Foreign Guest Workers or Domestic Workers? Farm Labor Decisions and Implications

Feng Wu
Assistant Research Scientist
Gulf Coast Research and Education Center
University of Florida
14625 County Road 672
Wimauma, FL 33598
Office: 813-633-4141
Email: fengwu@ufl.edu

Zhengfei Guan
Assistant Professor
Gulf Coast Research and Education Center &
Food and Resource Economics Department
University of Florida
14625 County Road 672
Wimauma, FL 33598
Office: 813-633-4138
guanz@ufl.edu

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In recent years stricter enforcement of U.S. immigration laws has contributed to the reduction of Mexican immigrants coming to the US, causing drying labor pool in the agricultural sector which heavily relies on immigrant workers for its labor supply. As a result, farmers have to raise wage rates while struggling to find enough labor to do the field work, particularly during the peak harvest season. Producers of the labor-intensive fruit and vegetable industry are particularly concerned about the cost and availability of labor. The most recent data from the USDA indicate that labor accounted for 42 percent of the variable production expenses for U.S. fruit and vegetable farms (USDA/ERS, 2016). For most crops, a delayed harvest due to lack of labor often means loss of revenue because of decreased quality and prices. Longer delays could even lead to loss of entire crop as most fruit and vegetable crops are highly perishable. Labor shortages and rising labor costs present an even greater challenge as many commodities are struggling with competition from developing countries where labor costs are low and supply is rich. In U.S. agriculture, labor has been a major issue for years, which, if not addressed, will continue to inflict the labor-intensive specialty crop industry and weigh down its market share.

Many farmers have come to the realization that labor planning and management is critical to stay in the business. Due to labor shortage, farmers across the United States are turning more and more to the guest worker program. The program admits nonimmigrant workers into the US under the H-2A visa to perform seasonal agricultural work. This program seems to be providing a promising solution. However, farmers were hesitant to adopt the program due to lack of knowledge on the costs and benefits of hiring domestic workers versus H-2A workers. On the one hand, farmers are accustomed to hiring domestic (largely illegal) labor, which is less expensive and simple. The use of temporary domestic workers seems to give employers the flexibility to adjust labor, but the supply of domestic labor is uncertain and fluctuates over the
season, and farmers may have to pay extra costs to hire workers when faced with a production shock. On the other hand, the current H-2A Program is “cumbersome and expensive” and most farmers lack the experience with it (Guan et al., 2015). The high transaction costs involved are believed to have deterred many employers from adopting the program. However, the program ensures a stable supply of labor force under the H-2A contract, which is critical the labor intensive industry in the context of severe labor shortages and high turnover rates.

In the literature there is little attention on modeling the optimal labor decisions in agriculture where risk and uncertainty in both commodity and input markets are pervasive. This study is to fill this knowledge gap and propose a framework for modeling labor use decisions under risk and uncertainty with an application to the strawberry industry. Farm labor decisions are modeled using a dynamic optimization framework, assuming farmers maximize profit by choosing the optimal contracting practices in terms of terms of contract, labor sources and hours. We develop a model that accounts for labor adjustment costs, which reflect transaction costs in recruiting domestic workers. We derive closed-form solutions to farm labor demand under uncertainty. In contrast to the case of domestic workers, adjusting the number of H-2A workers within the season is infeasible because of the setup of the program and the high fixed costs involved. Given the nature of the H-2A program, we assume there is no uncertainty in maintaining labor force once H-2A workers are hired under contract. Under this framework, we derive the optimal labor demand and further analyze the sensitivity of the optimal amounts to changes in various parameters, with a focus on the changes of wage, adjustment costs and program design. An empirical application to Florida strawberry farms is used to illustrate the methodology, demonstrate differences of using domestic and H-2A workers and identify the optimal hiring strategies.
To our knowledge, no previous study attempted to quantitatively analyze dynamic labor demand in the U.S. agriculture. In particular, we are the first to study the labor demand for both domestic and H-2A workers and assess the two labor sourcing and contracting strategies. Specifically, we derive optimal labor demand under different contracts and their respective values. The results have implications for the current heated debates on raising minimum wages and the reform of the H-2A program.

Models

Our approach begins with the specification of a dynamic optimization problem for a representative farm in terms of scale and operations. We focus on dynamic labor demand over the harvest season of fruit and vegetable crops. The representative farm is assumed to make labor decisions at each period of the season (weekly) to maximize the multi-period operating profit over the season. The operating profit is defined as revenue less wage and labor adjustment costs.

The model features production shocks. A positive shock in the production may result from higher production, e.g., due to favorable weather. We assume this shock follows uniform distributions with different intervals each week. Total wage is a function of working time and the wage rate. The wage difference between H-2A and domestic workers is taken into consideration.

In the following sections, we illustrate the models for demands for domestic and H2A workers and derive their optimal demand.

Demand of Domestic Workers

During the harvest season, number of workers and hours enter multiplicatively in the production function. Consistent with Meese (1980), we treat labor input as man-hours to simplify the model.
That is, we assume that the farmer chooses man-hours alone instead of separately choosing number of employees and hours of work to maximize operating profit.

Assume that the crop price at \( t \) is \( p_t \); the harvesting efficiency of domestic workers is \( \eta_t \) (e.g., pieces harvested by an average worker per hour); and the wage level is \( w_t \) (e.g., piece rate).

The farm employs man-hours \( (l_t) \) as the sole input to harvest crops. The labor output \( (\eta_t l_t) \) is subject to a production constraint as follows:

\[
\eta_t l_t \leq \bar{y}_t + e_t,
\]

where \( \bar{y}_t \) is the average production at time \( t \), and \( e_t \) is the production shock due to weather, disease, and other unexpected events. \( e_t \) is assumed to be serially independent and uniformly distributed with support \([g_t, \bar{g}_t]\).

Define the vector of state variables as \( S_t = (p_t, \eta_t, w_t) \), and let \( v(S_t) \) be the cumulative future profit of the farm. The representative farm chooses \( l_t \) to maximize its total profit by solving the problem

\[
v(S_t) = \max_{l_t} \{ E \sum_{t=1}^{n} [(p_t - w_t)\eta_t l_t - c_t] \},
\]

where \( c_t \) is labor adjustment costs.

The motion of the farm's labor force \( l_t \) is given by

\[
l_{t+1} = \beta_t l_t + h_t, \quad 0 < \beta_t < 1,
\]

where \( \beta_t \) is workforce retention rate, defined as one minus the quit rate, between time \( t \) and \( t+1 \), and \( h_t \) is gross hires, which can be positive (hire) or negative (fire). The quit rate is the rate at which workers leave the firm for voluntary reasons.

Labor adjustment costs consist of both hiring and firing costs. The literature has analyzed mostly the latter, but we focus on the former given the current labor shortage situation. Since most workers in the fruit and vegetable industry are seasonal or temporary, farmers does not
typically make a severance payment when terminating the temporary contract. As a result, we allow farmers to reduce employment without adjustment costs. In contrast, increasing man-hours will incur costs to farmers. Labor hiring costs include advertising of positions, training and screening of new workers, and disruption costs (output that is lost due to insufficient labor) (Belo et al., 2014). These costs could be divided into two categories: fixed and variable costs. Fixed costs are independent of the number of workers hired, e.g., the advertising cost, while variable costs are related to the number of new hires. A survey conducted by Guan and Wu (2016) suggests that fixed costs are negligible since farmers in the fruit and vegetable industry seldom advertise or train crop pickers. They hire temporary labor mostly through personal networks of employers and workers. Thus only the variable costs are accounted for, and we model the costs in the study with the convex structure. The convex hiring costs capture the fact that the adjustment costs may be related to the size of adjustment because of higher costs for larger changes. In this case, the optimal hiring strategy for the farmer is to adjust his labor demand smoothly over time, since it will be more costly to recruit a large number of workers immediately. This is consistent with the current reality of labor shortage. In contrast, if the farm faces non-convex hiring costs, e.g., linear adjustment costs, the optimal response to a large production shock is to adjust employment immediately. In the literature on employment adjustment, the functional form of labor adjustment costs has often been assumed to be quadratic (Sargent, 1978). We specify a similar structure of costs as:

\[ c_t = \begin{cases} 
0 & \text{if } h_t \leq 0 \\
\frac{\alpha_t}{2} h_t^2 & \text{if } h_t > 0
\end{cases} \tag{4} \]

where \( \alpha_t \) is the cost parameter.

Dynamic optimization techniques are applied to the maximization problem (2) subject to three constraints specified in (1), (3) and (4). Then the Bellman equation becomes
\[
v(l_{t-1}) = \max_{l_t} \{(p_t - w_t)\eta_t l_t - c_t + v(l_t)\}.
\]

The problem is non-standard, because the derivative of the Bellman equation changes with the sign of the change in employment. The first-order condition is:

\[
[(p_t - w_t)\eta_t - \alpha_t(l_t - \beta_t l_{t-1}) + v'(l_t)](\eta_t l_t - \bar{y}_t - e_t) = 0,
\]

where \(v'(l_t)\) is the value of expected future operating profit. Assume that \(\bar{l}_t = \frac{\bar{y}_t + e_t}{\eta_t}\), the optimal labor demand rule is then:

(i) if \([ (p_t - w_t)\eta_t - \alpha_t(\bar{l}_t - \beta l_{t-1}) + v'(\bar{l}_t) ] < 0 \),

the farm hires and labor demand \(l_t\) is the solution to \( (p_t - w_t)\eta_t - \alpha_t(l_t - \beta l_{t-1}) + v'(l_t) = 0 \).

We define one threshold value \(e_{2t}\) which holds (7) with equality.

(ii) if \([ (p_t - w_t)\eta_t - \alpha_t(\bar{l}_t - \beta l_{t-1}) + v'(\bar{l}_t) ] > 0 \),

labor demand is constrained by the bound established by crop yield. Therefore, \(l_t = \bar{l}_t\). We define the other threshold \(e_{1t} = \eta_t \beta l_{t-1} + \bar{y}_t\).

(a) if \(e_{1t} < e_t < e_{2t}\), the farm will hire workers to reach \(\bar{l}_t\) man-hours;

(b) if \(g_t < e_t < e_{1t}\), the farm will fire workers and only \(\bar{l}_t\) are demanded.

The value of expected marginal profits, \(v'(l_t)\), is derived in Appendix A, where the maximization problem is solved by backward recursion. The complete expression for \(v'(l_t)\) is:

\[
v'(l_t) = (\bar{g}_{t+1} - g_{t+1})^{-1} \beta_{t+1} \lambda_{t+1} + \beta_{t+1} \beta_{t+2} (\bar{g}_{t+2} - g_{t+2})^{-1} (\bar{g}_{t+1} - g_{t+1})^{-1} \lambda_{t+2} (\bar{g}_{t+1} - e_{2,t+1}) + \cdots + \prod_{i=1}^{T-t} (\bar{g}_{t+i} - g_{t+i})^{-1} \beta_{t+i} \prod_{i=1}^{T-t-1} (\bar{g}_{t+i} - e_{2,t+i}) \lambda_T,
\]

where \(\lambda_t = \frac{(p_t - w_t)^2 \eta_t^2}{2 \alpha_t}\).

Substituting eq. (9) into eq. (6) and rearranging gives the following solution:
where $s_t = v'(l_t)$. If there were no labor adjustment costs, the farm would harvest all crops if the marginal product of labor is greater than the wage across the season. Then the pattern of employment would reflect the high volatility of the production shocks. The farm would take advantage of the costlessly adjustable labor input to control payroll and maximize profit in response to the shocks. However, in real farm production, there exist adjustment costs associated with searching and hiring. These adjustment costs inhibit hiring and hence generate underemployment, suggesting a negative impact on output.

**Demand of H2A Workers**

If the farmer uses H-2A workers to crops, he has to make hours and number of workers decisions separately due to the nature of the Program. Bringing nonimmigrant foreign workers to perform seasonal or temporary agricultural work by the H-2A Program is administratively cumbersome, time-consuming and incurs enormous fixed costs. For example, the employers' H-2A labor certification applications involve a long lead time. In addition, farm employers must comply with a set of requirements and regulations. These characteristics suggest the number of H-2A workers could not be flexibly adjusted within the season. Faced with a demand shock, farmers are not able to bring extra H-2A workers in a short period of time. Therefore, the farmer has to make accurate prediction about the number of workers needed ahead of time, taking into account the variation of workloads over the season. These H-2A workers will be recruited before the season and kept till the end of the contracting period. After these workers are brought in to the farm, working hours will be flexible within bounds specified in the contract. Given crop growth and yield pattern over the season, farmers can adjust daily or weekly working hours at no cost. The
H-2A program requires the employer to offer each worker employment for at least three-fourths of total hours in the contracted period. Therefore, number of workers hired and number of hours worked have different marginal costs. Adding an hour may entail little cost while adding an employee may involve fixed costs such as housing or transportation. For this reason, we distinguish the decision variables as number of workers (L) and hours (H) per worker separately. The problem of the representative farm is to determine the optimal number and hour demand to maximize expected total profit over the season:

\[
V = \max_{t,H_t}\{E \sum_{t=1}^{n}[(p_t - W_t)\Gamma_t LH_t - C(L) - C_0]\},
\]  

(11)

where \(L\) is the number of H-2A workers, which is assumed to be unchanged over the season; \(H_t\) is the average working hours at \(t\). \(W\) is the piece rate paid to H-2A workers. Since the hourly rate of H-2A workers must be at least as high as the applicable Adverse Effect Wage Rate (AEWR), federal or state minimum wage, or the applicable prevailing hourly wage rate, whichever is higher, H-2A workers' piece rate are higher than domestic workers' most times. \(\Gamma\) is the harvest efficiency of H-2A workers, which reflects productivity of H-2A workers that is usually different from \(\eta\). \(C(L) + C_0\) is the non-wage cost of hiring H-2A workers; \(C(L)\) is the variable cost, varying with the number of workers, including visa application, housing, inbound and outbound travel, transportation and so on, while \(C_0\) is fixed costs, including H-2A labor certification application and worker recruitment. We assume that the variable cost is a linear function of the number of H-2A workers, that is, \(C(L) = AL\), where \(A\) is the parameter.

This maximization problem is subject to several constraints. First, as in the case of domestic workers, the harvested amount should be less than crop yield. Namely, \(\Gamma_t LH_t \leq \bar{y}_t + e_t\) for \(t = 1,2,\ldots,n\). Second, the farmer has to abide by the 75% rule, \(\sum_{t=1}^{n} H_t \geq nK\bar{H}\), where \(K = 0.75\) and \(\bar{H}\) is the contracted weekly working hours (n weeks). Third, working hours each
week cannot exceed the contracted hours limit, $H_t \leq \bar{H}$. This constrained maximization problem can be solved by setting up the Lagrange function and deriving the Kuhn-Tucker conditions (See Appendix B). The solution for optimal number of workers to hire is

$$L = \frac{\sum_j \overline{y}_t + 0.5(\overline{g}_t + \bar{g}_t)}{\bar{H} - 0.25n\bar{H}},$$

(12)

while the solution for optimal number of hours per week is

$$\begin{cases} H_t = \frac{\overline{y}_t + \bar{e}_t}{\Gamma_t L}, \text{for } j \text{ periods} \\ H_t = \bar{H}, \text{ for } n - j \text{ periods} \end{cases},$$

(13)

(12) and (13) are solved simultaneously. The optimal expected total profit over the season is

$$V^* = \left\{ \sum_j (p_t - W_t) \left( \overline{y}_t + 0.5(\overline{g}_t + \bar{g}_t) \right) + \sum_{n-j} (p_t - W_t) (n - j) \bar{H}L - AL - C_0 \right\}.$$  

(14)

We now analyze the effects of changes in "Three-fourths Guarantee rule" and "working hour limit" on the farm profit. The optimal labor solution in the H-2A case shows that the farmer is always bounded by the three-fourths guarantee. The response to a rise in $K$ of optimal labor demand $L^*$ can be written as

$$\frac{\partial L^*}{\partial K} = -n\bar{H} \frac{\sum_j \overline{y}_t + 0.5(\overline{g}_t + \bar{g}_t)}{(Kn\bar{H} - \bar{H} (n-j))^2} < 0,$$

(15)

which suggests the more restrictive/high working hour guarantee, the less H-2A workers will be demanded. This provision protects against over-recruitment and ensures a minimum workers income. However, the guarantee could have a significant impact on the hiring practices and may create a disincentive to hire, thus reducing the flexibility of labor use within the season and therefore farm profit. The corresponding derivative of profit with respect to $K$ is (See Appendix C):

$$\frac{\partial V^*}{\partial K} = -\left[ \sum_{n-j} (p_t - W_t) (n - j) \bar{H}L - AL \right] \frac{\sum_j \overline{y}_t + 0.5(\overline{g}_t + \bar{g}_t)}{(Kn\bar{H} - \bar{H} (n-j))^2} n\bar{H} < 0.$$  

(16)
This result suggests that the higher guarantee will reduce profit. Therefore, eliminating the existing three-fourths guarantee or relax the guarantee will enhance farm profit. In addition, labor contract sometimes regulates the hours per week a worker is expected to work during the contract period. This clause actually reduces the labor use flexibility, in particular, for crops with fluctuating yields. The lower working hour limit, the higher labor demand. The corresponding derivative is

\[
\frac{\partial L^*}{\partial \bar{H}} = -\frac{\sum_{j} y_{t}^{g} + 0.5(g_t + \delta_t) \Gamma_{t} j (\bar{H}_j - 0.25n\bar{H})}{(\bar{H} - 0.25n\bar{H})} < 0.
\]

(17)

The increase of flexibility will reduce the labor demand. More importantly, it will increase profit.

\[
\frac{\partial V^*}{\partial \bar{H}} = A L^* \bar{H} > 0.
\]

(18)

**Application and Model Calibration**

The labor demand models are examined for a representative strawberry farm in Florida. Labor use in strawberry production has distinctive characteristics for three reasons. First, harvesting fresh market strawberries is labor intensive, and labor is the largest cost item in the Florida strawberry production budget, accounting for about 40% of farm-gate sales. Second, the industry relies heavily on temporary workers for field work. The demand for temporary workers fluctuates over the season. It is low in November and December when harvest begins. As harvesting activities intensify in January through March, the number of workers increases dramatically. Third, in recent years labor has become an increasingly important issue for Florida farmers. Currently it is considered the number one threat or challenge for the industry. Drying labor pool and climbing labor costs are threatening the existence of the industry.

The representative farm is assumed to have 200 acres and makes hiring decisions weekly. The farm is allowed to abandon the crop unharvested in the field if the labor is too expensive,
which has been widely observed in the industry. The harvest season covers the first week of November through the end of March, totaling 21 weeks ($n = 21$). The weekly average production ($\bar{y}$) is determined by farm size and average yields. Weekly yield data between the 2011/12 and 2015/16 seasons are used and sourced from the United States Department of Agriculture, Agricultural Marketing Service (USDA,AMS). The lower and upper bounds of weekly yields (for $g_t$ and $\bar{g}_t$) take the lowest and highest historical yields in the same week during the period. Figure 2 shows the dynamics of weekly production of the farm and their lower and upper bounds, measured in number of flats, which is the standard measurement unit for strawberries in the country (one flat of strawberries weighs 8 lbs). Production variation over the season is a result of genetic and biological process subject to growth environments, such as weather and disease. Strawberry prices ($p_t$) are represented by weekly average prices at the shipment point of Central Florida and collected from USDA, AMS.

Workers’ quit rates are specified to be non-stochastic as in Shapiro (1986). Because the quit rates of domestic workers are available only at a monthly frequency, we convert it to weekly frequency by disaggregating the monthly data evenly across four weeks. Generally the quit rate is about 2% per week. At the late season of harvest, the quit rate increases to 3.7% as workers begin migrate to other crops. We calibrate the labor adjustment cost parameter in line with the reality of Florida labor market competition. In the early season, there is little adjustment costs as temporary workers gradually arrive and labor demand is fully met by supply. As the amount of ripen fruits pick up over the season, labor demand exceeds supply, which may cause yield loss and disruption costs.

Strawberries are hand harvested for the fresh market. Picking efficiency (flats of fruit harvested per man-hour) varies depending on the yield. In the early season, plants yield less fruit
so picking efficiency is low at about 2-3 flats/hour. As yield increases, picking efficiency improves substantially. An average picker can pick more than 8 flats/hour at the peak season. Figure 2 shows the dynamics of picking efficiency of domestic workers over the season. The pattern is consistent with the production curve in figure 1. Data shows H-2A workers are more efficient than domestic workers, which make the program attractive. We assume H-2A workers’ picking efficiency is 20% higher than that of domestic workers.

Farmers pay a piece rate for harvesting. Since the picking efficiency is low at the early season, the piece rate is relatively high to guarantee piece-rate workers to receive the statutory hourly minimum wage. The minimum wage in Florida was $8.05/hour in 2016. The piece rates, as shown in figure 3, varied with the picking efficiency. At the peak time, pickers' hourly payment will be higher than the minimum wage due to high picking efficiency. The hourly rate of H-2A workers (AEWR) was $10.7/hour in 2016. To guarantee the statutory wage, farmers have to pay higher piece rates at the beginning of harvest season. With the increase of picking efficiency, piece rates will be reduced to domestic workers' level (figure 2). H-2A workers are assumed to work 6 days each week and weekly working hour limit is 35 ($H$).

The parameter of variable cost ($A$) in bringing H-2A workers to Florida from a foreign country (mostly Mexico) is assumed to be $1,620 per worker, which is in the range of $1,400 to $1,800 reported in the literature (Roka, 2016). The fixed cost is assumed to be $1,875, including $1000 of application fee to Department of Labor, $325 per petition to the Department of Homeland Security, and $500 of advertisement of recruiting U.S. workers.

Results

Demand for Domestic Man-hours
We employ the Monte Carlo simulation approach when solving optimal demand for domestic man-hours. The production shock each period is drawn from a uniform distribution on the interval \([\bar{g}_t, \tilde{g}_t]\). The number of Monte Carlo replications is 5,000. In order to have a direct comparison with H-2A worker demand, we divide the optimal man-hours by 35 (weekly working hours) to obtain the number of workers employed. Figure 3 shows the average and median number of workers demanded. The results provide several insights. First, the demand pattern is consistent with production (yield) dynamics in almost all periods except the peak time. Since labor adjustment costs are high at the peak time, the optimal strategy may be not to recruit or recruit few workers. Figure 3 shows that the growth of employment is far below production growth in Feb (see figure 1), suggesting that some strawberries are abandoned in the field. The simulation results verify that labor output is always less than production at the peak time. Second, early-season fruit are fully harvested due to high prices and no or low adjustment costs. Third, the model generates a volatile farm-level employment rate with a standard deviation of 78 workers. Fourth, the total operating profit has an average of $36.65 million and standard deviation of 435,000.

We further analyze the sensitivity of labor demand to changes in market conditions, including the minimum wage and labor adjustment costs. Currently campaigns to raise the minimum wage are gaining momentum across the country. It is instructive to investigate the effect of raising the minimum wage on a typical industry, which will shed light on the minimum wage’s effects on the whole agriculture. Given the adverse effect wage is 26% higher than the minimum wage, we first increase the wage rate of domestic workers by the same percentage. The results suggest that 1) raising the minimum wage has no impact on harvesting and employment in the early season of strawberries; 2) fewer man-hours are employed and less fruit are harvested
in the later season due to the increase of the minimum wage. The prices at the later season are low, and the profit of adding employment will be offset by the adjustment costs. As a result, farms tend to under-hire.

Labor adjustment costs also have significant impacts on labor demand. To show this, we assume a frictionless labor market without adjustment costs. In the specification of equation 4, we assume $A=0$ and labor can be freely adjusted, which constitutes a natural benchmark for evaluating the importance of labor frictions. The results show that labor demand reflect the fluctuation of production and is more volatile (with a standard deviation of 82) than the case with adjustment costs.

**Demand of H2A Workers**

The total demand of H-2A workers is 148. The optimal weekly working hours are shown in figure 4. At the start of harvest season, fruit will be fully harvested and working hours are less than the hour limit; along with rising yields, workers have to work longer. Figure 4 shows that labor shortage will occur in January. When the limit is relaxed, for example, when $\bar{H} = 40$ or 45, the pattern of working hours won't change (Figure 4). Alternatively, farmers will reduce the number of workers needed, consistent with equation 17(Figure 5), in order to abide by the three-fourths guarantee. Further, the profit will increase as derived in equation 18. Figure 5 shows when the working hour limit is relaxed from 35 to 40, the profit has a significant growth. It suggests that strawberry farmers would substantially benefit from the flexibility with a higher limit. For this reason, the number of working hours specified in the contract may not be always honored by farmers.
Figure 6 shows the weekly working hours in terms of different guaranteed hours. The higher the guarantee, the more pervasive the labor shortages. For example, under the four-fifths guarantee, farmers will be faced with labor shortage in 64% of harvest season. In contrast, labor shortage only occurs in 23% of the season for the 65% guarantee. The existing three-quarter guarantee results in employers under-recruiting H-2A workers, as shown in Figure 7. Without the constraint of the guarantee, farmers would recruit 263 workers, while the number reduces to 148 under the existing guarantee. Evidently, it achieves the purpose of the guarantee to protect domestic workers since too many imported workers may drive down the wage of domestic workers. Figure 7 shows that the 70% guarantee may be better for strawberry farmers given the pattern of labor requirement during harvest season. Farmers can substantially improve their profit. Therefore, revising the three-quarter guarantee could be an option for discussion. In addition, this regulation also generates other unintended purposes, such as incentives to over-estimate the contract period needed (GAO, 1997).

Comparison

Under the current specification, hiring domestic workers is more beneficial to farmers. The total marginal revenue of hiring domestic workers is $36 million while hiring H-2A workers only generates $33 million. The result explains why strawberry farmers were slow in adoption of the H-2A program. However, use of H-2A workers could become more attractive. First, revise the three-fourths guarantee to 70% guarantee. The modification will increase total revenue of hiring H-2A workers to $41 million. Second, raise the minimum wage. If the minimum wage reaches the adverse effect wage level or $10.70/hour, the wage advantage of domestic workers disappears. Hiring domestic workers will be no longer attractive. Third, increase labor
adjustment costs. Labor use flexibility of domestic workers will be seriously affected if labor market competition is intense. A stable labor supply or H-2A workers will guarantee the harvest and farmers will benefit more. Currently legislative efforts are being made to raise the minimum wage. Meanwhile, stricter border control is slowing illegal immigrants, which intensifies the labor market competition. These signals imply that there will be more and more H-2A workers admitted into the U.S. in the future.

**Conclusions**

US farmers are suffering from labor shortages while immigration reform remains elusive. Although H2A program provides a promising solution, the costs involved are affecting the adoption. This research contributes to the literature by developing a framework to model farmer labor decision and derive optimal labor use strategies that maximize farmers’ profit. Our results show that the modification of three-fourths guarantee of H2A program will substantially improve strawberry farmers’ profitability, resulting in more wide adoption of H-2A workers relative to domestic workers. In addition, the trend of raising the minimum wage and the intensifying labor market competition also potentially put the use of domestic workers at a serious disadvantage. Therefore, more and more farmers are expected to resort to the H2A program to resolve the labor issue. These results provide a number of important insights with significant policy implications, especially for the immigration reform of agricultural guest worker (H2A) program.
Reference


Figure 1. The dynamics of average weekly production ($\bar{y}$) of the representative farm and corresponding lower and upper bounds $[g, \bar{g}]$.

![Graph showing the dynamics of average weekly production](image)

Figure 2. Domestic workers' wage rates ($/flat$) and picking efficiency (flat/hour) of domestic workers.

![Graph showing domestic workers' wages and efficiency](image)
Figure 3. Optimal number of domestic workers demanded

Figure 4. Optimal weekly working hours of H2A workers when $H = 35, 40$ or $45$. 
Figure 5. The effect of $\overline{H}$ on worker demand and operating profit

Figure 6. Optimal weekly working hours when $K=0, 0.65, 0.7, 0.75, 0.8$ and 0.85
Figure 7. The effect of $K$ on worker demand and operating profit
Appendix A: Derivation of the solution to the dynamic optimization problem (2)

We start from the last period, T and then work backwards.

(i) Single-period first-order condition is

\[
[(p_T - w_T)\eta_T - \alpha_T(l_T - \beta_{T-1}l_{T-1})](\eta_Tl_T - \bar{y}_T - e_T) = 0.
\]  

(A. 1)

The optimal labor demand rule is

(i) hiring, \(l_T = \beta_{T-1}l_{T-1} + \frac{(p_{T-1} - w_T)_T}{\alpha_T} \), if \(\bar{g}_T > e_T > \eta_T(\beta_{T-1}l_{T-1} + \frac{(p_{T-1} - w_T)_T}{\alpha_T}) - \bar{y}_T\)

(ii) hiring, \(l_T = \frac{\bar{y}_T + e_T}{\eta_T} \), if \(\eta_T\beta_{T-1} - \bar{y}_T < e_T < \eta_T(\beta_{T-1}l_{T-1} + \frac{(p_{T-1} - w_T)_T}{\alpha_T}) - \bar{y}_T\)

(iii) firing, \(l_T = \frac{\bar{y}_T + e_T}{\eta_T} \), if \(g_T < e_T < \eta_T(\beta_{T-1}l_{T-1} - \bar{y}_T\)

These formulae define the employment rule with bounds \(e_{1T} = \eta_T(\beta_{T-1}l_{T-1} - \bar{y}_T\) and \(e_{2T} = \eta_T(\beta_{T-1}l_{T-1} + \frac{(p_{T-1} - w_T)_T}{\alpha_T}) - \bar{y}_T\).

The expected optimal profit is (* means optimal values)

\[
E_{T-1}\pi_T^* = (\bar{g}_T - g_T)^{-1}
\int_{\bar{y}_T}^{e_{1T}} (\bar{y}_T + e_T)(p_T - w_T)de_T + \int_{e_{1T}}^{e_{2T}} [(\bar{y}_T + e_T)(p_T - w_T) - \frac{\alpha_T}{2} (\frac{\bar{y}_T + e_T}{\eta_T} - \beta_{T-1}l_{T-1})^2]de_T + \int_{e_{2T}}^{\bar{y}_T} (\beta_{T-1}l_{T-1} + \frac{(p_T - w_T)_T}{2\alpha_T})(p_T - w_T)\eta_Tde_T.
\]

(ii) For the two-period case, the value function is

\[v_{T-1} = \max l_{T-1} [\pi_{T-1} + E_{T-1}\pi_T^*].\]

The two-period first-order condition is

\[
\frac{d\pi_{T-1}}{dt_{T-1}} + E_{T-1} \frac{d\pi_T^*}{dt_{T-1}} = 0.
\]

Based on the formula of \(E_{T-1}\pi_T^*\) above,
\[ E_{T-1} \frac{d\pi^*_T}{dt_{T-1}} = (\bar{g}_T - \underline{g}_T)^{-1} \left[ \beta_{T-1} \alpha_T \left( \frac{\bar{y}_T}{\eta_T} - \beta_{T-1} \eta_{T-1} \right) (e_{2T} - e_{1T}) + \frac{e_{T}^2 - e_{T-1}^2}{2\eta_T} \right] + \beta_{T-1} \left( p_T - w_T \right) \eta_T (g_T - e_{2T}) \]

\[ \beta_{T-1} \lambda_T (\bar{g}_T - \underline{g}_T)^{-1}, \]

where \( \lambda_T = \frac{(p_T - w_T)^2 \eta_T^2}{2\alpha_T} + (p_T - w_T) \eta_T (g_T - e_{2T}) \).

(iii) For the three-period case, the value function is

\[ \nu_{T-2} = \max_{t_{T-2}} [\pi_{T-2} + E_{T-2} \pi^*_ {T-1} + E_{T-2} \pi^*_T]. \]

The three-period first-order condition is

\[ \frac{d\pi^*_{T-2}}{dt_{T-2}} + E_{T-2} \frac{d\pi^*_{T-1}}{dt_{T-2}} + E_{T-2} \frac{d\pi^*_T}{dt_{T-2}} = 0. \]

By the law of iterated expectations,

\[ E_{T-2} \frac{d\pi^*_T}{dt_{T-2}} = E_{T-2} \left[ \frac{dE_{T-1}\pi^*_T}{dt_{T-2}} \right] = (\bar{g}_T - \underline{g}_T)^{-1} \int_{\underline{g}_T}^{\bar{g}_T} \frac{dE_{T-1}\pi^*_T}{dt_{T-2}} \, de_{T-1}, \]

\[ = (\bar{g}_{T-1} - \underline{g}_{T-1})^{-1} \int_{\underline{g}_{T-1}}^{\bar{g}_{T-1}} \frac{dE_{T-1}\pi^*_T}{dt_{T-2}} \, de_{T-1} = \beta_{T-2} \left( \bar{g}_{T-1} - \underline{g}_{T-1} \right)^{-1} \int_{\underline{g}_{T-1}}^{\bar{g}_{T-1}} \frac{dE_{T-1}\pi^*_T}{dt_{T-1}} \, de_{T-1}, \]

\[ = (\bar{g}_T - \underline{g}_T)^{-1} \beta_{T-1} \beta_{T-2} \left( \bar{g}_{T-1} - \underline{g}_{T-1} \right)^{-1} \lambda_T (\bar{g}_{T-1} - e_{2,T-1}). \]

Correspondingly,

\[ E_t \frac{d\pi^*_t}{dt_t} = \prod_{i=1}^{T-t} (\bar{g}_{t+i} - \underline{g}_{t+i})^{-1} \beta_{t+i} \prod_{i=1}^{T-t} (\bar{g}_{t+i} - e_{2,t+i}) \lambda_T. \]

The hiring first-order condition for period \( t \) is

\[ (p_t - w_t) \eta_t - \alpha_t (l_t - \beta l_{t-1}) + (\bar{g}_{t+1} - \underline{g}_{t+1})^{-1} \beta_{t+1} \lambda_{t+1} + \beta_{t+1} \beta_{t+2} (\bar{g}_{t+2} - \underline{g}_{t+2})^{-1} (\bar{g}_{t+1} - \underline{g}_{t+1})^{-1} (\bar{g}_{t+1} - e_{2,t+1}) \lambda_{t+2} + \cdots + \prod_{i=1}^{T-t} (\bar{g}_{t+i} - \underline{g}_{t+i})^{-1} \beta_{t+i} \prod_{i=1}^{T-t} (\bar{g}_{t+i} - e_{2,t+i}) \lambda_T = 0. \]
Rearranging yields the expression

\[ l_t = \beta l_{t-1} + \frac{(p_t - w_t)\eta_t + s_t}{a_t}, \]

where

\[ s_t = \left( \bar{g}_{t+1} - g_{t+1} \right)^{-1} \beta_{t+1} \lambda_{t+1} + \beta_{t+1} \beta_{t+2} \left( \bar{g}_{t+2} - g_{t+2} \right)^{-1} \left( \bar{g}_{t+1} - g_{t+1} \right)^{-1} \lambda_{t+2} (\bar{g}_{t+1} - e_{2,t+1}) + \cdots + \prod_{i=1}^{t-1} \left( \bar{g}_{t+i} - g_{t+i} \right)^{-1} \beta_{t+i} \prod_{i=1}^{t-1} (\bar{g}_{t+i} - e_{2,t+i}) \lambda_T, \]

which is the expected future marginal profits.
Appendix B. The solution to the constrained maximization problem of H2A worker demand

The problem is

\[ V = \max_{L, H_t} \{ E \sum_{t=1}^{n} [(p_t - W_t) \Gamma_t L H_t - C(L) - C_0] \}, \]

s.t. \( \Gamma_t L H_t < \bar{y}_t + e_t \) for \( t = 1, 2, \ldots, n \),

\[ H_t \leq \bar{H} \text{ for } t = 1, 2, \ldots, n, \]

\[ \sum_{t=1}^{n} H_t \geq \frac{3}{4} n \bar{H}. \]

We first form the Lagrange function

\[ f(L, H, \lambda_1, \lambda_2, \lambda_3) = \{ E \sum_{t=1}^{n} [(p_t - W_t) \Gamma_t L H_t - AL - C_0] \} + \sum_{t=1}^{n} \lambda_{1t} (\bar{y}_t + e_t - \Gamma_t L H_t) + \sum_{t=1}^{n} \lambda_{2t} (\bar{H} - H_t) + \lambda_3 \left( \sum_{t=1}^{n} H_t - \frac{3}{4} n \bar{H} \right), \] (B.1)

and then maximize with respect to the variables \( L \) and \( H_t \)

\[ \frac{\partial f}{\partial L} = E \sum_{t=1}^{n} [(p_t - W_t - \lambda_{1t}) \Gamma_t H_t - A] = 0, \] (B.2)

\[ \frac{\partial f}{\partial H_t} = E (p_t - W_t) \Gamma_t L - \lambda_{1t} \Gamma_t L - \lambda_{2t} + \lambda_3 = 0 \text{ for } t = 1, 2, \ldots, n \] (B.3)

and minimize with respect to the variables \( \lambda_{1t}, \lambda_{2t} \) and \( \lambda_3 \) subject to the nonnegativity restrictions \( \lambda_{1t}, \lambda_{2t}, \lambda_3 \geq 0 \)

\[ \bar{y}_t + e_t - \Gamma_t L H_t \geq 0; \quad \lambda_{1t} \geq 0; \quad (\bar{y}_t + e_t - \Gamma_t L H_t) \lambda_{1t} = 0 \] (B.4)

\[ \bar{H} - H_t \geq 0; \quad \lambda_{2t} \geq 0; \quad (\bar{H} - H_t) \lambda_{2t} = 0 \] (B.5)

\[ \sum_{t=1}^{n} H_t - \frac{3}{4} n \bar{H} \geq 0; \quad \lambda_3 \geq 0; \quad \left( \sum_{t=1}^{n} H_t - \frac{3}{4} n \bar{H} \right) \lambda_3 = 0 \] (B.6)

Let’s guess that \( \lambda_{1t} > 0 \) and \( \lambda_3 > 0 \). This implies that: \( \sum_{t=1}^{n} H_t = \frac{3}{4} n \bar{H} \), and \( \bar{y}_t + e_t = \Gamma_t L H_t \).

Under the circumstance, \( \lambda_{2t} = 0 \). As a result, Eq. B.3 implies that \( \lambda_{1t} = \frac{(p_t - W_t - \lambda_{1t}) \Gamma_t}{\Gamma_t} \) for \( i \neq t \). Substituting the relationship into B.2 generates \( (p_t - W_t - \frac{(p_i - W_i - \lambda_{1i}) \Gamma_i}{\Gamma_i}) = \left( \sum_{i=1}^{n} H_t - \frac{3}{4} n \bar{H} \right) \lambda_3 = 0 \) for all \( t \).
\( \lambda_{1t} \Gamma_t = \frac{4A}{3nH} > 0 \), which contradicts B.3 given \( \lambda_3 > 0 \). The above derivation suggests that not all ripen fruit or vegetables will be harvested in the optimal case. Another guess is that production in some periods will be fully harvested while production in other periods will be partly harvested.

Assume \( \lambda_{1t} > 0 \) for \( j \) periods \((t \in \Omega_j)\) and \( \lambda_{1t} = 0 \) for the remaining \( n-j \) periods \((t \in \bar{\Omega}_j)\). This implies that \( \bar{y}_t + e_t = \Gamma_t LH_t \) for \( t \in \Omega_j \) and \( \bar{H} = H_t \) for \( t \in \bar{\Omega}_j \). Therefore, \( \sum_{t=1}^{n} H_t = \sum_j \frac{\bar{y}_t + 0.5(g_t + \bar{g}_t)}{\Gamma_t L} + \bar{H}(n - j) \). Once again, if \( \lambda_3 = 0 \), a contradiction will generate from B.2 and B.3. So \( \lambda_3 > 0 \) and the optimal H2A labor demand is derived as

\[
L^* = \frac{\sum_j \frac{\bar{y}_t + 0.5(g_t + \bar{g}_t)}{\Gamma_t L}}{\bar{H}j - 0.25nH}.
\] (B.7)

Furthermore, all other values have satisfied the Kuhn-Tucker conditions. As for the value \( j \), we will derive it based on the parameter calibration.
Appendix C: Derivatives of marginal revenue of using H2A workers with respect to contract guarantee coefficient (K) and \( \bar{H} \)

\[
\frac{\partial V^*}{\partial K} = \left[ \sum_{n-j}(p_t - W_t) (n - j) \bar{H} - A \right] \frac{\partial L^*}{\partial K},
\]

\[
= -\left[ \sum_{n-j}(p_t - W_t) (n - j) \bar{H} - A \right] \sum_j \frac{\gamma_t + 0.5(\gamma_t + \bar{\gamma}_t)}{i_t (KnH - H(n-j))^2} n \bar{H}.
\]

Since \( \sum_{n-j}(p_t - W_t) (n - j) \bar{H} > A \) when the labor and working hours demands are optimal, then \( \frac{\partial V^*}{\partial K} < 0 \).

\[
\frac{\partial V^*}{\partial \bar{H}} = \sum_{n-j}(p_t - W_t) (n - j) L^* + \left[ \sum_{n-j}(p_t - W_t) (n - j) \bar{H} - A \right] \frac{\partial L^*}{\partial \bar{H}},
\]

\[
= \sum_{n-j}(p_t - W_t) (n - j) L^* - \left[ \sum_{n-j}(p_t - W_t) (n - j) \bar{H} - A \right] \sum_j \frac{\gamma_t + 0.5(\gamma_t + \bar{\gamma}_t)}{i_t (\bar{H} - 0.25nH)^2} \bar{H},
\]

\[
= A \frac{L^*}{\bar{H}} > 0
\]