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# Balancing Challenges of Scale and Scope Economies in the Development of Labor-Saving Technology for Specialty Crop Production

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Technology adoption, often considered a fixed cost in the short run, is one of the key reasons why economists often argue for economies of scale in many agricultural operations (Stigler, 1958). Yet to increase the per acre value of an operation, economies of scope are also a common argument when evaluating whole farm enterprises (Fernandez-Cornejo et al., 1992). (See Box 1 for definitions of economies of scale and scope.)

**Box 1. Definitions**
*Economies of Scale* – The principle of scale economies is defined by the different types of production costs incurred, and a firm can cover those costs more efficiently by increasing the number of units produced. By reducing the marginal cost (cost per unit) of production, a firm can increase the amount of profit earned per unit (Stigler, 1958).

*Economies of Scope* – Economies of scope is based on the principle that goods/crops are easily interchanged within the production process (Fernandez-Cornejo et al., 1992). In the case of traditional row crop production, this could mean changing between varieties of the same crop or changing to an entirely different crop.

While economies of scale focus on the quantity side of the revenue equation, economies of scope often address price. Many farms growing row crops have taken advantage of economies of scale, but specialty crop operations must consider the scope, in terms of multiple varieties or crops, to optimize profitability. This is pertinent when considering the trade-off between perennial crops and annual crops, especially when considering varying pest and disease pressures. In other words, managing the risk of technology adoption in specialty crop operations is not as simple as spreading the cost across more acres.

Shifts in consumer preferences for a wider variety of produce that is locally, regionally, and globally produced and available year-round has placed a need for more efficient specialty crop systems. Such systems, though, depend heavily on labor and are the focus of much of the technological innovation within the sector. In general, finding labor locally is often difficult for larger operations and expensive for smaller operations—though it is often difficult and expensive for both, with different options to solve the issue (Castillo, et al., 2021). Larger operations typically look to workers from the H-2A Temporary Agricultural Program to fill their labor needs, which adds to the variable costs incurred, but these costs are somewhat alleviated due to economies of scale. Smaller operations typically lack the ability to hire H-2A workers and often look to family and part-time labor to fill their needs. Smaller operations also tend to be more diversified in crops and variety, leading to a need for more specialized skills and/or knowledge throughout the growing season.

Specialty crop operations must cope with both economies of scale and scope to meet their specific consumer demands while managing their varied and unique risks (Neill and Morgan, 2021). When it comes to the adoption of labor-saving technologies, proposed solutions must tackle the need for specialized skills while appealing to a wide range of operation sizes and geographic constraints. For example, wine grape growers in the northeast United States must contend with a different climate and terrain than their counterparts in California. This observation extends generally to the more than 270 American Viticultural Areas throughout the United States, where each growing region is better suited to certain varieties due to specific climate adaptations (U.S. Alcohol and Tobacco Tax and Trade Bureau, 2024). Between terracing and farming on contours to contending with drier or wetter climates, scaling labor-saving technology within one specialty crop across multiple geographies can be difficult if the technology is not flexible enough to accommodate the vast differences in regional production.

On the other end of the spectrum are small farms that predominately produce specialty crops for local consumption at farmers' markets and small grocery outlets. While most of the sales value throughout the country comes from a small percentage of large farms, small farms make up most of the farms in the United States (USDA-NASS, 2024). These producers take advantage of economies of scope to maximize profit and often switch out the varieties and mix of crops from one year to the next. While more localized production is often smaller than commercial operations,[1] the necessity to scale their operations is paramount if the goal is to maximize profits. Yet adopting labor-saving technology is often lacking unless it applies to multiple crop needs. For many local producers, the adoption of high tunnels, greenhouses, tractors, and tilling, and seeding equipment is common because they are crop-agnostic.

Given these variations in specialty crop production, the lackluster adoption of labor-saving technologies is no real mystery. However, it does beg the question of how we create change and encourage the development of labor-saving technology that can address the challenges of scope and scale. The remainder of this article offers three main ideas on this point and suggestions about where agricultural economists can contribute. First, labor-saving technology must be cost-effective to scale across the variation in farm sizes and diffuse across the market. Second, technology must have a generalized use or be easily adaptable to switch between crop types to address the scope problem on farms. Last, research and extension efforts must tackle the need to provide resources for managing the risks of labor-saving technology and how these risks interact with people throughout the production system.

## Cost Effectiveness of Technology—The Scale Perspective

Many labor-saving technologies tend to be crop-specific based on the physical characteristics of one particular crop. For example, a robotic strawberry harvester with color-sensing technology that is delicate enough not to bruise a large portion of the crop would reduce the need to have workers in the field harvesting. Several companies have created such robots and made the following claims: Their robots are the answer to the labor shortage, they are time saving, they are precise (many do not touch the fruit), and they collect better data on quality and yield, among other benefits (Dogtooth Technologies, 2024; Organifarms, 2024).

Let us start with the perspective of large, commercial growers. While a robotic strawberry harvester may be labor-saving, growers understand the need to be reactive to in-season market prices. Thus, the timing of harvesting is just as important of a decision as how much to harvest and take to market. This decision becomes less complicated if robotic harvesters can get into the field quickly and pick strawberries as quickly as their human counterparts. Most sources find that human labor is much faster and harvests a greater amount. The adverse effect wage rate (AEWR) of H-2A workers in major strawberry-growing regions ranged from $14.50 to $19.75 per hour in 2024 (U.S. Department of Labor, 2024). The capital cost of each robotic strawberry picker is above $50,000 by many estimates. Given that an acre of fruit requires an average 720 labor hours for harvesting each year (Klodd, Tepe, and Hoover, 2021), a robotic harvester would need to harvest between 3.5 and 4.8 acres to break even, assuming the robotic harvester works as fast as human laborers (Guillaumot, 2023). At the prevailing AEWRs, the cost of human labor per acre is between $10,440 and $14,220.

Let's now look at scaling this technology across the number of strawberry farms in the United States to better analyze how the potential demand could affect the cost-effectiveness of the technology itself. According to the 2017 Census of Agriculture (USDA-NASS, 2024), 9,000 farms produced approximately 60,000 acres of strawberries, for an average farm size of 6.7 acres. Looking more at the farm size distribution, 90% of strawberry farms in 2017 were 8 acres or less. If we were to examine the harvesting labor cost of an 8-acre strawberry farm at the high end of the AEWR, the total labor cost would be $113,760 (Santiago et al., 2021). This would require at least 2 robotic harvesters for any farm above 3.5 acres for a total robotic harvest cost of at least $100,000. This would be discounted over time with multiple years of use, but it only serves a single use, while human labor can be utilized in other types of farm labor. Moreover, even with rotational planting to allow for one acre to be harvested at a time during a 14-week season, the grower would likely lose money given the timing of price fluctuations under the robotic harvester only situation.

This means that for the vast majority of strawberry farmers, this particular robotic harvester is not cost-effective (Cruse, 2022). This leaves only 10% of farms as the main buyers of this technology, likely not enough to drive the costs of the technology down to be more widely adopted. Becoming cost-effective at replacing a

[1] The definition of a commercial operation varies and can be subjective based on size of operation in acres, sales, or geographic distribution. For the sake of discussion, commercial operations here are those classified above the Small Business Administration's threshold within the specific industry code found at https://www.sba.gov/sites/default/files/2023-06/Table of Size Standards_Effective March 17, 2023 (2).pdf

large portion of harvest labor requires the demand for the technology extend beyond large operations. The fact that many farms would likely need multiple robotic harvesters to optimize day-to-day price fluctuations increases the per acre cost, even for large growers.

At the same time, it seems extreme for anyone to assume that the harvesting technology would completely replace all labor hours. A better example would be to replace a percentage of the harvest labor. Having one machine for smaller farms to do a first pass, to focus on part of an acre, or to harvest for a more consistent buyer (a weekly distribution to a farmers' market or farmstand, for instance) are potential ways to spread the fixed cost over a small number of acres, although the payback period would be extended.

Another option would be to utilize the technology to optimize/lengthen the harvest timing/day. If the robotic harvester can start earlier in the day or go later into the day than humans, then a larger total area could be harvested per day. There are creative ways to augment the human labor aspect of harvest, but complete replacement is generally cost-prohibitive. Plus, the demand for such harvesters would still be limited to a very small number of farms given the current costs. Moreover, the farm owner/operator would still need to generate enough income to support themselves or have time to earn income off-farm. All of this is to say that labor-saving technology for specialty crops must scale both on farms and across industry to be cost-effective.

## General Use Technology on Farm—The Scope Perspective

The pursuit of technology development and eventual adoption of technologies by the specialty crop sector is motivated by a simple fact: technologies need to be beneficial across the scope of the whole farm. This fact is particularly relevant for smaller farms, which make up a majority of specialty crop producers. Many small farms in the specialty crop sector are highly diversified in the type of crops they produce, as they are focused on local sales and consumption. As such, the cost of crop-specific technology is often cost-prohibitive. For these producers, a labor-saving technology needs apply to the scope of the whole farm. Tractors are one of the most prominent labor-saving technologies adopted by small farms. While this example may seem outdated, tractors offer a model for future labor-saving technologies given the extensive amount of research conducted on this topic. As noted in Ankli and Olmstead (1981), the tractor was clearly an advantage on large monoculture-focused and small diversified farms in California. They found that this was due to the high fixed costs associated with horses and also the ability to use tractors across different crops.

While the tractor initially did not reduce harvest labor costs, it did save the time of the owner/operator. The diffusion of tractor technology was initially seen as inefficiently slow, though the reality is that the adoption of this labor-saving technology increased with the utility of the tractor and the development and improvement of implements for the tractor (Martini and Silberberg, 2006). Not only were tractors more cost-effective than horses, they also provided adaptability through the use of various implements, which enabled tractors to address the scope problem of the farm.

Labor-saving technologies for smaller, more diversified specialty crop operations must address economies of scope. At the same time, labor-saving technologies that are versatile across operations of different sizes, even if those operations are monocultural, are likely to have larger markets for adoption. While a specialized technology can solve specific labor issues, it will have a limited market. A technology that addresses the economies of scope within a specialty crop operation and across the entire specialty crop sector will likely see more success within the overall market.

## Managing Change Through Research and Extension

While the development of labor-saving technology is important, the key is to build upon our knowledge of all aspects of specialty crop production. Creating technology to replace or augment labor just for the sake of doing so ignores the impacts on profitability across the whole farm and income earning on and off farm. Managing the risks of technology, both from financial and labor-related, is vastly different in specialty crops as compared to traditional row crops. Thus, researchers and extension services must cater to the specific needs of the specialty crop industry.

Research on specialty crop development, frequently funded by the USDA's Specialty Crop Research Initiative grant program, is often initiated by lead investigators who have an idea for a new technology or the development of new varieties. Yet agricultural economists are rarely consulted in the core idea development stage. Instead, they are consulted as a necessary component to determine whether the project will lead to financial and market feasibility. This does a disservice to the field of agricultural economics as a vital component of idea generation and to specialty crop producers, who require *affordable* labor-saving technologies. Agricultural economists need to encourage our interdisciplinary collaborators to include them in the idea generation stage rather than proposal development.

From an extension perspective, many programs have been targeted to assisting small and mid-sized farms with business planning, enterprise analysis, and whole farm budgeting. But, as List (2022) notes, people do not scale. In fact, one thing has not changed since Holt's (1989) article: Extension professionals are often charged with running multiple programs and are asked to do more each year without a change in resources, responsibilities, or training. Extension resources continue to be stretched thin over a decreasing number of people. Change is not simply an inevitability for extension; it is truly the only constant. To manage that change, extension professionals need proper support in terms of finances, time, and people. New programs, often funded by research programs, must be assessed by their opportunity gain (cost) and the potential long-term viability of the program. Agricultural economists can better assess these costs if, again, they are consulted in idea generation rather than proposal development. With proper planning, future labor-saving technology can address the scale and scope issues within specialty crop production.

## Conclusions

Several concepts were discussed in this article, but the main focus was the scale and scope issue faced by potential adopters of labor-saving technologies in the specialty crop industry. While I provided two specific examples, and certainly not perfect representations of either, there are a plethora of applications for the economic trade-offs that specialty crop producers must consider when it comes to technology adoption. Scaling production is feasible for only a small percentage of specialty crop growers, which means that driving down the cost of a labor-saving technology through a larger market is a slow, if not impossible, task. For many small producers, crop-specific technology is often less useful than general technological advances due to on-farm economies of scope.

But this does not mean there is no hope. Instead, it is up to agricultural economists to step forward and engage with transdisciplinary teams of researchers and producers earlier in the idea generation phase when labor-saving technologies are developed. As Holt (1989) notes, the human element of change management is key and cannot be substituted by technology. Agricultural economists are the experts when it comes to analyzing and managing risk, and there are a vast number of prospects to find the opportunity gains for specialty crop producers.

## For More Information


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