Labor Cost and Technology Adoption: Least Squares Monte Carlo Method for the Case of Sugarcane Mechanization in Florida

Nobuyuki Iwai
International Agricultural Trade & Policy Center
Food and Resource Economics Department
PO Box 110240, University of Florida
Gainesville, FL 32611
niwai@ufl.edu

Robert D. Emerson
International Agricultural Trade & Policy Center
Food and Resource Economics Department
PO Box 110240, University of Florida
Gainesville, FL 32611
remerson@ufl.edu

Lurleen M. Walters
International Agricultural Trade & Policy Center
Food and Resource Economics Department
P.O. Box 110240, University of Florida
Gainesville, FL 32611
lwalters@ufl.edu

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Abstract

The prospect of immigration reform has renewed farmers' concerns of serious labor shortages and cost increases, which may urge highly labor-intensive specialty crop farmers to switch to less-labor-intensive technology. The large-scale mechanization of the Florida sugarcane harvest during the 1970s/80s serves as an historical example of how technologies evolved due to changes in local labor market conditions. We analyze the dynamic decision-making process of sugarcane farmers in the relevant period using net present value (NPV) approach and real options approach (ROA) with least squares Monte Carlo (LSMC).

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Introduction

The prospect of immigration reform has renewed farmers' concerns of serious labor shortages and cost increases, given that a large percentage of the workforce is unauthorized for U.S. employment. Clearly, this is more of a concern for specialty crop agriculture that is highly labor intensive. Sarig, et al. (2000) report that "…at least 20-25% of the U.S. vegetable acreage and 40-45% of the U.S. fruit acreage is totally dependent on hand harvesting." In addition to the large labor requirements, labor use is often concentrated in a very short period, particularly at harvest time (Emerson 2007).

This concern about labor-cost-increase seems quite legitimate if, as implied by the recent immigration reform proposals, only legal workers would be available for employers. This is because existing literature suggests a significant wage gap between legal and illegal workers (Taylor 1992; Ise and Perloff 1995; Iwai et al. 2006). There are several ways in which agricultural employers could deal with increased labor cost, but the most likely ones in the mid- to long-term would be the adoption of a technology with less labor use, and termination of current crop production if an alternative technology is not available (Emerson 2007). Mechanical harvesting is a typical example of the former option, whereas the latter option may involve changes to the cropping mix such that less labor is required.

It is not unusual that harvesting equipment is available for a number of years prior to its widespread adoption. Examples are the tomato harvester adoption in California and the mechanical cotton picker in the South. Mechanical harvesting equipment has been available in a number of formats for several years for citrus for the processing market, yet adoption is minimal. A similar pattern existed for Florida sugarcane, the majority of which was harvested with machetes by legal guest workers from the British West Indies under the H-2 labor program until the late 1980s.

Previous studies of Florida sugarcane production, which compared the cost and returns from mechanically harvested operations with those of hand cutting operations (Zepp and Clayton 1975, Zepp 1975, Walker 1972), found the cost advantage of the former as early as 1972-3 season. Although this cost advantage is offset by reduced revenue due to large field losses and higher trash content with mechanical harvesting for 1972-3 season, projected 1974-75 machinery operating rates and additional 10% labor cost increase would have been sufficient to give the net returns advantage to the mechanical operation (Zepp 1975). However, the historical fact shows that the large scale mechanization investment did not happen until mid- and late 1980s, as long as 15 years from 1972-3 season.

Using the data provided by Zepp and Clayton (1975) and Walker (1972), Iwai and Emerson (2008) analyze the dynamic decision making process of farmers with the two methodologies: net present value (NPV) approach and real options approach (ROA). The NPV approach simply compares the NPV of the projects of interest. In the case of Florida sugarcane, the farmer will switch to mechanical harvesting if the discounted future cash flow less the investment cost for mechanical operation is higher than the discounted future cash flow from the current operation. Their NPV comparisons between hand harvest and mechanical harvesting of Florida sugarcane supported the results from previous studies and indicated that it would have been advantageous for growers to switch to mechanical harvesting as early as the 1972-3 season, which is again contradictory to the historical fact.

The ROA, which applies financial option theory for investment in real assets, assumes that the producer has the option to invest or wait, called "investment flexibility". However, once the producer makes an irreversible investment, he exercises, or "kills" the option to invest and gives up the value of keeping the investment option alive. Hence the producer does not invest until the NPV of mechanical harvesting operation less the option value is greater than the NPV of hand cut operation (Dixit and Pindyck 1994, Trigeorgis 1996). The consideration for flexibility and irreversibility of investment in the real options approach often yields a much higher trigger value of the return (or cash flow) from mechanized harvesting operation than that calculated from NPV approach, delaying the investment decision until higher profit is more likely.[1] An application of real options analysis (ROA) by Iwai and Emerson. (2008) indicated that sugarcane farmers in Florida are exposed to highly volatile free cash flow (FCF), so that the value of keeping the flexibility option alive is very high, enough to overturn the NPV conclusion. Threshold level analysis finds a rather large margin between the actual and threshold level: for the immediate investment it takes more than 52% increase in the labor cost, so that the ROA explains the historical fact that large scale mechanization did not happen for as long as 15 years from 72-3 season. However, this threshold value may be conservative given the fact that the labor cost increased more than 100% between early 70s and mid 80s.

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[1] Real options approach can handle partially reversible investment decision. In our case this means that sugarcane farmer can turn back to hand cutting harvesting with some cost.

Iwai and Emerson (2008) used an approach in their ROA study for sugarcane suggested by Copeland and Antikarov (2003) combining multiple stochastic factors into one through a Monte Carlo simulation, referred to as a *consolidated approach*. Although the application of the consolidated approach in this case study gives reasonable results, the methodology is based on the rather restrictive assumption about the stochastic process of present value (PV) of FCF as shown below. The current paper uses an alternative ROA technique called least squares Monte Carlo (LSMC) method which does not depend on specific stochastic processes. We explain the advantage of the method in the next section.

Methodology

Our LSMC application starts with NPV calculation for each operational mode as the consolidated approach suggested by Copeland and Antikarov (2003). The NPV approach models and estimates the time series of stochastic factors, and generates the future sample paths of each factor from which the future sample paths are calculated for free cash flow (FCF) and present value (PV) of the model Florida sugarcane farmer. Generated sample paths for stochastic factors, FCF and PV are important inputs used in the LSMC, but the detailed explanation of the generation procedures are already presented in Iwai and Emerson (2008). Therefore, in this section, we focus on the methodology of the option valuation using the ROA, with special attention on the LSMC.

The technical difficulty in the ROA application such as Florida sugarcane mechanization is that there are at least four stochastic factors: price, yield, labor cost and other costs. Option valuation with early exercise features with multiple stochastic factors has so called "dimensionality problem". As a rule of thumb, standard numerical methods such as lattice solvers and finite difference methods become impractical for applications with more than three stochastic factors (Brandimarte 2006, Tavella 2002). The consolidated approach avoids the dimensionality problem by combining stochastic factors into one through the Monte Carlo simulation and using binomial lattices. However, the approach is based on the assumption that the rate of return from the project follows a random walk. The theorem often referred to as the foundation of the random walk assumption is the one by Samuelson (1965): regardless of the pattern of cash flows expected in the future, the changes in the asset value will follow a random process so that return is iid process, as long as all the information about the expected future cash flows is already backed into the current asset value in such a way that, if expectations are met, investors will earn exactly their expected cost of capital. Although the assumption is crucial for the validity of the consolidated approach, there is no data to test if this assumption is actually satisfied for the Florida sugarcane farming.

Even if the above assumption is reasonable for the current study, another serious problem is that the consolidated approach approximates the stochastic process of PV that follows the continuous geometric Brownian motion by discrete binomial tree. This is a reasonable treatment when Δt can be made close to zero in the calculation of option value. In the case of mechanical harvesting option, however, $\Delta t=1$ which is far from zero due to the once-a-year crop cycle and mechanization opportunity.

On the other hand, the LSMC (Longstaff and Schwartz 2001) does not depend on any specific stochastic process. The method differs fundamentally from the previous methods in that the continuation value of the option in any state is computed using the entire cross-sectional information[2] in each period (Tavella 2002, Brandimarte 2006). More specifically, it solves the dynamic optimization problem posed by the Bellman equation, where the value of continuation is computed on the basis of a regression on cross-sectional data which are the values of the stochastic variables in all nodes in each period. Also, the LSMC is known to be a biased low estimator when applied for a continuous time application, but there is no such problem when applied for a discrete time application like the current study.[3] Here we show the specific application of the LSMC for the case of valuing the option of mechanization investment by the Florida sugarcane farmer.

After harvesting in year $t \in [0,\mathrm{T}]$ a farmer has two options in the action set: a_t={0, 1} where 0 if he does not invest, 1 if he invests. The feasible control set is that the farmer can exercise the investment option one time in $t \in [0,\mathrm{T}]$. Given the action in this year, the cash flow function for the next year is given as,

$$f\left(t+1 \middle| a_t, \boldsymbol{X}_t\right) = \begin{cases} FCF_{t+1} & \text{if } a_t = 0, \\ NPV_{t+1}^{mech} - I_t & \text{if } a_t = 1, \end{cases}$$

$\boldsymbol{X}_t$ is the vector of stochastic factors in year *t*, and NPV_{t+1}^{mech} is the net present value of cash flow from year $t+1$ from the mechanized operation. After exercising the investment option, the cash flow becomes zero.[4] The farmer's objective function is given as

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[2] Tavella (2002) uses this term to define the whole information set of four processes generated in all nodes for each period. That is, "cross section" is not about agents, but over nodes and stochastic factors.

[3] See Proposition 1 in Longstaff and Schwartz (2001).

[4] Actually there is cash flow from mechanized operation, but they are included in PV_{t+1}^{mech}. This is made just for notation convenience, but the result is the same.

$$V^C(\boldsymbol{X}_0) = \tilde{E}\left[\sum_{t=0}^{T} \frac{f\left(t+1\middle|a_t, \boldsymbol{X}_t\right)}{(1+r_f)^{t+1}}\right],$$

where FCF_t^C is the FCF in year *t* given the actions up to year *t*, $\tilde{E}$ is the expectation operator with the risk neutral probability which is the martingale measure of the uncertain cash flow (Kijima 1994). The farmer chooses the control among the feasible control set $C_a(\boldsymbol{X}_0)$ to maximize the objective function so that,

$$V(\boldsymbol{X}_0) = \max_{C \in C_a(\boldsymbol{X}_0)} V^C(\boldsymbol{X}_0).$$

Note that the above $V(\boldsymbol{X}_0)$ is the net present value of the manual operation plus the option value of mechanization investment when the optimum control is taken. The value function $V_t(\boldsymbol{X}_t)$ can be expressed as the Bellman equations as

$$V_T(\boldsymbol{X}_T) = \max[\frac{NPV_{T+1}}{1+WACC}, \frac{NPV_{T+1}^{mech}}{1+WACC} - I_T], \tag{1}$$

$$V_t(\boldsymbol{X}_t) = \max\left[\tilde{E}\left[\frac{V_{t+1}(\boldsymbol{X}_{t+1})}{1+r_f}\middle|\boldsymbol{X}_t\right], \frac{NPV_{t+1}^{mech}}{1+WACC} - I_t\right], \tag{2}$$

where T is the year of expiration of the option, NPV_{T+1}^{mech}, NPV_{T+1} and NPV_{t+1}^{mech} include the perpetuity value. Also note that $\frac{NPV_{t+1}^{mech}}{1+WACC} - I_t$ is value of exercising the investment option, while $\tilde{E}\left[\frac{V_{t+1}(\boldsymbol{X}_{t+1})}{1+r_f}\middle|\boldsymbol{X}_t\right]$ is holding value of the current operation and the investment option (usually called the "continuation value") conditional on the current information. Solving the above equations iteratively backward results in $V_0(\boldsymbol{X}_0)$, which is the value function resulting from the optimum control. The unique aspect of the LSMC method is that the continuation value above is represented as a linear combination of a countable set of basis functions (Longstaff and Schwartz 2001) for which coefficients are estimated by least squares using generated sample paths. Then, they proved the LSMC estimator shown below converges in probability to the true value function as the number of sample paths goes to infinity, as long as the stochastic factors follow any Markov process.[5]

The set of generated paths is used to build an approximation of the conditional expectation of the continuation value for some choice of basis functions $\psi_k(\boldsymbol{X}_t)$. One simple choice is regressing the conditional expectation against a basis of polynomials. Following illustrations by Longstaff and Schwartz (2001) and Brandimarte (2006), we use the polynomials up to second order including cross products so that there are 15 basis functions:

$$\widetilde{E}\left[\frac{V_{t+1}(\boldsymbol{X}_{t+1})}{1+r_f}|\boldsymbol{X}_t\right] \approx \sum_{k=1}^{15} \alpha_{k,t}\psi_k(\boldsymbol{X}_t),$$

where $\psi_1(\boldsymbol{X}_t)=1, \psi_2(\boldsymbol{X}_t)=X_{1,t},\ldots,\psi_5(\boldsymbol{X}_t)=X_{4,t}$, $\psi_6(\boldsymbol{X}_t)=X_{1,t}^2,\ldots,\psi_9(\boldsymbol{X}_t)=X_{4,t}^2$, $\psi_{10}(\boldsymbol{X}_t)=X_{1,t}X_{2,t},\ldots,\psi_{15}(\boldsymbol{X}_t)=X_{3,t}X_{4,t}$. Note that the coefficient $\alpha_{k,t}$ varies over time which is estimated by least squares regression, going backward in time. In our specific application 100,000 sample paths are generated for nine-year path of stochastic factors (yield, price, labor cost and other cost), FCF and PV for which *i* (*i* = 1,2, …, 100,000) is used for the sample path index. At the year of expiration ($t = T = 9$), the value function of equation (1) is revised,

$$V_T(\boldsymbol{X}_{T,i}) = \max[\frac{NPV_{T+1}(\boldsymbol{X}_{T,i})}{1+WACC}, \frac{NPV_{T+1}^{mech}}{1+WACC} - I_T],$$

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[5] This assumption is satisfied for our application. See Iwai and Emerson (2008) for estimation results.

for sample path *i*. Further we revise the value function above by adding the FCF in that year which happens before the decision time:

$$V_T(\boldsymbol{X}_{T,i}) = \max[\frac{NPV_{T+1}(\boldsymbol{X}_{T,i})}{1+WACC}, \frac{NPV_{T+1}^{mech}}{1+WACC} - I_T] + FCF_{T,i}. \tag{3}$$

These values can be used as so called *Y*-values in a linear regression on $f_k(\boldsymbol{X}_{T-1,i})$, so that the following regression model is given at *T*-1:

$$\frac{V_T(\boldsymbol{X}_{T,i})}{1+r_f} = \sum_{k=1}^{15} \alpha_{k,T-1} f_k(\boldsymbol{X}_{T-1,i}) + e_{i,T-1},$$

where $e_{i,T-1}$ is the residual for sample path *i* at *T*-1. We can estimate $\alpha_{k,T-1}$ by simple least squares method which minimizes the sum of squared residuals. However, the efficiency gain is obtained by using the only paths which are "in the money" at *T*-1 (Longstaff and Schwartz 2001, Tavella 2002). In our case we impose the following "moneyness criterion": $P\mathrm{V}_{T-1}^{mech} - I_{T-1} > P\mathrm{V}_{T-1,i}$. Since the left hand side has to be larger than the right hand side by the margin of the option value for the exercising the investment option, paths that do not satisfy the above condition have no decision problem. Denoting this subset by I_{T-1}, coefficients are estimated from the following least squares problem:

$$\begin{aligned} &\min \sum_{i \in I_{T-1}} e_{i,T-1}^2 \\ &s.t.\ \frac{V_T(\boldsymbol{X}_{T,i})}{1+r_f} = \sum_{k=1}^{15} \alpha_{k,T-1} f_k(\boldsymbol{X}_{T-1,i}) + e_{i,T-1}, \quad i \in I_{T-1}. \end{aligned} \tag{4}$$

Using the estimated coefficients $\hat{\alpha}_{k,T-1}$ the value function for path *i* at *T*-1 is given as:

$$V_{T-1}(\boldsymbol{X}_{T-1,i}) = \max[\sum_{k=1}^{15} \hat{\alpha}_{k,T-1} f_k(\boldsymbol{X}_{T-1,i}), P\mathrm{V}_{T-1}^{mech} - I_{T-1}], \quad i = 1,2,...100,000.$$

where the first term in the square bracket is the continuation value, and the second is the exercising value. Again we revise the value function above by adding the FCF in the year which happens before the decision time:

$$V_{T-1}(\boldsymbol{X}_{T-1,i}) = \max[\sum_{k=1}^{15} \hat{\alpha}_{k,T-1} f_k\left(\boldsymbol{X}_{T-1,i}\right), PV_{T-1}^{mech} - I_{T-1}] + FCF_{T-1,i}, \qquad (5)$$

We continue these steps backward up to t=0. Further subtracting NPV from sample i for the year ($NPV_{0,i}$) yields the investment option value for sample i for the year ($OptValue_{0,i}$). Simply taking sample mean of the 100,000 option values yields the LSMC estimate for the value of investment option for the year.

Data

The most important source of data is cost for growing sugarcane from Walker (1972) and revenue and cost for harvesting sugarcane from Zepp and Clayton (1975). The second column of Table 1 shows activity-base cost for growing sugarcane for the model farm with 640 acres in total and 408 acres harvested in south Florida 1971-2 season, and the third column shows the forecasted value for each item provided by Walker (1972).

Table 1. Activity-base cost for growing sugarcane for the model farm with 640 acres in total and 408 acres harvested ($ per 408 acres harvested)

Season	1971-2	1972-3
Land preparation	6,131.35	6,437.92
Planting	13,816.94	14,507.79
Cultivate plant cane	4,970.96	5,219.51
Cultivate stubble cane	8,480.96	8,905.01
Overhead expense	14,351.94	15,069.54
Overhead taxes	7,648.00	8,030.40
Cost of land	53,760.00	56,448.00
Total	109,160.15	114,618.16

Source: Walker (1972).

We convert the above table to cost-item base. The result is shown as Table 2.

Table 2. Cost for growing sugarcane for a model farm with 640 acres in total and 408 acres harvested ($ per 408 acres harvested)

Season	1971-2	1972-3
Labor	11,352.66	11,920.29
Depreciation	7,044.24	7,396.45
Interest	4,514.51	4,740.24
Other costs	86,248.74	90,561.18
Total	109,160.15	114,618.16

Source: Authors calculated from Walker (1972).

The second column of Table 3 shows cost and revenue for harvesting sugarcane for a model farm with hand cut harvesting in south Florida 1971, and the third column shows those for mechanical harvesting farm.

Table 3. Revenue and cost for harvesting sugarcane for a model farm ($ per gross ton).

	Hand cut harvesting	Mechanical harvesting
Season	1972-3	1972-3
Initial investment[6]	**2.18**	**3.75**
Annual machinery cost		
Depreciation	0.21	0.36
Repair and maintenance	0.23	0.59
Taxes, licenses and insurance	0.04	0.02
Fuel, oil and grease	0.06	0.19
Interest	0.10	0.16
Total machinery cost	**0.64**	**1.34**
Labor cost		
Cane cutter	2.41	0.00
Cutter or loader operator	0.02	0.38
Tractor driver	0.15	0.54
Dump operator	0.04	0.02
Ticket writer	0.02	0.01
Supervisor	0.07	0.12
Maintenance and repair	0.07	0.26
Scrapper	0.04	0.03
Utility man	0.02	0.00
Other	0.00	0.03
Total labor costs	**2.85**	**1.39**
Total annual cost	**3.49**	**2.73**
Revenue[7]		
Sugarcane	10.88	10.46
Sugar payment	0.92	0.89
Molasses payment	0.36	0.36
Total revenue	**12.16**	**11.70**

Source: Zepp and Clayton (1975).

Next, we convert cost and revenue items in Table 3 into per net ton basis using net cane factor of 0.947 for hand cut harvesting and 0.893 for mechanical harvesting.[8] Further we convert them into model farm bases with 640 acres in total and 408 acres

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[6] Initial investment cost happens only for season when it is made, although depreciation and interest payment happens annually.

[7] Revenue items are recorded in per net ton basis. We converted them into per gross ton basis using net cane factor of 0.947 for hand cut harvesting and 0.893 for mechanical harvesting, both of which are presented by Zepp and Clayton (1975).

[8] See Appendix B in Zepp and Clayton (1975) for the definition and calculation method for the net cane factor.

harvested after converting to per harvested acre basis by using net tons per acre of 38.35 for hand cut harvesting and 37.02 for mechanical harvesting.[9] In Table 4 we show revenue and cost for growing and harvesting sugarcane for 72-5 seasons assuming that only labor and other harvesting cost for mechanical operation change as suggested by Zepp and Clayton (1975).[10]

Table 4. Revenue and cost for growing and harvesting sugarcane for a model farm ($ per 408 acres harvested)

	Hand cut harvesting	Mechanical harvesting	Mechanical harvesting	Mechanical harvesting
Season	72-5	72-3	73-4	74-5
Revenue				
Sugarcane	190,597.20	176,896.56	176,896.56	176,896.56
Sugar payment	16,169.04	15,026.64	15,026.64	15,026.64
Molasses payment	6,238.32	6,022.08	6,022.08	6,022.08
Total revenue	**213,004.56**	**197,945.28**	**197,945.28**	**197,945.28**
Cost				
Growing				
Labor	11,920.29	11,920.29	11,920.29	11,920.29
Depreciation	7,396.45	7,396.45	7,396.45	7,396.45
Interest expenses	4,740.24	4,740.24	4,740.24	4,740.24
Other costs	90,561.18	90,561.18	90,561.18	90,561.18
Total	114,618.16	114,618.16	114,618.16	114,618.16
Harvesting				
Labor	47,095.44	23,863.92	17,767.27	11,670.63
Depreciation[11]	3,459.15	6,172.75	6,172.75	6,172.75
Interest expenses	1,588.31	2,788.27	2,788.27	2,788.27
Other costs	5,434.06	13,695.23	12,107.01	10,518.79
Total	57,576.96	46,520.16	38,835.29	31,150.43
Total cost	**172,195.12**	**161,138.32**	**153,453.45**	**145,768.58**
Return	**40,809.44**	**36,806.96**	**44,491.83**	**52,176.70**

Source: Authors calculated from Zepp and Clayton (1975).

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[9] We directly used per harvested acre basis for variables for which per harvested acre value is available instead of converting from per gross ton basis.

[10] We use market data for all other items for 73-5 and all items including labor and other harvesting cost for further forecast, which is explained in the next section. See Iwai and Emerson (2008) for detail.

[11] Both Zepp and Clayton (1975) and Walker (1972) assume that depreciation and interest expenses are based on the initial investment value. Here we assume that the farmer is currently using hand cut harvesting so that depreciation and interest expenses are fixed on the current level for the hand cut harvesting, and they are fixed on the level of 72-3 season for the mechanical harvesting since we analyze the decision in that season.

Since Zepp and Clayton (1975) provide forecast of only labor and other cost for mechanical harvesting up to 1974-5 season, we need to use other sources for all other items in that period, and for all items after 1974-5 season. We use market data for time series of sugarcane yield, price, labor cost and other costs. We use the sugarcane yield and price data from the Florida *Field Crops Summary* (Florida Agricultural Statistics). The labor cost data are from unpublished U.S. Department of Labor administrative records; the other cost data is similarly from unpublished U.S. Department of Agriculture administrative records. We use the time series of sugarcane yield and price as long as possible but still in the relevant period: 1960-95. On the other hand, the time series of labor cost and other costs have many missing periods so that we use the following more restricted period to estimate the stochastic process: 1960-81.

Traditional NPV approach

In this section the mechanization decision by Florida sugarcane farmers is analyzed using NPV approach, which is the single, most widely used tool for large investments made by U.S. corporations (Copeland and Antikarov 2003). The NPV approach simply assumes that the farmer would invest in mechanization if the discounted future free cash flow (FCF) forecasted for the mechanical-harvesting-operation less the investment cost is greater than that from the hand-cut-operation. Therefore, the first step of the approach is to estimate FCF for 1972-3 season for each operational mode using estimates from Zepp and Clayton (1975) and Walker (1972). Then, we model and estimate the stochastic process of sugarcane yield, price, labor cost and other costs and run the Monte Carlo simulation to forecast FCF for the seasons after 1972-3. The forecasted FCF from each operation (the entity value) should be discounted at the opportunity cost of capital that is consistent with riskiness of these cash flows. We compute this discount rate which is called “Weighted Average Cost of Capital (WACC)”. The straightforward calculation of discounted free cash flow for each operational mode follows the above steps.

Instead of showing the detailed procedures of the NPV approach, we refer the reader to the existing study (Iwai and Emerson 2008) which takes exactly the same procedures as ours. The only difference is that, while the previous study generates one set of 100,000 sample paths and calculates the sample means of interest variables from the set, we generate 100 sets of 100,000 sample paths. Then we calculate sample means and standard deviations of 100 sets of interest variables which were calculated from each set of 100,000 sample paths. This way we can calculate the standard deviations and confidence intervals of estimates (Brandimarte 2006). The following table shows the sample means and standard deviations (inside parentheses) for the forecasted FCF for each operational mode.

Table 5. Forecasted FCF from growing and harvesting sugarcane after 72-3 season ($)

	73-4	74-5	75-6	76-7	77-8
Hand cut	32,976.88 (61.76)	33,036.51 (96.43)	26,054.16 (113.58)	20,464.95 (119.42)	21,082.32 (129.87)
Mechanical	36,592.87 (55.00)	43,121.23 (87.72)	37,636.11 (101.12)	33,511.37 (105.65)	35,228.68 (116.79)

	78-9	79-80	80-1	81-2
Hand cut	17,389.07 (154.91)	9,837.14 (162.10)	4,833.33 (182.87)	-55.98 (219.82)
Mechanical	33,012.68 (134.82)	27,289.29 (140.73)	24,023.59 (160.78)	20,952.24 (189.70)

Note that standard deviation of the FCF samples from hand cut operation is greater than that from mechanical operation for all years. We can see the same result for NPV for

72-3 season in Table 7. Before that we summarize the sample mean of PV and NPV for 10 seasons for each operational mode.

Table 6. PV and NPV from growing and harvesting sugarcane with each mode of operation ($)

Season	72-3	73-4	74-5	75-6	76-7
PV from hand cut	142,095.34	123,654.81	103,268.19	87,778.37	76,293.15
NPV from hand cut	175,563.31	156,631.69	136,304.70	113,832.53	96,758.10
FCF as % of NPV	19.06%	21.05%	24.24%	22.89%	21.15%
PV from mechanical	291,283.54	284,488.97	270,470.96	260,504.03	253,642.23
NPV from mechanical harvesting	322,761.72	321,081.85	313,592.20	298,140.14	287,153.60
FCF as % of NPV	9.75%	11.40%	13.75%	12.62%	11.67%
Season	77-8	78-9	79-80	80-1	81-2
PV from hand cut	63,015.62	52,073.05	47,562.97	47,595.33	52,520.31
NPV from hand cut	84,097.94	69,462.12	57,400.12	52,428.67	52,464.33
FCF as % of NPV	25.07%	25.03%	17.14%	9.22%	-0.11%
PV from mechanical	244,361.15	236,346.61	233,235.58	233,071.99	235,963.02
NPV from mechanical	279,589.83	269,359.29	260,524.86	257,095.58	256,915.25
FCF as % of NPV	12.60%	12.26%	10.47%	9.34%	8.16%

In Table 7 we pick up the sample means (standard deviations inside parentheses) for the NPV, and initial investment cost in 72-3 season to show the decision of the model farmer as to mechanizing harvesting at that time using the traditional NPV approach.

Table 7. NPV and initial investment cost for each operation for 1972-3 season ($)

	NPV	Initial investment cost	NPV – inv. cost
Hand cut harvesting	175,563.31 (8,863.06)		175,974.05
Mechanical harvesting	322,761.72 (1,550.89)	63,431.21	259,330.51

Since NPV less initial investment cost of mechanization is more than NPV for operation with hand cut harvesting, the traditional NPV approach suggests that the model farmer should have switched to mechanized operation even in 72-3 season. We can see this from the data: negative growth rate of FCF (-21.49 %) and relatively high FCF/PV ratio (over 19%), that is, growing and harvesting with hand cut operation generates relatively high FCF, but its expected growth is negative in the future. In comparison the FCF of mechanized operation has relatively higher growth rate (-4.42%) and lower FCF/PV ratio (less than 10%). But, remember that only 15% of sugarcane was mechanically harvested at that time (much of which was experimental) and most farmers delayed mechanization until mid- and late 1980s (Figure 1). The traditional NPV approach cannot explain why Florida sugarcane farmers had not made the investment for mechanization in the early 1970s.

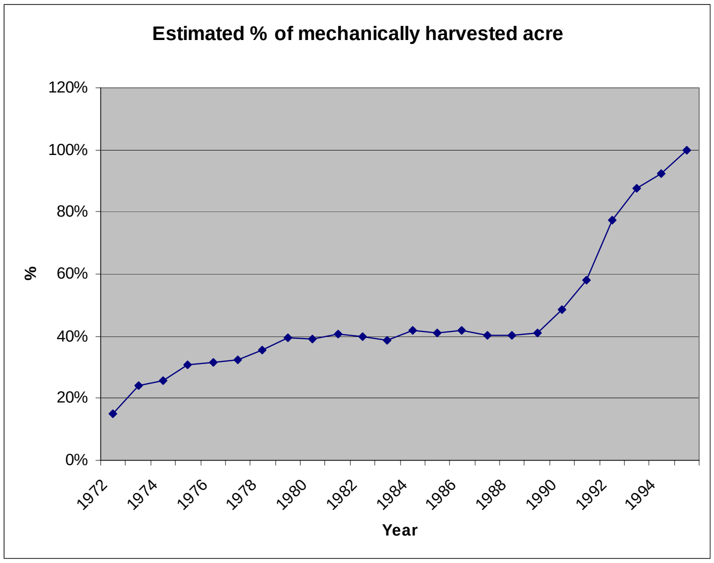

Figure 1. Estimated % of mechanically harvested acre (source: Iwai and Emerson 2008)

Another thing to note is much higher volatility of FCF and NPV of the sugarcane farming with hand cut harvesting compared to that with mechanical harvesting. From Table 7, 95% confidence interval for the NPV is [158,191.72, 192,934.90] for hand cut harvesting and [319,721.99, 325,801.46] for mechanical harvesting.[12] This is already noticed in the previous study of the consolidated approach (Iwai and Emerson 2008). It finds that the volatility of annual rate of return from the sugarcane farming with hand cut harvesting is 1.77 which is much higher than that from the mechanical harvesting (1.09). We could say this is the typical situation of the abandonment option in which an agent has an option to abandon a highly risky project and switch to the alternative which has more stable NPV. However, higher volatility of the current project generally results in a high value of keeping the option alive which gives the agent an incentive to further delay the investment, since the volatility raises the value of waiting to see what is going to happen in the future (Dixit and Pindyck 1994). Then the ROA analysis using the LSMC may overturn the conclusion of the NPV analysis that the model Florida sugarcane farmers should have switched to mechanical harvesting even in 72-3 season.

ROA with Least Squares Monte Carlo

In this section we analyze the mechanization decision by Florida sugarcane farmers by using the ROA with least squares Monte Carlo (LSMC) method. We have already introduced the formula and procedures of the LSMC method. More specifically we solve equations (3), (4) and (5) backward, from season 81-2 to season 72-3. Taking these steps up to 72-3 season yields 100,000 samples of value function $V_{72}(\boldsymbol{X}_{72,i}), \mathrm{i} = 1,2,...,100{,}000$ which is the NPV plus value of investment option for the season. Further subtracting NPV from sample *i* for the season ($NPV_{72,i}$) yields the

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[12] A sample mean $\overline{X}$ from a sufficiently large sample set is approximately normally distributed with mean *X* and variance var($\overline{X}$) from the central limit theorem; and var($\overline{X}$) = var(*X*)/*n* where *n* is number of random samples (Brandimarte 2006).

investment option value for sample i for the season ($OptValue_{72,i}$). Simply taking sample mean of the 100,000 option values yields the LSMC estimate of value of investment option for the season. Our LSMC estimate of the option value is \$136,398.63 with standard deviation of \$9,956.76. We summarize this result with the NPV result as Table 8.

Table 8. NPV, initial investment cost and option value for 1972-3 season (\$)

	NPV	Initial investment cost	Option value	NPV -Inv cost -Option value
Hand cut harvesting	175,563.31 (8,863.06)			175,563.31
Mechanical harvesting	322,761.72 (1,550.89)	63,431.21	136,398.63 (9,956.76)	122,931.88

The decision rule of investment for the farmer from the ROA is "invest if NPV of mechanized operation less investment cost and option value is greater than NPV of the current operation". The calculation is given as: $NPV_{1972}^{mech} - InvCost_{1972} - OptValue_{1972} =$ \$322,762 - \$63,431 - \$136,399 = \$122,932 < \$175,563 $= NPV_{1972}$, which suggests that the farmer should not invest in the mechanization in 1972-3 season. This is qualitatively the same result as the previous study by Iwai and Emerson (2008). However, there is a rather large margin between our LSMC estimate and their estimate from the consolidated approach. The following table shows 95% confidence interval of the option value from the current study as well as the point estimate from their study.

Table 9. Comparison of option value estimates ($)

	Lower bound of 95% confidence interval	Sample Mean	Upper bound of 95% confidence interval
LSMC	116,883.38	136,398.63	155,913.87
Consolidated Approach		176,165.58	

As you can see the estimate from the consolidated approach is out of 95% confidence interval from the LSMC estimate. As presented in the Methodology section there are at least two sources of bias in estimator from the consolidated approach applied for the sugarcane mechanization case. Further research searching for a more appropriate consolidated approach which corrects the sources of bias is necessary for the full comparison with the LSMC estimator. The important point, however, is that the conclusion from the ROA is robust for sugarcane mechanization in Florida regardless of the estimation method of the option value.

Finally, in Table 10, we show the threshold value of labor cost which could have initiated the mechanization in 72-3 season, assuming that the labor cost increased at the same rate for both operational modes. We also show the 95% confidence interval of the labor cost.

Table 10. Threshold value for the labor cost ($)

	Lower bound of 95% confidence interval	Sample Mean	Upper bound of 95% confidence interval
Hand cut harvesting	93,152.95	93,519.05 (58.46% increase)	93,885.16
Mechanical harvesting	56,483.32	56,705.31 (58.46% increase)	56,927.30

This threshold level analysis indicates that the labor cost should have increased more than 58% from the actual level for the immediate mechanization in 72-3 season. That is, there was a rather large margin between the actual and the threshold level of labor cost. The threshold level of labor cost estimated from the consolidated approach was 52.76% labor cost increase. Given the fact that the labor cost increased more than 100% between early 70s and mid 80s, our estimate of threshold value is more reasonable, although still a conservative level.

Concluding remarks

Previous studies of Florida sugarcane production, which compared the cost and returns from mechanically harvested operations with those of hand cutting operations (Zepp and Clayton 1975, Zepp 1975, Walker 1972), found the cost advantage of the former as early as 1972-3 season. Using the data provided by these authors, Iwai and Emerson (2008) analyzed the dynamic decision making process of farmers with the two methodologies: net present value (NPV) approach and real options approach (ROA). Their NPV approach supported the views of previous research that the model sugarcane farmer should have switched to mechanized operation even in 72-3 season. Their conclusion from the ROA, however, is exactly opposite to that from the NPV approach. The mechanical operation NPV less investment cost and option value is lower than NPV for the manual operation, so that the sugarcane farmer should not have switched to the mechanical operation, which better explains the historical fact that only 15% of sugarcane was harvested by machine for 72-3 season.

However, the methodology used by Iwai and Emerson (2008) known as the consolidated approach is based on the assumption that the rate of return from the project follows a random walk, an assumption which was not empirically tested for the sugarcane farming case. In addition, the methodology approximates the stochastic process of PV that follows a continuous geometric Brownian motion by a discrete binomial tree; this is not a reasonable treatment for the case of sugarcane farming since $\Delta t=1$ due to the once-a-year crop cycle and mechanization opportunity. Considering these sources of bias in the estimator, the current study uses an alternative ROA technique called least squares Monte Carlo (LSMC) method which does not depend on any specific stochastic process.

Our conclusion from the LSMC method is qualitatively the same as the previous study that the model Florida sugarcane farmer should not have switched to a mechanical operation in the 72-3 season. However, our option value estimate ($136,399) is much lower than in the previous study ($176,166). The threshold level analysis indicates that the labor cost would have had to increase by 58.46% from the actual level for immediate mechanization in the 72-3 season. Given the fact that the labor cost increased more than 100% between early 70s and mid 80s, our estimate of threshold value is more reasonable than that from the previous study (52.76%), although is still at a conservative level.

Further research into a more appropriate consolidated approach which corrects the sources of bias is necessary for a full comparison with the LSMC estimator. The important point, however, is that the conclusion from the ROA is robust for the sugarcane mechanization in Florida regardless of the estimation method of the option value, suggesting a more satisfactory explanation for the mechanization decision over the NPV approach.

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