Preferences and Prevention:
Risk Management in Seed Potato Production

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Introduction

Potatoes were planted to over 1 million acres in the United States in 2015. The two most important potato growing states, Idaho and Washington, produced over 23 billion pounds of potatoes in 2015 (USDA 2016). Because potatoes are grown from potato tuber pieces rather than true seed, they are susceptible to a number of seedborne diseases.

Potato Virus Y

One of the most serious potato diseases is Potato Virus Y (PVY), also known as "common mosaic virus" or "severe mosaic virus." Viruses are an especially strong threat because once they infect a plant, there is no way of removing the virus without destruction of the plant. PVY is a potyvirus, currently the largest of the plant virus groups and is thought to be one of the most destructive families of plant viruses affecting potatoes (Ivanov et al., 2014). Symptoms can vary greatly across potato variety and each of five main virus strains and range from having little effect on the plant and its tubers to plant death, decreases in tuber size, and tuber necrosis (dead spots) (Nolte, et al., 2009). Yield losses for plants grown from infected seed also vary dramatically. Hane and Hamm (1999) found that yield loss ranged from 29–79%, based on the variety. Whitworth et al. (2006) found yield reductions ranging from 38–63%, based on soil nitrogen levels and potato variety. Other studies (e.g. Nolte et al. (2009), have investigated the role of spread over the season in determining end losses when seed planted is infected at less than 100% levels. In recent years, concern over detectability has been raised after news strains of PVY that show few foliar symptoms but still cause tuber necrosis have made their way into North America (Nolte, et al., 2009).

PVY is mainly transmitted in the field by aphids and can be acquired from an infected plant and transmitted to a healthy plant within seconds (Burrows and Zitter, 2005). In aphids, PVY is a non-persistent virus; it can only be transmitted by the aphid for a number of hours. PVY can also be transmitted by contaminated machinery and tools, or by damaging plants while walking through the field (Burrows and Zitter, 2005).

Because PVY is a non-persistent virus with quick transmission, insecticides are generally ineffective in to controlling spread, though crop oils have shown some success. The best method of controlling PVY remains planting seed potatoes certified to have low or no virus content, reducing mechanical spread by sanitizing equipment and reducing field traffic, along with rogueing (removing) symptomatic plants. Other plants from the nightshade (Solanaceae) family, such as tomatoes, peppers, nightshade, and ground cherry can serve as sources of inoculum as well, so avoiding plating potatoes next to those sources or weedy areas is also recommended. Some potato varieties are more resistant or tolerant to PVY than others; these include Eva, Dark Red Norland, Belrus, HiLite Russet, Kennebec, Monona, Norwis, and Sebago (Burrows and Zitter, 2005).

Potato Production

Potatoes are the top vegetable crop in the United States (Bosse, et al., 2014), with a 2013 value of $3.93 billion (NASS 2014). Most potatoes (60% in 2015) are processed to make potato chips, French fries, dehydrated potatoes and other products. In 2014, 28% were sold fresh, 6% were considered "shrinkage and loss", and 6% are sold or used as seed potatoes in the following season. Less than one percent are used as feed for farm animals (USDA 2016).

In this analysis, we examine potato production in Idaho with seed produced in Montana. Idaho is the number one potato-producing state in terms of volume of potatoes produced, and a large portion of the seed potatoes planted there originate in Montana. Nationally, the number of potato acres planted has declined since the early 90's (USDA ESMIS, various issues), and this is true to a lesser extent for Idaho (Figure 1). However, yields have increased substantially during that same period (see Figure), and as a result potato production has remained relatively flat (Figure 1).

[Figure 1: Potato Acreage, 1988–2014]

[Figure 2: Potato Yields per Acre (cwt), 1988–2014]

[Figure 3: Total Potato Production (cwt), 1988–2014]

Figure 4 shows the Idaho and national marketing year average potato price per hundredweight (cwt), all of which move together, for the most part. The national price has ranged from slightly less than $7.00 in 2000 up to $12.50 in 1989 without showing a clear trend over that time period. The 2013 price was $9.90 per hundredweight. (All prices are adjusted for inflation).

[Figure 4: Marketing Year Average Potato Price, 1988–2013 (2014$/cwt)]

Several potato virus testing centers screen for PVY, along with other economically important potato viruses. The Montana State University Seed Potato Certification program is a grower-supported program that provides seed testing and inspection as well as information and research for seed potato growers in Montana. Based on tests and field inspections, they provide a certification for seed potato producers on a year-to-year basis. Seed potatoes produced in Montana are sold to commercial growers throughout the United States, so this program has wide-ranging impacts.

Previous Economic Studies

Although several studies have examined the impact of PVY on commercial potato production (e.g. Nolte et al., 2004 Whitworth et al., 2006), no studies to date have evaluated the economic benefits from screening for PVY in seed potatoes. Perhaps the closest related study was conducted by Fuglie et al. (1999), who estimated the value of introducing virus-free sweet potato planting material in Shandong Province in China. They estimate an annual benefit of $145 million per year in the Shandong province, and $1.6 billion per year for all of China from the introduction of the program. Olson et al. (2005) estimated benefits from using crop borders as a PVY control. They found a large, statistically significant effect of using crop borders in farmers' ability to pass winter virus tests, but did not estimate the economic effects of the disease or the economic effect of the using the border. Other studies have examined the economic effects of other plant viruses and/or virus control including exclusion of banana bunchy top virus exclusion in Australia (Cook, et al., 2012), optimal control of vector-virus-plant interactions in a potato leafroll virus context (Marsh, et al., 2000), combined effects of climate, aphid infestation, and viruses on pulse crop production (Elbakidze, et al., 2011). Economic effects of viruses and virus screening programs for grapes were examined in Atallah et al. (2015) and Fuller et al. (2015).

Model

Potato yields, prices, PVY and other pest pressures, and other factors vary by both variety and region, among other factors. Additionally, the severity of the effects from PVY differ over each of the five main virus strains (Schramm, et al., 2011) and it is possible to find more than one strain in a given potato crop. As a result, we examine the effects of a "representative strain."

The losses incurred by seed potato growers as a result of PVY, and the benefit from using PVY-screened plants, were estimated based on measures of "variable profits," defined for the purposes of this paper as gross revenue minus virus-related costs for a representative acre of commercial potato production. Virus-related costs include the costs of labor and materials required for rogueing plants with virus symptoms, any price premium for PVY-screened plants, and loss of production from reduced yield from diseased plants. The remaining "profit" must cover overhead costs including equipment depreciation, maintenance, and property taxes, as well as cultural costs not related to PVY, such as fertilizer application and irrigation.

Equation (1) describes variable profit, for a representative acre in this region, in a given year. Put most simply, variable profit—only considering costs and losses relating to PVY—is revenue minus losses from PVY, less costs relating to PVY in terms of various forms of prevention. Price (*p*) and yield (*y*), as well as PVY-related losses at harvest (d^H), vary over potato variety (*i*) and generation (*j*).

$$\pi = \sum_{i,j} \left(p_{ij} y_{ij} \left(1 - d_{ij}^H \left(d_{ij}^P \right) \right) - c\left(d_{ij}^P \right) \right) \quad (1)$$

Variable profit, π , is a function of:

p, the price per hundredweight of potatoes; *y*, the yield, in hundredweight per bearing acre, of plants without PVY; d^H, the percent of loss from PVY at the end of the season which is a function of the amount of virus planted d^P; *c*, the costs associated with screening and certification and PVY prevention. PVY-related costs consist of monitoring for PVY, seed costs, which are in turn a function of disease tolerance at planting, and insecticide applications or other prevention or control methods.

Optimally, growers would choose a level of disease at planting such that the value of the marginal effect of resulting loss at harvest, is offset by the marginal difference in costs from a marginal change in disease at planting d^P.

$$-p_{ij} y_{ij} \frac{\partial d_{ij}^H}{\partial d_{ij}^P} = \frac{\partial c_{ij}}{\partial d_{ij}^P} \quad (2)$$

Because there is some tolerance for disease (Montana State University Potato Lab, 2015), d^P is often not equal to zero; in this way the potato program is inherently different from screening efforts that aim to provide 100% disease-free plants. Table 1 shows the tolerance level for certification of seed tubers by generation. (Note that commercial potatoes are typically grown from G3 seed). Another key difference is that the span of time over which the disease spreads is shorter than in a perennial crop, where it can spread over multiple years, but the fact that it does spread after planting is important. However, here, the dynamics of within-season spread are most important.

[Table 1: PVY field tolerance rates by generation and state]

Net income per representative acre is calculated using parameters derived from a range of sources. In the years 2011–2014 potato growers in the United States region received an average of $9.16 per hundredweight and the average yield was 412 hundredweight per acre, so the average revenue was $3,842 per acre. In Idaho, average potato revenue was calculated to be $3,159 during that time period (NASS 2015). Table 2 illustrates the average production, yield and price for potatoes for the 2011 – 2014 period.

[Table 2: Average Potato Production in Idaho and National, 2011–2014]

Montana Seed Potato Lab Data

Using PVY test data from Montana Seed Potato Certification Program, we can estimate PVY spread over the course of a season. We draw upon 2,133 observations from 2005–2015 that include information on summer and winter test results for PVY along with several other diseases, grower location, variety, and generation. Each observation represents one seed lot submitted for testing. Notably, these data are from seed growers actively suppressing disease by rogueing and in some cases, spraying pesticide during the summer growing season. Additionally, while summer testing and winter testing approximate the beginning-of-season (BOS) and end-of-season (EOS) tests, they actually measure end-of-season tests for two separate seasons—the summer test, in which seed potatoes are grown to be sold in Montana, and the winter test, in which they are grown for testing purposes in Hawaii.

Figure 5 shows winter test results, plotted over summer test results. Each test result—summer and winter—shows the percent of PVY in a particular lot of potatoes tested. The results are densely clustered near zero.

[Figure 5: Summer and Winter PVY Test Results]

In order to better understand the relationship between PVY levels in the summer and winter tests, estimate a series of OLS regression models that control for a number of factors for which we have data. The general equation estimated was:

$$winter_i = \beta_0 + \beta_1 summer_i + \sum_j \beta_{2,j}\delta_{i,j}\, variety_i + \sum_k \beta_{3,k}\delta_{i,k}\, year_{i,k} + \sum_i \beta_{4,l}\delta_{i,l}\, county_{i,l} + \sum_m \beta_{5,m}\delta_{i,m}\, generation_{i,m} + \sum_n \beta_{6,n}\delta_{i,n}\, farm\_id_{i,n} + \varepsilon_i \quad (3)$$

Table 3 shows regression results using these data and dummy controls for potato variety (since some varieties are more PVY-susceptible than others), year (some years are "outbreak" years), county (some counties have higher disease pressure than others), generation grown (since different generations have different disease tolerances), and an identifier for the farm. The percent PVY incidence in the winter test is the dependent variable in all regressions. The coefficient on $summer_i$ can be interpreted as the multiplication factor of spread over a season based on the amount of PVY in the seed planted.

The role of eight 100% PVY incidences in the winter tests play a large role in regression results and the seven columns in the table show alternative methods of addressing these values. Anecdotal evidence and conversations with researchers involved in seed potato testing suggests that the sampling method employed works well for lower percentages of PVY with larger lot sizes but is less dependable for smaller lot sizes and higher PVY incidences (Siemsen 2016, personal communication).[1] Regardless of how we address the issue of very high (100%) winter PVY tests, the coefficient on summer incidence is positive and significant in all regressions. However, it does range substantially—from 3.8 to 9.5 depending on how the 100% PVY winter tests are treated, whether regressions are weighted by sample size (columns 4, 5, and 7), and whether dummies for other control factors are included (columns 6 and 7).

[Table 3. Disease Spread Regression Results]

Calculating the Value of Foregone Production

The impact of seedborne PVY on commercial potato production is a combination of quantity and quality impacts. PVY has been shown to reduce yields by as much as 79% (Hane and Hamm, 1999). Other researchers (Aryal et al., 2016) have examined the qualitative impacts. They found that in the two most common varieties grown in Idaho, Russet Burbank and Russet Norkotah, PVY infections not only reduced yield but reduced the amount of U.S. No. 1 potatoes (the most valuable potato grade) produced.[2] PVY also tended to increase the amount of “dry-eliminators,” or process-grade potatoes—lower-valued potatoes only usable in dehydration or otherwise processed. Combining all of the yield and grade impact information McIntosh et al. (2016) estimated that PVY reduced net returns from commercial potato production by $9.17 to $12.27

[1] Work is underway to better understand this method and the formula used.
[2] 91% of all Idaho potatoes produced are Russet potatoes (USDA ESMIS 2017).

per acre for every percent of PVY in seed stocks. We estimate that Montana-sourced seed potatoes accounted for approximately 41% of all G3 and higher seed certified in Idaho in 2014, using Idaho Crop Improvement Association data on seed lots submitted for testing (Westra 2014). The average disease incidence for across all seed tested by the Montana lab is 0.058%. Using models for PVY spread in commercial potatoes estimated by McIntosh (2017) for Russet Norkotah and Russet Burbank varieties to predict EOS losses, we estimate the loss to Idaho commercial producers that would result from all Montana-sourced seed to be $15.4 million in one year. Seed that passes Montana inspection has an average PVY incidence of 0.006%, or roughly 10% of the average for all seed submitted for testing. Again using McIntosh (2017), we estimate the projected amount of loss from seed that passes inspection to be $8.1 million annually. The difference between these two values provides a back-of-the-envelope estimate of the benefit of the Montana seed certification program to Idaho growers of $7.3 million annually. Note, however that these numbers don't take into account several important factors—importantly, they leave out the benefits accruing as one generation of clean seed progresses to later generations of seed and commercial production.

Conclusion

Our work supports existing research suggesting that PVY spreads in dramatic ways over the course of a growing season. We introduce new data and analysis that connects PVY incidence and spread in seed potato production with models of disease spread and corresponding economic losses in the commercial potato industry.

Seed certification programs, such as the Montana State University Seed Potato Certification Program, screen seed for PVY and other viruses and provide certification that disease in seed is below certain pre-established tolerances. Our analysis suggests this screening is important; the amount of PVY in seed in the summer test is a strong predictor of PVY in the winter test. The amount of PVY in the seed when it is planted, and the spread over the course of the growing season can have major effects on seed and commercial potato grower revenues and profitability. Seed growers observe losses in quantity and quality as well as potentially catastrophic losses if their seed lot does not meet tolerance and cannot be sold in the seed market. Commercial potato grower returns are significantly reduced by the presence of PVY in seed stocks due to reductions in yield and decreases in quality.

Assuming that increasing yields would not negatively impact prices, more effective screening and elimination of PVY in seed potatoes could significantly improve yields and profits for commercial potato growers. The benefits from existing screening and certification programs should not be overlooked, however. Future work will explore the existing benefits from screening and certification of potatoes over several time horizons—from a single season, which we explore here, to several seasons—for example, in the event that the certification program was suspended.

A remaining question is why is PVY a continuing problem for U.S. seed and commercial potato industries? As noted before, there are few effective management tools to reduce spread of the disease once it is in a field. Planting clean seed remains the single most important tool for eliminating the negative impacts from PVY. There has been a disconnect between breeding efforts and pathology, which has allowed the release of varieties of potatoes that carry the infection but do not exhibit visible symptoms, which would allow them to be rogued from a field.

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Tables and Figures

Table 1: PVY field tolerance rates by generation and state

	Nuclear	G1	G2	G3	G4	G5	G6
				%			
MT	0.00	0.00	0.10	0.20	0.50	n/a	n/a
ID	0.00	0.00	0.25	0.50	0.75	1.00	1.00
OR	0.00	0.10	0.30	2.00	2.00	3.00	n/a
WA	0.00	0.10	0.20	0.50	1.00	2.00	n/a
CO	0.00	0.00	0.20	3.00	3.00	3.00	3.00

Table notes: Disease tolerance rates are for tolerance in the field; some states have standards specific to PVY for post-harvest testing, additional field visits if the first is a failed visit. *Sources:* Montana: Montana State University Seed Potato Certification Program (2014); Idaho: Idaho Crop Improvement Association (2014); Oregon: Oregon Seed Certification Service (2016); Washington: State of Washington Department of Agriculture (2015); Colorado: Colorado State University (2015).

Table 2: Average Potato Production in Idaho and National, 2011–2014

	Acres Planted	Production	Yield	Price	% Planting MT Seed
	(1,000 acres)	*(Million cwt)*	*(cwt/acre)*	*($/cwt)*	*%*
Idaho	326	134	414	7.63	33
National	1,096	444	412	9.33	-

Source: Acres planted, production, yield and price from NASS (2015). Acres planted, yield, and price are computed as production-weighted averages. Acres planted over the four-year period are weighted by production. Yield, and price are a production weighted average over the four years for each state and nationally and a production-weighted average over the years. The Percent from MT is estimated from seed lot data, provided by Alan Westra for Idaho (personal communication, 2015).

Table 3: Disease Spread Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant (*a*)	0.092	0.151*	0.255***	0.04	0.097*	1.431	0.099
% Summer Positives	9.500***	6.738***	3.825***	8.351***	6.380***	6.663***	6.241***
Variety controls						x	x
Year controls						x	x
County controls						x	x
Generation controls						x	x
Farm ID						x	x
R^2	0.398	0.387	0.419	0.489	0.663	0.481	0.712

Notes: (1) No transformation; (2) Winsorizing the four observations that show up in both *dfbeta* and *Cook's D* outlier diagnostics; (3) Winsorizing all eight observations where winter PVY = 100%; (4) Weighting by number of samples submitted for test; (5) Weighting as in (4) and winsorizing as in (2); (6) Winsorizing as in (2) + adding in dummy regressors as indicated.; (7) Column (6) plus weighting.

N = 2,133. Right-hand-side variable is % Winter PVY Positives. We report robust standard errors in all regressions.

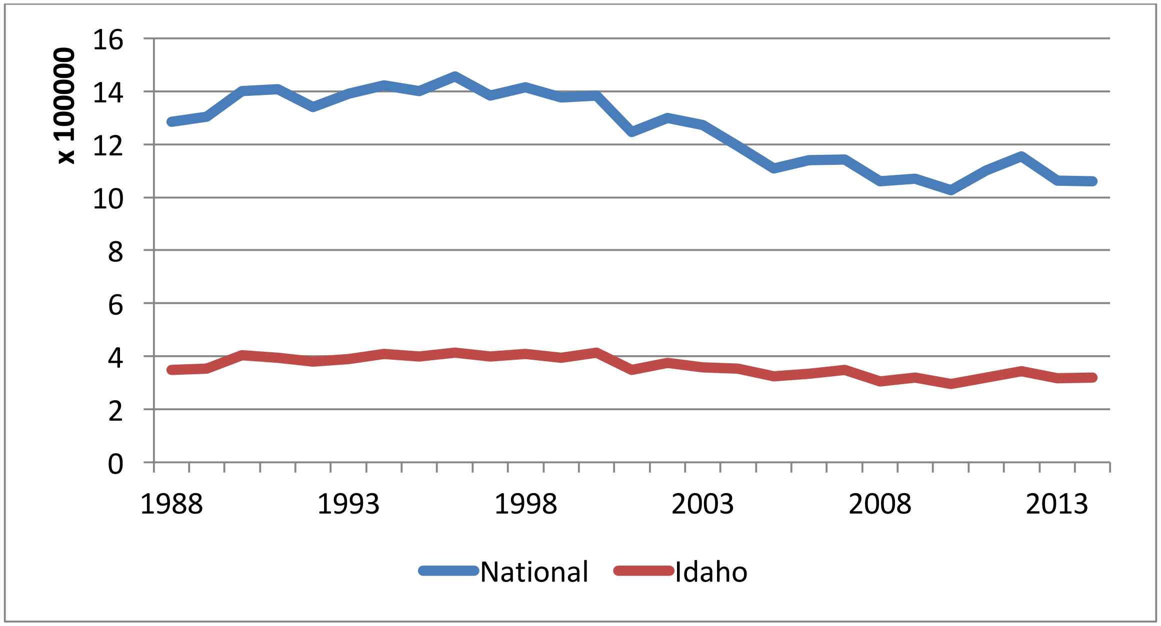

Figure 1: Potato Acreage, 1988–2014

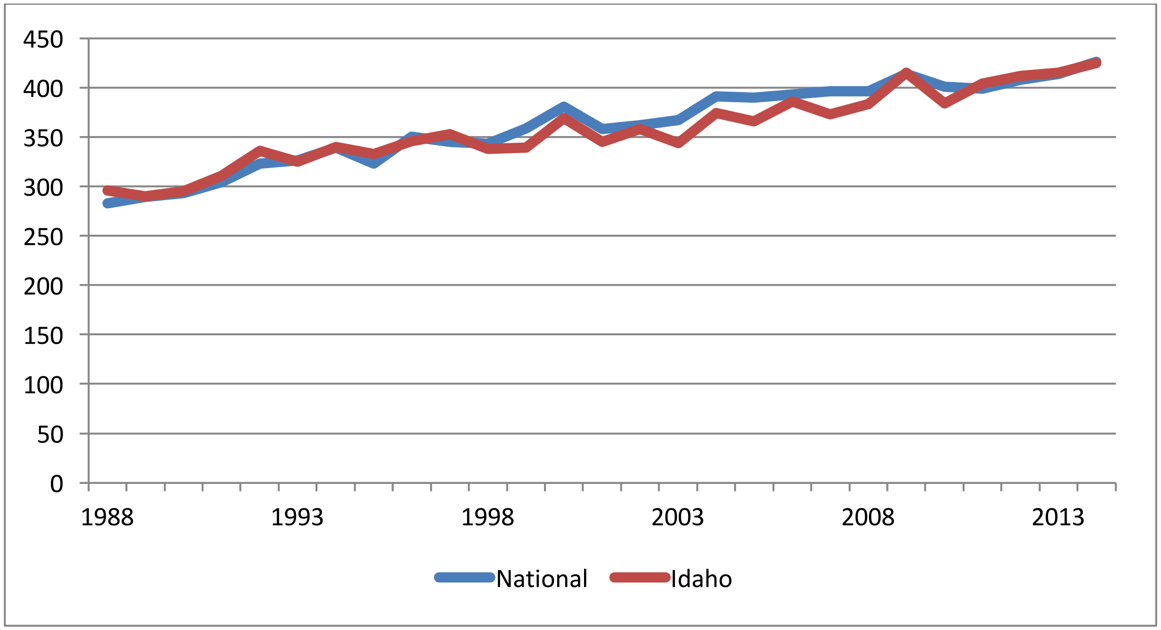

Figure 2: Potato Yields per Acre (cwt), 1988–2014

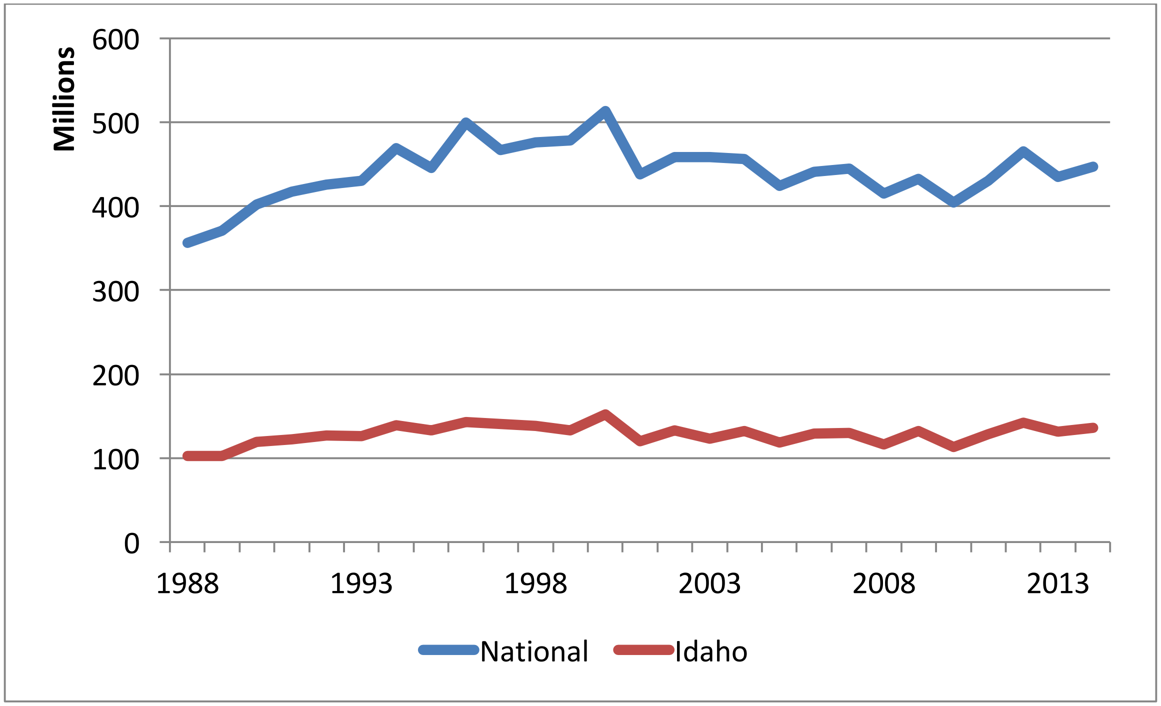

Figure 1: Total Potato Production (cwt), 1988–2014

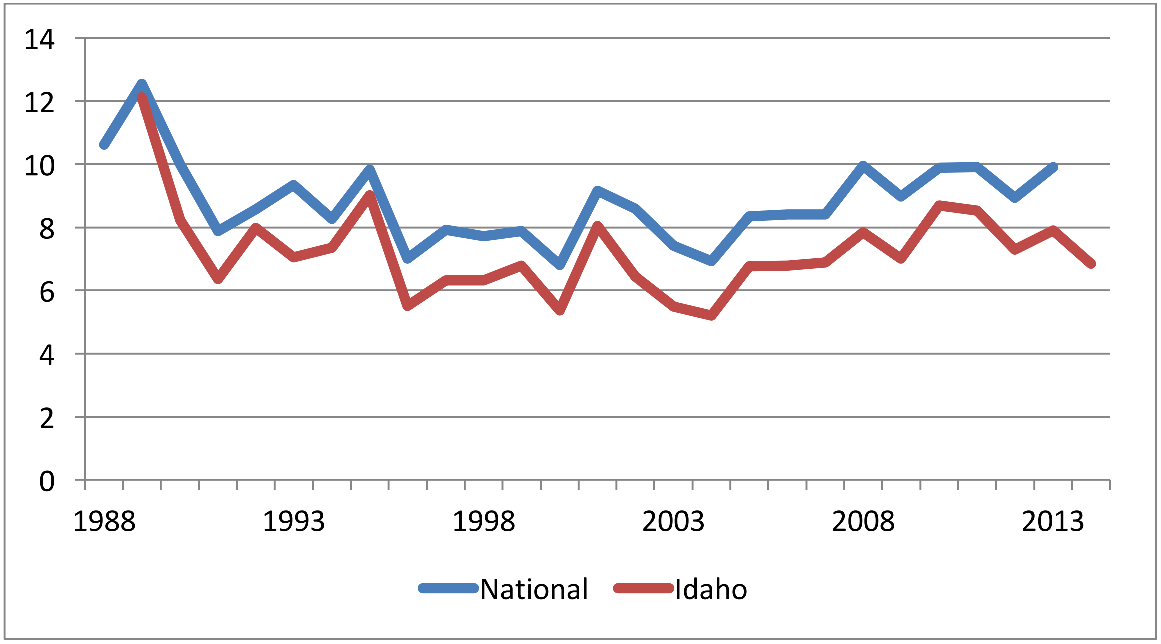

Figure 2: Marketing Year Average Potato Price, 1988–2013 (2014$/cwt)

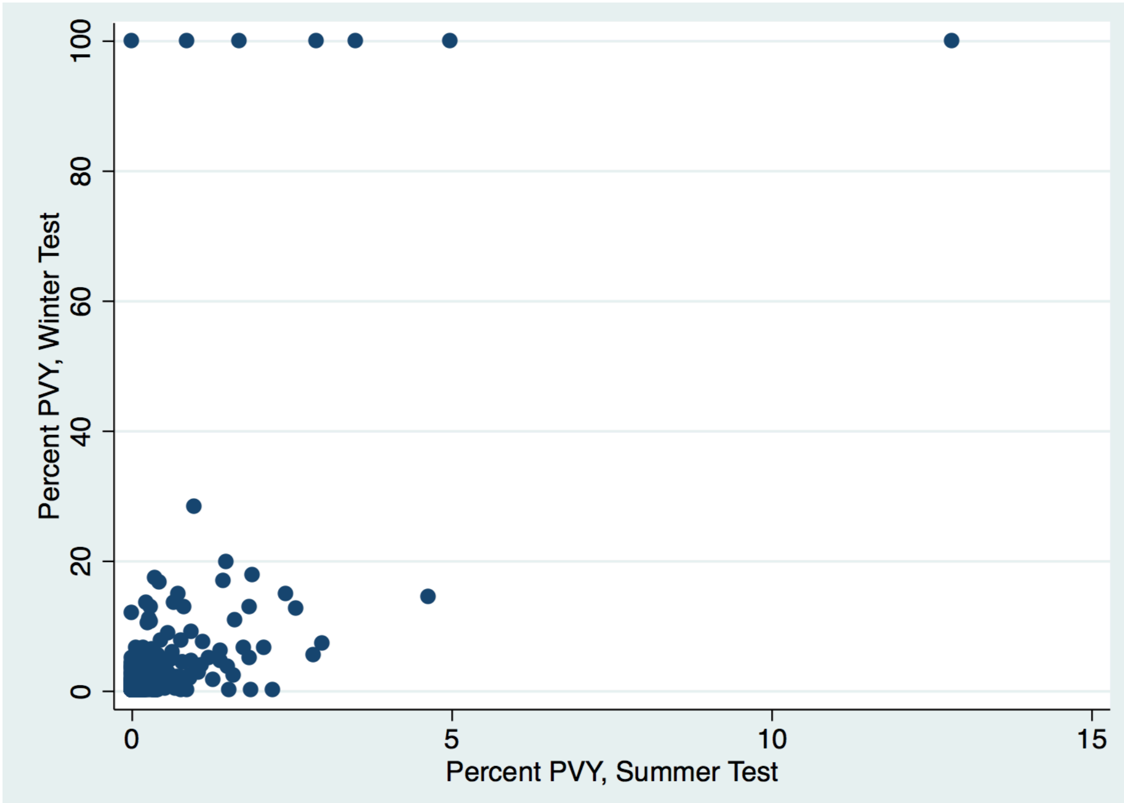

Figure 5: Summer and Winter PVY Test Results