	63,600	*0*	7,100	24,400	*0*	0	0	0	0	0	66,100	**218,000**
2013	22,000	28,500	*0*	*0*	62,400	*0*	7,500	25,000	*0*	0	0	0	0	0	73,600	**219,000**
2012	27,900	28,300	*0*	6,300	64,700	*0*	8,400	26,700	5,600	0	0	0	0	0	71,100	**239,000**
2011	23,000	28,100	23,900	*0*	66,100	31,900	8,300	23,800	5,500	0	0	0	0	0	9,900	**220,500**
2010	21,400	27,900	23,800	3,600	61,800	28,400	7,700	22,300	5,300	0	0	0	0	0	4,800	**207,000**
2009	21,400	29,900	27,000	4,600	67,800	29,600	7,800	21,700	5,500	0	0	0	0	0	5,800	**221,100**
2008	24,900	24,900	20,400	4,300	51,800	40,300	7,600	27,400	5,600	0	0	0	0	0	5,400	**212,600**
2007	30,400	28,400	23,100	5,300	60,200	43,800	7,300	30,700	6,500	0	0	0	0	0	6,300	**242,000**
2006	29,200	28,400	23,400	4,700	55,800	40,900	7,200	30,400	6,300	0	0	0	0	0	5,500	**231,800**
2005	26,600	29,000	24,300	3,500	52,200	40,200	6,900	26,800	6,300	700	0	0	0	0	3,900	**220,400**
2004	29,900	30,100	24,200	3,500	56,000	38,700	6,600	29,300	6,800	2,000	0	0	0	600	4,600	**232,300**
2003	29,800	31,300	32,000	3,800	60,300	36,600	7,400	28,600	7,000	2,700	0	500	500	500	1,300	**242,300**
2002	31,200	31,900	36,700	3,500	59,700	36,800	7,400	28,400	7,400	1,600	600	0	0	500	2,800	**248,500**

Table A.11: OLS Models for Estimating Acreage Planted by Budget Region

Region	Intercept	District Acrea	t - stat	p - value	Year	t - stat	p - value	Observations	R^2	Adjusted R^2
North	2551198.06	0.3711	2.69	0.03	-1272.91	-2.04	0.08	10	0.8699	0.8327
South	-3640686.35	0.4837	6.86	0	1809.48	4.92	0	9	0.8883	0.851
Seed	658775.81	0.1482	2.47	0.04	-324.92	-133	0.22	11	0.6554	0.5693

Using these models, we estimated the acreage planted in the North, South, and Seed regions for those years where we lacked complete county level data, allocating the remaining acreage to Other Counties. Together with production data from the southwest and southcentral agricultural districts we now have an estimated breakdown of total potato acreage within the various regions of Idaho (Table A.12).

Using the same plot-level certification data used to earlier estimate $f(S^*)$ we can find seed acreage planted within each county, and thus each district/region, for 2010 – 2015 (Table A.13). For 2002-2009 we did not have plot data; for these years we used the 2010 – 2015 average for each budget area.

Table A.12: Acreage Planted by District/Region

Year	**Southcentral**	**Southeast**				**Southwest**
		North	South	Seed	Other	
2015	85,800	*68,255*	*112,407*	*36,764*	*3,574*	16,000
2014	85,900	*68,785*	*109,614*	*36,809*	*3,792*	15,900
2013	79,800	*70,436*	*108,272*	*37,293*	*4,000*	17,000
2012	84,800	*79,184*	*116,113*	40,800	*3,903*	20,000
2011	79,800	75,200	*105,103*	37,600	*3,097*	19,000
2010	71,000	73,500	94,200	35,500	4,800	16,000
2009	79,000	78,500	102,400	35,300	5,800	19,000
2008	76,600	70,500	96,800	40,700	5,400	15,000
2007	86,000	82,200	109,700	44,600	6,300	21,000
2006	81,300	81,300	101,700	44,000	5,500	21,000
2005	82,000	80,500	96,500	40,200	4,600	21,000
2004	96,000	84,700	98,900	42,900	7,200	25,000
2003	91,000	93,700	101,200	43,300	5,500	25,000
2002	98,000	100,400	100,400	43,500	5,500	27,000

Table A.13: Seed Acres Planted by District/Region (2010 – 2015)

Year	**Southcentral**	**Southeast**				**Southwest**
		North	South	Seed	Other	
2015	2,277	5,494	1,928	19,343	3,997	260
2014	2,499	5,333	1,849	19,697	3,136	288
2013	2,736	2,938	2,121	21,635	3,689	351
2012	2,709	4,494	2,642	21,738	3,077	375
2011	2,763	4,039	2,325	22,075	2,905	344
2010	2,439	3,719	2,067	19,381	2,411	315
Mean (2002-2009)	2,571	4,336	2,155	20,645	3,203	322

Having estimated both seed and total acreage within each budget area we can then estimate annual commercial acreage by subtracting the former from the latter (Table A.14). We transform this data into the share of acreage planted in each budget area in each year by dividing the estimated commercial acreage in each budget area by the total commercial acreage within Idaho (Table A.15).

Table A.14: Estimated Commercial Acreage

Year	**Southcentral**	**Southeast**				**Southwest**	**State**
		North	South	Seed	Other		
2015	83,523	62,761	110,479	17,421	-424	15,740	289,500
2014	83,401	63,452	107,766	17,112	656	15,612	287,999
2013	77,064	67,498	106,151	15,658	311	16,649	283,330
2012	82,091	74,690	113,471	19,062	826	19,625	309,765
2011	77,037	71,161	102,778	15,525	192	18,656	285,348
2010	68,561	69,781	92,133	16,119	2,390	15,685	264,669
2009	76,536	74,343	100,334	15,511	2,730	18,691	288,145
2008	74,213	66,473	94,799	21,528	2,426	14,701	274,139
2007	83,568	78,098	107,661	25,071	3,271	20,695	318,365
2006	78,802	77,086	99,606	23,936	2,388	20,687	302,504
2005	79,561	76,386	94,455	20,611	1,561	20,694	293,268
2004	93,173	79,932	96,530	20,199	3,679	24,646	318,159
2003	87,887	88,449	98,590	18,300	1,622	24,610	319,457
2002	94,835	95,062	97,747	18,085	1,558	26,603	333,890

Table A.15: Budget Area Commercial Planting Shares

Year	**Southcentral**	**Southeast**				**Southwest**
		North	South	Seed	Other	
2015	0.2885	0.2168	0.3816	0.0602	-0.0015	0.0544
2014	0.2896	0.2203	0.3742	0.0594	0.0023	0.0542
2013	0.2720	0.2382	0.3747	0.0553	0.0011	0.0588
2012	0.2650	0.2411	0.3663	0.0615	0.0027	0.0634
2011	0.2700	0.2494	0.3602	0.0544	0.0007	0.0654
2010	0.2590	0.2637	0.3481	0.0609	0.0090	0.0593
2009	0.2656	0.2580	0.3482	0.0538	0.0095	0.0649
2008	0.2707	0.2425	0.3458	0.0785	0.0088	0.0536
2007	0.2625	0.2453	0.3382	0.0788	0.0103	0.0650
2006	0.2605	0.2548	0.3293	0.0791	0.0079	0.0684
2005	0.2713	0.2605	0.3221	0.0703	0.0053	0.0706
2004	0.2929	0.2512	0.3034	0.0635	0.0116	0.0775
2003	0.2751	0.2769	0.3086	0.0573	0.0051	0.0770
2002	0.2840	0.2847	0.2928	0.0542	0.0047	0.0797

Using this data, we calculate a statewide composite budget weighted by the share of commercial production that occurs in each budget area each year. For the seed and other regions of the southeast agricultural district we use the average of the north and south regional budgets. With the composite budget (Table A.16) we are able estimate Q_S, Q_0, $g(S^*)$, $g'(S^*)$, and $c_P(Q_C)$. It also provides us with values for P_C and P_P.

Table A.16: Composite Budget

Year	Price Received per cwt	cwt Seed Used per Acre	Seed Cost per cwt	Cutting Cost per Acre	Seed Cost per Acre	Operating Cost (less seed) per Acre	Cash Ownership Cost per Acre	Non-Cash Ownership Cost per Acre
2015	$7.19	21.74	$12.14	$1.70	$301.08	$1,679.13	$784.67	$178.48
2014	$7.19	21.74	$12.13	$1.70	$301.06	$1,677.09	$784.18	$178.48
2013	$7.20	21.72	$12.01	$1.65	$297.24	$1,672.15	$756.71	$171.49
2012	$7.20	21.72	$12.01	$1.65	$297.19	$1,670.24	$756.42	$171.50
2011	$7.46	21.74	$13.45	$1.66	$328.84	$1,522.34	$691.84	$192.67
2010	$7.48	21.70	$13.43	$1.66	$327.74	$1,509.90	$686.22	$192.40
2009	$6.75	21.73	$14.27	$2.00	$354.00	$1,358.39	$648.92	$209.89
2008	$6.75	21.70	$14.26	$2.00	$353.37	$1,356.12	$646.74	$209.10
2007	$5.48	21.37	$9.53	$1.90	$244.86	$1,203.94	$518.23	$183.98
2006	$5.48	21.36	$9.53	$1.90	$244.81	$1,202.07	$518.40	$184.19
2005	$4.89	21.39	$6.95	$1.55	$182.43	$978.94	$433.25	$157.50
2004	$4.89	21.45	$6.98	$1.55	$183.64	$987.46	$437.45	$158.37
2003	$4.82	21.40	$8.11	$1.65	$209.49	$841.32	$402.22	$128.88
2002	$4.82	21.41	$8.12	$1.65	$209.85	$842.53	$402.74	$128.96

Q_C

With no available data on the quantity of certified seed planted by Idaho commercial potato growers we must estimate Q_C. We assume that all commercial acreage is planted using certified seed. Multiplying the seed use per acre from our composite budget by the estimated commercial acreage in Idaho gives us a yearly estimate of the quantity of certified seed that is used by commercial farmers (Table A.17). Under the assumptions made in our theoretical model this is also the quantity of certified seed potatoes produced by seed potato growers, Q_S.

Our annual estimates for Q_C are generally less than the reported quantity of certified seed produced by Idaho seed producers; part of this difference can be attributed to limited-generation seed potato production. The reported quantity of certified seed produced by growers includes nuclear, 1st generation, and 2nd generation seed potatoes that are not sold to commercial growers but rather re-planted as part of the limited-generation seed potato production process. This production would not be included in Q_C or Q_S under our model. For our purposes this early generation production should be viewed as an intermediate input both produced and utilized by the certified seed potato industry as part of the production of the 3rd, 4th, and later generation certified seed that is sold to commercial farmers.

Table A.17: Estimated Certified Seed Use by Year

Year	Composite Budget Certified Seed Used Per Commercial Acre	Estimated Commercial Acres in Idaho (cwt)	Estimated Certified Seed Used by Commercial Farmers (cwt)	Reported Quantity of Certified Seed Produced by Idaho Seed Growers (cwt)	Estimated Seed Use as a % of Reported Quantity of Seed Produced
2015	21.74	289,500	6,293,770	7,330,000	85.86%
2014	21.74	287,999	6,261,610	7,760,000	80.69%
2013	21.72	283,330	6,153,998	7,500,000	82.05%
2012	21.72	309,765	6,728,111	7,470,000	90.07%
2011	21.74	285,348	6,202,354	6,710,000	92.43%
2010	21.70	264,669	5,742,229	6,480,000	88.61%
2009	21.73	288,145	6,260,198	6,510,000	96.16%
2008	21.70	274,139	5,949,455	6,390,000	93.11%
2007	21.37	318,365	6,801,925	6,890,000	98.72%
2006	21.36	302,504	6,461,307	6,520,000	99.10%
2005	21.39	293,268	6,271,675	6,400,000	97.99%
2004	21.45	318,159	6,825,115	6,600,000	103.41%
2003	21.40	319,457	6,835,191	7,100,000	96.27%
2002	21.41	333,890	7,149,694	7,200,000	99.30%

$\boldsymbol{Q_0}$

We estimate the quantity of seed entered for certification using the equation $Q_0 = \frac{Q_S}{f(S^*)} = \frac{Q_C}{f(S^*)}$. With three different estimates for $f(S^*)$ we also have three estimates of Q_0 (Table A.18).

Table A.18: Estimated Quantity of Seed Entered for Certification

Year	Using f(S*) calculated from Idaho State Data	Using f(S*) calculated from Idaho County Acreage Data	Using f(S*) calculated from Idaho County Plot Data
2015	6336732	6694031	6920199
2014	6296239	6361179	6565846
2013	6240226	6244441	6199631
2012	6935289	6861625	6952898
2011	6274510	6323935	6442819
2010	5742229	5813588	5810589
2009	6270010	6410731	6504819
2008	5972804	6092516	6181933
2007	6828782	6965484	7067714
2006	6568783	6616676	6713786
2005	6404727	6422484	6516744
2004	6825860	6989231	7091810
2003	6856936	6999550	7102280
2002	7193876	7321616	7429073

$\boldsymbol{g(S^*)}$

We calculate the per unit yield of the certified seed potatoes planted by commercial potato farmers (Table A.19) using the equation $g(S^*) = \frac{Q_P}{Q_C}$ where Q_P is estimated commercial sales and Q_C is the estimated quantity of certified seed used by commercial farmers.

Table A.19: Estimated Commercial Yield per unit of Certified Seed Planted

Year	Commercial Sales (cwt)	Certified Seed Planted (per cwt)	$\boldsymbol{g(S^*)}$
2015	113,716,356	6,293,770	18.07
2014	116,366,750	6,261,610	18.58
2013	114,762,150	6,153,998	18.65
2012	124,288,318	6,728,111	18.47
2011	112,572,646	6,202,354	18.15
2010	98,032,587	5,742,229	17.07
2009	116,193,817	6,260,198	18.56
2008	101,624,409	5,949,455	17.08
2007	114,122,398	6,801,925	16.78
2006	112,530,338	6,461,307	17.42
2005	102,810,949	6,271,675	16.39
2004	113,496,543	6,825,115	16.63
2003	106,062,746	6,835,191	15.52
2002	116,436,430	7,149,694	16.29

$g'(S)$

We estimate the marginal yield impact of a change in the standard S using experimental data produced from test plots planted during the 2010 and 2012 growing seasons as part of an investigation of the in-season spread of PVY in commercial potato fields. The analysis of this data found that per acre commercial yield decreased by 1.17 cwt for each percentage point of PVY infection within a commercial field. For the purpose of evaluating the equations within our theoretical model we must convert this to the marginal change in yield per cwt of seed planted. We do this by dividing the marginal yield impact per acre by the quantity of seed planted per acre, drawn from the composite budget. Depending on the year this ranges from a yield decrease of 0.054 – 0.055 cwt per point of PVY infection for each cwt of certified seed planted.

$c_P(Q_C)$

For unit agreement within our model we have to transform the per-acre costs in the composite budget (Table A.16, above) into costs per cwt of certified seed planted (Table A.20, below); this is accomplished by dividing operating cost less seed, cash ownership cost, and non-cash ownership cost by the quantity in cwt of seed planted per acre.

Table A.20: Idaho Commercial Potato Production Costs per Cwt of Certified Seed Planted

Year	Per cwt of Seed Operating Cost Less Seed	Per cwt of Seed Cash Ownership Cost	Per cwt of Seed Non-Cash Ownership Cost
2015	$77.24	$36.09	$8.21
2014	$77.14	$36.07	$8.21
2013	$76.99	$34.84	$7.90
2012	$76.90	$34.83	$7.90
2011	$70.04	$31.83	$8.86
2010	$69.59	$31.63	$8.87
2009	$62.52	$29.87	$9.66
2008	$62.49	$29.80	$9.64
2007	$56.35	$24.26	$8.61
2006	$56.28	$24.27	$8.62
2005	$45.78	$20.26	$7.36
2004	$46.03	$20.39	$7.38
2003	$39.32	$18.80	$6.02
2002	$39.35	$18.81	$6.02

From this data we can find three different cost levels: Operating Cost less Seed, Total Cash Cost (Operating Cost plus Cash Ownership Cost), and Total Cost (Operating Cost plus Cash Ownership Cost plus Non-Cash Ownership Cost). These costs do not include the cost of storing production after it is harvested but before it is sold; these costs must be estimated separately.

Estimating the cost of storing commercial potato production is complicated by two features of Idaho potato production: different agricultural regions have different per-acre yields and not all commercial potato production is stored on-farm where it is grown. We therefore have to make some concessions in estimating the effective storage cost realized by Idaho commercial potato producers.

Because the agricultural district and county data reports only total yield we have to estimate the share of Q_P to allocate to each budget area. We do this using the per-acre yields of the Idaho AgBiz budgets as a guideline for the relative difference in yield among the budget areas. The first step is to calculate the yield within each budget area if all estimated commercial acreage produced at the applicable budgeted marketable yield. Under these hypothetical conditions the estimated commercial acreage within Idaho would have produced at the levels summarized in Table A.21. For comparison actual Estimated Commercial Sales are included at the far right of the table.

Table A.21: Hypothetical Production of Actual Acreage at Budgeted Yield (Cwt)

Year	**Southcentral**	**Southeast**				**Southwest**	**Total**	**Estimated Commercial Sales**
		North	South	Seed	Other			
2015	39,255,777	22,593,909	46,953,752	6,837,557	-166,258	8,342,216	123,816,952	113,716,356
2014	39,198,489	22,842,760	45,800,396	6,716,563	257,362	8,274,310	123,089,880	116,366,750
2013	35,064,006	23,624,237	44,052,756	5,989,056	118,862	8,823,732	117,672,650	114,762,150
2012	37,351,382	26,141,532	47,090,436	7,291,059	316,089	10,401,038	128,591,537	124,288,318
2011	35,436,933	25,617,932	42,139,037	5,977,102	73,759	9,887,585	119,132,347	112,572,646
2010	31,538,014	25,121,160	37,774,612	6,205,896	919,958	8,313,220	109,872,859	98,032,587
2009	35,589,199	24,905,071	39,632,009	5,661,352	996,508	9,906,261	116,690,400	116,193,817
2008	34,508,953	22,268,522	37,445,472	7,857,750	885,473	7,791,371	110,757,541	101,624,409
2007	37,605,771	26,162,919	41,449,647	9,025,674	1,177,420	10,451,040	125,872,470	114,122,398
2006	35,460,785	25,823,764	38,348,139	8,617,019	859,534	10,446,821	119,556,064	112,530,338
2005	34,211,186	24,443,407	35,892,956	7,213,932	546,452	10,347,096	112,655,029	102,810,949
2004	40,064,575	25,578,257	36,681,518	7,069,800	1,287,500	12,322,806	123,004,457	113,496,543
2003	37,791,441	27,861,439	35,492,485	6,176,129	547,363	11,812,660	119,681,519	106,062,746
2002	40,779,255	29,944,524	35,188,913	6,103,779	525,669	12,769,555	125,311,696	116,436,430

We then calculate the share of this hypothetical production that occurs in each budget area (Table A.22); we use these weights to calculate a composite per cwt storage cost for Idaho potato production in each year of our study using the Idaho AgBiz budgets to estimate storage cost (Table A.23); for the Seed and Other areas of the Southeast district we again you the average of the North and South budgets. From this we can find mean storage cost per cwt (Table A.24); as with production cost we estimate three levels: Operating Cost, Total Cash Cost, and Total Cost.

Table A.22: Hypothetical Statewide Production Share of Actual Acreage at Budgeted Yield

Year	Southcentral	Southeast				Southwest
		North	South	Seed	Other	
2015	0.3170	0.1825	0.3792	0.0552	-0.0013	0.0674
2014	0.3185	0.1856	0.3721	0.0546	0.0021	0.0672
2013	0.2980	0.2008	0.3744	0.0509	0.0010	0.0750
2012	0.2905	0.2033	0.3662	0.0567	0.0025	0.0809
2011	0.2975	0.2150	0.3537	0.0502	0.0006	0.0830
2010	0.2870	0.2286	0.3438	0.0565	0.0084	0.0757
2009	0.3050	0.2134	0.3396	0.0485	0.0085	0.0849
2008	0.3116	0.2011	0.3381	0.0709	0.0080	0.0703
2007	0.2988	0.2079	0.3293	0.0717	0.0094	0.0830
2006	0.2966	0.2160	0.3208	0.0721	0.0072	0.0874
2005	0.3037	0.2170	0.3186	0.0640	0.0049	0.0918
2004	0.3257	0.2079	0.2982	0.0575	0.0105	0.1002
2003	0.3158	0.2328	0.2966	0.0516	0.0046	0.0987
2002	0.3254	0.2390	0.2808	0.0487	0.0042	0.1019

Table A.23: Budget Area Storage Cost per Cwt of Commercial Production

Year	Southcentral				Southeast - North				Southeast - South				Southwest			
	Operating Cost	Cash Ownership Cost	Non-Cash Ownership Cost	Total cost	Operating Cost	Cash Ownership Cost	Non-Cash Ownership Cost	Total cost	Operating Cost	Cash Ownership Cost	Non-Cash Ownership Cost	Total cost	Operating Cost	Cash Ownership Cost	Non-Cash Ownership Cost	Total cost
2015	$0.57	$0.36	$0.04	$0.97	$0.57	$0.36	$0.04	$0.96	$0.57	$0.36	$0.04	$0.96	$0.57	$0.51	$0.04	$1.11
2014	$0.57	$0.36	$0.04	$0.97	$0.57	$0.36	$0.04	$0.96	$0.57	$0.36	$0.04	$0.96	$0.57	$0.51	$0.04	$1.11
2013	$0.62	$0.51	$0.04	$1.17	$0.59	$0.51	$0.07	$1.17	$0.60	$0.51	$0.04	$1.15	$0.72	$0.51	$0.04	$1.27
2012	$0.62	$0.51	$0.04	$1.17	$0.59	$0.51	$0.07	$1.17	$0.60	$0.51	$0.04	$1.15	$0.72	$0.51	$0.04	$1.27
2011	$0.80	$0.47	$0.06	$1.34	$0.80	$0.47	$0.06	$1.34	$0.80	$0.47	$0.06	$1.34	$0.80	$0.47	$0.06	$1.34
2010	$0.80	$0.47	$0.06	$1.34	$0.80	$0.47	$0.06	$1.34	$0.80	$0.47	$0.06	$1.34	$0.80	$0.47	$0.06	$1.34
2009	$0.78	$0.43	$0.04	$1.25	$0.78	$0.43	$0.05	$1.25	$0.78	$0.43	$0.05	$1.25	$0.78	$0.44	$0.05	$1.26
2008	$0.78	$0.43	$0.04	$1.25	$0.78	$0.43	$0.05	$1.25	$0.78	$0.43	$0.05	$1.25	$0.78	$0.44	$0.05	$1.26
2007	$0.64	$0.39	$0.04	$1.07	$0.64	$0.39	$0.04	$1.07	$0.64	$0.35	$0.04	$1.03	$0.64	$0.38	$0.04	$1.05
2006	$0.64	$0.39	$0.04	$1.07	$0.64	$0.39	$0.04	$1.07	$0.64	$0.35	$0.04	$1.03	$0.64	$0.38	$0.04	$1.05
2005	$0.51	$0.17	$0.16	$0.84	$0.51	$0.17	$0.17	$0.84	$0.51	$0.16	$0.15	$0.81	$0.51	$0.16	$0.16	$0.83
2004	$0.51	$0.17	$0.16	$0.84	$0.51	$0.17	$0.17	$0.84	$0.51	$0.16	$0.15	$0.81	$0.51	$0.16	$0.16	$0.83
2003	$0.50	$0.14	$0.14	$0.78	$0.50	$0.14	$0.15	$0.79	$0.50	$0.14	$0.13	$0.77	$0.50	$0.14	$0.14	$0.78
2002	$0.50	$0.14	$0.14	$0.78	$0.50	$0.14	$0.15	$0.79	$0.50	$0.14	$0.13	$0.77	$0.50	$0.14	$0.14	$0.78

Table A.24: Estimated Storage Cost per Cwt of Commercial Production

Year	Storage Operating Cost per cwt	Storage Total Cash Cost per cwt	Storage Total Cost per cwt
2015	$0.57	$0.94	$0.98
2014	$0.57	$0.94	$0.98
2013	$0.62	$1.13	$1.17
2012	$0.62	$1.13	$1.17
2011	$0.80	$1.28	$1.34
2010	$0.80	$1.28	$1.34
2009	$0.78	$1.21	$1.25
2008	$0.78	$1.21	$1.25
2007	$0.64	$1.01	$1.05
2006	$0.64	$1.01	$1.05
2005	$0.51	$0.67	$0.83
2004	$0.51	$0.67	$0.83
2003	$0.50	$0.64	$0.78
2002	$0.50	$0.64	$0.78

We must add production cost and storage cost together to find $c_P(Q_C)$, the cost of producing commercial potatoes. For unit agreement we need to find storage cost per cwt of certified seed planted rather than per cwt of commercial production. We do this by multiplying the three levels of storage cost by $g(S^*)$, the per-unit yield multiplier of certified seed potatoes. This gives us the Storage Operating Cost, Storage Total Cash Cost, and Storage Total Cost per cwt of certified seed planted (Table A.25). These values assume that all production is stored where it is grown.

Table A.25: Estimated Storage Cost of Output from One Cwt of Certified Seed

Year	Storage Operating Cost per cwt	Storage Total Cash Cost per cwt	Storage Total Cost per cwt
2015	$10.32	$16.96	$17.69
2014	$10.62	$17.44	$18.20
2013	$11.49	$20.99	$21.84
2012	$11.40	$20.80	$21.65
2011	$14.59	$23.15	$24.24
2010	$13.73	$21.78	$22.80
2009	$14.40	$22.42	$23.25
2008	$13.26	$20.63	$21.40
2007	$10.74	$17.02	$17.65
2006	$11.15	$17.68	$18.32
2005	$8.36	$11.02	$13.59
2004	$8.48	$11.18	$13.80
2003	$7.76	$9.89	$12.07
2002	$8.14	$10.38	$12.67

Next, we must account that not all commercial potatoes are stored where they are grown. With no data available regarding on-farm storage we chose to estimate $c_P(Q_C)$ at various shares of production being stored where grown (Table A.26 a-c). This method of estimation assumes that the share of production stored where grown is consistent across all budget areas.

Table A.26a: Operating Cost Less Seed per Cwt of Certified Seed Planted

Year	Production Cost per cwt of Seed	Storage Cost per cwt of Seed	Share of Production Stored Where Grown				
			0.3	0.4	0.5	0.6	0.7
2015	$77.24	$10.32	$80.33	$81.36	$82.40	$83.43	$84.46
2014	$77.14	$10.62	$80.32	$81.38	$82.44	$83.51	$84.57
2013	$76.99	$11.49	$80.43	$81.58	$82.73	$83.88	$85.03
2012	$76.90	$11.40	$80.32	$81.46	$82.60	$83.74	$84.88
2011	$70.04	$14.59	$74.42	$75.87	$77.33	$78.79	$80.25
2010	$69.59	$13.73	$73.71	$75.08	$76.46	$77.83	$79.20
2009	$62.52	$14.40	$66.84	$68.29	$69.73	$71.17	$72.61
2008	$62.49	$13.26	$66.46	$67.79	$69.12	$70.44	$71.77
2007	$56.35	$10.74	$59.57	$60.65	$61.72	$62.79	$63.87
2006	$56.28	$11.15	$59.62	$60.74	$61.85	$62.97	$64.08
2005	$45.78	$8.36	$48.28	$49.12	$49.96	$50.79	$51.63
2004	$46.03	$8.48	$48.58	$49.42	$50.27	$51.12	$51.97
2003	$39.32	$7.76	$41.65	$42.42	$43.20	$43.98	$44.75
2002	$39.35	$8.14	$41.79	$42.60	$43.42	$44.23	$45.05

Table A.26b: Total Cash Cost Less Seed per Cwt of Certified Seed Planted

Year	Production Cost per cwt of Seed	Storage Cost per cwt of Seed	Share of Production Stored Where Grown				
			0.3	0.4	0.5	0.6	0.7
2015	$113.33	$16.96	$118.42	$120.11	$121.81	$123.50	$125.20
2014	$113.20	$18.20	$118.44	$120.18	$121.92	$123.67	$125.41
2013	$111.82	$21.84	$118.12	$120.22	$122.32	$124.42	$126.52
2012	$111.72	$21.65	$117.96	$120.04	$122.12	$124.20	$126.28
2011	$101.87	$24.24	$108.81	$111.13	$113.44	$115.76	$118.07
2010	$101.22	$22.80	$107.76	$109.93	$112.11	$114.29	$116.47
2009	$92.39	$23.25	$99.12	$101.36	$103.60	$105.84	$108.09
2008	$92.29	$21.40	$98.48	$100.54	$102.60	$104.67	$106.73
2007	$80.61	$17.65	$85.71	$87.42	$89.12	$90.82	$92.52
2006	$80.55	$18.32	$85.85	$87.62	$89.39	$91.15	$92.92
2005	$66.04	$13.59	$69.34	$70.44	$71.54	$72.65	$73.75
2004	$66.42	$13.80	$69.78	$70.90	$72.01	$73.13	$74.25
2003	$58.12	$12.07	$61.09	$62.07	$63.06	$64.05	$65.04
2002	$58.15	$12.67	$61.27	$62.31	$63.34	$64.38	$65.42

Table A.26c: Total Cost Less Seed per cwt of Certified Seed Planted

Year	Production Cost per cwt of Seed	Storage Cost per cwt of Seed	Share of Production Stored Where Grown				
			0.3	0.4	0.5	0.6	0.7
2015	$121.54	$17.69	$126.85	$128.62	$130.39	$132.15	$133.92
2014	$121.41	$18.20	$126.87	$128.69	$130.51	$132.33	$134.15
2013	$119.72	$21.84	$126.27	$128.46	$130.64	$132.82	$135.01
2012	$119.62	$21.65	$126.11	$128.28	$130.44	$132.61	$134.77
2011	$110.73	$24.24	$118.00	$120.43	$122.85	$125.27	$127.70
2010	$110.09	$22.80	$116.93	$119.21	$121.49	$123.77	$126.05
2009	$102.05	$23.25	$109.03	$111.35	$113.68	$116.01	$118.33
2008	$101.92	$21.40	$108.34	$110.48	$112.62	$114.76	$116.90
2007	$89.22	$17.65	$94.51	$96.28	$98.04	$99.80	$101.57
2006	$89.17	$18.32	$94.67	$96.50	$98.33	$100.16	$102.00
2005	$73.40	$13.59	$77.48	$78.84	$80.20	$81.56	$82.92
2004	$73.81	$13.80	$77.95	$79.33	$80.70	$82.08	$83.46
2003	$64.14	$12.07	$67.76	$68.97	$70.18	$71.38	$72.59
2002	$64.18	$12.67	$67.98	$69.24	$70.51	$71.78	$73.04

Up through the 2011 Idaho AgBiz budgets storage cost per cwt is presented as a single value reflecting the average cost of storing commercial potatoes during the growing season. As commercial potatoes can be stored for 10 – 12 months before being sold there is a large disparity between the storage cost for potatoes sold early in the marketing year (October – November) and those sold near the end of the marketing year (May – June). Beginning with the 2013 AgBiz budgets, storage operating cost is presented differently, with the monthly storage cost for September – June listed separately (Table A.27). To determine the average storage cost per cwt for production this year we must determine the share of production stored that remains in storage during any given month.

Table A.27: 2013 & 2015 Potato Storage Cost by Month

Budget Area	Cumulative Storage Cost per cwt – 2015 Budget								
	October	November	December	January	February	March	April	May	June
Southcentral	$0.208	$0.376	$0.461	$0.545	$0.630	$0.714	$0.899	$1.003	$1.124
Southeast (North Region)	$0.205	$0.372	$0.456	$0.539	$0.623	$0.706	$0.890	$0.992	$1.112
Southeast (South Region)	$0.205	$0.372	$0.456	$0.539	$0.623	$0.706	$0.890	$0.992	$1.112
Southwest	$0.204	$0.372	$0.457	$0.514	$0.625	$0.709	$0.894	$0.997	$1.117
Budget Area	**Cumulative Storage Cost per cwt – 2013 Budget**								
	October	November	December	January	February	March	April	May	June
Southcentral	$0.215	$0.387	$0.476	$0.564	$0.652	$0.741	$0.930	$1.039	$1.166
Southeast (North Region)	$0.202	$0.369	$0.453	$0.536	$0.619	$0.702	$0.885	$0.988	$1.106
Southeast (South Region)	$0.206	$0.375	$0.460	$0.545	$0.630	$0.702	$0.900	$1.004	$1.126
Southwest	$0.358	$0.527	$0.611	$0.695	$0.778	$0.862	$1.046	$1.149	$1.269

The USDA Potatoes Annual Summery contains data on the share of production sold during each month of the marketing year, which runs from August to July (Table A.28). We can use this data along with the 2013 & 2015 month storage costs to find a weighted average storage cost per cwt of commercial production. We assume that potatoes sold during August and September have a storage cost of zero. We estimate the cost of storing the production sold in July with the following equation:

$$July\ Storage\ Cost = June\ Storage\ Cost + \frac{June\ Storage\ Cost - April\ Storage\ Cost}{2}$$

Table A.28: Share of Total Farm Marketings by Month

Year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
2015	0.06	0.12	0.12	0.07	0.07	0.07	0.07	0.09	0.11	0.09	0.07	0.06
2014	0.05	0.11	0.10	0.07	0.07	0.08	0.08	0.09	0.12	0.09	0.08	0.06
2013	0.03	0.11	0.10	0.08	0.07	0.07	0.08	0.10	0.10	0.11	0.07	0.08
2012	0.03	0.11	0.10	0.08	0.07	0.07	0.08	0.10	0.10	0.11	0.07	0.08
2011	0.03	0.12	0.11	0.08	0.07	0.07	0.08	0.10	0.11	0.08	0.08	0.07
2010	0.01	0.11	0.13	0.08	0.07	0.08	0.08	0.10	0.11	0.09	0.07	0.07
2009	0.02	0.10	0.10	0.07	0.07	0.07	0.08	0.11	0.11	0.09	0.08	0.10
2008	0.01	0.11	0.13	0.08	0.07	0.08	0.07	0.10	0.10	0.09	0.07	0.09
2007	0.03	0.12	0.12	0.08	0.07	0.07	0.08	0.09	0.10	0.09	0.07	0.08
2006	0.03	0.11	0.12	0.08	0.07	0.08	0.08	0.10	0.10	0.09	0.07	0.07
2005	0.02	0.11	0.13	0.08	0.07	0.08	0.07	0.11	0.10	0.10	0.06	0.07
2004	0.06	0.09	0.10	0.11	0.07	0.06	0.06	0.09	0.10	0.09	0.10	0.07
2003	0.04	0.08	0.10	0.11	0.08	0.07	0.08	0.10	0.11	0.11	0.06	0.06
2002	0.04	0.08	0.11	0.10	0.07	0.08	0.08	0.10	0.11	0.10	0.07	0.06

Under the assumption that all budget areas sell at the same rate (and thus the rate in the above table) we can then produce weighted average storage cost per cwt of commercial potatoes (Table A.29) for the 2013 and 2015 budgets. These values are used to compute the composite storage budget above.

Table A.29: Storage Cost per cwt of Commercial Production

Budget Area	2013	2015
Southcentral	$0.62	$0.57
Southeast (North Region)	$0.59	$0.57
Southeast (South Region)	$0.60	$0.57
Southwest	$0.72	$0.57

P_P

We source four estimates of P_P, the price received by commercial growers per cwt (Table A.30). The first comes from the USDA Potatoes Annual Summery, the second is from our composite budget developed from the Idaho AgBiz production budgets. Our final prices are from the Grower Return Index (GRI) produced by North American Potato Market News. The GRI is produced weekly using a proprietary formula to estimate the price received by commercial growers based on market potato prices for the week. We converted these weekly prices into monthly averages (Table A.31); we then computed an average annual GRI and a weighted average annual GRI using the monthly marketing data in Table A1.27 above.

Table A.30: Estimated Price Received per cwt of Commercial Sales

Year	Composite Budget Price	Annual Summery Price	August - March GRI	Weighted GRI
2015	$7.19	$7.00	$5.93	$5.77
2014	$7.19	$7.20	$5.64	$5.46
2013	$7.20	$7.75	$8.18	$7.04
2012	$7.20	$7.05	$4.33	$5.05
2011	$7.46	$8.10	$8.99	$8.00
2010	$7.48	$8.10	$9.35	$10.40
2009	$6.75	$6.45	$4.51	$4.52
2008	$6.75	$7.15	$11.20	$9.34
2007	$5.48	$6.15	$6.14	$7.27
2006	$5.48	$5.90	$6.82	$6.61
2005	$4.89	$5.70	$6.68	$6.97
2004	$4.89	$4.25	$3.08	$3.02
2003	$4.82	$4.40	$3.93	$3.69
2002	$4.82	$5.00	$5.98	$4.82

Table A.31: Monthly Grower Return Index

Year	Grower Return Index Monthly Average Prices												
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
2015	$6.38	$4.80	$5.74	$6.22	$6.10	$6.59	$5.98	$5.66	$5.59	$5.97	$5.88	$5.15	$5.26
2014	$5.34	$4.32	$5.16	$6.46	$6.75	$6.52	$5.28	$5.30	$5.46	$5.41	$5.36	$4.73	$4.54
2013	$15.45	$9.31	$7.81	$7.33	$6.70	$6.70	$6.35	$5.83	$5.78	$7.10	$6.65	$4.09	$3.65
2012	$6.29	$3.92	$4.51	$5.01	$3.93	$3.91	$3.63	$3.46	$3.42	$4.65	$7.18	$13.00	$13.65
2011	$14.81	$10.25	$7.38	$7.71	$7.64	$7.40	$7.42	$9.31	$9.10	$7.38	$5.08	$4.53	$5.39
2010	$9.37	$9.24	$7.73	$8.40	$8.70	$8.91	$10.68	$11.78	$12.34	$10.83	$12.12	$15.48	$13.36
2009	$7.93	$5.95	$4.87	$4.08	$3.63	$3.41	$2.97	$3.26	$3.83	$4.50	$4.57	$7.15	$8.11
2008	$17.96	$16.49	$12.58	$10.39	$9.08	$8.40	$7.55	$7.18	$6.94	$6.83	$6.46	$6.25	$6.38
2007	$5.97	$5.37	$5.39	$6.47	$6.54	$6.68	$6.58	$6.16	$6.07	$8.10	$12.97	$12.95	$14.06
2006	$9.23	$7.10	$6.86	$6.55	$6.04	$6.82	$6.12	$5.89	$6.91	$7.04	$6.38	$5.55	$5.64
2005	$7.31	$7.56	$6.76	$6.79	$6.38	$5.71	$6.27	$6.66	$7.02	$7.07	$7.58	$9.01	$8.72
2004	$5.53	$3.05	$3.05	$3.22	$3.15	$2.41	$1.96	$2.26	$2.00	$2.78	$3.56	$3.73	$3.71
2003	$5.55	$3.55	$4.04	$4.36	$3.60	$3.55	$3.16	$3.65	$3.90	$3.15	$3.00	$3.19	$4.46
2002	$10.22	$6.88	$6.07	$5.96	$4.97	$4.92	$4.44	$4.37	$3.94	$3.29	$2.72	$1.82	$3.31

$\boldsymbol{P_C}$

With a lack of available data on certified seed potato prices (at least at the volume purchased by commercial growers) we use composite budget price for G3 certified seed plus the composite budget cutting cost as an estimate for P_C. We chose to consider cutting cost as part of the cost of seed, rather than part of operating cost as this is how it is treated in the Idaho AgBiz Budgets.

$\boldsymbol{c_{SP}(Q_0)}$

We use the Idaho AgBiz Southeast Agricultural District 3rd Generation (G3) Seed Potato Budget (Table A.32) for all certified seed production within the state of Idaho. This assumes that non-G3 seed potatoes have the same costs and returns as the AgBiz budget.

Table A: 32: Per Acre 3rd Generation (G3) Certified Seed Production Budget

Year	With Fumigation	Seed yield (cwt)	Seed tops yield (cwt)	Seed price per cwt	Seed tops price per cwt	Gross return per acre	G2 Seed Use (cwt)	Seed cost per cwt	Cutting cost per cwt	Seed Cost	Operating Cost less Seed	Cash Overhead Cost	Non-Cash Overhead Cost	Total Cost
2015	NA	275	25	$10.50	$5.25	$3,018.75	26	$12.10	$1.70	$358.80	$1,928.86	$733.03	$204.09	$3,224.78
2013	NA	275	20	$10.50	$4.50	$2,977.50	26	$14.00	$1.65	$406.90	$1,770.01	$627.63	$197.77	$3,002.31
2011	NA	270	20	$10.00	$4.00	$2,780.00	26	$17.15	$1.60	$487.50	$1,677.12	$535.51	$203.73	$2,903.86
2009	NA	255	20	$11.00	$4.00	$2,885.00	23	$14.65	$2.00	$382.95	$1,310.72	$512.65	$227.00	$2,433.32
2007	NA	255	20	$7.50	$4.00	$1,992.50	23	$10.20	$1.90	$278.30	$1,152.05	$378.26	$181.90	$1,990.51
2005	NA	250	--	$6.25	--	$1,562.50	23	$7.75	$1.55	$213.90	$975.42	$304.59	$150.82	$1,644.73
2003	NA	250	--	$6.25	--	$1,562.50	23	$9.55	$1.65	$257.60	$897.23	$302.35	$123.59	$1,580.77