LABOR SUBSTITUTABILITY IN LABOR INTENSIVE AGRICULTURE AND TECHNOLOGICAL CHANGE IN THE PRESENCE OF FOREIGN LABOR

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Abstract

The Morishima elasticity of substitution (MES) is estimated to address factor substitutability in Florida agriculture during 1960-1999. By adopting a profit maximization model of induced innovation theory, the MES's between hired and self-employed labor and the MES's between labor and capital provide implications for future immigration policies.

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Labor Substitutability in Labor Intensive Agriculture and Technological Change in the Presence of Foreign Labor

Introduction

The link between foreign labor availability and the rate of development and innovation of farm mechanization in U.S. agriculture is examined in this paper. According to the induced innovation theory, an increasing price of labor (due to a more stringent immigration policy) would induce the development of labor-saving technology. In the study of technological change based on induced innovation theory, it is commonly assumed that labor and capital are substitutes for a given technology set. Thus, when labor becomes more expensive, it should induce the development of technology that uses less labor relative to capital. In order to draw implications from the study of technological change (e.g., immigration policy implications), it is important to understand the substitutability among inputs. For example, if labor and capital are easily substitutable, only a small increase in wage rate (reduction of foreign workers availability) could increase the adoption of mechanized technology. Recognizing the importance of the substitution relationship among inputs, particularly labor and capital, instead of assuming the substitutability among them, this study attempts to measure the ease of substitutability using the Morishima elasticity of substitution.

The extensive studies of technological change in U.S. agriculture (e.g., Binswanger 1974) have primarily used the Allen-Uzawa elasticity of substitution (AES) as a measure of substitutability of inputs. The original concept of elasticity of substitution was introduced by Hicks (1932) to measure the effect of changes in the capital/labor ratio on the relative shares of labor and capital or the measurement of the curvature of the isoquant. However, as shown by Blackorby and Russell (1989), when there are more than two factors of production the AES is *not* the measure of the ease of substitution or curvature of the isoquant, provides no information about relative factor shares, and cannot be interpreted as a derivative of a quantity ratio with respect to the price ratio. In contrast, the Morishima elasticity of substitution (MES) does preserve the original Hicks concept. It measures the curvature, determines the effects of changes in price or quantity ratios on relative factor shares, and is the log derivative of a quantity ratio with respect to a marginal rate of substitution.

The MES is a two-factor, one-price elasticity of substitution. It can be interpreted as a cross-price elasticity of relative (Hicksian) demand because it measures the relative adjustment of factor quantities when a single factor price changes (Fernandez-Cornejo 1992). The original concept of MES defined by Morishima was in the cost minimization context (Blackorby and Russell 1981). We adopt the Sharma (2002) extension of the MES to the variable profit function. This is particularly advantageous since the MES among inputs may be calculated while holding output constant. The variable profit function is adopted in recognition of the simultaneous determination of output mix and variable inputs for given prices. An increasing importance of changes in trade policy, trade agreement, and biotechnology results in a greater influence of input prices on the choice of commodity mix. For instance, the production of a new genetically modified crop variety may require different input requirements than the production of the old variety. The choice of production commodity mix is a part of the production decision, and should also be influenced by input prices.

We are interested in the impact of changes in input and output prices on biased technological progress in Florida agriculture. We draw from the induced innovation theory literature for the analysis of technological change. To the extent that immigration policy affects wage rates, changes in immigration policy can clearly have an influence on the rate and form of technological progress. Estimates of the MES between labor and other inputs over the 1960 to 1999 period are used to evaluate the extent to which substitutability has changed since the passage of the Immigration Reform and Control Act (IRCA) in 1986, and the resulting implications for the demand for labor. Changes in input and output mix caused by changes in input prices reflect movements along the isoquant. The MES is the appropriate concept to properly analyze these effects. When changes in input prices induce further input substitution through biased technological progress, the MES addresses the extent to which changes in input prices creating substitution among inputs (and outputs) also influence the direction of technological change.

There are two major objectives of this study. The first is to evaluate the bias of technological change in Florida between 1960 and 1999, and compare the rates of change before and after the passage of IRCA. Agricultural production in Florida remains highly labor-intensive, and the majority of farm workers in Florida are also foreign workers. The number of foreign workers in Florida is higher than in most other states. They account for 75% of hired workers (Emerson and Roka 2002) while 42% of U.S. farm workers are foreign (those who have their home outside the U.S.) (Mehta, Gabbard, Barrat, Lewis, Carroll, and Mines 2003). Moreover, about 52% of hired farm workers in the U.S. are unauthorized (Mehta, Gabbard, Barrat, Lewis, Carroll, and Mines 2003).

The study of technological change in a labor intensive area will provide key implications in evaluating the impact of immigration policy on the development of farm mechanization.

The second objective is to analyze the ease of substitutability between labor and other inputs, particularly capital. A limited availability of foreign workers in labor intensive production would induce the development of new mechanized technology such as the success of tomato mechanical harvester in California at the end of the Bracero program in 1964. Thus, labor and capital are generally substitutes. However, it is important to properly measure the ease of substitutability and understand the mechanism of the substitution between capital and labor to provide future immigration and farm policy associated with technological change.

Methodology

A translog profit function of the induced innovation model is adopted. The time variable is included to represent the state of technology at a particular time, and allows a point estimation of the biases and elasticities over the study period. In order for the model to be consistent with economic theory, the symmetry, homogeneity, and curvature restrictions are imposed. The Wiley-Schmidt-Bramble reparameterization technique is used to locally impose the curvature restrictions. Parameter estimates of the translog profit function are used to calculate the Morishima elasticity of substitution.

Model

Assume that outputs $Y = (Y_1, ..., Y_N)$ use variable inputs $X = (X_1, ..., X_M)$ and fixed inputs $K = (K_1, ..., K_L)$. The vectors of output prices, input prices and fixed input prices are denoted by $P = (P_1, ..., P_N)$, $W = (W_1, ..., W_M)$, and $R = (R_1, \ldots, R_L)$, respectively. Let

$Q = (Q_1,\ldots,Q_{N+M})$ be a vector of variable input and output quantities, and $Z = (Z_1,\ldots, Z_{N+M})$ be a corresponding price vector.

The profit function is defined as: $\pi(Z,K,t) = \max_Q\{Z'Q \mid K,t\}$ for $Z > 0$ and $K \geq 0$, and the translog variable profit function can be written as

$$\begin{aligned}\ln\pi = \alpha_0 &+ \sum_{i=1}^{N+M}\alpha_i \ln Z_i + \sum_{j=1}^{L}\beta_j \ln K_j + \frac{1}{2}\sum_{i=1}^{N+M}\sum_{h=1}^{N+M}\gamma_{ih}\ln Z_i \ln Z_h \\ &+ \frac{1}{2}\sum_{j=1}^{L}\sum_{k=1}^{L}\phi_{jk}\ln K_j \ln K_k + \sum_{i=1}^{N+M}\sum_{j=1}^{L}\delta_{ij}\ln Z_i \ln K_j \\ &+ \sum_{i=1}^{N+M}\delta_{it}\ln Z_i t + \sum_{j=1}^{L}\phi_{jt}\ln K_j t + \beta_t t + \frac{1}{2}\phi_{tt}t^2\end{aligned} \tag{1}$$

where t represents technological knowledge. Utilizing Hotelling's Lemma, profit share equations can be derived from the derivatives of the log of profit with respect to the log of prices.

$$\frac{\partial \ln\pi}{\partial \ln Z_i} = \frac{Q_i Z_i}{\pi} = \pi_i \qquad i = 1,\ldots,N+M \tag{2}$$

where $\pi_i > 0$ if Z_i is an output price, and $\pi_i < 0$ if Z_i is a variable input price.

The marginal revenue of a fixed input is equal to its cost under competitive conditions. Thus, the derivative of the variable profit function with respect to a fixed input quantity is equal to its cost, $\partial\pi/\partial K_j = R_j \geq 0$, and the derivatives of the logs yield profit share equations.

$$\frac{\partial \ln\pi}{\partial \ln K_j} = \frac{R_j K_j}{\pi} = \pi_j \qquad j = 1,\ldots,L \tag{3}$$

In the case of the translog variable profit function, share equations are derived as follows:

$$\pi_i = \frac{\partial \ln\pi}{\partial \ln Z_i} = \alpha_i + \sum_{h=1}^{N+M}\gamma_{ih}\ln Z_h + \sum_{j=1}^{L}\delta_{ij}\ln K_j + \delta_{it}t \qquad i = 1,\ldots,N+M \tag{4}$$

$$\pi_j = \frac{\partial \ln\pi}{\partial \ln K_j} = \beta_j + \sum_{i=1}^{N+M}\delta_{ij}\ln Z_i + \sum_{k=1}^{L}\phi_{jk}\ln K_k + \phi_{jt}t \qquad j = 1,\ldots,L \tag{5}$$

A well-defined nonnegative variable profit function for positive prices and nonnegative fixed input quantities satisfies the following restrictions:

1. A variable profit function is linearly homogeneous in prices of outputs and variable inputs and in fixed input quantities. The homogeneity restrictions are

$$\sum_{i=1}^{N+M}\alpha_i = 1; \ \sum_{j=1}^{L}\beta_j = 1$$
$$\sum_{i=1}^{N+M}\gamma_{ih} = \sum_{h=1}^{N+M}\gamma_{ih} = \sum_{j=1}^{L}\phi_{jk} = \sum_{k=1}^{L}\phi_{jk} = \sum_{i=1}^{N+M}\delta_{ij} = \sum_{j=1}^{L}\delta_{ij} = 0 \qquad (6)$$
$$\sum_{i=1}^{N+M}\delta_{it} = \sum_{j=1}^{L}\phi_{jt} = 0$$

2. For a twice continuously differentiable profit function, Young's theorem implies that the Hessian of the profit function is symmetric. In terms of the translog profit function,

$$\gamma_{ih} = \gamma_{hi}\,;\phi_{jk} = \phi_{kj} \ . \qquad (7)$$

3. The convexity of a variable profit function in prices implies that the output supply and variable input demand functions are non-decreasing with respect to their own price. If i is a variable input ($X_i \le 0$), an increase in its price reduces the quantity demanded, $\partial X_i/\partial W_i \ge 0$. In other words, an increase in variable input price decreases its demand in absolute value. The concavity of a variable profit function in fixed inputs implies that the inverse demand equations are non-increasing with respect to their own quantities, $\partial R_i/\partial K_i \le 0$. The necessary and sufficient conditions for a convex (concave) profit function are that the Hessian of the profit function evaluated at output and variable input prices (fixed input quantities) is positive (negative) semidefinite or all principal minors are non-negative (non-positive).

Lau (1978) introduced the concept of the Cholesky decomposition as an alternative to characterize the definiteness of the Hessian matrix. Every positive (negative) semidefinite matrix **A** has a Cholesky factorization

$$A = LDL' \qquad (8)$$

where L is a unit lower triangular matrix, and D is a diagonal matrix. L is defined as a unit lower triangular matrix if $L_{ii} = 1, \forall i$ and $L_{ij} = 0, j > i, \forall i,j$. D is defined as a diagonal matrix if $D_{ij} = 0, \forall i, j, i \neq j$. The diagonal elements, D_{ii}, of D are called Cholesky values. A real symmetric matrix **A** is positive (negative) semidefinite if and only if its Cholesky values are non-negative (non-positive). A variable profit function is convex in variable input and output prices. Thus, all Cholesky values (δs) must be non-negative for the Hessian of the variable profit function with respect to prices to be positive semidefinite. Similarly, if the **A** matrix is the Hessian of a variable profit function with respect to fixed input quantities, all Cholesky values must be non-positive. We check the curvature properties by checking the sign of the Cholesky values.

Wiley, Schmidt, and Bramble (1973) also proposed a necessary and sufficient condition for a matrix **A** to be positive (negative) semidefinite if it can be written as:

$$A = (-)TT' \qquad (9)$$

where T is a lower triangular matrix and $T_{ij} = 0, j > i, \forall\, i,j$. For a translog variable profit function, the Hessian matrix of the profit function with respect to output and variable input prices, A_{II}, is positive semidefinite. The restrictions for convexity are

$$A_{II} = \begin{bmatrix} \gamma_{11} + \alpha_1^{\;2} - \alpha_1 & \gamma_{12} + \alpha_1\alpha_2 & \ldots & \gamma_{1N+M} + \alpha_1\alpha_{N+M} \\ \gamma_{12} + \alpha_1\alpha_2 & \gamma_{22} + \alpha_2^{\;2} - \alpha_2 & \ldots & \gamma_{2,N+M} + \alpha_2\alpha_{N+M} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{N+M,1} + \alpha_{N+M}\alpha_1 & \gamma_{N+M,2} + \alpha_{N+M}\alpha_2 & \ldots & \gamma_{N+M,N+M} + \alpha_{N+M}^{\;\;2} - \alpha_{N+M} \end{bmatrix}$$

$$= \begin{bmatrix} \tau_{11}^{\;2} & \tau_{11}\tau_{12} & \cdots & \tau_{11}\tau_{1,N+M} \\ \tau_{11}\tau_{12} & \tau_{12}^{\;2}\tau_{22}^{\;2} & \cdots & \tau_{12}\tau_{1N+M} + \tau_{22}\tau_{2N+M} \\ \vdots & \vdots & \ddots & \vdots \\ \tau_{11}\tau_{1,N+M} & \tau_{12}\tau_{1N+M} + \tau_{22}\tau_{2N+M} & \cdots & \tau_{1N+M}^{\;\;2} + \ldots + \tau_{N+M,N+M}^{\;\;2} \end{bmatrix} \tag{10}$$

The Hessian matrix of the profit function with respect to fixed input quantities, A_{JJ}, is negative semidefinite. The concavity restrictions are

$$A_{JJ} = \begin{bmatrix} \phi_{11} + \beta_1^{\;2} - \beta_1 & \phi_{12} + \beta_1\beta_2 & \ldots & \phi_{1L} + \beta_1\beta_L \\ \phi_{12} + \beta_1\beta_2 & \phi_{22} + \beta_2^{\;2} - \beta_2 & \ldots & \phi_{2,L} + \beta_2\beta_L \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{L,1} + \beta_L\beta_1 & \phi_{L,2} + \beta_{N+M}\beta_2 & \ldots & \beta_{L,L} + \beta_L^{\;2} - \beta_L \end{bmatrix}$$

$$= -\begin{bmatrix} \tau_{11}*^2 & \tau_{11}*\tau_{12}* & \cdots & \tau_{11}*\tau_{1,L}* \\ \tau_{11}*\tau_{12}* & \tau_{12}*^2\,\tau_{22}*^2 & \cdots & \tau_{12}*\tau_{1L}*+\tau_{22}*\tau_{2L}* \\ \vdots & \vdots & \ddots & \vdots \\ \tau_{11}*\tau_{1,L}* & \tau_{12}*\tau_{1L}*+\tau_{22}*\tau_{2L}* & \cdots & \tau_{1L}*^2 + \ldots + \tau_{L,L}*^2 \end{bmatrix} \tag{11}$$

When the curvature property is violated, the Wiley-Schmidt-Bramble reparameterization is used to impose the curvature restrictions.

<u>Elasticity</u>

The price elasticities of variable inputs and outputs are

$$\varepsilon_{ii} = \frac{d\ln Q_i}{d\ln Z_i} = \frac{\gamma_{ii}}{\pi_i} - 1 + \pi_i \qquad i = 1, \ldots, N+M \tag{12}$$

$$\varepsilon_{ij} = \frac{d\ln Q_i}{d\ln Z_J} = \frac{\gamma_{ij}}{\pi_i} + \pi_j \qquad \forall\, i, j; i \neq j \tag{13}$$

Inputs i and j are gross substitutes if $\varepsilon_{ij} > 0$, and gross complements if $\varepsilon_{ij} < 0$; the signs are reversed for outputs which are gross substitutes if $\varepsilon_{ij} < 0$, and gross complements if $\varepsilon_{ij} > 0$.

The Morishima elasticity of substitution originally defined by Morishima (Blackorby and Russell 1981) in the cost minimization is defined as

$$\mathrm{MES}_{ij} = \frac{\partial \ln(X^*_i / X^*_j)}{\partial \ln(P_j / P_i)} \tag{14}$$

where X^*_i's are the optimal cost minimizing inputs, and P_j's are the input prices. Applying Shephard's Lemma and homogeneity of the cost function, and assuming that the percentage change in the price ratio is only induced by P_j,

$$\mathrm{MES}_{ij} = \frac{P_j C_{ij}(Y,P)}{C_i(Y,P)} - \frac{P_j C_{jj}(Y,P)}{C_j(Y,P)} \tag{15}$$

$$\mathrm{MES}_{ij} = \varepsilon_{ij}^{\ c} - \varepsilon_{jj}^{\ c} \tag{16}$$

where $\varepsilon_{ij}^{c}(Y,P)$ is the constant-output cross-price elasticity of input demand. Inputs i and j are Morishima substitutes if $\mathrm{MES}_{ij} > 0$; that is if and only if an increase in P_j results in an increase in the input ratio X^*_i/X^*_j, and Morishima complements if $\mathrm{MES}_{ij} < 0$. Sharma (2002) applied the concept of the MES to the profit maximization approach as summarized in the following paragraph.

Assume that $Y_i = f_i(P, K, W)$, $R_k = h_k(P, K, W)$, and $X_j = g_j(P, K, W)$,

$$dY = \frac{\partial Y}{\partial P} dP + \frac{\partial Y}{\partial K} dK + \frac{\partial Y}{\partial W} dW \tag{17}$$

$$\frac{dY}{Y} = \frac{\partial \ln Y}{\partial \ln P}\frac{dP}{P} + \frac{\partial \ln Y}{\partial \ln K}\frac{dK}{K} + \frac{\partial \ln Y}{\partial \ln W}\frac{dW}{W} \tag{18}$$

$$d\widetilde{Y} = \frac{\partial \ln Y}{\partial \ln P} d\widetilde{P} + \frac{\partial \ln Y}{\partial \ln K} d\widetilde{K} + \frac{\partial \ln Y}{\partial \ln W} d\widetilde{W} \tag{19}$$

where ~ is the relative change. Similarly,

$$d\widetilde{R} = \frac{\partial \ln R}{\partial \ln P} d\widetilde{P} + \frac{\partial \ln R}{\partial \ln K} d\widetilde{K} + \frac{\partial \ln R}{\partial \ln W} d\widetilde{W} \tag{20}$$

$$d\widetilde{X} = \frac{\partial \ln X}{\partial \ln P} d\widetilde{P} + \frac{\partial \ln X}{\partial \ln K} d\widetilde{K} + \frac{\partial \ln X}{\partial \ln W} d\widetilde{W} \tag{21}$$

Define Q* = (Y: R)′ and Z* = (P: K)′, then Eq. 19 to 21 can be written as:

$$\begin{bmatrix} \widetilde{Q}^* \\ \widetilde{X} \end{bmatrix} = \begin{bmatrix} E_{Q^*Z^*} & E_{Q^*W} \\ E_{XZ^*} & E_{XW} \end{bmatrix} \begin{bmatrix} \widetilde{Z}^* \\ \widetilde{W} \end{bmatrix} \tag{22}$$

$$\widetilde{Q}^* = E_{Q^*Z^*}\widetilde{Z}^* + E_{Q^*W}\widetilde{W} \tag{23}$$

$$\widetilde{X} = E_{XZ^*}\widetilde{Z}^* + E_{XW}\widetilde{W} \tag{24}$$

From Eq. 23, $\widetilde{Z}^* = E_{Q^*Z^*}{}^{-1}\widetilde{Q}^* - E_{Q^*Z^*}{}^{-1}E_{Q^*W}\widetilde{W}$. (25)

Substitute Eq. 25 into Eq. 24,

$$\widetilde{X} = E_{XZ^*}E_{Q^*Z^*}{}^{-1}\widetilde{Q}^* + (E_{XW} - E_{XZ^*}E_{Q^*Z^*}{}^{-1}E_{Q^*W})\widetilde{W}\,. \tag{26}$$

Equation 22 can be written as:

$$\begin{bmatrix} \widetilde{Z}^* \\ \widetilde{X} \end{bmatrix} = \begin{bmatrix} E_{Q^*Z^*}{}^{-1} & -E_{Q^*Z^*}{}^{-1}E_{Q^*W} \\ E_{XZ^*}E_{Q^*Z^*}{}^{-1} & E_{XW} - E_{XZ^*}E_{Q^*Z^*}{}^{-1}E_{Q^*W} \end{bmatrix} \begin{bmatrix} \widetilde{Q}^* \\ \widetilde{W} \end{bmatrix}. \tag{27}$$

Holding the output level constant,

$$\frac{\partial \widetilde{X}}{\partial \widetilde{W}} = E_{XW} - E_{XZ^*}E_{Q^*Z^*}{}^{-1}E_{Q^*W} \tag{28}$$

The MES can be calculated by the definition in Eq. 16 where ε_{ij}^{c} is the ij element in Eq. 27. Notice that the MES is not symmetric, and unlike the Allen elasticity of substitution, the sign of MES is not symmetric either (Chambers 1988, p.96-97). Thus, the classification of substitute and complement between two inputs depends critically on which price changes. A detailed derivation of elements of matrices in Eq. 27 can be found in Napasintuwong (2004, Appendix B).

Biased Technological Change

The definitions of the rate of technological change and biased technological change are adopted from Kohli (1991). Employing Euler's theorem, linear homogeneity of the variable profit function in Z and K implies that

$$\frac{\partial \pi}{\partial t} = \sum_i Z_i \frac{\partial^2 \pi}{\partial t \partial Z_i} = \sum_j K_j \frac{\partial^2 \pi}{\partial t \partial K_j}. \qquad (29)$$

The semielasticity of the supply of output and the demand for variable inputs with respect to the state of technology is defined as:

$$\varepsilon_{it} \equiv \frac{\partial \ln Q_i}{\partial t}, \qquad i = 1,\ldots, N+M \qquad (30)$$

and the semielasticity of the inverse fixed input demand with respect to the state of technology is defined as:

$$\varepsilon_{jt} \equiv \frac{\partial \ln R_j}{\partial t} \qquad j = 1,\ldots, L \qquad (31)$$

Dividing through by π, and using Hotelling's Lemma and the marginal revenue of fixed input condition, Eq. 29 can be written as:

$$\mu = \frac{\partial \ln \pi}{\partial t} = \sum_i \pi_i \varepsilon_{it} = \sum_j \pi_j \varepsilon_{jt}, \qquad (32)$$

where μ is the *rate of technological change*. A positive rate of technological change implies that there is technological progress. The *bias of technology* is defined as

$$B_i \equiv \varepsilon_{it} - \mu \qquad i = 1,\ldots, N+M \qquad (33)$$

$$B_j \equiv \varepsilon_{jt} - \mu \qquad j = 1,\ldots, L \qquad (34)$$

A technological change is output i-producing if B_i is positive, and it is output i-reducing if B_i is negative. Similarly, a technological change is variable input i-using if B_i is positive, and it is variable input i-saving if B_i is negative. A technological change is fixed input j-using if B_j is positive, and it is fixed input j-saving if B_j is negative.

Data

Data used in this study are provided by Eldon Ball, Economic Research Service (ERS), USDA. The construction of these data is similar to the published production account data available from ERS (Ball et al. 1997, 1999, 2001). The data include series of agricultural output and input price indices and their implicit quantities in Florida from 1960-1999. Price indices of these series are appropriate for this study since they are adjusted for quality change of each input category. It is important to use quality-adjusted data when analyzing induced technological change because using unadjusted quality indices will result in biased estimation of parameters in the induced innovation model.

Data used in the analysis are aggregated into two outputs—perishable crops and all other outputs; four variable inputs—hired labor, self-employed labor, chemicals, and materials; and two fixed inputs—land and capital. Perishable crops include vegetables, fruits and nuts, and nursery products. Other outputs consist of livestock, grains, forage, industrial crops, potatoes, household consumption crops, secondary products, and other crops. Hired labor includes direct-hired labor and contract labor. The wage of self-employed labor is imputed from the average wage of hired workers with the same demographics and occupational characteristics. Chemicals include fertilizers and pesticides. Materials include feed, seed, and livestock purchases. Capital includes autos, trucks, tractors, other machinery, buildings, and inventories.

Estimation

The translog profit function with linear homogeneity imposed and including an IRCA dummy variable is defined as

$$\begin{aligned}\ln\pi = {} & \alpha_0 + \sum_{i=1}^{5}\alpha_i \ln\frac{Z_i}{Z_{matl}} + \beta_1 \ln\frac{K_j}{K_{capital}} + \frac{1}{2}\sum_{i=1}^{5}\sum_{h=1}^{5}\gamma_{ih}\ln\frac{Z_i}{Z_{matl}}\ln\frac{Z_h}{Z_{matl}} \\ & + \frac{1}{2}\phi_{11}\left(\ln\frac{K_{land}}{K_{capital}}\right)^2 + \sum_{i=1}^{5}\delta_{i1}\ln\frac{Z_i}{Z_{matl}}\ln\frac{K_{land}}{K_{capital}} \\ & + \sum_{i=1}^{5}\delta_{it1}\ln\frac{Z_i}{Z_{matl}}t + \sum_{i=1}^{5}T_2\delta_{it2}\ln\frac{Z_i}{Z_{matl}}t + \phi_{1t1}\ln\frac{K_{land}}{K_{capital}}t + \phi_{1t2}T_2\ln\frac{K_{land}}{K_{capital}}t \\ & + \beta_t t + \beta_{t2}tT_2 + \frac{1}{2}\phi_{tt}t^2 + \frac{1}{2}\phi_{tt}t^2T_2 + u_{0t}\end{aligned} \tag{35}$$

where T_2 is a time dummy variable for years after the passage of IRCA in 1986. It is added to capture the potential difference in the biases and the rate of technological change. Linear homogeneity in prices is imposed by dividing through all prices by the price of materials (the variable input equation dropped from the system), and linear homogeneity in fixed inputs is imposed by dividing fixed inputs by the quantity of capital (the fixed input equation dropped from the system). In addition to the homogeneity and symmetry constraints, the continuity of the profit function in 1987 requires the additional constraint:

$$\sum_{i=1}^{5}\delta_{it2}\ln\frac{Z^{87}{}_i}{Z^{87}{}_{matl}} + \phi_{1t2}\ln\frac{K^{87}{}_{land}}{K^{87}{}_{capital}} + \beta_{t2} + \frac{1}{2}\phi_{tt2}t^{87} = 0 \tag{36}$$

where Z^{87}, K^{87}, and t^{87} represent the observed values in 1987.

The profit shares are derived by taking the first derivative of the translog profit function with respect to the log of variable input and output prices and fixed input quantities. The system of share equations becomes

$$\pi_i = \alpha_i + \sum_{h=1}^{5} \gamma_{ih} \ln \frac{Z_h}{Z_{matl}} + \delta_{1j} \ln \frac{K_j}{K_{capital}} + \delta_{it1} t + T_2 \delta_{it2} t + u_{it} \qquad i = 1,...,5 \qquad (37)$$

$$\pi_j = \beta_j + \sum_{i=1}^{5} \delta_{il} \ln \frac{Z_i}{Z_{matl}} + \phi_{11} \ln \frac{K_{land}}{K_{capital}} + \phi_{lt1} t + T_2 \phi_{lt2} t + u_{jt} \qquad j = 1 \qquad (38)$$

The seemingly unrelated regression procedures were applied to the system of share equations Eq. 37 and Eq. 38 and the translog profit function Eq. 35 using the Full Information Maximum Likelihood (FIML) procedure.[1] The disturbances are assumed to be jointly normally distributed with zero means, scalar covariance matrices, but non-zero contemporaneous covariances between equations. The profit equation is included because parameters β_t and ϕ_{tt} are needed to calculate the rate of technological change and cannot be estimated directly from the share equations.

Following from Eq. 37 and 38,

$$\frac{\partial \pi_i}{\partial t} = \frac{Z_i \frac{\partial Q_i}{\partial t}}{\pi} - \frac{Q_i Z_i}{\pi^2} \frac{\partial \pi}{\partial t} = \delta_{it1} + T_2 \delta_{it2} \qquad i = 1,\ldots, 6 \qquad (39)$$

solving for $\partial Q_i/\partial t$ from Eq. 39 and dividing by Q_i,

$$\varepsilon_{it} \equiv \frac{1}{Q_i} \frac{\partial Q_i}{\partial t} = \frac{\delta_{it1} + T_2 \delta_{it2}}{\pi_i} + \frac{\partial \ln \pi}{\partial t} \qquad (40)$$

$$\varepsilon_{it} = \frac{\delta_{it1} + T_2 \delta_{it2}}{\pi_i} + \mu \qquad (41)$$

Thus, the biased technological change defined in Eq. 33 and 34 can be estimated as

$$B_i = \frac{\delta_{it1} + T_2 \delta_{it2}}{\pi_i} \qquad i = 1,\ldots, 6 \qquad (42)$$

$$B_j = \frac{\phi_{jt1} + T_2 \phi_{jt2}}{\pi_j} \qquad j = 1, 2 \qquad (43)$$

[1] Time Series Processor (TSP) through the looking glass version 4.4 is used for statistical analysis.

Results

We first checked the Cholesky values of the Hessian with respect to the fixed inputs, and found that they are negative at every observation. However, the Cholesky matrix of the Hessian with respect to the variable inputs and outputs has one negative Cholesky value at every observation. This means that the convexity property of the estimated profit function is violated within the region of data among the outputs and variable inputs, but the concavity property is not violated for the fixed inputs. The most negative Cholesky value, -3.1440, is found in 1998. Since only convexity is violated, subsequent curvature attention is given only to convexity.

The convexity is imposed using the Wiley-Schmidt-Bramble reparameterization technique as presented in Eq. 10 and Eq. 11. The right hand side variables are normalized to one and the time variable is normalized to zero in 1998. This guarantees that convexity will be satisfied at this point. Table 1 presents the estimates transformed back to the original parameters of the translog profit function satisfying the regularity constraints, including convexity.

Rate of Technological Change and Biased Technological Change

Table 2 reports the estimates of Florida biased technological change before and after the passage of IRCA, evaluated at the means of the explanatory variables for each subperiod. A test that the biases are jointly different between the two periods is highly significant as suggested by a Wald test statistic value of 47.06; the critical value for the $\chi^2(8)$ is 21.95 at the 0.005 significance level. The individual differences of biases between the two periods and their standard errors suggest whether the changes are individually significant. After the passage of IRCA in 1986, the technology suggested significant bias toward more perishable crop-producing, but significant bias against the production of other outputs. The technology became more self-employed labor-using, but the biases of hired labor and capital were not significantly different. The technology significantly used more chemicals and less materials whereas, the use of land did not change. The results suggest that although the technology significantly saved both types of labor before IRCA, it used more self-employed labor afterward. The technology switched from hired labor-saving to hired labor-neutral following IRCA; similarly, there was no significant adoption of mechanized technology as reflected by the capital bias estimates. The technology suggested an increase in the production of perishable crops. Instead of hiring more workers or adopting new mechanized technology, the technology apparently became more self-employed labor-using in the production of perishable crops in the labor intensive areas.

Elasticity

The own-price elasticities of both outputs were positive, and those of inputs were negative as expected at all observations. Table 3 summarizes the own-price elasticities of output supply and variable input demand and the inverse fixed input demand for selected years. The correct signs of the elasticities indicated that they were consistent with economic theory.

Figure 1 shows point estimates of the MES between hired labor and self-employed labor, and the MES between two types of labor and capital. Hired labor and self-employed labor are substitutes, and the substitution became more elastic and more volatile after the passage of IRCA, particularly the MES between types of labor when hired labor wage changes. Labor and capital are also substitutes, except for the substitution between hired labor and capital when capital price changes in some years in the early 1960s and between the mid-1980s to early 1990s. The negative MES's between hired labor and capital when capital price changes in some years suggest that even when capital becomes cheaper, the employment of hired labor increases. This is important particularly after the passage of IRCA. If more stringent immigration legislation were to stimulate the ready availability of new mechanized technology and at a lower cost, it would not necessarily follow that the employment of hired labor would decrease. In Florida, where agricultural production is still highly labor intensive, capital may not be able to substitute for labor. For instance, the harvest of citrus for fresh market is still done manually because mechanical citrus harvesters still cannot preserve the post-harvest quality to meet high standards for the fresh market. The MES's between capital and two types of labor when returns to labor change are more elastic than the MES's between capital and labor when capital price changes. This implies that it is easier to substitute capital for labor (adopt mechanized technology) when labor becomes more expensive than to substitute labor for capital when capital becomes more expensive.

The average MES's before and after the passage of IRCA are summarized in Table 4. The results reveal that hired labor and self-employed labor were substitutes in both periods. The MES's between the two types of labor increased after IRCA. As values of a type of labor changed, the increase of another type of labor became easier following IRCA. For instance, if hired workers became more expensive, self-employed labor would increase in efficiency units, either through increased quality, or through more hours, than before the passage of IRCA, and vice versa. Similarly, both types of labor were substitutes for capital in both periods. The only MES's that switched signs are between self-employed labor and land, and between chemicals and land when land price changed. Self-employed labor and chemicals were each substitutes for land when land price changed before IRCA. However, after IRCA, if land became more expensive, the use of chemicals would decrease and producers would work fewer hours. The passage of IRCA did not change the substitutability between labor and capital or between the two types of labor; however, technological progress required less chemicals and self-employed labor when agricultural land area became more scarce. An example of a possible technological change is drip pesticide and fertilizer applications. This technology allows the minimal use of chemicals while conserving the environment, and perhaps requiring less labor. As this technology was adopted, it increased land productivity without necessarily increasing the use of chemicals even when land price was increasing.

Conclusions

The study of technological change, own-price elasticity, and the Morishima elasticity of substitution in Florida suggests implications for policies related to mechanized technology development and immigration. We found that the technology became perishable crops producing relative to other outputs in Florida following IRCA. The technology also became more self-employed labor using while the bias toward hired labor and the use of capital did not significantly change. We also found that self-employed labor and hired labor are substitutes, and that they are each substitutes for capital. In addition, it is easier to substitute hired labor for self-employed labor when returns to self-employed labor increase than to substitute self-employed labor for hired labor when hired labor wages increase.

The substitution between the two types of labor became more elastic following IRCA, suggesting that it became less difficult to substitute one type of labor for the other. IRCA created less incentive for self-employed labor to hire other farm workers even when returns to self-employed labor increased. At the same time, producers who use hired workers in their production are more likely to increase their work efficiency even if hired workers become less expensive. This may be due to increasing risks associated with hiring foreign workers, who are a major component of hired labor in Florida.

Capital will be substituted for both types of labor when labor becomes more expensive. This suggests that a more stringent immigration legislation that makes hiring foreign labor become more expensive, particularly in labor-intensive agricultural production as in Florida, there will be increased adoption of farm mechanized technology. However, when capital prices change, hired labor became a complement to capital after the passage of IRCA (Figure 1) at some observations. Thus, under the post-IRCA scenario, if the adoption of the new mechanized technology became less expensive due to greater availability and technology advancement, the employment of hired labor could also increase. It is widely recognized that IRCA did not limit the availability of foreign labor, and the demand for foreign workers in labor intensive agricultural production remains high. Under a scenario of readily available labor as in the post-IRCA era, even when mechanized technology is available, there will be limited adoption of new mechanization.

This study also suggests implications for the current debate about guest worker programs. Proposed immigration legislation such as AgJOBS (S. 1645 and H.R. 3142) provides a combination of a legalization path for existing unauthorized workers, and a streamlined H-2A guest worker program. Whether or not this would result in an increased supply of farm labor depends upon a multitude of factors such as the retention of existing workers in agriculture, changes in labor cost due to legalization, and border enforcement for new illegal workers. In a competitive low-skilled labor market such as agriculture, a significant increase in the supply of foreign labor would be expected to suppress farm wages. Legalizing current unauthorized workers can also create an increasing flow of illegal workers in the future based on the expectation that there will be another legalization at some future date.

Stated in a scenario reverse to the proposed AgJOBS legislation, an alternative extreme policy approach of sealing the border, deporting all unauthorized workers, and authorizing no guest workers would be likely to increase wage rates in the short run. This study suggests that such an approach would stimulate technology development and adoption, with increased substitution of capital for labor. Drawing from Table 4, the MES between capital and hired labor when the hired labor wage increases (MES_{khl}), suggests about an 18% increase in the capital to hired labor ratio with a 10% increase in the hired labor wage. It would simultaneously slow the bias toward perishable crops. By contrast, our results suggest that a less restrictive policy toward foreign workers, such as the AgJOBS bill would reduce the incentives for developing and adopting new mechanical technology, and reduce the extent of substitution of capital for labor.

Table 1. Estimates with homogeneity, symmetry, and convexity constraints.

Parameter	Estimate	Parameter	Estimate	Parameter	Estimate
α0	14.9548* (0.0709)	γ hlc	-0.2270* (0.0300)	δ pt1	-0.0129* (0.0033)
α oout	0.7824* (0.0387)	γ hlm	-0.3627* (0.0643)	δ pt2	0.0152* (0.0055)
α persh	1.5541* (0.0407)	γ slsl	0.0933 (0.0735)	δ hlt1	0.0113* (0.0021)
α hired	-0.4307* (0.0272)	γ slc	0.0155 (0.0250)	δ hlt2	-0.0060* (0.0025)
α self	-0.1364* (0.0109)	γ slm	0.1659* (0.0449)	δ slt1	0.0059* (0.0009)
α chem	-0.2372* (0.0113)	γ cc	-0.0805* (0.0230)	δ slt2	-0.0065* (0.0017)
α matl	-0.5321* (0.0290)	γ cm	-0.0323 (0.0376)	δ ct1	0.0035* (0.0011)
β land	0.3829* (0.0465)	γ mm	-0.4065* (0.0744)	δ ct2	-0.0043* (0.0013)
β capital	0.6171* (0.0465)	δ ol	-0.0140 (0.0723)	δ mt1	0.0097* (0.0027)
γ oo	0.2792* (0.0613)	δ pl	0.1440* (0.0736)	δ mt2	0.0144* (0.0048)
γ op	-0.9916* (0.0703)	δ hll	0.0567 (0.0627)	ϕ ll	-0.3022* (0.0893)
γ ohl	0.3463* (0.0553)	δ sll	-0.1386* (0.0330)	ϕ lk	0.3022* (0.0893)
γ osl	0.0461 (0.0339)	δ cl	-0.1075* (0.0239)	ϕ kl	0.3022* (0.0893)
γ oc	0.0682 (0.0378)	δ ml	0.0594 (0.0556)	ϕ kk	-0.3022* (0.0893)
γ om	0.2519* (0.0642)	δ ok	0.0140 (0.0723)	ϕ lt1	0.0007 (0.0034)
γ pp	-0.2016 (0.1245)	δ pk	-0.1440* (0.0736)	ϕ lt2	0.0023 (0.0060)
γ phl	0.4601* (0.0528)	δ hlk	-0.0567 0.0627	ϕ kt1	-0.0007 (0.0034)
γ psl	0.0932* (0.0352)	δ slk	0.1386* (0.0330)	ϕ kt2	-0.0023 (0.0060)
γ pc	0.2561* (0.0288)	δ ck	0.1075* (0.0239)	βt	0.0236* (0.0068)
γ pm	0.3838* (0.0762)	δ mk	-0.0594 (0.0556)	βt2	-0.0165 (0.0133)
γ hlhl	0.1973 (0.1416)	δ ot1	-0.0175* (0.0029)	ϕtt	-0.0044* (0.0004)
γ hlsl	-0.4140* (0.1010)	δ ot2	-0.0128* (0.0036)	ϕtt2	-0.0024 (0.0024)

Note: Estimated standard errors are in parentheses; convexity imposed in 1998.
o=other outputs, p=perishable crops, hl=hired labor, sl=self-employed labor, c=chemicals, m=materials, l=land, k=capital.
* Significant at the 0.05 level.

Table 2. Biased technological change calculated at the means.

	Pre-IRCA	Post-IRCA	Difference
Other Outputs	-0.0173*	-0.0341*	-0.0168*
	(0.0024)	(0.0039)	(0.0030)
Persh Crops	-0.0089*	0.0016	0.0105*
	(0.0020)	(0.0052)	(0.0039)
Hired Labor	-0.0260*	-0.0138	0.0122
	(0.0035)	(0.0099)	(0.0074)
Self-employed	-0.0342*	0.0052	0.0394*
	(0.0034)	(0.0181)	(0.0161)
Chemicals	-0.0160*	0.0035	0.0195*
	(0.0037)	(0.0094)	(0.0069)
Materials	-0.0153*	-0.0379*	-0.0225*
	(0.0034)	(0.0065)	(0.0059)
Land	0.0018	0.0075	0.0057
	(0.0092)	(0.0200)	(0.0152)
Capital	-0.0011	-0.0050	-0.0039
	(0.0055)	(0.01314)	(0.0100)

Note: Estimated standard errors are in parentheses. * significant at 0.05 level.

Table 3. Own-price elasticity and inverse price elasticity.

	1960	1970	1980	1987	1998*
Other Outputs	0.2884	0.3398	0.2458	0.2326	0.1392
Perish Crop	0.2148	0.2677	0.3531	0.0838	0.4244
Hired Labor	-1.8973	-1.8883	-1.8886	-2.0371	-1.8887
Self-employed	-1.6794	-1.6972	-1.7463	-2.1786	-1.8203
Chemicals	-0.8529	-0.8827	-0.8138	-0.5499	-0.8980
Materials	-0.8785	-0.9953	-1.0146	-1.1299	-0.7681
Land	-2.0361	-1.5132	-1.1346	-1.2255	-1.4064
Capital	-0.6335	-0.8150	-1.0751	-0.9963	-0.8726

* Normalized year

Table 4. Average Morhishima elasticity of substitution.

	Pre-IRCA	Post-IRCA		Pre-IRCA	Post-IRCA
MEShlsl	2.6867	3.2241	MESslk	1.0542	1.0753
MEShlc	1.7065	1.0805	MEScl	0.6754	-0.0583
MEShlm	0.9742	0.9981	MESck	0.5621	0.7086
MESslhl	4.2290	5.5092	MESml	0.6469	0.4660
MESslc	1.0441	0.1358	MESmk	0.5147	0.4873
MESslm	-0.4193	-0.9324	MESlhl	1.8694	1.9718
MESchl	2.8108	2.7913	MESlsl	1.6428	2.0206
MEScsl	1.6221	1.8495	MESlc	1.3093	0.5030
MEScm	0.4551	0.4445	MESlm	0.7503	0.7452
MESmhl	2.2169	2.2881	MESkhl	1.7862	1.8262
MESmsl	1.5234	1.8712	MESksl	1.9344	2.2591
MESmc	1.2236	0.6231	MESkc	1.2763	0.7263
MEShll	0.4624	0.2950	MESkm	0.5592	0.5686
MEShlk	0.2956	0.1379	MESlk	0.5537	0.4951
MESsll	0.2175	-0.0522	MESkl	0.5694	0.3555

Note: hl=hired labor, sl=self-employed labor, c=chemicals, m=materials, k=capital, l=land.

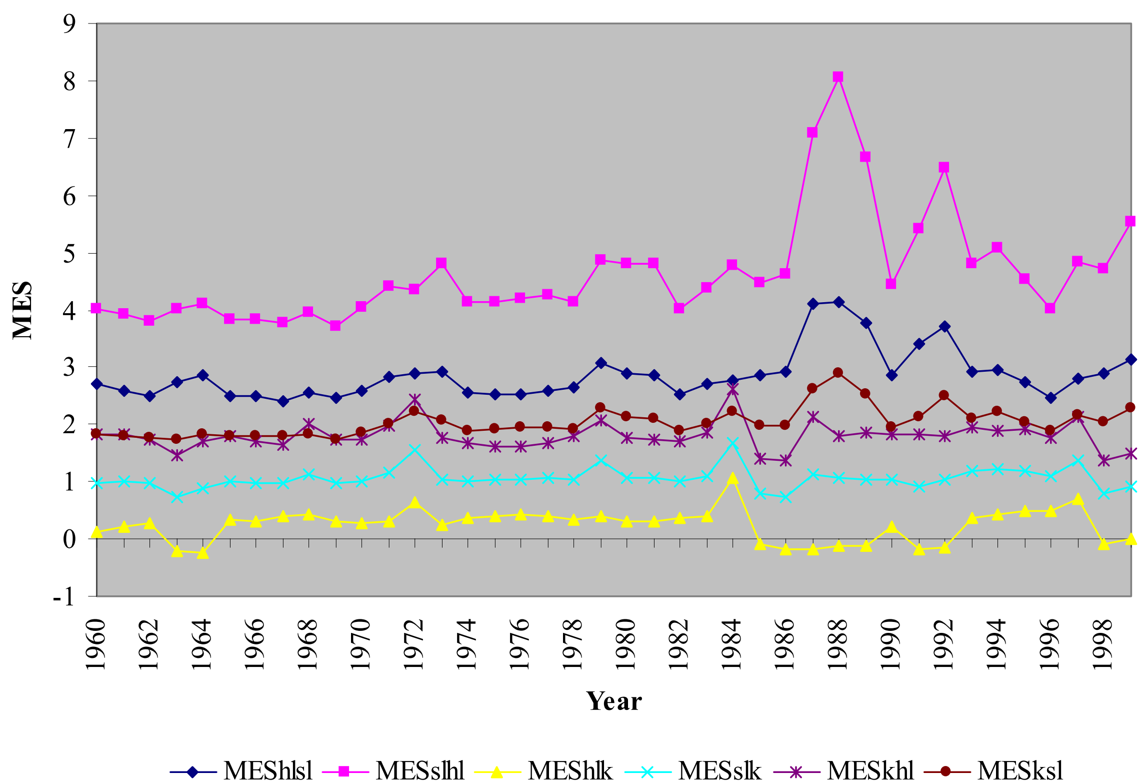

Figure 1. Morishima elasticity of substitution between hired and self-employed labor and between labor and capital.

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