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The Intractable Strawberry: Labor, Mechanization, and the Digital Revolution

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The Intractable Strawberry:
Labor, Mechanization, and the Digital Revolution

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Abstract

This thesis will explore a technological attempt to develop an autonomous mechanized harvester for strawberries undertaken by Harvest Bot in the coastal strawberry-growing region of California. Through a qualitative approach of interviews, participant observation, and discourse analysis the research focused on the experience of Harvest Bot's project, the broader impacts seen from this development, and how various stakeholders experienced those impacts. While the prototype of the harvester did not reach commercial development during the research period, the thesis argues that multiple stakeholders saw varied positive and negative impacts that can be understood as technical and conceptual. The long-term importance of those impacts is largely determined by the power structures that shape decision-making in the industry, the role of agricultural start-ups, the direct experience of workers with automated harvester technologies, and further connections to the expansion of the metabolic rift.

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Introduction

Over the last two decades the agricultural technology industry continues to focus on reducing industry reliance on manual labor and creating more cost-efficient ways to grow, harvest, and otherwise manage their crops. Recent focus has been brought on these technologies in the wake of increasing concern surrounding labor shortages in United States agriculture further exacerbated by the COVID-19 pandemic as well as more stringent immigration policies (Peterson et al., 2023). The drive to use innovative technologies in agriculture is not new, as investment into mechanization has been a notable part of the agriculture industry since the early 1900s (Hightower, 1972). However, developments in a particular subset of machine learning technologies, automated harvesters, have attracted interest across the academic, engineering, and business fields in recent years. These autonomous robots use machine learning and gesture tracking to mimic the hand movements of the worker, utilizing more recent advances in robotics and machine learning. In many ways, these technologies have reopened conversations surrounding harvesting niche crops such as table strawberries, which were, for many decades, otherwise considered too complex to mechanize due to the genetics of the plant and the fruit itself. The main motivation for the creation and implementation of agricultural technologies is to increase production efficiency and reduce the overall costs associated with growing for producers. To accomplish those goals, reducing costs associated with manual labor remains a critical impediment of increases in production and efficiency through technological development both within agriculture and across its complementary industries.

In this constant drive for efficiency, as Marx observed, innovation is a key force. Questions surrounding rate of adoption as well as the complexities and concerns of small farmers and farm workers are often unaddressed amongst the broader discussions relating to an increase in efficiency. The adoption of these recent technologies is not scale-neutral and requires significant capital investment, which favors larger farmers and agricultural consolidation (Kloppenburg, 2005). Considering this oversight, the consequences of developing these technologies can be far-reaching and thus, important to understand. In broad strokes, mechanization, and automation, almost always, reduce the amount of labor needed per unit of produce, and thus prima facie would supplant the work that is currently available for farm workers—unless total production increases. Nonetheless, the accessibility of mechanization can vary depending on the type of crop grown by producers, as the cultivar qualities and the planting style of different crops can make them easier or harder to mechanize.

Much of the discourse surrounding the development of mechanized harvesters and other autonomous robots either highlights how the human workforce will be replaced, pushes back on the importance of that replacement, or notes the economic and political influences behind these motivations for investment (Baur & Iles, 2023). While these conversations are important, academic attention afforded to these technologies often fails to acknowledge the more complex and unpredictable ways through which the development process of these technologies impact the broader industry. It is perhaps more straightforward to see how a technology that has been developed and implemented commercially has transpired in terms of replacement, consolidation, or other factors. However, the progression of technological development does not always occur in a linear fashion, instead, technologies go through varying periods of development before the setting of a successful model (Basalla, 1988). Because of this, it is important to analyze how instances of technological attempts, successful or not, impact key stakeholders across the industry. This emphasizes the importance of scale and context when it comes to technological developments and adoption.

To analyze a particular instance of the development of one of these technologies and the company's experiences in this process, this thesis is a case study of the development of a mechanized strawberry harvester in the coastal strawberry-growing region of California. Strawberries were chosen to focus on due to their niche crop qualities and unique industry environment focused on by many academics historically. More specifically, the thesis focuses on the technological attempt and experience of one company which will be referred to throughout this thesis as "Harvest Bot." This company developed an autonomous robotic mechanized harvester for strawberries that ultimately did not reach the stage of commercial sale. Through this case study technological attempt, this thesis will elucidate the experience as a piece of the broader understanding of how mechanization has factored into the strawberry industry. It will also offer perspective on how this development has impacted relevant stakeholders including growers, the start-up pursuing this technology, and farm workers. To address these perspectives and impacts, this thesis will use two guiding research questions:

1. What was the experience of Harvest Bot's development of their strawberry harvester? How did the industry, environment, and economic contexts influence this?

2. What were the broader impacts of the development of this harvester and how were they experienced perceived by various industry stakeholders specifically: growers, the company itself, and farm workers? And what lessons can be extrapolated from these impacts to understand further technological developments in the industry?

Through an in-depth case study of Harvest Bot's technological attempt, this thesis provides an understanding of Harvest Bot as a strand in the larger technological and industry trends seen in the California strawberry industry as digitization and mechanization continues to be introduced. Thus, a positioned, high-level systems perspective on the broad adoption of autonomous mechanized harvesters or mass technological adoption across the strawberry industry is beyond the scope of this thesis. It does, however, contribute to a larger understanding of trends and challenges with automation in agriculture in the face of labor shortages and demographic shifts which are important to understanding the immediate impacts of technology developments and a consideration of how they may shape future trends (Goodhue & Martin, 2020). Further, it challenges policymakers to think of how to prepare industry and workers for a future alongside informated machines while also extrapolating predictions for how robotics may to some extent alleviate physical strain on labor both from the grower and farm worker perspective. Particularly, as the labor pool continues to change across agriculture and concerns around labor proliferate.

As the analysis shows, the technology project put forward by Harvest Bot did not go as planned in many ways and did not result in the mass adoption of their commercialized product, which is generally the ultimate goal of a technology start-up. However, I argue there were a series of "wins" and "losses" that occurred as a result of this process, each with different implications for future directions of technological development in this sector. While these outcomes are immediately important for the company itself and its future, they also present material and conceptual impacts for growers and workers across the strawberry industry. It is through these more far-reaching impacts that this thesis shows the importance of these singular technological development projects to the industry.

Literature Review and Conceptual Framework

Mechanization in Strawberries and Beyond

Mechanization in table strawberry production has seen considerable progress, particularly through cross-species technological developments such as machines that can perform routine but labor-intensive tasks such as planting and weeding. For example, a mechanical transplanter can be used to plant fields of strawberries, though uptake has not been universal. These types of machines are loaded with live strawberry plants which are then inserted into the beds following “punch wheels" which create the spot for the plant in the bed (Mechanical Transplanter for Tomatoes, Strawberries Kennco, n.d.). Companies have also developed mechanical weeders that can be used on strawberry fields. These utilize cameras and machine learning to identify and remove weeds in the strawberry beds using small blades (*Vulcan Brochure*, 2024). Both examples of mechanization in the field cut down on physically challenging manual labor and can be utilized across many different crops. These types of technologies could be more easily adopted within the strawberry growing process due to the inherent nature of these tasks. Aspects such as planting and weeding can be replaced by machines as they do not deal with the delicate fruit of the matured strawberry plant. Similarly, more broadly designed technologies for agriculture processes often do not require the creation of unique designs for the strawberry field layout and can be more easily integrated into the system (*Immigration and Farm Labor*, 2024). Despite these developments in mechanization, the greatest difficulties in innovation for table strawberry production remains harvesting.

In contrast with more easily adopted pieces of the mechanization process, the act of harvesting in the field remains a significant challenge. For decades, between the 1980s and the

2010s, strawberries were largely left out of the discussion of large-scale mechanization of harvest due to their unique qualities leading to industry complications with early prototypes (Booster et al., 1970). In large part, the lack of industry movement in designing mechanized harvesters for strawberries can be connected to the fruit itself. In comparison to other crops, matured strawberries are a delicate fruit, meaning that to handle them effectively, the movement of grabbing them off the plant and sorting them must both be relatively gentle. If this is not done the fruit can easily incur bruising. This has proven to be a puzzling design challenge in combination with a demand for the harvester to move as fast as possible for maximum efficiency (Delbridge, 2021). Even for the human hand, it is challenging to move fast while also being gentle enough to not damage the fruit.

However, this is not often the most cited problem that engineers have struggled with in the development of mechanized harvesters for strawberries. In addition to their delicate nature, strawberries are concealed by foliage, which increases in density as the harvest season continues, this makes it difficult for the observer to see all ripe berries from a single angle or without moving the leaves multiple times to reveal hidden berries (See Figure 1; Tiedemann et al., 2022). Because of these unique aspects of the plant, machines that were developed to pick similar sizes or types of fruits or vegetables are unable to pick effectively when utilized with strawberry plants—suggesting the need for a unique harvesting product for strawberries (Guthman, 2019). Overall, these complications relating both to the speed of harvest and foliage have remained a key problem with the development of technologies and are referred to often by engineers across the industry.

Figure 1: Strawberries in field (*Health Benefits, Recipes & Stories, California Strawberries*, n.d.)

In agriculture, the problem with mechanical harvesting is sometimes solved by plant breeding, i.e., reengineering the plant itself. In part, these constraints are aspects that could be addressed by the breeding of a cultivar of the strawberry plant that both has a more durable berry and grows in a way that makes the berries more visible. However, strawberries face a unique breeding issue as well, it takes around a year for a new strawberry plant to bear viable fruit for harvest. So, to evaluate the quality of a variation a breeder must wait at least a year to review each attempt (Parajuli et al., 2022). Because of this, breeding new variations is a costly and slow process—though the effectiveness of the breeding of cultivars is rapidly changing with the strawberry industry's more broadscale adoption of genetic technologies (Lee, 2019). While this may limit the speed at which cultivar development takes place, this has not halted progress in this area of research. In this context, engineers involved in the development of these harvesters have expressed that they feel they must design their equipment based on the assumption that the utilization of cultivars that are optimized for mechanization with less foliage will not be implemented in the foreseeable future. This is due to its slow progress and the competing prioritization of cultivars in the industry with better taste, shelf-life, and firmness (Yue et al., 2014). Thus, the nature of the plant itself remains an ever-present and key challenge for engineers trying to mechanize the process of harvesting strawberries.

In addition to the time investment challenges associated with the breeding of cultivars of strawberries, other motivations for cultivar development have conflicting priorities with the development of machine-ready strawberry plants including concerns surrounding weather changes and related to pests and disease resistance (Hernández-Martínez et al., 2023). Strawberries rank as one of the most highly contaminated fruits on the Environmental Working Group's "Dirty Dozen" list, noting particularly elevated levels of presence of pesticides and fungicides on non-organic and to a lesser extent organic produce (EWG, 2019). This notoriety and consumer health concerns reinforce a market-fueled motivation to look for ways to reduce and alter the pesticides and fungicides used on strawberries (Guthman, 2019). One way this has taken place is through the development of disease-resistant cultivars. This has become prevalent in recent discussions in the strawberry industry related to soil-borne pathogens like Macrophomina phaseolina, Fusarium oxysporum, Verticillium dahliae, and Phytophthora. These pathogens have all been a recent concern for farmers across the central coast strawberry growing region, even more so with farmers who are working on organic farms, leading to broadscale reinforcement and justification of the use of pesticides and fungicides on non-organic farms (Steele et al., 2023). These concerns are not new, however, as the growth of the strawberry industry can be largely credited to the development of efficient fumigants and pesticides, allowing for the mass production of a plant that would normally be difficult to grow on the scale at which it is done now (Guthman, 2019). In turn, much contestation has also surrounded these developments in pesticides and fungicides. The passing of the ban on Methyl bromide in 2005 and the phasing out of it in the industry by 2016 spurred not only the use of new chemicals like Methyl iodide but also the development of competition among strawberry breeders to find and encourage qualities in the plan that reduce the spread of these pathogens (Guthman, 2019). In addition to the profit-focused motivations to reduce the use of pesticides and other chemicals, there are further pressures from activists focused on environmental and economic sustainability as well as farm worker health and safety (Guthman & Brown, 2016; Saxton, 2015). So, while there is some development of strawberries aimed at becoming easier for machines to interact with, there are conflicting industry motivations for researchers to look at and prioritize other traits in the plant when investigating new cultivars. As the analysis presented here will show, it is the combination of the unique qualities of the plant, as well as pressures from the organization of the industry itself have created a bottleneck through which the mechanization of strawberry harvest has remained a challenge.

Evolution of Technology

Broadscale recognition of motivations for mechanization in the strawberry industry are best understood through the rooting of historical research surrounding the evolution of technology across the industry as a whole. The relationship between automation and labor in capitalist societies has a long history extending back to Marx’s observation of the constant drive among industries to substitute capital for labor (Marx, 1867). Building upon the theories of Adam Smith, these theories paid special attention to the division of labor, which in the factory took the artisan’s holistic labor process and divided it into simple and discrete activities (Smith 1828; Marx, 1867). By separating the various tasks, mechanization was streamlined as the introduction of these technologies was particularly well suited to the simple repetitive tasks created through this division of labor.

In the factory setting, the machine separated the tool from the worker's hand and thus allowed the rationalization of production by the application of engineering and science to the work process. Multiple reasons for automation exist, including diminishing worker control as well as a way to lower the cost of production. Machinery can increase the volume produced by the complement of workers gathered together in a factory. In contrast, using the steam hammer as an example, scholars have also suggested that mechanization also allows for production that without it, would have been unthinkable (Rosenberg, 1976). This trend towards increased productivity is reflected in agricultural mechanization such as with the tomato harvester where the uniform nature of the field and crop for processed canned tomatoes allowed for easy mechanization and resulted in the standardization of mass production and harvest (Hightower, 1972). The application of this large-scale automation allowed for the growth of the tomato harvesting industry into a massive production, valued at around $1.2 billion annually (California Agricultural Statistics Review 2021-2022, 2023). However, the reverse of these patterns is shown in the complex nature of the strawberry crop where this mechanization has been harder to adopt.

Digitalization—i.e., the application of computer processing power to production—is a particularly powerful tool in innovation and can be understood as a further development of the dynamic that Marx observed. The application of computer technologies to work has led to significant labor-focused academic studies, providing context on labor in general and examining specific social structure changes over time (Noble, 1984; Peck, 1996; Zuboff, 1988). These scholars offer diverse ways through which labor structures have fundamentally changed due to technological adoption and give context to how these have taken shape, pointing to the ways in which assumptions about businesses fail to see the larger structural motivations that feed into their decision-making. Some scholars contend with arguments of efficiency, noting that decisions in manufacturing to increase efficiency are more related to controlling the worker (Braverman, 1998; Burawoy, 1979). Others emphasize how labor markets are socially structured, and spatially uneven, based on the idea of labor as a "fictive commodity" (Peck, 1996). However, technological developments and how they play out are determined by a complex set of factors that are more than just the economic measures presented at the time, and can, in fact, be fueled more by social and structural motivations in the industry and larger capitalist structures.

Other research has argued in more depth, how technological developments themselves have factored into those broader shifts (Noble, 1984; Zuboff, 1988). These studies offer broad contexts for the impact technology has had and will continue to have on industry, labor, and society and argue for a complex understanding of the adoption of technology, noting that ultimately the broad adoption of technology is that of social choice not of inevitability (Noble, 1984). Others emphasize the importance of the manager in terms of technological and data applications. By this, they make the argument that a firm having a piece of technology does not matter if the system and forms of control are not utilized by management (Zuboff, 1988). These authors offer an analytical lens through which to understand the reasoning behind the adoption of mechanized harvesters and shed light on the motivations behind the adoption of these technologies. Beyond the economic viability of the strawberry harvester, as it was developed, the technology would have required an immense amount of cooperation from managers, workers, and growers and a fundamental restructuring of their production line in order to reach mass adoption levels. This further illustrates how technological adoption only goes as far into complete adoption as social structures will allow.

Agricultural mechanization holds a significant spot in the academic study of technological developments (Cochrane, 1979). There has been a long history of interest particularly in the impacts of mechanization on both the demand for labor and the labor process, particularly surrounding those of replacement and to a lesser extent augmentation. Fields of research surrounding agriculture technology and technological impact on labor and society are both well-developed and highly politically controversial. Scholarship in this area focuses not only on the current debates and decisions occurring within agriculture but how those discussions, in turn, “future” the reality they predict (Carolan, 2018; 2019; 2020). This has been instrumental in the framing of digital technologies and other shifts in agriculture; arguing that many political and social factors go into determining a farmer's choice and how perceptions of agriculture's future shape the choices that growers make, thus realizing those futures, with robots, technology, and labor (Carolan, 2020; Carolan et al., 2021). This work prompts a critical analysis of how and why growers are thinking and preparing for the future of agricultural technologies and labor as well as the wide-ranging impacts that those choices will have.

Previous research has emphasized the importance of looking into the labor and social implications of agricultural technologies. Most notably, in Jim Hightower’s “Hard Tomatoes, Hard Times”, he examines how the development of the tomato harvester in the 1960s occurred with little concern of how it might impact farm workers or small farm owners and thus the rollout of the technology on a massive scale occurred without preparation or consideration for their livelihoods (Hightower, 1972). This critical scholarship highlighted how what is considered from the start, creates the future in terms of labor composition and suggests that understanding and prioritizing the complexities of the application and struggles with the uptake of these technologies allows for a more holistic preparation for the mass adoption of technologies and their impacts across the industry and throughout society.

The California Strawberry Industry and Mechanization

According to the U.S. Department of Agriculture, California consistently ranks as the top agricultural-producing state in the country in terms of cash receipts (*FAQs*, 2023). The state's agricultural abundance includes over four hundred commodities, comprising more than one-third of the country's vegetables, and nearly three-quarters of the country's fruits and nuts. Strawberry production is a key part of this industry. Strawberries grown in California constitute over 89% of the total United States production of strawberries (Noncitrus Fruits and Nuts 2022 Summary, 2023). The main competitive region in the United States for California strawberries is Florida. In comparison, Florida produces only about 10% of strawberries in the country (Noncitrus Fruits and Nuts 2022 Summary, 2023). Despite the small market share, technological development is occurring in the industry in Florida as well, notably with the development of a large-scale autonomous mechanized strawberry harvester intended to harvest four rows at once. However, just as with Harvest Bot, this version of the mechanized harvester has yet to be commercialized. This suggests both that mechanization has come to prevalence in research interests in part simply due to market share and the ways in which the circumstances of the strawberry crop and industry have made mechanization a particularly complicated endeavor across both states.

The bulk of California table strawberry production is concentrated in a few firms such as Driscoll's and Naturipe but also includes a limited number of smaller growers and organic growers (Goodhue & Martin, 2020). Despite a few organic producers, the majority of participants are non-organic as only 5,871 acres of organic strawberries were harvested in 2022 compared to the 39,000 acres total harvested (California Agricultural Organics Report, 2023; California Agricultural Statistics Review 2021-2022, 2023; Goodhue & Martin, 2020). These large strawberry firms manage a distinctive system, wherein the growers agree to use the joint label of a company (*Our Heritage*, n.d.). Through this system, individual growers collectively sell through a firm such as "Driscoll's." Organizing the firm in this manner gives the farmers the benefits of joint marketing and increased access to the national and global strawberry market as well as collective funding for breeding and production development. However, these positive benefits were not the initial reason for adopting this style, this firm structure is also rooted in a history of sharecropping that took place in the California strawberry industry. In this system, strawberry growers were leased land through contracts given by larger firms and were indebted to provide their product to the firm, which would serve as the marketer. After a series of legal cases, this system of sharecropping officially ended in California. Yet, remnants of that system are still seen in how, largely, the industry has not shifted from these large-scale firms as they are still the ones who have significant control over the industry including what cultivars are produced and what price they will accept from their contracted growers (Goodhue & Martin, 2020). The organization of firms in this manner is critical when it comes to the grower's relationship to technology. In a typical manufacturing industry, for example, hierarchical control facilitates rapid technological adoption (Zuboff, 1988). In comparison, this is not the case in the strawberry industry as these large firms do not control the management decisions or technology purchasing decisions made by the individual growers working under their label. Notably, they also do not exert control over the growing style utilized by individual farmers, an important aspect to technological adoption (Fuentes & Rabkin, 2010).

The majority of California production takes place in the coastal areas. This cluster region stretches along the coastline from San Diego and to Monterey Bay, but with the highest percentage of acreage (39.9%) in the Santa Maria region (Figure 2; California Agricultural Statistics Review 2021-2022, 2023). The coastal California strawberry region has maintained its dominance due to several factors. Location-specific aspects like climate, soil, and proximity to the metropolitan Bay Area play a significant part, along with innovations related to the plant itself such as the development of new cultivars of strawberries, fumigants, and pesticides (Tourte et al, 2016). In addition, technological improvements, and productive developments have all come out of the coastal strawberry industry cluster. These include designs for drip irrigation, organizational models—such as grower-shipper models and large transportation centers—and packaging methods used uniquely in the strawberry industry such as strawberry clamshells, cardboard flats, and other plastic containers. All these technological developments have centered around making strawberry harvests more efficient and profitable (California Strawberry Commission, n.d.).

These natural factors and the innovation witnessed in the industry cluster, along with the control and market and research support provided through large agricultural firms such as Driscoll's and Naturripe, the organization and political power of the California Strawberry Commission, and collaboration with research projects through university groups such as the Cal Poly Strawberry Center have helped the region maintain its dominance over the industry (*About*, n.d.; *The History of Strawberry Farming in California*, n.d.). Such realities underscore the reason that technology has emerged related to the development of mechanization of the strawberry growing process, including those being pursued through autonomous mechanized harvesters.

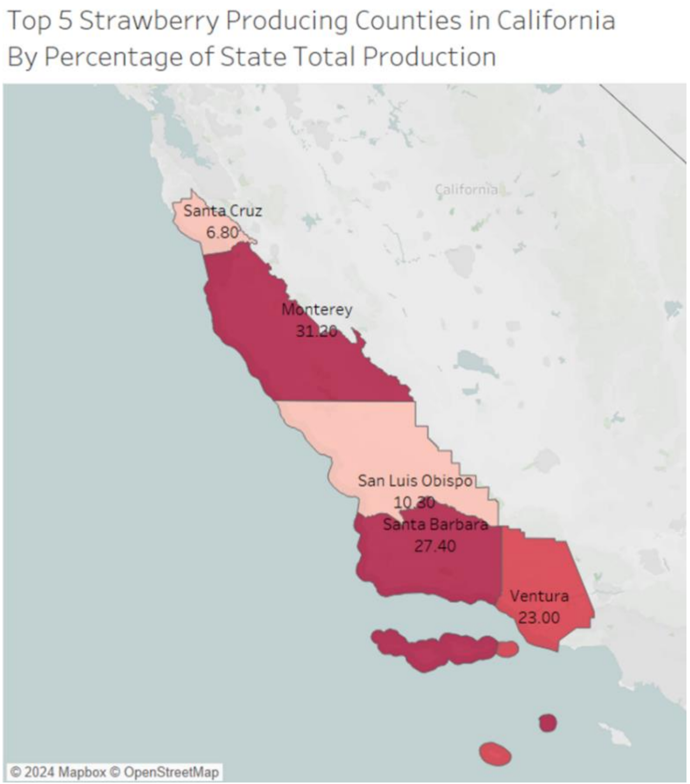

Figure 2: Top 5 Strawberry Producing Counties in California by Percentage of State Total Production (Map created by author. Data from: California Agricultural Statistics Review 2021-2022, 2023)

In lieu of the mass adoption of commercial mechanized harvesters, other supportive technologies or “harvest aids" were adopted. These include tractor-based machines that follow workers through the field carrying flats. This alleviates the need for workers to continuously run to the end of the row to deposit their full trays and due to their design are able to provide other benefits to workers and growers such as providing shade on hot days or light for working at night (*Berry Ferry*, n.d.). However, there are limitations to this kind of design as well, specifically in that they follow several workers at the same time—in the case of GK Machine’s design they can follow between two to four farm workers while they harvest. This can be an issue in maximizing efficiency as workers naturally pick at different rates, meaning that the slow worker must set the pace for the faster workers (Calvin et al., 2022). This can lead to production slowdowns and discontent among workers who rely on a pay system that is based on the volume they pick (*Immigration and Farm Labor*, 2024; Rosenberg, 2003). To combat this inefficiency, newer versions have introduced more personalized machines. One such system is a tray carrying robot, which can meet the immediate need of the workers through use of a predictive dispatcher, ideally finding the worker when they need to offload a tray (Peng et al., 2022). Importantly, these technologies do not seek to replace the hand motion of the farm worker, nor remove the workers from the field. Their main objective is to make the harvesting process more efficient and less strenuous; the physical act of picking is not addressed by these technologies.

The Process of Strawberry Harvesting

As discussed, strawberry harvesting mechanization has proven difficult due to the delicate nature of the fruit, the presence of substantial foliage on the plant, and the unstructured nature of the strawberry bed. Strawberry fields are set up in beds, the makeup of which can depend on many varied factors and choices made by the growers. These decisions are ultimately guided mainly by the quality and type of soil as well as the cultivar of strawberries they are growing in that particular field. Beds can be of varying height and width. A wider bed can hold more rows of strawberries but can also decrease production yield. Whereas taller beds might be used in soil that drains more slowly and might have irrigation issues. Depending on the dimensions of the bed and other factors, the bed can include between two to four planted rows of strawberries—see Figure 3 for examples of this customizable planting style. Between each bed is what is referred to as the furrow, this is where people and equipment can move throughout the field, through the rows, and can also have a varying size depending on the type of equipment used on the farm. Typically, though, a furrow’s width ranges from 10 to 14 inches (Bolda et al., 2015). While these variations in the field are necessary to adapt to the different soil, cultivars, and goals of the grower, the inconsistency seen because of it creates challenges as an unstructured environment to engineers designing machinery to fit in the fields.

The strawberry plant itself also lends to its unstructured environment with clusters of the crop thicker and thinner in different areas leading to variation in the presence of both foliage and fruit (Xiong et al., 2020). This is shown in Figure 3 where it is possible to see how some of the plants have more green foliage visible than others and only some of the individual strawberry plants have any visible fruit from the angle at which the photograph was taken. Visually, this can be a challenge for the cameras used in robotic mechanization as they try to identify where a single fruit is on the plant and then pick it. Foliage and the clustering of fruit in an area can complicate the image making it harder to distinguish the target for harvest and can also lead to mis-picking unripe fruit that only appears ripe at that particular camera angle—as strawberries do not always ripen uniformly on the fruit nor across the crop. Furthermore, the foliage continues to grow as the strawberry harvesting season continues. Strawberry fields are not harvested in a single pass through by workers, instead, they are picked multiple times throughout the season, with the typical field being picked around every two to three days (Bolda et al., 2015). The dynamics of both increasing foliage and continued interaction with the field presents an increasing number of issues with the visual processing used for mechanized harvesting.

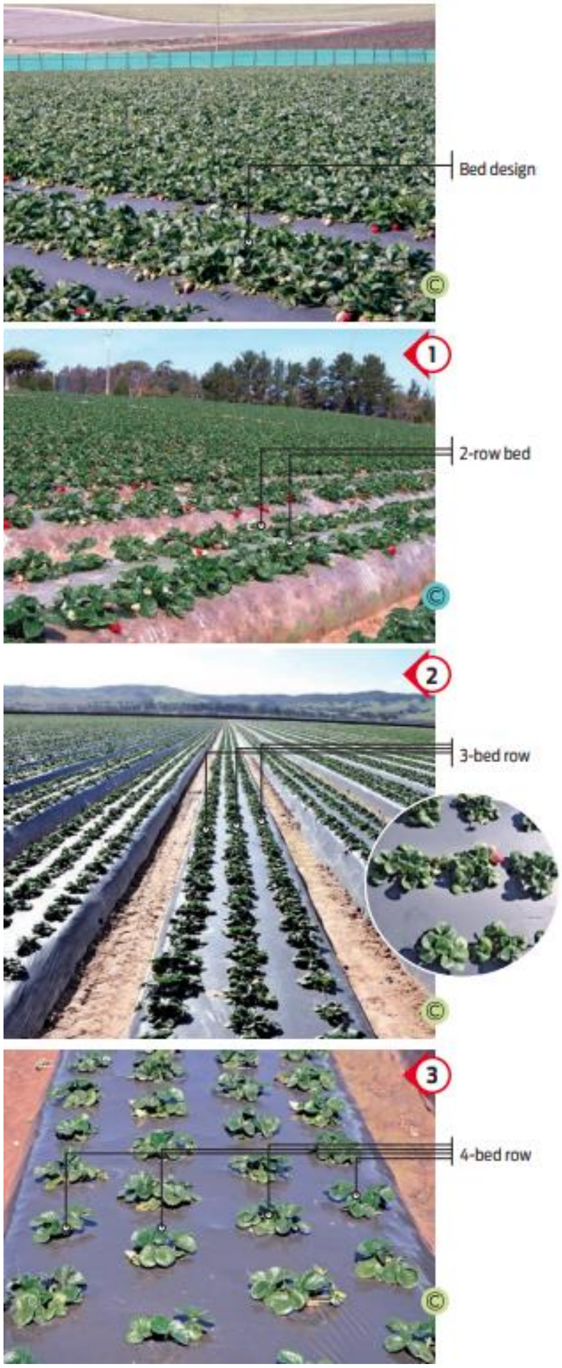

Figure 3: Examples of two, three, and four-row strawberry beds (Bolda et al., 2015)

The Political Ecology of Strawberry Harvesting

This thesis fits into the larger geographic theoretical literature of political ecology and how mechanization is conceptualized in this literature, and further connects back to the Marxian-rooted conception of the "metabolic rift." The metabolic rift is a concept coined by John Bellamy Foster but attributed to Karl Marx, in which the system of capitalism creates and upholds a theorized rift in the metabolic relationship between nature and society. This rift, Foster argues, was created through the combination of capitalist-based movements such as mass-produced industry and agriculture, long-distance trade, and the exploitation and degradation of soil—particularly through the use of artificial fertilizers. As these kinds of impacts on this relationship expand and continue over time, this rift has and will continue to reinforce itself through a positive feedback loop making the impacts as well as the tear in the relationship between nature and society more dramatic. This loop results in a profound alienation between humans and their environment (Foster, 1999). Parallels can be seen in this alienation as it is connected to automation and mechanization in agriculture. This has largely trended across mass-produced food in California and the United States more broadly as increased mechanization has significantly severed human connection physically and mentally from the land from which they get their food. However, the difficulties in mechanization brought up by the niche crop complexities inherent in strawberries provide a more complex reading of the metabolic rift in specific settings. Instead of a linear decline in human and non-human relationships as put forth by scholarship more generally, it can also be argued that through these complexities there are some ways in which the rift does not widen in a linear fashion through mechanization of harvesting and people largely stay in the field. Despite this added complexity, it can still be seen that the overall trend towards mechanization and increased use of pesticides and other assistive technologies, in turn, widen the rift.

Political ecology offers a lens through which to analyze crucial viewpoints on technological changes, this is naturally highlighted in this case study due to the ecologically rooted issues facing the strawberry industry. Political ecology, in general terms, is the study of the environment through the context and power relations inherent in political, economic, and social structures (Robbins, 2020). Within the confines of this thesis, political ecology makes visible the impacts and motivations behind these current and potential shifts in agriculture, technology, and industry. Political ecologists have often looked at the interactions of land, labor, politics, economics, culture, and society (Radel, 2018; Watts 1994; Watts and Goodman 1997). This framework emphasizes the importance of power in these interactions, noting the complex interchanges that power can have on a multiscale level. The centering of political ecology as conceptual framework for this thesis research offers a multidimensional approach that will be used to analyze politics, economics, and technology through relevant agricultural realities facing strawberries.

Using this political ecological framework, two guiding research questions underscore this case study. First, the research seeks to bring forward the experience of the Harvest Bot company as a case of a technological attempt to mechanize the industry and explore the contexts that shape this experience. Second, the study seeks to understand the broader impacts of the specific innovation by Harvest Bot across industry stakeholder groups. By exploring the experience and impact of Harvest Bot's technological attempt, the case study provides insight into factors and processes that will affect future technological attempts at mechanization and who they will benefit.

Methodology

This study focuses on an attempt at mechanized strawberry harvesting by a start-up robotics firm, referred to as Harvest Bot throughout the research. Harvest Bot was established with the goal of solving unsafe and uncomfortable working conditions that were not being addressed in technological development circles. After the development and sale of their first product which met these stated goals, they again identified other technological opportunities that were being overlooked, especially in areas where workers faced physically difficult conditions. Beginning in 2017, Harvest Bot began working on at strawberry harvesters.

There was clear opportunity in this development. As previously mentioned, development in strawberry harvesting mechanization has remained largely stagnant for decades, so when Harvest Bot started the development of their robotic autonomous mechanized harvesters, they were among only a handful of companies looking at strawberry harvesting mechanization. Despite this slow-moving technological development, the strawberry industry employs over 50,000 farm workers for harvest annually and earns upwards of $3.02 trillion annually. By these measures, the potential for profit for Harvest Bot appeared to be high and being one of the only companies in the country working on the issue, the potential appeared high (Delbridge, 2021). While there was a clear opportunity in the strawberry industry to build off grower interest and potential for profit, there were also challenges moving into this field which have plagued the industry specifically meaning that both the risk and reward within this area was particularly high. This recognition of the risk was understood by Harvest Bot leadership, but seemed to provide as much fuel as it did caution. This alludes to the reasoning behind focusing not simply on an economic assessment of this technological development attempt. As reflected in this clear opportunity but still ultimate failure of the attempt, the economic aspects do not show the full story of the experience. This is the basis of both the reliance on political ecology as well as the focus primarily on qualitative methods. Political and social relationships of power will determine what changes and what does not in agriculture so those naturally became the focus of the thesis once a political ecology approach was taken.

In many ways the story of Harvest Bot's founding is similar to other start-ups and other agricultural companies, although crucial differences exist. Agriculture is seasonal, meaning that product research and development is dependent on what part of the production is happening at any given point in the season. This can shift quickly in importance depending on the type of crop, in that some crops have longer harvest periods than others allowing for longer periods for field testing. This cycle means that extensive field trials—necessary for a robotic firm like Harvest Bot—typically must occur over multiple growing seasons, resulting in essentially once-a-year field trial periods for a prototype. Dependence on the natural cycle differs from that of many other firms. For example, software development can be assessed almost continuously, allowing research and development to take place at a rapid pace.

Agricultural robotic start-up testing also requires significant investment in time and relationship building, particularly in garnering trust among growers. These types of relationships and levels of trust are difficult to build, meaning that overall access to growers in this industry can be limited. Growers may be hesitant to involve themselves with start-ups if they are unsure about the risk and crop loss they may incur. The fact that Harvest Bot was successful in building these relationships further connects to the reasoning behind the selection of Harvest Bot for the company analyzed in this case study. They were able to secure strong partnerships with growers who allowed them time and space to evaluate their prototypes of the mechanical harvester and the pack house—where strawberries are sorted and placed into clamshells for sale.

The importance and precarious nature of access also reflects a larger limitation to the research study. Access to growers was burdened by an understandable lack of trust both in research projects more broadly and in relationships with university partners. Due to the historical political contexts that created this distrust, there were not many doors open to engagement in this regard. There were also difficulties with access when it came to farm workers. This more so revolved around the common employment structure of workers through the H-2A visa program. This program employs foreign workers for seasonal work, meaning that getting access to these communities is limited in timing and their months spent in the United States is often the busy harvest season. Further it means that the classical approach to reaching farm workers through community groups and labor organizations is less effective. The program also ties workers to the employer for employment across this period, meaning that workers may face more fear of retaliation or simply not feel comfortable speaking to researchers under these conditions (*H-2A Temporary Agricultural Workers,* 2023). The limited access to these stakeholder groups created major gaps in the research study and resulted in a reliance on extrapolation from secondary sources for key parts. It is important to note as well that leaving these two groups out of the interview process does add a degree of bias to the thesis, by not including these perspectives it is not possible to say that this thesis captures the entire systems approach analysis of the harvester in the industry.

With those limitations in consideration, data for the analysis was collected through a multitiered process including participant observation, informal interviews, and textual analysis of industry reports and company reports. Field visits to Harvest Bot's headquarters, field test sites, and other operating areas were conducted and a total of seven informal and formal interviews were conducted with Harvest Bot employees including management, engineers, and in-field supervisors (elaborated in Appendix A). Secondary discourse text analysis was utilized to collect data from academic articles, news articles, industry marketing content, and conference materials. The content was selected and organized for analysis and categorized based on key themes and topics. After this data was analyzed alongside the interviews and participant observations, a triangulation approach was used to gather themes across all three methods, and they were synthesized for clarity. This method is critical for those using multiple data sources and methods as it allows for validation and consistency and includes the incorporation of various perspectives of stakeholders both within the direct interaction and across experts across the field (Flick et al., 2004). The use of the triangulation approach allows for a more nuanced understanding of the phenomenon observed in a given case study and more reliability of the conclusions drawn from qualitative methods such as observations and interviews.

To the extent possible, anonymity was guaranteed to the firm and workers throughout data collection and in the writing of this thesis with respect to both the privacy of Harvest Bot as well as for the workers who participated in the interview process. This was necessary to safeguard sensitive information about the company, its operations, and its workforce. To assure this anonymity, the start-up company's name and names of all individuals, titles, or positions throughout the thesis have been assigned pseudonyms or were omitted entirely.

Results

In the following sections I will present the results of the analysis beginning with an overview of the attempt at mechanization pursued by Harvest Bot, the current standing of their research development projects, and their plans in the strawberry industry in terms of technological innovation and integration. The analysis will then cover the specific positive and negative impacts experienced by key stakeholders in the specific context of this technological development attempt. These stakeholders include the strawberry growers, Harvest Bot, the farm workers, and the analysis of their learning will be broken down into their material and conceptual connections, alluding to the importance of which group experiences which kinds of impacts and learnings. The results section will end by generalizing from these experiences and impacts to the broader strawberry industry and tie these experiences, impacts, and learnings to the larger inherent power relations and motivations that will determine the future of mechanization for table strawberry harvesting in California.

The Technological: Attempt Experience

Harvest Bot started development on the robotic strawberry harvester prototype in the late 2010s, in the preliminary stages of their fundings series they received significant investments from technology companies as well as hardware venture capital firms. The autonomous mechanical harvester that they designed was developed to be controlled by a single human operator. The machine is equipped with multiple cameras that scan the crop as it slowly moves down the row. The cameras look for the color differentiation of the ripe dark red strawberry against the foliage, soil, plastic sheeting, and lighter unripe strawberries. Once the camera and integrated machine learning software have identified a ripe strawberry, the machine then uses one of four robotic hands to pick the fruit gently. That robotic hand combines suction and claw movements to then place the strawberry in a large carton (See Figures 3 and 4 for the machine in operation using the flats designed by Harvest Bot). This carton is a proprietary flat that is used to bulk-pick strawberries, instead of placing strawberries directly into clamshells or trays for sale. Harvest Bot uniquely designed this flat to fit and stack on their harvester prototype, but it is similar in style to that of the flats used to bulk harvest for the frozen strawberry market, so it is not entirely unfamiliar to the industry (Bolda et al., 2015).

Once gathered, these strawberries are taken to a refrigerated indoor pack house—like the trays, this pack house was specially designed by Harvest Bot to accompany their machine. In the pack house workers sorted the berries into smaller plastic clamshells for sale (see Figure 6). This secondary sorting process was a unique addition to the strawberry industry as typically the berries are organized into sale-ready clamshells on the field itself, only being touched once by the worker (Bolda et al., 2015). After the Harvest Bot robotic harvesters have done a pass through the field, a team of farm workers must do an additional harvest, picking any berries missed by the machines. This team of farm workers is smaller than the number needed for a normal harvest and Harvest Bot reported that this team was typically able to pick around 25% faster than a normal harvest crew. This increase in speed is largely related to the smaller number of strawberries left in the field. It was clear from the vantage point where I stood watching these machines work, a large number of workers still remained in the field despite the use of the new harvester. Not only were there a large team of workers waiting to follow the machine, but there were also workers added to the pack house facility which required workers to sort the strawberries and operate the sorting conveyor belt machinery.

The continued use of workers in the field was something that Harvest Bot thought they could never avoid entirely. Their management emphasized that they do not currently see the mechanized harvester as a replacement for human labor but rather as a complement to it. Despite the acknowledgment of this, interest coming from the grower side is still focused on the total replacement of the labor force (Hernández-Martínez et al., 2023). Harvest Bot boasts that their harvesters pick around one hundred pounds of strawberries per hour, which they state is around the rate of an average human harvester. They argue that from this they can save the grower 30% from their total headcount of farm labor. Additionally, their mechanized harvester can operate throughout the night, extending the potential working hours for the growers in the tight season of strawberry harvesting. All these advantages made the company an interesting potential investment for growers and industry investors, reflected in their impressive series A and B early venture capital investments. However, there were key issues in the implementation that went beyond the cost-benefit of the harvester itself and prevented its commercial viability in the current state of the strawberry field.

Figure 4: A single mechanized harvester moving through a strawberry field with the proprietary flats stacked on the back. A single operator can control eight of these machines at once.

Figure 5: The interior of the mechanized harvester in operation, the blue claws and yellow suction cups are seen grasping at ripe strawberries.

Figure 6: The new refrigerated strawberry pack house in operation.

In the early summer of 2023, Harvest Bot decided to decelerate the development of the strawberry harvester for commercial use. Even before this decision was finalized, Harvest Bot management admitted there were many hurdles to overcome with the development of their mechanized harvester. These issues are related not only to the technology and industry makeup but also to the inherent nature of the crop itself. An overview of these challenges is laid out in Table 1:

Table 1: Challenges with the implementation of the strawberry harvester

Technology/Industry Challenges	**Strawberry Crop Challenges**
Scalability: Could not pick faster than human rate.	The Foliage Issue: Less accurate picking as the season progresses.
Initial Training Gap: Growers are required to provide knowledgeable workers to operate machinery.	Non-uniformity: Shape and length of the strawberry field.
Initial Setup Cost: Required use of pack house to sort fruit into clamshells for sale.	

One of their biggest challenges, Harvest Bot management explained, was rooted in the machine's repeatability, or the machines' ability to consistently repeat the harvesting task with a high success rate. This is not simply connected to the technology itself but also in its scalability and related necessary worksite training. The machines, as expressed, were about in line with the efficiency of current manual labor costs; furthermore, in the next year's trials, they were optimistic about bringing that efficiency up. One of the harder aspects was integrating the machines with the understandably resistant farm workers. Since the manual harvesters had to follow the machines that had already picked most of the berries, there was less for them to pick, making the standard piece-rate incentive system less appealing and resulting in lower pay for the same hours. This created tensions between the workers and the growers. To lessen these divisions, at the time of my initial visit in 2023, the growers were in discussions to increase the piece-rate wages for the workers. This would allow them to follow the machines which resulted in them picking fewer strawberries but still making a similar total amount of money by the end of the day.

There were also additional complications with the initial worker training gap and setup when it came to the machine operation itself. The plan with these harvesters was to lease them to growers in sets of eight machines, overseen by a single trained operator provided by the grower. This presented labor considerations as, though the machines may not be owned by the grower, the grower is expected to provide a worker who is knowledgeable generally about the machines and able to operate them with only minimal assistance in set-up and on-the-job management from Harvest Bot. Ideally, they would have set up the grower and the operator and then be able to give simple instructions and updates on the machine's performance from their offices—around 300 miles from their current test site. This is a significant amount of set-up cost required of the growers and a different initial setup program from what some other agricultural technology companies are pursuing.

The set-up of the mechanized harvester required the use of proprietary flats and a pack house, since the berries were not put in clamshells for sale on the field, as is the industry standard (Bolda et al., 2015). This change was novel and there were many additional steps that the growers had to consider as part of this setup. First, the pack house itself had to be designed, this was undertaken by Harvest Bot who designed a sorting system and conveyor belt for a refrigerated pack house. This sorting system featured a robotic arm that carefully placed strawberries from the proprietary flats onto the conveyor belt so as to not be damaged, then controlled the speed of the machine using sensors to optimize sorting. This sorting system was operated by a team of around six people during a site visit in 2023.

This deceleration of the strawberry harvester development, while seen as a loss by the technology company, also resulted in some net gains for the company as a result. The adoption of the conveyor belt and pack house was highly popular among the strawberry growers. This interest was garnered because the pack house increased efficiency simply by using the proprietary flats in the field along with the pack house. Just by using these two technologies growers have been able to increase harvest speed by 50% and the conveyor belt enables the packaging of 9,000 pounds per hour or the equivalent of 100 acres of strawberries in a single day. These highly efficient speeds have been shown to be of interest even without the addition of the robotic mechanized harvester. The introduction of the pack house was a more seamless transition as well. A pack house is a standard industry process in other locally grown crops, this meant that it was easy to implement other necessary complementary aspects to take it on such as transportation and refrigerated warehouses nearby to the harvesting fields. These measures have meant that this aspect of Harvest Bot's production has not ended.

When I returned to the field in 2024, growers were continuing to utilize the proprietary flats in the field and the custom pack house to sort, even without the use of the mechanized harvester. This highlights interesting insights in terms of the future of the strawberry industry. It implies that these more intermediary steps such as the use of a new style of flat or inclusion of a refrigerated pack house are likely to occur fueled by their dramatic effects on efficiency despite their comparatively smaller changes in cost and technological adoption. However, it also suggests that in future ventures into the strawberry industry, sorting and packing strawberries in a pack house may be more integrated into the standard operation of harvesting. This might decrease the initial setup cost of mechanization, therefore making future iterations of the strawberry harvester easier for the industry to adopt.

In terms of limiting factors for the mechanical harvester as developed by Harvest Bot, the need for a pack house and trays that work with the machine are important, but from research across the industry and in speaking with the engineers at Harvest Bot, the foliage issue remains at the heart of this repeatability and scalability question. The increase in foliage over the harvesting season greatly decreased the repeatability of the reported effectiveness of the technology—an issue reported across most models of harvesters assessed in strawberry fields as well (Tiedemann et al., 2022). This complicates the necessity for labor as it shifts in demand over the course of the harvest season period. Thus, this implies that if the machines were implemented, the labor pool needed to harvest would increase as the harvest season continued and the foliage becomes thicker, making the machine less accurate. A shifting labor pool is particularly hard to prepare for, especially considering the prevalence of the H-2A program for seasonal workers which requires a contract with minimum and maximum working hours, making it complex for growers to implement and prepare for such variation and unpredictability (*H-2A Temporary Agricultural Workers*, 2023).

The importance of this foliage issue can also be seen in the development of alternative harvesters that have emerged in tandem and after Harvest Bot. One of which has developed a similar technology to Harvest Bot’s but has put into use a paddle that moves the foliage around allowing the camera and claw to analyze and reach more of the crop from a single angle. Ideally, this paddle would increase the effectiveness of the mechanized harvester and make it repeatable over the entire season, however, long term results from this prototype have yet to be seen. While these innovations among other companies might address the symptom of the foliage issue that has proven to be critical with the development technology itself it does not address the broad issues of uniformity across the field.

In addition to the foliage issue, and as mentioned previously, the shape of the strawberry field holds an immense amount of variability both in height, width, and the number of strawberry rows in each bed. All of this contributes to the high amount of adjustments that are necessary to use the harvester. The mechanized harvester is expected to use machine learning to mimic the critical thinking and adaptation skills of a human and still be able to maintain a picking speed that is faster than human farm workers. This is a challenge that almost all companies who have sought to undertake the development of mechanical harvester have struggled with. Research estimates that these machines would need to meet a picking success rate of 90% and a speed of 7 seconds per berry in order to be competitive with human workers, these are both the most optimistic success rate and speed reported by mechanical harvester design teams (Delbridge, 2021). Additionally, while a cultivar could be developed with less foliage, there are many factors that add to these alternative areas of complexity in the field including those related to the environment such as soil type and quality, quality of the fruit, and yield of the fruit, as well as high production market motivations (Bolda et al., 2015). Such realities suggest that future mechanization developments will likely need to be able to adjust to many of these variations, though some may be easier to address than others in future variations of cultivars developed.

Such realities were also understood by the leadership at Harvest Bot, and leadership was aware that there were significant hurdles to overcome in order to make their harvester commercially viable which led them to the decision to decelerate the development of the strawberry harvester itself. However, using the knowledge and technology developed for the strawberry harvester, the Harvest Bot team has now moved to focus their efforts and investment on developing a mechanized harvester working with a different crop altogether. This shift utilizes both their knowledge of the mechanics of harvesting a more delicate fruit using robotic technology as well as their understanding of the conceptual problems relating to variability in the field.

While Harvest Bot has mostly shifted away from mechanical strawberry harvesters, they have continued to expand the pack house line in the strawberry industry. The spring harvest season of 2024 marked another round of testing the pack house in the coastal region of California seeing improvements both in speed and scale. In the 2023 season, they were operating the pack house in twenty-second cycles with a cycle being a single instance of the robotic arm placing a box of strawberries onto the conveyor belt. This is equivalent to about three to four pallets per hour. In the current season, this has now been reduced to fourteen-second cycles or about fifteen pallets of strawberries packed per hour. This speed of improvement has been largely credited to the ability of the technology to scale up, an increase in the number of workers, and their skill level, and adjustments to the pay scale for more equitable and motivational pay. Moreover, around half of the workers from the 2023 season returned to work on the pack line in 2024, most of these workers otherwise were employed in the fields. These retention rates show the quality and appeal of the jobs in the pack house over the current conditions of the jobs present in the field. Additionally, interest has grown from word-of-mouth comments across the industry surrounding the accuracy and quality of the pallets that have come out of the pack house as well. Harvest Bot reported that during the 2023 season, there were no rejects from stores that received pallets of clamshells sorted in the pack house, which they say is a rare occurrence for the strawberry industry.

Based on the progress with the pack house seen in their second harvest cycle, the goal of the Harvest Bot team in terms of the production of the pack house as a commercial product is that the system could be fully automated in the next two to three years. To the Harvest Bot team, this would ideally look like a system in which the line manager from the grower could take over the pack house, with no oversight from the technology company. This would mean that the only workers on the pack line itself would be those to close the clamshells after they are filled. This would require the development of some “missing pieces" of the pack line, specifically a mechanized sorter that would classify the good strawberries and place them into the clamshells up to the appropriate weight. Both these tasks are now done by humans on the pack line. However, the company also acknowledges that some variations of this pack house might be sold to growers such as the robotic arm used to place the strawberry trays onto the conveyor belt and the pack line conveyor belt itself which could both be removed from the whole pack line and sold separately. Similarly, proprietary flats could also be sold as their own product, as farmers have found that simply using those trays in lieu of the standard ones increase efficiency by 40%. Therefore, these trays and many pieces of the pack line hold commercial value on their own.

Finally, Harvest Bot continues to run limited tests on the mechanical harvesters they designed, testing them in the spring 2024 harvest season. In comparison with the previous year, this is on a smaller scale due to their decreased investment in this area of development. As of the time of writing this thesis they are only running five of the mechanical harvesters in the field—in comparison to last year’s eight—and they are not using the proprietary flats with the machine. Instead, they are using the standard harvesting pallets and packing the berries in the field, per industry standard, which allows them to run the test without the design and creation of an additional pack house.

Understanding Impact: Wins, Losses, and Spillover Effects

Overall, the outcomes of this case study are more complex and nuanced than initially predicted in terms of impact on growers, the technology company, and labor. This is in part because of the “failure” of the technology developed. Here I use the term in quotations because, while the technology was not adopted in the commercially anticipated way during the time frame provided by the case study in the thesis, there are still many lessons that can be seen across these key stakeholders. This alludes to a larger question surrounding the importance of context and power in the perceptions of the case study. Who deems an attempt at development as a failure, why, and to what end? While this case study may have resulted in some aspects of technological development being stopped or stalled, other more far-reaching consequences were successes, particularly for certain groups. An overview of these different conceptions of wins and losses relating to the case study are presented in Table 2:

Table 2: Overview of Outcomes Understood as Wins and Losses

	Wins	**Losses**
Growers	• Increased knowledge of limitations of mechanized harvest. • Increased knowledge of how the field would need to look for mechanization. • Increased efficiency with pack house and trays.	• No mechanization of harvest in the near future • Labor access crisis continues with growers. • Potentially increased labor tensions with continued interest in mechanization.
Harvest Bot	• Potential profit from pack house and tray sales. • Technology and learnings applicable for the next venture. • Future standardization of pack houses could lead to mechanization.	• Did not win this run for strawberry mechanized harvesting. • Sunk cost into harvester through time and investment. • Potential grower and investor relationship challenges related to the harvester.
Workers	• Less physically demanding jobs in the pack house. • Introduction of lighter trays and easier on-field jobs. • Potentially better pay scale for altered and new jobs. • Opened negotiations related to slower work and more pay.	• Job loss potential in the future with trends toward mechanization. • Job reskilling required to work pack house conveyor belt or future mechanized harvesters. • Potential contract changes for H-2A workers with new work modalities.

This provides an overview of the interconnected ways through which groups of stakeholders have been impacted and will likely be impacted both in the immediate term and in the future by this attempt at technological development. Understanding these wins and losses makes it possible to conceptualize how the development of this case study has progressed within the larger field of agricultural technology. Furthermore, these more complex understandings of wins and losses presents the results in combination with the industry and environmental situations present, arguing for these as more than just the results of individual actors but as a part of a nexus of power present between these three sectors. This emphasis on the importance of power and context in these wins and losses, further connects back to the political ecological grounding of this case study. In the next sections I explore in detail how this technological attempt impacted each stakeholder group below.

Growers: Inches Closer

For growers, who crucially sit with the power to largely determine the future of this technological development through their investments and industry connections, research into the mechanized harvester undertaken by Harvest Bot was overall a win, with some losses. The growers did not receive a fully commercial product in this endeavor and the experience revealed challenges in the industry that need to be addressed before the harvesting process can be fully mechanized. However, being able to identify what issues need to be addressed for full-scale mechanization is ultimately a win for growers as it can help to identify how to proceed towards these goals. However, the experience with this development also did not immediately alleviate their labor crisis and in some ways may have opened the door for more contentious labor relations as growers begin to consider labor-replacing technologies more publicly.

Critically from this technological attempt, though, growers were able to gain the immense amount of knowledge and increased stability in their product provided by the inclusion of the Harvest Bot pack house. The pack house allows for future development into mechanization to work without the need to pack in the field and has largely proven that packing in this new format may increase efficiency and quality of their product. This type of broader scale production design learning is one that can be carried forward into new collaborations with technology companies and serves as a step towards mechanization.

Harvest Bot: Lessons from Setbacks

Understandably, Harvest Bot may view their participation in this project through the blow it took as a company. Ideally, for Harvest Bot, this project should have ended with a viable commercial mechanized strawberry harvester. However, this was not achieved in this attempt. Additionally, it is possible that they may see less interest in a strawberry harvester after this research due to industry sentiments and a growing recognition of the large amount of investment necessary to fully automate that was further revealed through Harvest Bot's attempt at development.

From the perspective of a commercial firm, these are certainly negatives, however despite this, there were many benefits to the firm. The most significant was the redesign of the pack house that has significant benefits for the strawberry industry, and they are the leader in this area. The continued investment into the pack house has also helped maintain relationships with people in the strawberry industry that could lead to future interest and investment in their endeavors both in the diffusion of their pack house design across the industry. They also developed capabilities that may allow them to develop machines to harvest other crops.

Farm Workers: Short Term Gains

Finally, for farm workers in the strawberry industry, there are some, surprising, key changes seen in the results of this case study. The pack house provides less physically demanding jobs while there continues to be employment in the field. This change in jobs aligns with the demographic shifts in the labor force as older workers enter the agricultural workforce (Houston et al., 2023). Similarly, the in-field jobs associated with the use of the pack house use the lighter proprietary flats while offering higher wages than those of the typical harvesting positions due to the streamlined and thus quickened ability to harvest using these trays. Along with the creation of these new jobs and technologies on the field, there has been the opportunity to discuss and negotiate pay changes as they are able to work more efficiently for the grower. In addition, many jobs added in this transition may require job reskilling or upskilling which may be achievable for some workers but not others as the complexity of new jobs can range from the simpler sorting to highly technical engineering.

Taken together these wins and losses can be argued to show that more broadly, the losses experienced in this attempt are in the technical space, while the wins are conceptual. The losses center around the development of the product in this attempt and its failure to see the expected commercial adoption across the industry. Additionally, the industry still does not hold the harvester that they have invested in significantly over the years. The exception to this is the conceptual win of the pack house. However, that was still not the anticipated result from the onset of the project and is rather more clearly seen as a positive spillover effect. In contrast to these technical losses, the wins sit more in the conceptual realm regarding learnings on the harvester and the industry and physical contexts of the field gained. These wins have the potential to push the industry one step further toward the eventual development and adoption of a mechanized harvester. Harvest Bot may also be able to take these industry and technology learnings and apply them to their future projects while continuing to work on this one, broadening their conceptual horizons. Workers, however, seem to sit in contrast to these trends, while they may have technical benefits from these advancements, in terms of workplace conditions and higher wages especially surrounding the adoption of the pack house, their losses are more conceptual and placed into future contexts—particularly in relation to the impact of employment.

These trends importantly put the specific technical attempt in the larger grounding political and economic contexts of this industry. For example, while in the short term, farm worker jobs will likely remain intact and may see general improvements, there remains a continued rhetoric and investment towards a full replacement of the manual workforce across the industry more broadly. This overarching goal, reaffirmed by the growers and associated groups emphasizes the power differential at play. While workers may experience these gains and potential losses, their ability to change the system is often called into play due to their lack of capital in comparison to the much more powerful growers, despite the fact that they have critical leverage as labor is unlikely to be completely replaced by these harvesters. These perceived limitations of the workforce's power, therefore, is not clear, nor is it reaffirmed that only capital plays a role here in terms of power. Access to growers and land is also critical as shown in the experience of the start-up. While Harvest Bot had significant capital investment, they also faced hurdles, enough to forestall production. These hurdles were based not only around access to the market, but also natural limitations put up by the environment. These supplementary burdens show the ineffectiveness of determining power relations purely based on capital valuations.

The complexity of the dynamics associated to power in this context reaffirm the importance of questioning the term “failure” in this attempt. Emphasizing the environment, the political motivations, and the economic complexities that surround this case study show that this is not a story in which the start-up comes into an environment with the intent to disrupt and takes control of the market. Instead, this case study puts forward a more complex reading of this experience, wherein Harvest Bots fate, despite having common determinants of success through capital investment, was more so determined by the nexus of power relations and complexities surrounding it. Such a reality suggests that future technological attempts towards strawberry mechanization will likely have to contend with such relations and complexities as well.

Impacts on the Broader Industry

The outcomes of these wins and losses are poised to determine the strategies and motivations for those in the strawberry industry, guiding future technological advancements and investments. However, while stakeholders may base their decisions on these perceived wins and losses, the determinants of full adoption rest in the power and thus capital they possess to influence outcomes in their favor. Consequently, while workers may perceive movement towards these technologies as losses and may desire different outcomes other than widespread mechanical harvester development and adoption, the capital to determine future investment and change lies mainly with the growers. This power manifests through their command of financial resources, market influence, political affiliations, and network effects. In this way, they are afforded the advantage of shaping market and political outcomes to align primarily with their interests. Yet, the ultimate adoption of technologies is rooted in their efficiencies which so far appear to be illusive in the immediate to long-term range given the uniqueness of the strawberry industry.

Such realities connect this research back to the political-ecological framework of this case study. The interplay of progress, politics, and power is always significant in the context of technological innovation. This is perhaps made more obvious in an agricultural context where the involvement of crops will always provide an unstructured environment and a degree of unpredictability, allowing for the potential to slow down research and development efforts and reveal the underlying motivations and strategies of those involved. In any organization though, the contextual situation in which technologies are developed undoubtedly influences their trajectory. This can be either in terms of financial support, what they prioritize in development, and the uptick of the product by the public or targeted industry.

Significantly, while this attempt by Harvest Bot may have forestalled, the production of these technologies continues both within the confines of their company and beyond by other actors and this continuity is intrinsically connected to power. While the number of wins and losses may have been spread across the board. It is likely that the most influential are the wins that were felt more strongly by the growers. While the situation may have fallen short for the growers in certain aspects—in that they were not able to see the commercialization of the product they had hoped for—they have accrued invaluable insights and experience into mechanization. This appears to have encouraged them to continue to invest time and money into these innovations across the industry, as their power to influence these decisions was not changed by the results of this attempt. In addition, recent research in academic fields includes investigations into the efficiency and robotic capabilities of more standardized systems such as greenhouses, the viability of different variations of the mechanical harvester, and the economic baseline these projects need to meet for mass adoption of these technologies (Delbridge, 2021; Hernández-Martínez et al., 2023; Woo et al., 2020). These areas of research all reflect the ongoing motivations and market interest in automation, standardization, and mechanization in the mass production of strawberries.

Interest from growers and investors in the strawberry industry for the continuation of research into the mechanized harvester and the long-term goal of a decrease in reliance on physical labor in the field suggests the importance of further understanding of this economic, political, and social context. In this sense there continues to be support for the overarching capitalist fueled historical move towards a metabolic rift—or a space both physically and conceptually between humans and the environment. However, as this case study has shown, a more complex story may be surrounding the development of technologies. Research continues to show an interest in the prevalence and acceptance of intermediary technologies that facilitate the augmented interaction between farm workers and the field. While this larger trend towards a widening metabolic rift exists, the simplistic notion of a linear increase in the metabolic rift misses the more complex nature of technological development and the spillover effects that occur because of it.

The progression of the development of a technology is dependent on its context, and the power relations inherent in it. Such progression is not just connected to the political and economic spheres, but as this thesis has also shown, the environment itself serves as a powerful structure in these larger relationships. Based on the context of the strawberry industry, it can be understood that this process will take a significant amount of time to take place as the industry decides if it will undertake standardization practices to support further mechanization and that the technological development itself will take more time as it progresses and expands by each attempt. Despite this comparatively slow progression, it is clear from the historical and current contexts of this industry that this research and development will continue, and other technologies that are able to adapt to these unstructured environments may see more success along this long path to mechanization.

Limitations and Generalizability of the Research Study

As previously explained in the methodology section, the most prominent limitation of this thesis is that it leaves out the perspectives of the growers and the farm workers. While the thesis suggests an alternative perspective on technological development, it is forced to extrapolate based on the known history and stated positions of these groups analyzed through secondary sources. These extrapolations were done delicately regarding impact on labor as that is a popular and highly politicized field. These limitations highlight larger difficulties in gaining trust in the agricultural industry in California. It was easy going into this project to assume that people would be enthusiastic about participation and to some extent that was true, as seen in the eager participation of Harvest Bot. However, as the complex politics of the strawberry and agricultural industry more broadly was revealed, doors also began to close. It also mattered, in terms of access, who the research was positioned through. Reaching out from the particular angle of interest in mechanization assuredly colored the perspective people had on the project. There is a lot to say here too about navigating agricultural research as an outsider and learning what to say and what not to say. This definitely affected the breadth of the research and the generalizability of the research and in particular the amount that the research was able to speak to the labor aspect which was woefully left out of the research as a whole.

Additionally, while it is easy to lean on quantitative data as the universal truth in research, there is more going on, even when it seems like a simple answer. For example, when looking at the question of optimal performance for a mechanical strawberry harvester the answer is out there but is contingent on the conditions both on and off the field. Even in articles where they clearly lay this statistic out, the answer is not just one number, but many numbers determined by the current state of farm worker wages—for example one such article determines that with piece rates between $1.70 to $2.70 the corresponding robotic efficiencies need to be between 40% to 90% (Delbridge, 2021). The fluidity of this economic viewpoint is key. A technological development attempt can be commercially successful even if it is not the most efficient or best "version" of itself. Alternatively, the opposite can be true, and an attempt can fail regardless of its performance. This underscores the importance of qualitative data in how we think about these technological attempts because it's these political, economic, and social relationships of power that will determine what changes and what doesn't in agriculture both in terms of economics and in terms of labor.

In terms of generalizability, this thesis utilizes the theoretical background of political ecology to emphasize the complexity of the agricultural industry more broadly and more specifically the niche crop industry. This is important particularly as the niche crop industry will experience mechanization uniquely from agriculture more broadly due not only to its political and social relations, but perhaps more critically its ecological setting. While there are clear limitations to this thesis, it also opens the door to future research especially those considering the experiences of key stakeholders missed in this thesis. This thesis also aims to serves as a piece of the larger historical, political, and social background when it comes to future research into these economic and labor focused questions. It is through the deep and far-reaching acknowledgment of political ecological contexts that meaningful and actionable research can be made and hopefully this thesis can serve as one piece to that larger knowledge base.

Conclusions and Future Directions

This case study has shown the unique attributes and experiences surrounding an attempt at mechanization in the California strawberry industry and how this attempt when considered as part of a long process of technological development has broader implications across stakeholders wherein a more complex understanding of gains and challenges can be seen. It also reveals connections to the power structures of technological development and agriculture highlighted through the focus on the California strawberry industry. While this singular experience of technological innovation may not have been one of commercial adoption, it still had a profound impact and the wins and losses felt by key stakeholders have potential large ramifications for what the future of automation and mechanization is and how that process will play out in the strawberry industry.

As policy makers look to address the concerns of growers and workers alongside these technology innovations, they should look towards these larger political, economic, and environmental contexts to gain an understanding not just of what technologies or products will be successful commercially, but also how different technologies will impact in vastly different ways depending on how they alter the interaction between the human and the environment. Policy that better understands this nuance and complexity in technological development has the potential to better advocate for their constituents who are faced with more complex choices than just for or against technological additions to agriculture. Particularly, as these technologies continue to develop and integrate, questions should be centered around what groups are integrated and which are displaced as both will require different policy approaches. However, to completely address and prepare for those larger policy questions, a full understanding of the impact of mechanized harvesting in the strawberry industry is needed. This large-scale systems analysis has yet to be seen in academia—and the state of development of the technology itself suggests that such an analysis undertaken at this point in time would only be speculative. Considering these realities, this case study offers a key insight into this question by highlighting the learnings and larger understandings of the complexities related to technology and agriculture and raises new questions for future research towards a system wide perspective.

Further research is needed into expanded areas of study on agricultural start-ups as unique entities both among agricultural companies and among other start-ups. How much of the Harvest Bot experience is unique, or is this a repeated cycle among other agricultural start-ups, and why is that the case? Questions surrounding the industry's influence on this are also needed. Does the agricultural industry, or the California agricultural industry more specifically create a challenging environment for start-ups? Conversely, is it the start-up setup and mentality that makes it hard to work in the agricultural landscape? This connects to questions about the timeline of projects. While a typical start-up might expect a return on investment at maximum by the end of a 7-10-year period, agricultural environments can make that a daunting goal simply based on the involvement of a natural setting (Janeway et al., 2021).

More investigation should be undertaken to address the missing piece of this thesis as it relates to labor impacts and perceptions. While this thesis was limited in its ability to cover an in-depth analysis of labor impacts beyond media perceptions, there is a call to understand what can be done to address these concerns. These center both around the growers' decreasing access to labor, the farm workers' concern for future employment, as well as how the H-2A program has changed both these aspects and will change them in the future.

Additional research questions convene around the need for expanded knowledge of geographical theories surrounding the concept of the metabolic rift. In what ways is the widening of the metabolic rift an antecedent for the mechanization of agriculture? It could be argued that the metabolic rift inherently supports the creation of structured environments which could more easily lend itself to mechanization through more intensified division of labor. The classic examples of pesticides and mass transit technologies lead to this as well and the learnings gained from the attempt at mechanization seen in the case study hint at this. The creation of structured environments such as greenhouses for mass agricultural processes that are highly mechanized also feeds into this theory. But to what extent is the metabolic rift a necessity for this mechanical adoption? Or is it better understood as an effect of the mechanization process? Beyond the origins and paths that the widening of the metabolic rift opens for agriculture, what are the broader effects that happen because of it; on labor, the environment, firm consolidation, and politics?

Appendix

Appendix A: Additional Details on Data Sources and Collection

Source Type	Details	Date Collected
Field Visits	Exploratory Visit to Research Area/Site	February 4th and 5th, 2023
	Initial visit to research site during harvest including field and pack house	May 23rd, 2023
	Visit to Assembly Room and Office	November 29th, 2023
	Secondary visit to research site to see updates to pack house	April 26th, 2024
Interviewees	Founder of Harvest Bot	April 26th and August 24th, 2023 November 29th, 2024
	Manager of in field operations and pack house	May 23rd, 2023
	Operator of in field harvester	May 23rd, 2023
	Engineer for Harvest Bot	November 29th, 2023
	Business lead for Harvest Bot	November 29th, 2023
	Manager of pack house	April 26th, 2024
Conferences	Immigration and Farm Labor Conference 2023 – Gifford Center for Population Studies, UC Davis	March 16th, 2023

	Immigration and Farm Labor Conference 2024 – Gifford Center for Population Studies, UC Davis	April 5th, 2024
	19th International Conference on Informatics in Control, Automation and Robotics	July 14th-16th, 2022 [Reviewed proceedings]
Industry Publications*	California Strawberry Commission	
	University of California Cooperative Extension and Agricultural and Natural Resources	
	Cal Poly Strawberry Center	
	U.S. Citizenship and Immigration Services	
	California Department of Food and Agriculture	
	USDA National Agricultural Statistics Service (NASS) and Economic Research Service	
	Companies including: Driscolls, Naturipe, Berry Ferry, Farmwise	

*full citations provided in works cited

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