Economic Impact of Virus-Free Sweet Potato Seed in Shandong Province, China

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Abstract

Shandong Province on China's northern coastline produces about 17 million metric tons of sweet potatoes annually, or about 12 percent of global production. Between 1994 and 1998, virus-free seed was extended to about 80 percent of the hectares planted to sweet potatoes in the province, resulting in significantly improved yield. This paper examines the economic impact of improved seed in this province and discusses the financial sustainability of the seed multiplication system. Information for the study comes from group interviews with farmers in 30 villages conducted in the province in 1998. These data are supplemented with estimates of the costs of research, extension, and seed multiplication provided by the Shandong Academy of Agricultural Sciences. The availability of virus-free seed is estimated to have increased average sweet potato yield amongst adopters by at least 30 percent, with little or no change in the use of other inputs. The internal rate of return is estimated at 202 percent, with a net present value (assuming a 10 percent real discount rate) of $550 million. By 1998, annual productivity increases were valued at $145 million annually, improving the agricultural income of the province's 7 million sweet potato growers by 3-4 percent.

Key words: China, economic returns to research, sweet potato, virus-free seed.

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Introduction

In many developing countries, yields of root and tuber crops are significantly reduced below their potential due to seed-borne diseases and pests (Clark and Moyer 1988). Because these crops are generally clonally reproduced from cuttings, roots, or tubers, it is relatively easy for diseases to be transmitted through seed from generation to generation. However, the development and transfer of new methods and technologies for producing disease-free clonal seed can overcome this constraint and help unlock the significant yield potential of these crops.

In the late 1980s, the International Potato Center (CIP) in collaboration with Chinese agricultural scientists began a project to develop and transfer new methods for propagating virus-free seed roots and vines for sweet potatoes in China. Average farm yields were observed to be significantly below potential yields, and it was hypothesized that disease transmission, especially from viruses, through farmer-saved seed roots may be a significant factor in suppressing yields (Moyer and Salazar 1989). The approach was to use tissue culture propagation and ELISA testing methods to develop disease-free mother plants for existing varieties and then multiply the clean material under controlled conditions for distribution to farmers. Such systems are now being developed in the main sweet potato growing areas of China. The most advanced seed program can be found in Shandong Province, where virus-free seed was first distributed to farmers in 1994. Virus-free seed was targeted to reach 80 percent of the sweet potato area in the province by 1998 (Zhang et al. 1995).

This paper examines the economic impact of virus-free sweet potato seed in Shandong Province.[2] Sweet potatoes are currently grown by small farmers on 600,000 hectares in the province for an annual production of about 17 million metric tons. Shandong Province alone accounts for 15 percent of China's sweet potato production and about 12 percent of global production. Once an important staple food, sweet potatoes are today used primarily for livestock feed and processed food products such as starch noodles (Gitomer 1996). The rapidly changing utilization of sweet potatoes from a low-valued staple food to a raw material for higher-valued products is an important element is understanding the apparent high demand for and the rapid diffusion of improved planting materials among China's sweet potato farmers.

In the next section of the paper we describe the development of the virus-free sweet potato seed system in Shandong, China. We then present the materials and methods for the present study: Group interviews with farmers in 30 villages provide the basis for the impact assessment on crop yields, input use, and area planted. These data are supplemented with yield data from demonstration trials conducted in the province in the early 1990s. Estimates of the costs of research, extension, and seed multiplication are from the Shandong Academy of Agricultural Sciences (SAAS). Benefit-cost analysis is used to examine the returns to the virus-free program. To preview the main findings, the availability of virus-free seed is estimated to have increased average sweet potato yield amongst adopters in Shandong Province by 30-40 percent, with little change or even a reduction in the use of other inputs. As Shandong is the second largest producer of sweet potatoes in China after Sichuan Province, producing about 15 percent of the national total, normally a production increase of this size might be expected to have a noticeable downward effect on market prices. However, due to the strong growth in foreign and domestic demand for sweet potato starch-based noodles, demand for sweet potatoes appears to be highly elastic. Thus, a large share of the project benefits, estimated at over $100 million annually once wide adoption was achieved, is retained by farm households. The final section summarizes the main findings and discusses some of the implications for extending the Shandong experience to the rest of China.

A note on nomenclature: In this paper we adopt the terminology of "virus-free" seed to describe the improved seed provided by the sweet potato seed program in Shandong Province as this is the term used by the seed multiplication program. A more accurate descriptor might be "disease-free" seed or "disease-reduced" seed. The seed program has probably reduced the incidence of other seed borne diseases in addition to viruses, although viruses are undoubtedly the most significant. During multiplication (by the program or by farmers) the seed gradually becomes reinfected with diseases as it is saved from one season to the next. Thus, much of the improved seed in use could be more accurately labeled "disease-reduced" seed. We also use the labels adopted by the Shandong seed multiplication program to measure the age of seed (pre-original seed, original seed, first and second generation production seed – see the following section), which differ somewhat from the G0, G1, G2, etc., nomenclature normally used in seed propagation programs.

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[2] This is one of the first studies to examine the economic impact of CIP-related technology on sweet potatoes. Previous studies of economic impact of CIP technology have focused primarily on potatoes (see Walker and Crissman, 1996).

Development of the Virus-Free Sweet Potato Seed System

Sweet potato is the third ranking crop in Shandong province after maize and wheat. In the farmers' traditional seed system, sweet potato roots are stored from the fall harvest to the following spring planting. Sweet potatoes are typically grown on poorer quality unirrigated land in rotation with maize or groundnuts, as a monocrop, or in a winter wheat-sweet potato-maize rotation that produces three crops every two years. The "Spring" sweet potato crop is planted in late March or April and harvested in September or October. When following winter wheat, sweet potato is planted as a "Summer' crop in July and then harvested in October after the spring crop. The spring crop accounts for about 60 percent of the total sweet potato area in Shandong and exhibits a higher average yield than the summer crop due to its longer growing season. Planting material for the summer crop comes from vines cut from the previously established spring crop.

In the late 1980s, propagation of virus-free seed was identified by international and national sweet potato scientists as a possible means of improving farm yields of existing sweet potato varieties in China. Field observations together with laboratory testing indicated high levels of virus infection in sweet potato plants in farmer's fields, especially the sweet potato feathery mottle virus (Zhang 1996). With technical assistance from CIP, training courses were organized beginning in 1988 to demonstrate how to produce and multiply virus-free sweet potato seed. The technique involves taking meristem tips from selected plants and then regenerating the entire plant using a culture medium (Salazar 1996). Heat treatment is used to reduce virus multiplication in the plants, and ELISA tests are conducted to confirm that plantlets after meristem culture are free of viruses. Virus-free plantlets, after a period of adaptation outside test tubes, are then grown out in heated green houses and used as mother plants to multiply seed for farmers.

Following the CIP training courses, SAAS scientists conducted applied research in tissue culture and seed multiplication techniques to establish the most appropriate medium for the cultures, the best timing for transplanting, and other multiplication methods. Beginning in 1992 SAAS conducted field trials in different locations of the province to compare yields of virus-free seed to yields from farmers' seed. These trials showed an average yield increase of around 40 percent in plots using virus-free seed of popular new varieties and even larger increases with older varieties (Zhang 1995). The success of the trials led to additional financial support from the provincial and local governments for extension and seed multiplication. In 1993 and 1994, large-scale extension and demonstration trials were carried out in all of the major sweet potato producing counties of the province. The first virus-free seed was extended to farmers in 1994 and extension activities were intensified in 1995. The sweet potato multiplication program in Shandong Province estimated that in 1997 40 percent of the sweet potato area was planted to virus-free seed and projected more than 80 percent diffusion by 1998 (SAAS, unpublished data).

The organization of the virus-free sweet potato seed multiplication system in Shandong is depicted in Figure 1. At the provincial agricultural research center (the Shandong Academy of Agricultural Sciences) virus-free plantlets are produced in a tissue culture lab and multiplied during winter months in a heated glass house to produce virus-free cuttings. These cuttings are further multiplied in net houses during the spring and summer growing season. Net houses may be managed by district or county-level governments. Pre-original seed from the net houses is then multiplied at the township level in open fields to produce original seed. Original seed is again multiplied at the village or farm level to produce first generation production seed. Farmers may purchase original or production seed from the program, and typically use the improved seed for two to three years before repurchasing clean seed. Due to the possibility of getting two multiplications of seed per year (the spring and summer crops), the Shandong seed program has achieved exceptionally high rates of multiplication – one hectare planted the first year can provide sufficient seed roots for 250-400 hectares the following year. In 1998, net houses in the province had a capacity to produce 10,000 pre-original seed cuttings per year, enough to produce first generation production seed for 533,333 hectares two years later.

The Chinese system for producing virus-free sweet potato seed from tissue culture appears to have few precedents. In the U.S., farmers typically renew their propagation material in the form of roots about every three years to maintain cultivar purity as mutations are a problem. But tissue culture techniques are not used on a commercial basis and no emphasis is placed on generating virus-free material (Wanda Collins, personal communication, 1999). In South Africa, tissue culture has been used as a starting point to supply seed material to a small number of large growers who export fresh sweet potatoes to Europe during the European winter season. Low labor costs and the possibility of high multiplication ratios may make this technology particularly favorable to China.

Data and Methods for Impact Assessment

Two main sources of information were used to examine the impact of virus-free sweet potato seed on farm yields, production, and income: (1) a survey of sweet potato farmers in 30 villages conducted in 1998, and (2) data on yield demonstration trials, seed production, and costs of research, extension, and seed multiplication provided by the Shandong Academy of Agricultural Sciences.

The village survey was designed and conducted by a multidisciplinary team of researchers from SAAS and CIP in August and September, 1998. Thirty villages were selected from the seven districts with the greatest area planted to sweet potato in Shandong Province. Two districts (Yantai and Weifang) are located in the north-eastern coastal part of the province. These districts are relatively more industrialized and richer than the rest of the province. The other districts are located in the mountainous central and south-central part of the province (Jinan, Tai'an, Lin Yi, Ri Zhao, and Jining) where land quality is poorer and rural household income is noticeably less than the north-eastern coastal areas (Figure 2).

In each village, a group interview was conducted with the village head and 4 to 10 sweet potato farmers to determine the extent of area planted to sweet potatoes, the diffusion of improved sweet potato seed, yield comparisons between virus-free seed and farmer's seed, and whether the adoption of virus-free seed led to changes in the levels of other inputs and market prices. It was expected that yield would gradually decrease as improved seed aged, so farmers were asked to estimate the yield of original seed, first generation production seed, second generation production seed, and their traditional seed for each of the major varieties grown in the village.[3] Yield estimates were elicited for both the spring and summer crops, since summer crop yields are generally lower due to a shorter growing season. Questions were also posed on the prices paid for sweet potato seed and prices received for the harvested crop, the utilization of sweet potatoes

[3] In some cases farmers did not have direct experience with all age types and were not able to provide yield estimates for these cases.

in the village, household income levels in the village, and the contribution of sweet potatoes to the agricultural income of the village. An English translation of the questionnaire is included as an appendix.

With data on seed production from the seed multiplication program it is possible to determine the extent of area planted to virus-free seed in Shandong Province for each year from the beginning of the program in 1994. The village survey data provides a further check on the percentage of sweet potato area planted to seed of various ages. The yield impact of virus-free seed can be estimated in two ways: from the demonstration plot data and directly from the elicited yield estimates from the farm survey.

With these estimates, benefit-cost analysis is used to quantify the economic impact of the virus-free sweet potato seed program. Under certain assumptions, benefit-cost analysis provides a valid measure of economic welfare gains from an activity or project. The relationship between benefit-cost analysis and the standard consumer and producer surplus measures of welfare changes is shown in Figure 3. In Figure 3.a, demand for a commodity is shown to be downward sloping and supply upward sloping. Improved technology that reduces unit costs of production is represented by a downward shift in supply from S_1 to S_2. The decline in unit production costs may be due to a new technology that either increases yield or saves inputs, or to some combination of the two. The downward shift in supply represents the net benefit per unit of output from the adoption of improved technology. Since demand is less than perfectly elastic, an increase in supply causes the output price to fall. Supply is also price responsive, so that a decline in the market price partially discourages the supply response to the new technology.

In Figure 3.a, the total net welfare benefit from the new technology is measured by the shaded region, which is the area below the demand curve and between the supply curves.

In benefit-cost analysis, market prices are general held fixed, or at least assumed to be exogenous to the project. Quantities of inputs (costs) and outputs (benefits) are varied by the project to generate economic losses and gains. For projects that increase output or yield, demand is assumed to be perfectly elastic and supply perfectly inelastic so that output price is not affected. Perfectly or very elastic demand is likely to be the case when the supply shift is relatively local so that the increase in quantity does not have a significant effect on total market supply. For example, if a large share of production from a region or country is exported and the amount exported is small compared with total world supply, then an increase in supply from the region will not have much affect on the global market price. The inelastic supply function assumes that farmers have very little scope for increasing output by increasing the use of other inputs such as fertilizer and that output is unresponsive to market price. Benefits are given by the increase in supply due to the new technology valued at the exogenously-determined market price, as shown by the shaded region in Figure 3.b.

A major difference between the approaches in Figure 3.a and Figure 3.b is how each treats the distribution of the total benefits among producers and consumers (Alston, Norton, and Pardey, 1995). In benefit-cost analysis, all welfare gains are assumed to go to producers. In the more general model given in Figure 3.a, not only do producers benefit from lower unit production costs, but consumers also benefit from lower prices. Generally, as demand becomes more inelastic, a larger share of benefits goes to consumers.[4]

A third way of modeling the effect of new technology is provided in Figure 3.c. Here, demand is assumed to be perfectly elastic as in Figure 3.b, so an increase in quantity supplied does not affect market price. In Figure 3.c, however, supply is no long inelastic. In this case, new technology increases the marginal productivity of other inputs causing their use to go up. For example, an improved variety that is more responsive to fertilizers might be expected to cause farmers to increase fertilizer use in order to raise yield. As in Figure 3.b, all of the benefits from the new technology go to producers. However, in this case benefit-cost analysis will generally over-estimate the size of the welfare gains from the new technology. As shown in Figure 3.c, benefit-cost analysis measures welfare gains by the area of the shaded region. But the correct estimate of the welfare gain is given by region A (the area under the demand curve and between the supply curve). By the "law of parallelograms," the shaded region equals area A plus area B. Thus benefit-cost analysis overestimates the true welfare gain by area B. The degree of overestimation will depend on the size of the production shift relative to the elasticity of supply.[5]

Absent formal economic studies, we must rely on heuristic evidence to assess which of the alternatives in Figure 3 best characterizes the structure of sweet potato supply and demand in Shandong Province. Regarding demand, our assessment is that currently demand is highly

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[4] Some models assume that the supply function shift is “pivotal” from the intercept instead of parallel as shown in Figure 3. In this case, it is possible that producers may become worse off when supply increases (i.e., all benefits go to consumers plus some producer surplus is transferred to consumers) although total welfare improvements are nevertheless positive (Alston, Norton and Pardey, 1996).

[5] Specifically, the ratio of the welfare gain given by region A to that estimated by benefit-cost analysis in Figure 3.c is given by $(J+2)/2e$, where J is the percent increase in output relative to Q_1 and e is the elasticity of supply. Thus, benefit-cost analysis will overestimate the true welfare gains whenever $J<2(?-1)$.

elastic. Not only is the production impact regional, but more than 80 percent of the sweet potatoes produced in the province are either fed to livestock (where they compete against locally-grown and imported maize-based feed) or processed into starch and/or noodles for export to other provinces and countries. Further, in the survey farmers were asked whether sweet potato market prices had been affected in recent years by the increase in production due to virus-free seed. In all cases farmers responded that market prices for sweet potatoes had been stable over the past several years, and that demand from the processing industry was strong and could absorb whatever they produced. Thus, the assumption of perfectly elastic demand appears to be warranted.

Survey responses also provide evidence of an inelastic supply, at least with respect to the adoption of virus-free seed. Villages were asked in the survey whether adoption of virus-free seed caused changes in levels of other inputs. Responses showed that in some villages the adoption of virus-free seed was accompanied by a reduction in planting density, nitrogen fertilizer use, and chemical pesticide application rates, although phosphate and potassium use may have increased somewhat (Table 1). The reduction in inputs apparently resulted from having a healthier, more vigorous crop. Overall, the adoption of virus-free seed appears to have resulted in either no change or a modest decline in other input costs.[6] Thus an assumption of inelastic supply appears to be supported. We chose this along with perfectly elastic demand for our "baseline" (most likely) estimate of the economic impact of virus-free seed in Shandong

[6] However, it may be too early to assess the full effect of virus-free seed adoption on the use of other inputs. It may take several seasons for farmers to observe changes in the marginal productivity of other inputs and adjust application rates accordingly. Furthermore, studies show that farmers tend to adopt innovations in a step-wise manner, rather than as a package (Byerlee and de Polanco, 1986). Such changes would, however, further increase welfare benefits from virus-free seed since any increase in costs would be associated with an even larger increase in output.

Province. Sensitivity analysis is used to estimate the economic impact of the project under alternative assumptions about market structure.

Results and Discussion

Estimation of benefits

According to the sweet potato seed multiplication program, virus-free seed was estimated to have reached 84 percent of the sweet potato area in Shandong Province by 1998 (Table 2). This estimate includes area planted to original seed and first and second generation production seed. Among the 30-village survey, virus-free seed was first used in 1995, and by 1998 had spread to 78 percent of the sweet potato hectares in the villages (Figure 4). The adoption of virus-free seed in the 30 villages was higher for summer sweet potatoes than the spring crop. Farmers may purchase a small amount of virus-free seed for the spring crop, and use this to multiply their own virus-free seed for their summer crop.

The rapid diffusion of virus-free seed can probably best be explained by its significant and noticeable affect on yield. Both large-scale demonstration plots conducted by the Shandong agricultural extension service during 1993-1994 and the village survey show similar levels of average yield improvement from virus-free seed (Table 3). For the most widely grown variety, Xushu 18, virus-free original seed is estimated to have increased yield of the spring crop by 11 tn/ha, or by more than 30 percent, over the yield obtained from farmers' traditional seed. Yield gains from other important varieties (Lushu 7, Lushu 8, Beijing 553) ranged from 6.7 to 10 tn/ha according to village survey and by between 13 and 16 tn/ha in the demonstration plots.

For the summer crop, yield of Xushu 18 was estimated by farmers to have increased by an average of 10.6 tn/ha, or by 41 percent. Yields of other varieties were estimate to have increased by 8.5 to 10 tn/ha. It should be noted that these are estimates of the average yield gain for the villages as a whole, and may not be representative of individual farmers. Some farmers in the village may experience higher or lower yield changes than these averages according to their individual cropping practices and land quality. Since virus-free seed is more likely to have been adopted on fields with the largest yield gain, the marginal yield gain (i.e., the yield gain that could be achieved if one more hectare of sweet potatoes is planted with virus-free seed) is most likely less than the reported averages. Thus, even with large average yield gains, it may not be profitable for all farmers in a village to use virus-free seed, and adoption rates may peak at below 100 percent.

Table 4 shows the result of a simple multiple regression of possible factors affecting the diffusion of virus-free seed among the sample villages. Average household income in the village, the importance of sweet potato in the agricultural economy of the village, and the average yield gain of virus-free seed over farmers' traditional seed are included as possible factors in the model. Only the yield gain is statistically significant, and this variable alone explains about 70 percent of the variation in adoption rates among the 30 villages. The lack of statistical significance of the other variables suggests that virus-free seed spread as rapidly in poor villages as in richer villages, and in villages where sweet potato is only a relatively minor crop as in villages where sweet potato is relatively more important.

Estimates of the annual benefits of the virus-free seed program for Shandong Province are presented in Table 5. Gross benefits are estimated by multiplying the estimated area planted with virus-free seed by the average production increase per hectare, by age of seed. The production increase for original seed is estimated to be 10.35 tn/ha, for first generation seed it is estimated to be 9.6 tn/ha, and for second generation seed it is estimated to be 6.9 tn/ha. These figures are derived from the village survey reported in Table 3. Area planted to virus-free seed is derived from data on seed production provided by the provincial seed program and assumes a seeding rate of 750 kg/ha. The benefit estimation also assumes that the total area planted to sweet potatoes remains at 533,000 hectares in the future and that the diffusion of virus-free seed reaches an upper limit of 78 percent of the total sweet potato area. This estimate of the benefit area is from the 30-village survey and is below the estimate of 84 percent for the province as a whole (Table 2). If the yield effect of virus-free seed on the remaining non-adopting areas is sufficient to offset the higher cost of virus-free seed, or if the cost of virus-free seed declines, further penetration of virus-free seed can be expected. In the sensitivity analysis reported below, the maximum diffusion level is varied to 90 percent to see how the benefits would be affected by an increase in peak diffusion.

At a peak adoption rate of 78 percent (assumed to be reached in 1998), the program is estimated to increase sweet potato production in the province by 3.956 million metric tons annually for a value of gross benefits of $167 million/year. Benefits are assumed to remain at this level until the end of the activity in 2020.[7] The diffusion of virus-free seed between 1994 and 1998

[7] The choice of 2020 as an end date of the project is arbitrary. Benefits could be assumed to last indefinitely. However, the assumption of later date has little or no consequence on the calculation of net present value (NPV) or internal rate of return (IIR), since at the assumed or calculated interest rates the present value of net benefits more than two decades hence are near zero.

amounts to a 22 percent increase in sweet potato production in the province, equivalent to a 2.64 percent increase in global production.

Costs of research, extension and seed multiplication

Table 5 shows the estimates of the principal cost components of seed program: international and local research, extension, and seed multiplication. Local research and extension costs are estimated by determining annual staff and material costs, and then increasing these costs by a certain percent in order to account for the costs of fixed factors such as land, buildings, and equipment that are shared with other projects. We assume that fixed factors account for 50 percent of the total research costs and 25 percent of total extension costs.[8] International research includes the costs of research materials, training and evaluation costs provided by CIP.

For the seed multiplication program, labor and some material costs are provided by the government, but the major source of revenue is from seed sales. The program may either sell original seed or first generation production seed to farmers, although original seed is expected to be used mainly to produce seed for farmers' subsequent crops. Table 6 shows a partial budgeting analysis for seed according to age. This analysis assumes that the use of all other inputs remains unchanged. Note that if the seed is used strictly for production (and not for seed multiplication), first generation seed is more profitable than original seed even though yield from original seed is higher. First generation seed provides net benefits of about 3,500 Yuan/ha for the spring crop. However, many farmers who purchase original seed are interested not only in the current yield

[8] This is a simplified way to treat the difficult task of assigning depreciation to fixed factors that are often shared between several activities. Assuming 50 percent of total research costs for fixed factors may seem high – a comparable figures for public agricultural research in the United States is 10 percent – but it may better reflect the lower share of research costs in labor due to relatively low wages in China. The result is a research expenditure of about 78,000 Yuan per full-time-equivalent (FTE) scientist per year, which is close to Pray et al.'s estimate of

but also subsequent yields, and view it as a multi-year investment. For the benefit-cost calculation, we assume that the seed program only sells first generation production seed and is the sole source of this seed. Thus, farmers who buy original seed for their own seed multiplication are considered for the analysis as part of the seed program. It is assumed that all of the revenues from the sale of first generation seed are used for seed multiplication costs, although some of these benefits may be retained as profits by the seed producers. Thus, seed multiplication costs may be overestimated. This assumption errs on the conservative side in estimating net welfare gains from the program.

An important question for the long-term sustainability of the seed program is whether it can be financially self-sufficient in the future. As can be seen from Table 5, research and extension costs are mainly incurred early in the project. Seed multiplication costs are by far the major cost component once the multiplication system is established. Figure 5 shows how the cost structure of the program evolved over time: research[9] was the principle activity for the first four years of the program but were then overshadowed by extension and seed multiplication. As virus-free seed was being tested and extended to farmers, government subsidies, especially for technical training, net house construction and other materials, played an important role in getting the seed multiplication system established and providing farmers with relatively low-cost seed. Once farmers were convinced of the benefits of virus-free seed and adopted it, revenues from seed sales soon provided for most of the costs of the program. By the eighth year of the program, about 90 percent of the costs of the program were derived from seed sales.

76,900 Yuan/FTE for all Chinese agricultural research institutes for 1994. Similar arguments apply to agricultural extension costs.

One factor accounting for the rapid diffusion of improved seed was that virus-free seed was relatively cheap compared with the benefits of higher yield. The partial budgeting exercise in Table 6 shows that for farmers, adoption of first generation production seed for the spring sweet potato crop produced on average nearly 7 Yuan in additional value of yield for each 1 Yuan of added seed costs. The initial subsidies provided to the seed program helped keep the price of improved seed low, and thus promoted its rapid diffusion. Although it may have been possible to fund a larger share of the program from seed sales, it would have required charging farmers higher prices for improved seed and slowed diffusion. Thus there may be a tradeoff between the goal of financial self-sufficiency and rapid technology diffusion. If the information asymmetry between farmers and scientists on the value of improved seed is large, then an initial subsidy to promote rapid diffusion can increase the social rate of return to the program. Once the value of improved seed is well-established in the minds of farmers, continuing the subsidy will no longer improve economic efficiency, but rather represent a pure welfare transfer from taxpayers to farmers. After large-scale adoption has occurred, it should also be possible to recover the initial subsidies through a small, temporary tax on seed sales. Such a tax could provide revenues for funding the development and diffusion of improved seed in other regions or provinces.

The success of the sweet potato seed program in Shandong Province suggests it may be possible to conduct the seed multiplication program through the private sector once farmers recognize the value of improved seed. Successful privatization of the seed program, however, may require the development of strong grower associations especially to serve the export market. The principal role of the public sector in the seed program could then be regulatory to assure seed quality. Research and extension are unlikely to be supported by the private sector even when these

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onal and local research are combined in Figure 5.

activities produce large economic benefits. The problem is that research and extension have a large "public good" content, i.e., they produce benefits that are shared by all and which are difficult to exclude from non-payers once the results are made public. Thus, individual companies or farmers have a strong incentive to "free-ride" on these activities and avoid incurring their costs. Getting individual companies or farmers to voluntarily support their share of research and extension costs is therefore difficult, and these activities are likely to remain public-sector responsibilities.

Benefit-cost measures and sensitivity analysis

Under the baseline assumptions described above, benefit-cost analysis shows that the virus-free seed program in Shandong Province had an internal rate of return of 202 percent, and, assuming a 10 percent real discount rate, yielded a net present value of $550 million (Table 7). Once the program was fully established (1998 and beyond) virus-free seed provided net benefits of $145 million per year. This baseline assumption assumes a 78 percent peak adoption rate. If peak adoption were to instead reach 90 percent[10] then the internal rate of return remains at 202 percent but the net present value (10 percent discount rate) increases to $620 million. Annual net benefits at full adoption (2002 and beyond) are $168 million per year.

It was previously noted that if the underlying market structure is closer to the model presented in Figure 3.c rather than Figure 3.b, then the welfare effects will likely be overestimated. For example, given an estimate of supply increase of 24 percent and a supply elasticity of 2, benefit-cost analysis will overestimate the actually welfare gains by 45 percent (see footnote 5). Adjusting the estimate of annual gross benefits to reflect the model in Figure 3.c under these assumptions results in an estimated internal rate of return to the project of 174 percent and a net present value (10 percent discount rate) of $265 million. Recall that a positive supply response such as that in Figure 3.c should be accompanied by an increase in use of other inputs to account for the rise in marginal costs. However, in the survey farmers reported no net increase in fertilizer, pesticide, or labor inputs as a result of adoption of virus-free seed.

Other scenarios examine the sensitivity of the results to the estimates of yield gains and project costs. Doubling the estimates for research, extension and seed multiplication costs results in an internal rate of return to the project of 170 percent and a net present value of $467 million. Annual net benefits at full adoption are $124 million. If the estimate of yield gain due to virus-free seed is halved, the project still gives an internal rate of return of 170 percent but net present value falls to $234 million. A final scenario doubles project costs and reduces yield gains by half. This reduces the internal rate of return to 132 percent and gives a net present value of $151 million. Even under grossly conservative assumptions, the virus-free seed project appears to have resulted in impressively high returns.

Impact on producers' income

Responses to the village survey also provide a picture of the impact of virus-free seed on producer's income. Villages located in the more industrialized parts of Shandong Province, such as those in Yantai and Weifang Districts, are noticeably better off than villages in other parts of the province. Villages in the mountainous central and southern districts (including RiZhao, LinYi, and Jinzing Districts), are significantly poorer. In the poorer districts, sweet potato area per household is larger and sweet potatoes make up a larger component of household income. In

[10] In this scenario, diffusion is assumed to increase from 78 percent in 1998 to 90 percent in 1999 through an increase in use of 1st and 2nd generation virus-free seed.

the survey, village heads were able to report average per capita income in the village for 1997, a figure they also report to the local government authorities. Survey responses from the 12 villages in Yantai and Weifang indicated an average total income for 1997 of 3,064 Yuan/capita (or 9,817 Yuan/household), and an average agricultural income of 1,798 Yuan/capita. In these villages, average area planted to sweet potatoes was 0.07 ha/household, and sweet potatoes contributed 15 percent of agricultural income. Among the 18 other villages in the survey that were located in poorer areas, average income was reported to be 2,091 Yuan/capita (or 7,316 Yuan/household), with 1,394 Yuan/capita from agriculture. Sweet potato area per household was 0.14 ha, and sweet potatoes contributed 25 percent of agricultural income. From the regression analysis reported in Table 4, virus-free seed diffused equally well in poor villages as in relatively rich villages, and in villages where sweet potatoes are relatively minor or important. Farmers' estimates of the yield effects of virus-free seed were not significantly different across locations.

The partial budgeting exercise shows that first generation virus-free seed provided a net benefit of 3,500 Yuan/ha for the spring crop and about 1,600 Yuan/ha for the summer crop. Multiplying these figures by the average sweet potato area planted to virus-free seed suggests that in the Yantai and Weifang areas, improved sweet potato seed increased household incomes by an average of 160 Yuan/household/year. In the poorer villages of the hilly regions in the center and south of the province, adoption of virus-free seed increased household incomes by an average of 265 Yuan/household/year, due to the larger area planted to virus-free seed per household. In the richer areas virus-free seed only increased average household income by around 1.6 percent/year, and in the poorer regions the increase in total household income from virus-free seed was 3.6

percent/year. The income effects were thus progressive, with a larger share going to households in relatively poor regions, due to the increased importance of sweet potato production in these areas. Furthermore, while the effects on household income do not appear to be large, this is because the benefits are so widely distributed among 7 million small farmers of the province, each of which, on average, plants only less than one-tenth of a hectare to sweet potatoes annually.

Valuing the contribution of CIP

While the resources devoted by CIP to the virus-free seed program in Shandong were relatively small, CIP played a crucial role in enabling China to obtain timely access to this technology. Without CIP's participation, Chinese agricultural scientists would probably have eventually learned of these methods from other sources. But CIP's presence in the country helped speed up the international transfer of this technology to China. CIP's relations with the Chinese agricultural research program date back to the late 1970's and initially focused on potato research. CIP established a scientific liason office in Beijing to coordinate collaborative research activities in 1985, the same year that sweet potatoes were added to CIP's research portfolio. CIP scientists were able to take advantage of this earlier scientific networking to rapidly establish collaborative sweet potato research.

One way to value CIP's economic contribution to the virus-free seed program is to examine how early access to the technology affects the present value of net benefits. We may assume that without CIP's participation, the project would have started several years later than 1988 (after Chinese scientists obtained the technology from other sources). Assuming a five-year delay in the starting date of the program would reduce the net present value of the program from $550 million to $376 million (at a 10 percent discount rate). With a ten-year delay, the net present value would fall to $212 million. The reduction in program value from delaying its initiation is even higher if a higher discount rate is used. Thus, CIP's presence, by facilitating more rapid access on the part of Chinese scientists to virus-free seed technology, added substantially to the economic benefits realized by Chinese farmers.

Summary and Conclusions

The rapid diffusion of virus-free sweet potato seed in Shandong Province, reaching 80 percent of the province's small growers in only 4 years, can be explained by several factors. Most important is the significant impact on yield and farm income. Users of original seed saw yields increase by 10 tn/ha, or 30 percent, on average. Further, the technical package was simple and required only one small change in the farmers production system: the replacement of the source of seed. Strong demand for sweet potatoes from the food processing industry also contributed to rapid diffusion by keeping prices from falling in the face of increased supply. This enabled farmers, including late adopters, to continue to capture the gains from technical change. Finally, government subsidies for the establishment of the seed program made large-scale seed production possible in a short time and helped keep the farm price of improved seed low.

Shandong Province represents only about 9 percent of the total area planted to sweet potatoes in China. It would seem that virus-free seed would have considerable potential for increasing yield in other provinces as well. In fact, virus-free seed programs are currently under development in all of the major sweet potato producing provinces in the country. A straight-line extrapolation of the net value of productivity increases achieved in Shandong in 1998 (where 78 percent adoption is estimated to have generated $145 million in net benefits annually) would imply potential benefits to all of China of around $1,600 million per year. Indeed, the success of this one intervention is more than enough to pay for all of the resources devoted to sweet potato research and extension in the developing world.

It is not yet known whether China's success with virus-free sweet potato seed can be extended to other countries. Experiments with virus-free seed in East Africa, for example, have not resulted in much yield gain (Ted Carey, personal communication, 1999). The reasons for this not yet well understood, but might imply that the success of the seed program in Shandong Province may not be replicable in some other important sweet potato growing areas, such as those found in Sub-Saharan Africa.

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Table 1: Effects of adoption of virus-free seed on input use

Input	Increase	No change	Decrease
Planting density	0	24	6
Nitrogen fertilizer	0	17	13
P&K fertilizer	6	24	0
Pesticide	0	26	4
Labor*	0	30	0

Figures report number of villages reporting increase, decrease, or no change in the use of inputs.
* Presumably, the higher yield would increase labor use at harvest.

Table 2: Diffusion of virus-free sweet potato seed in Shandong Province, China
(area in thousands of hectares)

District	Area planted to sweet potatoes 1997	Area planted to virus-free seed 1997 estimate	Area planted to virus-free seed 1998 projected	Percent of area planted to virus-free seed 1997	Percent of area planted to virus-free seed 1998
Linyi	167	37	133	0.22	0.80
Jining	53	40	47	0.75	0.88
Taian	53	33	50	0.63	0.94
Weifang	48	27	43	0.56	0.90
Rizhao	44	36	43	0.82	0.98
Yantai	38	3	37	0.08	0.96
Jinan	32	14	30	0.44	0.94
Zaozhuang	27	19	20	0.70	0.75
Heze	27	13	20	0.50	0.75
Qingdao	20	10	13	0.50	0.67
Weihai	20	5	13	0.24	0.67
Liaocheng	17	10	13	0.57	0.80
Zibo	13	1	10	0.10	0.75
Dezhou	13	5	10	0.40	0.75
Binshou	11	1	7	0.06	0.65
Laiwu	9	9	9	0.91	1.00
Total	593	263	500	0.44	0.84

Source: Crop Research Institute, Shandong Academy of Agricultural Sciences

Table 3: Effect of virus-free seed on sweet potato yield in Shandong Province, China

Extension Demonstration Plots - Spring Crop (ton/ha)

Variety	Virus-free seed	Farmer's seed	Change	% change
Xushu 18	42.8	31.7	11.1	36.6%
Lushu 7	49.7	36.7	13.0	36.6%
Beijing 553	49.1	32.5	16.5	57.6%
Lushu 8	48.7	35.5	13.1	38.3%
Average	47.6	34.1	13.5	39.4%

Farm Survey - Spring Crop (ton/ha)

	Virus-free seed			Farmer's seed	Yield difference with farmer's seed		
	Original seed	1st gen.	2nd gen.		orig. seed	1st gen.	2nd gen.
Xushu 18	47.9	46.0	44.6	35.6	12.4	10.4	9.0
Lushu 7	49.6	44.8	44.3	34.5	15.1	10.3	9.8
Beijing 553	38.3	36.3	37.5	30.0	8.3	6.3	7.5
Lushu 8	40.2	42.8	34.2	35.3	4.9	7.5	-1.1
Average	44.0	42.5	40.1	33.8	10.2	8.6	6.3

Farm Survey - Summer Crop (tn/ha)

	Virus-free seed			Farmer's seed	Yield difference with farmer's seed		
	Original seed	1st gen.	2nd gen.		orig. seed	1st gen.	2nd gen.
Xushu 18	36.4	34.0	32.8	25.0	11.4	8.9	7.8
Lushu 7	35.9	33.2	32.2	24.1	11.8	9.1	8.2
Beijing 553	31.5	26.5	18.8	20.0	11.5	6.5	-1.3
Lushu 8	34.6	32.8	33.2	26.0	8.6	6.8	7.2
Average	34.6	31.6	29.3	23.8	10.8	7.8	5.5

Note: Demonstration trials used virus-free original seed.

Table 4: Factors affecting diffusion of virus-free sweet potato seed

Dependent variable = share of sweet potato area planted to virus-free seed in village in 1998; Mean = 0.78, Standard deviation = 0.29; Minimum = 0.00; Maximum = 1.00
(In the survey, 5 out of 30 villages planted less than 40% of sweet potato area to virus-free seed in 1998, 5 out of 30 planted between 40 and 80 percent, and 20 out of 30 planted more than 80%).

Explanatory variables[1]	Coefficient	Standard error	t statistic	P-value
Intercept	-0.561	1.096	-0.512	0.616
ln(Yield change)	0.311	0.047	6.589	0.000
ln(HH income)	-0.091	0.148	-0.611	0.550
SP share of ag income	0.445	0.466	0.956	0.353
F statistic	14.583			
Significance of F statistic	0.000			
R-squared	0.732			
Adjusted R-squared	0.682			
Standard Error of Regression	0.178			
Observations	20.00	(not all villages in survey had relevant data)		

[1] ln(Yield change) measures the difference between first generation production seed and farmer's seed for the spring crop, measured in natural log of ton/ha. Ln(HH income) is natural log of average household income in the village from agricultural and nonagricultural sources (yuan/year). SP share of ag income is the average share of household agricultural income in the village contributed by sweet potatoes.

Table 5. Benefit and Cost Streams of the Virus-Free Seed Program in Shandong Province, China

Year	Seed Production (tons)				Area planted with virus-free seed (ha)				Farmer's seed	Total area	Production increase (tons)			
	Pre-original	Original	1st gen.	2nd gen.	Original	1st gen.	2nd gen.	Total	(ha)	(ha)	Original	1st gen.	2nd gen.	Total
1988	0	0	0	0	0	0	0	0	592,667	592,667	0	0	0	0
1989	0	0	0	0	0	0	0	0	592,667	592,667	0	0	0	0
1990	0	0	0	0	0	0	0	0	592,667	592,667	0	0	0	0
1991	0	0	0	0	0	0	0	0	592,667	592,667	0	0	0	0
1992	0	0	0	0	0	0	0	0	592,667	592,667	0	0	0	0
1993	0	0	0	0	0	0	0	0	592,667	592,667	0	0	0	0
1994	2	50	2,000	0	67	2,667	0	2,733	589,933	592,667	690	25,600	0	26,290
1995	10	1,000	15,000	5,000	1,333	20,000	6,667	28,000	564,667	592,667	13,800	192,000	46,000	251,800
1996	50	5,000	60,000	40,000	6,667	80,000	53,333	140,000	452,667	592,667	69,000	768,000	368,000	1,205,000
1997	110	10,000	120,000	80,000	13,333	160,000	106,667	280,000	312,667	592,667	138,000	1,536,000	736,000	2,410,000
1998	110	15,000	180,000	120,000	20,000	240,000	160,000	420,000	172,667	592,667	207,000	2,304,000	1,104,000	3,615,000
1999	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2000	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2001	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2002	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2003	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2004	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2005	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2006	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2007	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2008	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2009	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2010	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2011	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2012	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2013	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2014	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2015	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2016	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2017	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2018	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2019	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800
2020	110	15,000	198,000	132,000	20,000	264,000	176,000	460,000	132,667	592,667	207,000	2,534,400	1,214,400	3,955,800

Table 5 continued.

Year	Total Benefit (U.S. $)	Costs (U.S. $)					Net Benefits (U.S. $)
		Research-CIP[1]	Research-local	Extension	Seed Multiplic.	Total Cost	
1988	0	14,200	1,446	0	0	15,646	(15,646)
1989	0	2,700	1,446	0	0	4,146	(4,146)
1990	0	0	2,530	331	0	2,861	(2,861)
1991	0	0	14,241	5,181	0	19,422	(19,422)
1992	0	7,000	19,157	18,313	0	44,470	(44,470)
1993	0	1,000	31,084	61,446	0	93,530	(93,530)
1994	1,108,614	0	31,084	81,928	216,867	329,880	778,735
1995	10,618,072	0	33,253	113,253	1,626,506	1,773,012	8,845,060
1996	50,813,253	4,500	107,711	213,855	6,506,024	6,832,090	43,981,163
1997	101,626,506	0	71,566	377,108	13,012,048	13,460,723	88,165,783
1998	152,439,759	9,300	47,855	222,892	19,518,072	19,798,119	132,641,640
1999	166,810,843	0	46,988	103,614	21,469,880	21,620,482	145,190,361
2000	166,810,843	0	46,988	103,614	21,469,880	21,620,482	145,190,361
2001	166,810,843	0	46,988	103,615	21,469,880	21,620,482	145,190,361
2002	166,810,843	0	46,988	103,615	21,469,880	21,620,482	145,190,361
2003	166,810,843	0	46,988	103,615	21,469,880	21,620,482	145,190,361
2004	166,810,843	0	46,988	103,615	21,469,880	21,620,483	145,190,361
2005	166,810,843	0	46,988	103,615	21,469,880	21,620,483	145,190,361
2006	166,810,843	0	46,988	103,615	21,469,880	21,620,483	145,190,361
2007	166,810,843	0	46,988	103,616	21,469,880	21,620,483	145,190,360
2008	166,810,843	0	46,988	103,616	21,469,880	21,620,483	145,190,360
2009	166,810,843	0	46,988	103,616	21,469,880	21,620,483	145,190,360
2010	166,810,843	0	46,988	103,616	21,469,880	21,620,483	145,190,360
2011	166,810,843	0	46,988	103,616	21,469,880	21,620,484	145,190,360
2012	166,810,843	0	46,988	103,616	21,469,880	21,620,484	145,190,360
2013	166,810,843	0	46,988	103,616	21,469,880	21,620,484	145,190,359
2014	166,810,843	0	46,988	103,617	21,469,880	21,620,484	145,190,359
2015	166,810,843	0	46,988	103,617	21,469,880	21,620,484	145,190,359
2016	166,810,843	0	46,988	103,617	21,469,880	21,620,484	145,190,359
2017	166,810,843	0	46,988	103,617	21,469,880	21,620,484	145,190,359
2018	166,810,843	0	46,988	103,617	21,469,880	21,620,485	145,190,359
2019	166,810,843	0	46,988	103,617	21,469,880	21,620,485	145,190,359
2020	166,810,843	0	46,988	103,617	21,469,880	21,620,485	145,190,358

[1]Costs borne by CIP for training and materials provided to Chinese scientists in virus detection and seed multiplication.

Table 6: Partial budget for virus-free seed adoption by age of seed for Xushu 18

	Spring crop				Summer crop			
Output	Unit (tn/ha)	Price (Y/kg)	Value (Yuan/ha)	Net Change (Yuan/ha)	Unit (tn/ha)	Price (Y/kg)	Value (Yuan/ha)	Net Change (Yuan/ha)
Original seed	47.9	0.4	19,160	4,920	36.5	0.4	14,600	4,600
1st generation	46.0	0.4	18,400	4,160	34.0	0.4	13,600	3,600
2nd generation	44.6	0.4	17,840	3,600	32.9	0.4	13,160	3,160
Farmer's seed	35.6	0.4	14,240	--	25.0	0.4	10,000	--
Input	Unit (kg/ha)	Price (Y/kg)	Value (Yuan/ha)	Net Change (Yuan/ha)	Unit (100 vine/ha)	Price (Y/100)	Value (Yuan/ha)	Net Change (Yuan/ha)
Original seed	750	4.9	3,675	3,000	600	7.1	4,260	3,300
1st generation	750	1.7	1,275	600	600	4.9	2,940	1,980
2nd generation	750	1.4	1,050	375	600	3.8	2,280	1,320
Farmer's seed	750	0.9	675	--	600	1.6	960	--

Net Benefits	(Yuan/ha)	Net Benefits	(Yuan/ha)
Original seed	1,920	Original seed	1,300
1st generation	3,560	1st generation	1,620
2nd generation	3,225	2nd generation	1,840

Benefit-to-cost ratio		Benefit-to-cost ratio	
Original seed	1.64	Original seed	1.39
1st generation	6.93	1st generation	1.82
2nd generation	9.60	2nd generation	2.39

Table 7: Benefit-cost analysis of virus-free sweet potato seed in Shandong Province, China

Assumptions	Internal Rate of Return (%)	Net Present Value[1] (million $U.S.) 10%	15%	20%	Annual Net Benefits at Full Diffusion (million $U.S.)
1.Baseline assumptions (Table 5)	202	550	264	139	145
2. Adoption peaks at 90%	202	620	296	154	168
3. Elastic supply (see Figure 3.c), elasticity = 2	174	265	127	67	70
4. Costs of research, extension and seed multiplication doubled	170	467	225	118	124
5.Yield improvement estimate halved	170	234	112	59	62
6. Costs doubled and yield improvement halved	132	151	72	38	40

[1]Net present value is calculated assuming a real discount rate of 10%, 15%, and 20%.
Figures in 1998 U.S. dollars.

Figure 1: The virus-free seed propagation system in Shandong Province

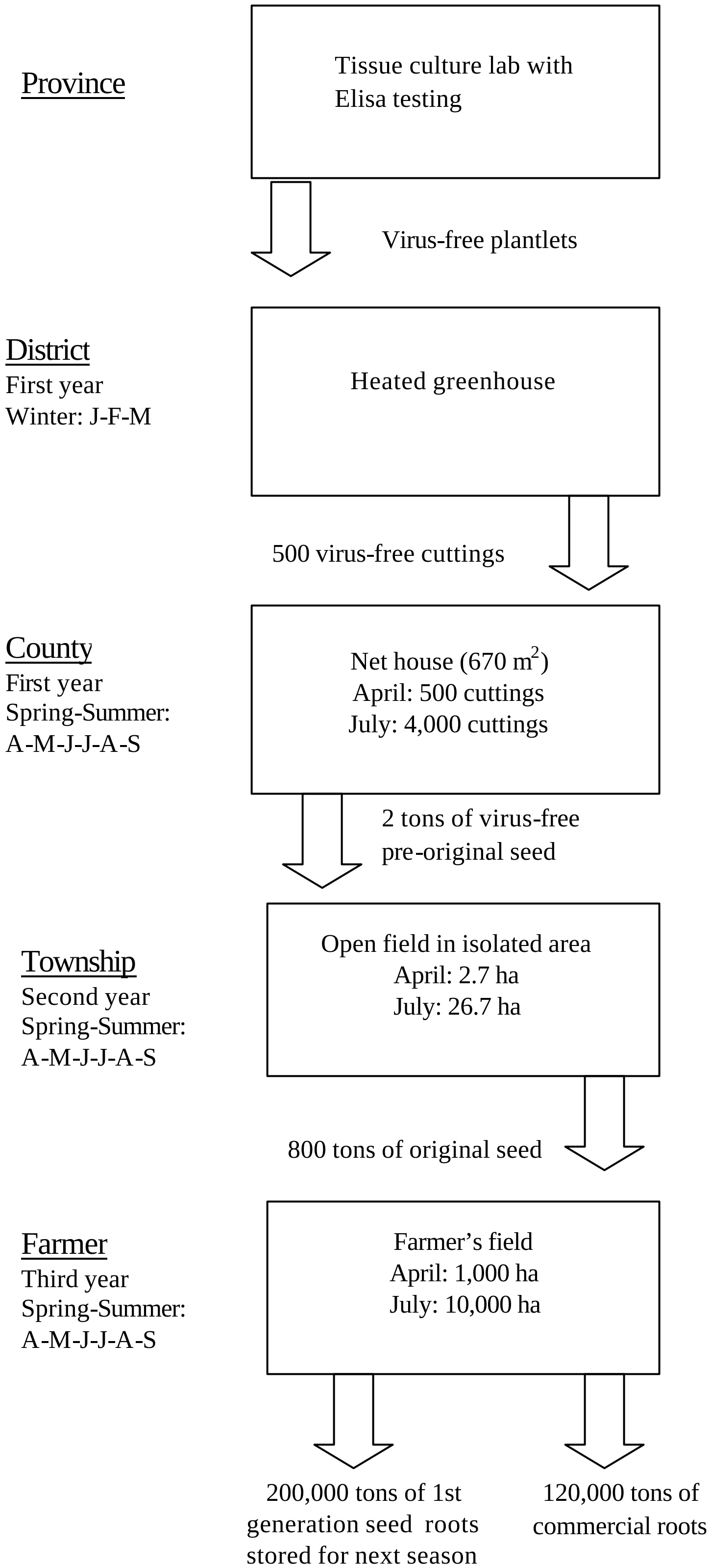
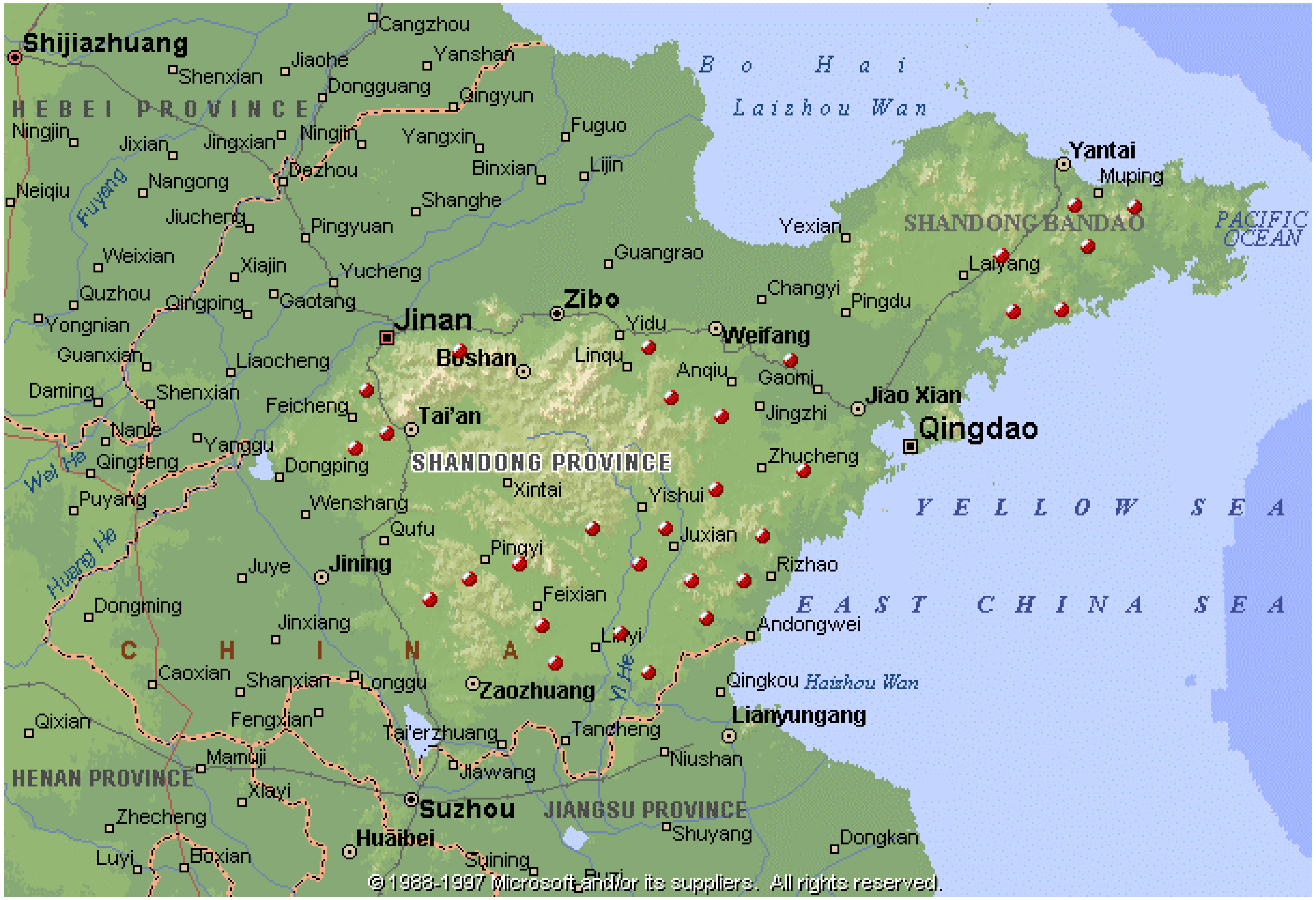


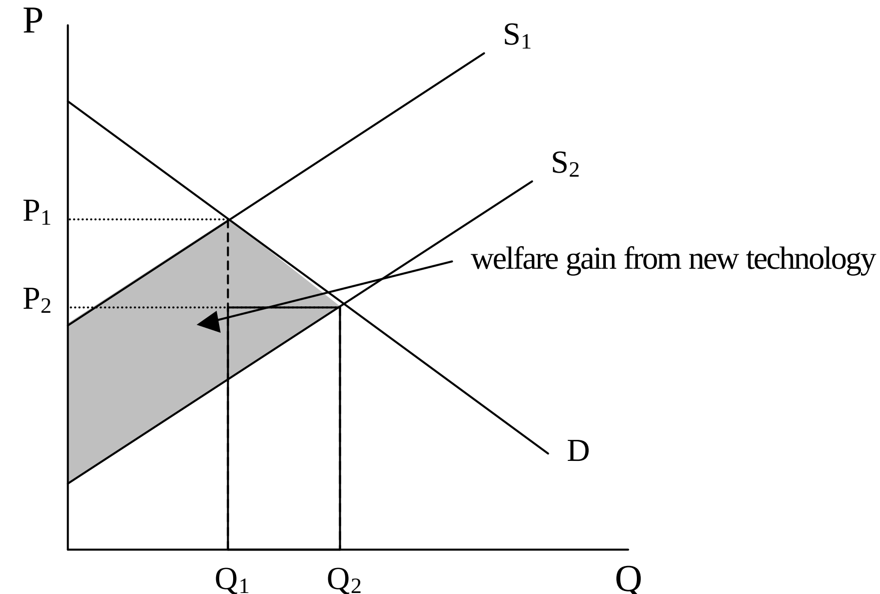
Figure 2: Map of Shandong Province showing locations of the villages surveyed



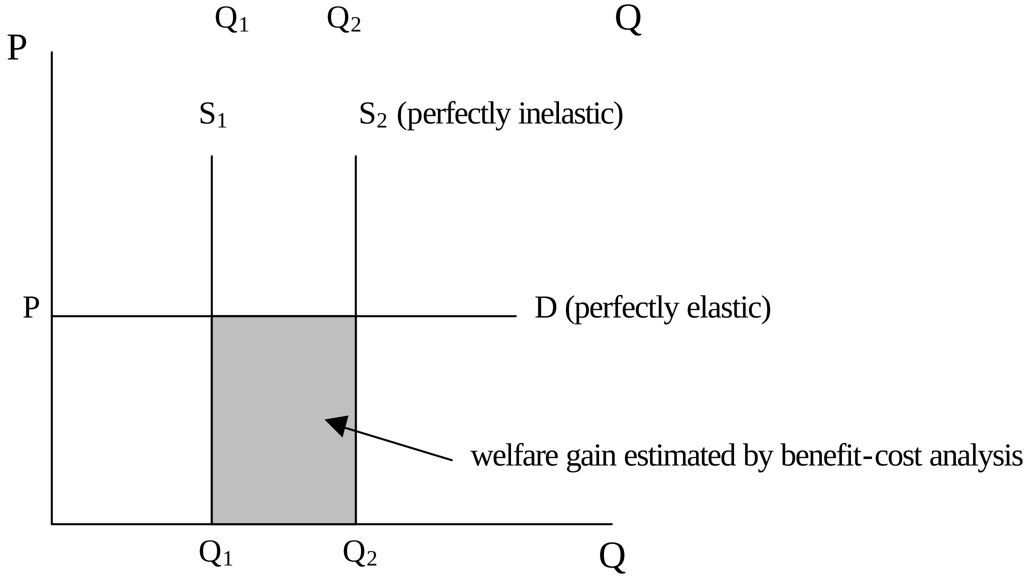
● Location of survey villages

Figure 3: Market structure and measuring economic impact of technological change

a.



b.



c.

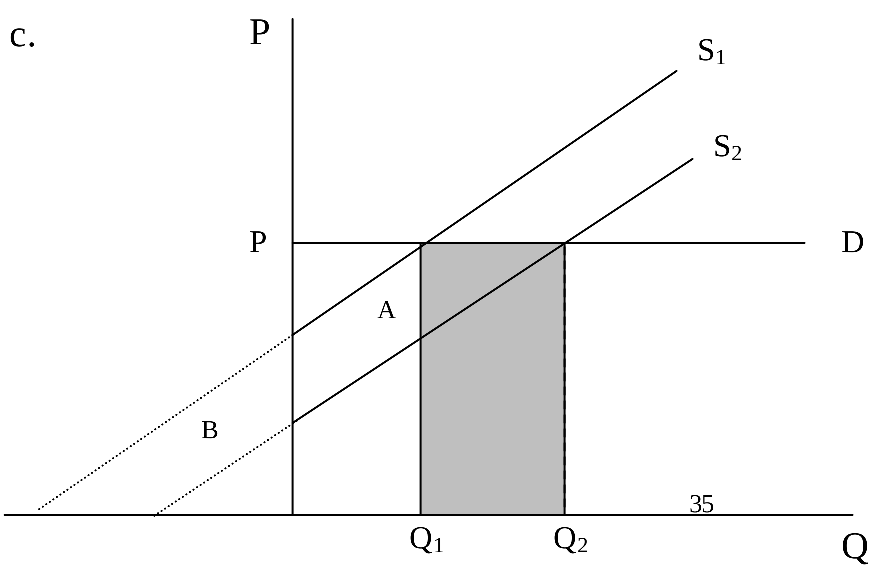


Figure 4: Diffusion of virus-free sweet potato seed in the 30-village survey

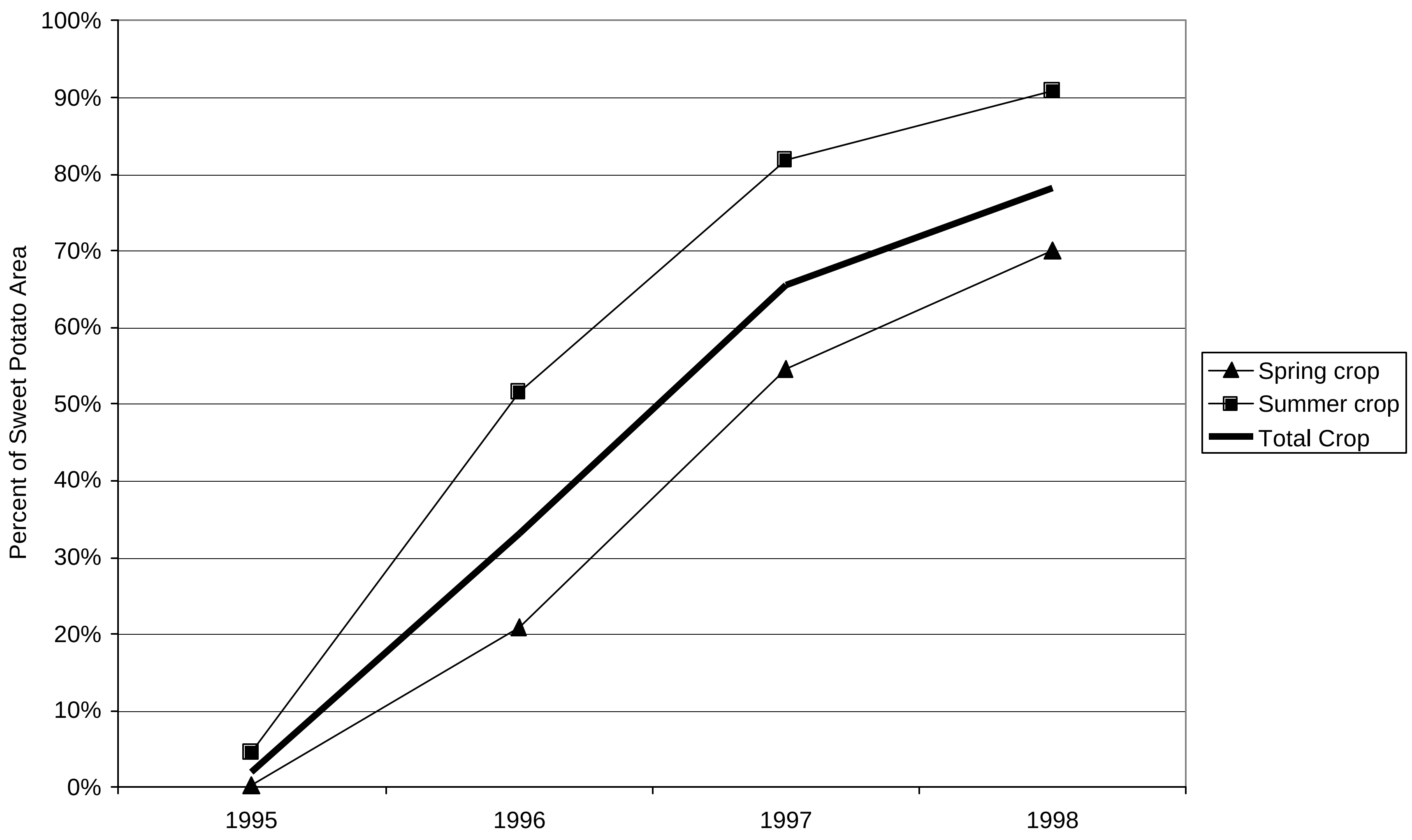


Figure 5: Cost structure of the virus-free seed program