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# INSTITUTIONAL AND SOCIOECONOMIC MODEL OF FARM MECHANIZATION AND FOREIGN WORKERS

By

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# INSTITUTIONAL AND SOCIOECONOMIC MODEL OF FARM MECHANIZATION AND FOREIGN WORKERS

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# INSTITUTIONAL AND SOCIOECONOMIC MODEL OF FARM MECHANIZATION AND FOREIGN WORKERS

## Introduction

The United States has a long history of technological innovation in agriculture. The recent focus of technological development in agriculture has been on agricultural biotechnology and farm mechanization. The development of farm mechanization received special attention following changes in immigration policy in 1986, the Immigration Reform and Control Act. The uncertainty of labor availability and difficulties associated with hiring foreign workers are argued to induce the development of advanced labor-saving technology such as mechanical harvesters in labor intensive agricultural production. Several previous studies on technological change adopted the induced innovation theory developed by Hayami and Ruttan. Although their basic theory of induced innovation can explain the pattern of technological change, subsequent variations in the theory generate additional insights.

First, the standard theory of induced innovations is applied in a comparative statics framework, but does not explain the mechanism of technological change. Second, the theory assumes that prices are the major (if not the only) driving force of technological innovation. The original induced innovation theory assumed market perfection, although producers and other agents often face different prices, and thus do not necessarily demand the same technology. Specifically, producers with different demands for technology may not have the same political power to influence the supply of the technology. Consequently, the supply of technology is influenced not only by prices, but also by the political pressure from different economic agents having different

interests. In other words, different transaction costs of various market agents may distort the technological developments from the social optimum. Finally, the basic theory does not consider the importance of the changing social and institutional environment that often influences the direction of technological change.

The new direction of induced innovation theory emphasizes the role of institutions and their relationship with technological change as suggested by Binswanger; de Janvry (1973, 1978); de Janvry, Fafchamps, and Sadoulet; Roumasset; and Ruttan. Previous empirical studies of technological change largely ignore the importance of the socioeconomic and institutional environment. To our knowledge, de Janvry, et al. are the fist to develop an empirical model of induced innovation that includes transaction costs. Their study assumes that each producer demands a different technology based on farm size. The explanatory variables are chosen to reflect the price, structural, institutional, and political determinants of factor biases. The results based on 27 developed countries indicate that the structural, institutional, and political variables (farm size, farm distribution, and research budget) indeed affect the direction of technological change. We, Napasintuwong and Emerson (2003), also developed an empirical socioeconomic model of induced innovation based on a cost minimization model. Our study in 2003 incorporated the socioeconomic variables believed to influence the change of agricultural technology, particularly to explain the path of farm mechanization in the presence of foreign workers in U.S. agriculture. In that study, we included the number of deportable aliens, argued to represent changes in immigration and labor policy enforcement. Also included were government payments on conservation programs and the market share of large producers to reflect the importance of the size of producer in determining the

direction of technological change.

In this paper, the social and institutional structure that can influence the direction of technological change is emphasized. In order to understand the determinants of technological development in the U.S., particularly farm mechanization in the context of immigration policy, we emphasize the characteristics of the labor market and the role of government in the development of farm mechanization resulting from immigration policy concerns. The variables most closely associated with immigration policy are changes in the number of unauthorized farm workers (which reflects the stringency of policy enforcement) and changes in the number of temporary guest workers in agriculture (H-2A). In addition, the budget allocation among biological efficiency, mechanization, noncommercial biotech and biometry, and pesticides and herbicides of publicly funded agricultural research is assumed to reflect the demand for technology through the political institutions, and is included in the analysis. Private research expenditures respond more directly to market incentives, and have a different pattern than public expenditures, and are also included.

## Methodology

A multi-output translog cost function model is adopted in this study. The direction of input use indicates the biased technological change as defined by the theory of induced innovation. A time variable is included in the model to represent the state of technology. The socioeconomic variables are also included to capture their effects on the rate of biased technological change. The parameter estimates of the translog cost

function provide estimates for elasticities of factor demand and elasticities of factor substitution.

Model

The model assumes multiple agricultural outputs and multiple inputs, and that the mixture of outputs as well as input prices may affect the relative use of inputs at the optimal cost minimization. The production of m agricultural products Q = ($Q_1$, $Q_2$,…, $Q_m$) at output prices P = ($P_1$, $P_2$,…, $P_m$) requires n variable inputs X = ($X_1$, $X_2$,…, $X_n$) with a vector of input prices W = ($W_1$, $W_2$,…, $W_n$) and fixed input K = ($K_1$, $K_2$,…, $K_l$) at price R = ($R_1$, $R_2$,…, $R_l$). Using time as representative of technological knowledge, production cost is therefore a function of output quantities, variable input prices, fixed input quantities, and the technology variable. This model, we assume only one fixed input, land. Thus, the translog cost function C = f($W_1$,…, $W_n$, $P_1$, $P_2$,…, $P_m$, K, t) can be written as

$$\begin{aligned}\ln C = {} & \nu_0 + \sum_{i=1}^{n} \nu_i \ln W_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln W_i \ln W_j + \sum_{r=1}^{m} \alpha_r \ln Q_r + \frac{1}{2}\sum_{r=1}^{m}\sum_{s=1}^{m} \lambda_{rs} \ln Q_r \ln Q_s \\ & + \frac{1}{2}\sum_{r=1}^{m}\sum_{i=1}^{n} \delta_{ri} \ln Q_r \ln W_i + \nu_k \ln K + \omega_k (\ln K)^2 + \sum_{i=1}^{n} \theta_i \ln W_i \ln K + \sum_{r=1}^{m} \eta_r \ln Q_r \ln K \quad (1) \\ & + \nu_t \ln t + \omega_t (\ln t)^2 + \sum_{i=1}^{n} \omega_i \ln W_i \ln t + \sum_{r=1}^{m} \phi_r \ln Q_r \ln t \quad + \varphi \ln K \ln t\end{aligned}$$

A cost function linearly homogeneous in variable input prices implies that

$$\sum_i \nu_i = 1; \qquad \sum_i \gamma_{ij} = 0; \qquad \sum_j \gamma_{ij} = 0; \qquad \sum_i \delta_{ri} = 0.$$

In addition, a symmetry restriction is also assumed to hold.

$$\gamma_{ij} = \gamma_{ji}; \qquad \lambda_{rs} = \lambda_{sr} \qquad \text{for all i, j, i} \neq \text{j and all r, s, r} \neq \text{s}$$

Utilizing Shepard's Lemma, $\partial C/\partial W_i = X_i$, the first derivative of a translog cost function with respect to an input price generates the input share equation.

$$\frac{\partial \ln C}{\partial \ln W_i} = \frac{X_i W_i}{C} = S_i \qquad \text{i} = 1,\ldots,\text{n} \qquad (2)$$

$$S_i = \nu_i + \sum_{j=1}^{n} \gamma_{ij} \ln W_j + \sum_{r=1}^{m} \delta_{ri} \ln Q_r + \theta_i \ln K + \omega_i \ln t \qquad \text{i} = 1,\ldots,\text{n} \qquad (3)$$

Assuming that marginal cost equals output price in the perfectly competitive market, $\partial C/\partial Q_r = P_r$, we obtain a revenue share equation from

$$\frac{\partial \ln C}{\partial \ln Q_r} = \frac{P_r Q_r}{C} = Y_r \qquad \text{r} = 1,\ldots,\text{m} \qquad (4)$$

$$\mathrm{Y_r} = \alpha_\mathrm{r} + \sum_{\mathrm{s}=1}^{\mathrm{m}} \lambda_{\mathrm{rs}} \ln \mathrm{Q_s} + \sum_{\mathrm{i}=1}^{\mathrm{n}} \delta_{\mathrm{ri}} \ln \mathrm{W_i} + \eta_\mathrm{r} \ln \mathrm{K} + \phi_\mathrm{r} \ln t \qquad \mathrm{r} = 1,\ldots,\mathrm{m} \qquad (5)$$

From equation (3), we can see that a change in the factor share is a result of changes in factor prices, output quantities, the fixed input, and a change in the state of technology. Applying the induced innovation theory, the direction of bias in technological change is measured by the change in the factor share, given that relative factor prices, level of outputs and fixed inputs remain constant. In a multi-input case, a bias in technological change of input i ($B_i$) is defined as input i-saving, i-neutral, or i-using if the share of factor i in variable costs decreases, stays constant, or increases.

$$B_i \,|_{relative\ factor\ price,\, output,\, \text{fixed input}} = \frac{\partial S_i}{\partial t} \frac{1}{S_i} \begin{matrix} < \\ = 0 \\ > \end{matrix} \quad \begin{cases} i - saving \\ neutral \\ i - using \end{cases} \qquad (6)$$

A technological bias can be calculated from $dS_i$*

$$dS_i^* = \omega_i d \ln t \qquad \text{i} = 1,\ldots,\text{n} \qquad (7)$$

where $dS_i$* is changes in the factor share as a result of changes only in the technology variable. From equation (7), the sign of $\omega_i$ determines the bias of technical change, and $\omega_i$, can be interpreted as a constant rate of bias of factor i during the study period. We assume that the socioeconomic factors such as immigration policy and public research expenditures endogenously influence the rate of biased technological change. As a result, we estimate the bias as a function of those factors. The vector of socioeconomic and institutional factors is Z = ($Z_1$, $Z_2$,…, $Z_l$). The input share equation in equation (3) can then be written as

$$S_i = \nu_i + \sum_{j=1}^{n} \gamma_{ij} \ln W_j + \sum_{r=1}^{m} \delta_{ri} \ln Q_r + \theta_i \ln K + (a_i + \sum_{l=1}^{L} b_l Z_l)lnt \qquad i = 1,...,n \qquad (8)$$

Similarly, we can estimate the impact of technological advance on changes in output prices for given factor prices, levels of output quantities, and a fixed input. For a multi-output production, an alteration in product prices ($A_r$) is defined as output price r-decreasing, r-neutral, or r-rising if the revenue share of output r in variable costs decreases, remains constant, or increases.

$$A_r \mid_{relative\ factor\ price,\ output,\ fixed\ input} = \frac{\partial Y_r}{\partial t} \frac{1}{Y_r} \begin{matrix} < \\ = 0 \\ > \end{matrix} \quad \begin{cases} r - decrea\sin g \\ neutral \\ r - ri\sin g \end{cases} \qquad (9)$$

The alteration in product price can be calculated from $dY_i$*, a change in revenue share as a result of changes only in the technology variable.

$$dY_r^* = \phi_r d\ln t \qquad \mathrm{r} = 1,...,\mathrm{m} \qquad (10)$$

The sign of $\phi_r$ indicates the direction of output price alteration, and the magnitude of $\phi_r$ is the rate of output price alteration.

The price elasticities of factor demand ($\eta_{ij}$) may be calculated from the parameter estimates of input share equations as follows.

$$\eta_{ij} = \frac{\gamma_{ij}}{S_i} + S_j \qquad \text{for all } i, j; i \neq j \qquad (11)$$

$$\eta_{ii} = \frac{\gamma_{ii}}{S_i} + S_i - 1 \qquad \text{for all } i \qquad (12)$$

Most studies of technological change use the Allen elasticity of substitution; we instead adopt the Morishima elasticity of substitution (MES). Blackorby and Russell (1989) show that MES preserves the original Hicks concept of measuring 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. 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 in cost minimization is defined as

$$MES_{ij} = \frac{\partial \ln(X^*_i / X^*_j)}{\partial \ln(W_j / W_i)} \qquad (13)$$

where $X^*_i$'s are the optimal cost minimizing inputs, and $W_j$'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 $P_j$,

$$MES_{ij} = \frac{P_j C_{ij}}{C_i} - \frac{P_j C_{jj}}{C_j} \qquad (14)$$

$$MES_{ij} = \eta_{ij} - \eta_{jj} \qquad (15)$$

The Morishima elasticity of substitution ($MES_{ij}$) can be calculated from the parameter estimates. Unlike the Allen elasticity of substitution, MES is not symmetric,

but depends on which input price changes. Two inputs are substitutes if the MES >0, and are complements if MES<0.

Data

The input prices are quality-adjusted prepared by Eldon Ball, Economic Research Service, USDA. One difference between using this data set and the published production account data is that we could aggregate the contract labor with other types of labor (self-employed and hired) instead of including it in the material inputs category in the published series. The input data include price indices and implicit quantities of aggregate inputs, providing total variable cost and input shares. We use the study period from 1971 to 1995 for the United States. There are four variable inputs - capital, labor, chemicals, and materials; one fixed input - land; and three outputs - perishable crops, cereals, and all other outputs. Capital includes autos, trucks, tractors, other machinery, inventory, and buildings. Labor includes self-employed labor, contract labor, and hired labor. Chemicals are comprised of pesticides and herbicides, and materials include feed, seeds, and livestock purchases. Perishable crops include horticultural products, vegetables, fruits and nuts. Livestock, forage, potatoes, industrial crops, household consumption crops, secondary products, and all other products are included in other outputs.

There are eleven socioeconomic variables and institutional factors to capture the changes in political and institutional environment related to immigration policy and the research and development of new agricultural technology. Included are the number of deportable Mexican aliens working in agriculture, the number of H-2A workers, the shares of public expenditures on biological efficiency, non-commodity biotechnology and

biometry, pesticides and herbicides, and mechanization, and the share of private expenditures on plant breeding, chemicals, machinery, and veterinary pharmaceuticals.

We hypothesize that labor and machinery (or capital in our definition) are substitutes even though some mechanical technology may not be able to replace labor, and vice versa. As a result, the change in immigration policy which may largely change the supply of farm labor will change the incentive for the adoption of farm mechanization. From this perspective, we include the two variables that reflect changes in immigration policy. First, the percentage of deportable Mexican aliens working in agriculture relative to total hired workers represents the proportion of unauthorized farm workers. It also characterizes the level of stringency of border crossing and internal enforcement of unauthorized workers which is an indicator of the political market, and the influence of anti-foreign worker activists and producers who may favor the availability of foreign workers. A large flow of illegal workers across the border and a high level of apprehensions reflect a lax policy. By contrast, with a very stringent policy, there would be few apprehensions since there would be few attempts to cross the border for work. Figure 1 shows that the percentage of the number of deportable Mexican workers dropped dramatically after passage of IRCA in 1986. The IRCA legislation was designed to reduce the flow of illegal workers, and the decrease in the number of deportable Mexican workers suggests that there may have been less incentive for unauthorized workers to cross the border, or those workers may have found jobs in other industries where it may be less likely to be captured, or they may have become more careful to avoid getting caught since it is more difficult to cross the border. The data on deportable aliens are obtained from selected INS yearbooks.

The second variable is the number of H-2A workers. We use the data on H-2A from Emerson (1988) and Martin (2004). The temporary guest workers program or H-2 program was established in 1952, and modified into the H-2A program as part of IRCA. The H-2 and successor H-2A programs allow agricultural employers who anticipate a shortage of domestic labor supply to apply for nonimmigrant alien workers to perform work of a seasonal or temporary nature.[1] Figure 1 displays the number of H-2A certifications. As may be seen, the number of guest workers increased after the passage of IRCA, but declined a few years afterwards.

Our next variable is the plant variety protection certificates (PVPCs). Intellectual property rights have become more important in agricultural practice because of the technological advance in biotechnology. The structure of institutions that facilitate the protection intellectual property rights is very important for the incentive for future development. The number of PVPCs represents both the awareness of government to protect new knowledge and also how the public and private sector are actively involved in the biological technology. Figure 2 shows that the number of PVPCs has increased over time.

The next set of variables includes the public and private expenditures on research and development of different categories of research. The shares of research expenditures do not sum up to one because other categories are excluded in our model. The data are obtained from Fernandez-Cornejo (2004). Figure 3 displays the public research expenditure shares, and Figure 4 displays the private research expenditure shares. As

[1] H-2A workers are nonimmigrant workers certified at the request of petitioning employers for temporary agricultural work in the U.S. Certification involves a determination that domestic workers are not available for the work, and that the nonimmigrant workers will not adversely affect similarly employed domestic workers.

may be seen from Figure 3, the public expenditure on mechanization is very small compared to other technology, and seems to decline over time. From Figure 4, the share of private expenditure on mechanization is much greater in the private sector, but also has a decreasing trend.

Estimation

The estimates of biased technical change for each factor and the output price alternation are obtained from the share equation estimates. There are four variable inputs - capital, labor, chemicals, and materials; one fixed input - land, and three outputs - perishable crops, cereals, and other outputs. We assume that there are eleven socioeconomic variables and institutional factors (as discussed in the data section) that endogenously affect the rate of biased technological change.

A system of revenue share equations (5) and factor share equations (8) is estimated with the homogeneity and symmetry restrictions imposed. The sum of factor share equations (8) must equal to unity. In order to solve the singularity of the disturbance covariance matrix, the material equation is dropped from the system, and the price of material becomes the numeraire. All input prices in the model are relative to the price of material. The remaining equations are estimated using seemingly unrelated regression (SUR). We also added a dummy variable, T2, for years after 1986 to capture the shift of the rate of bias and alteration after the passage of IRCA. Each factor share equation can be written as

$$S_i = \nu_i + \sum_{j=1}^{3} \gamma_{ij} \ln \frac{W_j}{W_{matl}} + \sum_{r=1}^{3} \delta_{ri} \ln Q_r + \theta_i \ln(\text{land}) + (a_i + \sum_{l=1}^{11} b_{il} Z_l + c_i T_2) \ln t \qquad i = 1,2,3$$

(16)

$$Y_r = \alpha_r + \sum_{s=1}^{3} \lambda_{rs} \ln Q_s + \sum_{i=1}^{3} \delta_{ri} \ln \frac{W_i}{W_{matl}} + \eta_r \ln(land) + (d_r + \sum_{l=1}^{11} e_{rk} Z_l + f_r T_2) \ln t \qquad r = 1,2,3$$

(17)

where j includes all other variable inputs except materials, and $Z_l$ are the eleven socioeconomic variables.

## Results

Parameter estimates of the input share equations and revenue share equations are summarized in Table 1. The estimates of coefficients in the materials share equation and coefficients of material price in each equation are derived from the other estimates based on homogeneity, symmetry, and adding-up restrictions. The signs of socioeconomic variables in each input share equation suggest the impact of those variables on the share of input cost. It is interesting that the number of unauthorized workers has no significant impact on the share of any input, but significantly increases the revenue shares of cereals and other outputs. The number of H-2A or guest workers significantly decreases the cost share of capital, but has no significant impact on the share of labor. However, it increases the revenue share of cereals. The public expenditure on mechanization decreases the cost share of capital, but private expenditure on machinery increases the cost share of capital. Public expenditure on mechanization increases the revenue share of cereal, but decreases the revenue share of perishable crops and other outputs.

The plant variety protection certificates have no significant effect on the cost shares of inputs, but significantly increase the revenue shares of all outputs. Private research investment seems to have no significant influence on the cost shares of most inputs except for the share of capital. Private investment in plant breeding and veterinary

pharmaceuticals decreases the cost share of capital, and private investment in plant breeding increases the revenue share of cereal whereas it decreases the revenue share of perishable crops. Public investment in biological efficiency and non-commodity biotechnology and biometry also increases the revenue share of cereal. Public investment in herbicides and pesticides increases the cost share of chemicals, but decreases the cost share of labor. It also increases the revenue share of perishable crops and decreases the revenue share of cereal.

The rates of bias of technological change for each input and the rate of output price alteration calculated from the socioeconomic variable coefficients are estimated at the means of each socioeconomic variable in each period, and are summarized in Table 2. The signs of the rate of biased technological change indicate the combined effects of socioeconomic variables on the direction of technological change. Over all, the technological change has been biased toward labor-saving, and was capital- neutral. After IRCA, the technology became more labor-saving while remaining capital-neutral. The result is the similar to Binswanger's (1974a, 1974b) and Antle's results that the technology was labor-saving in the early and mid 1900s. The total effects of socioeconomic variables significantly increase the price of perishable crops, but decrease the price of cereal and both at greater rates after IRCA.

The price elasticities of input demand calculated from expected shares are reported in Table 3. The estimates of all own price elasticities of demand have negative signs and are significant (except for labor). The elasticity of demand for capital is inelastic whereas those of chemicals and materials are elastic. This implies that even

when the price of capital or mechanized technology became less expensive, producers did not increase the use of it very much.

The Morishima elasticities of substitution are calculated indirectly from elasticities of demand (equation 15). Our results show that capital and labor are substitutes only when the price of capital changes. However, when the price of labor changes, capital is not a significant substitute. This result is similar to our paper on the labor substitutability, Napasintuwong and Emerson (2004), that when the price of capital changes, the average MES of both hired labor and self-employed labor to capital are positive during 1960-1998 in Florida. Other MESs also show that all input pairs are significant substitutes.

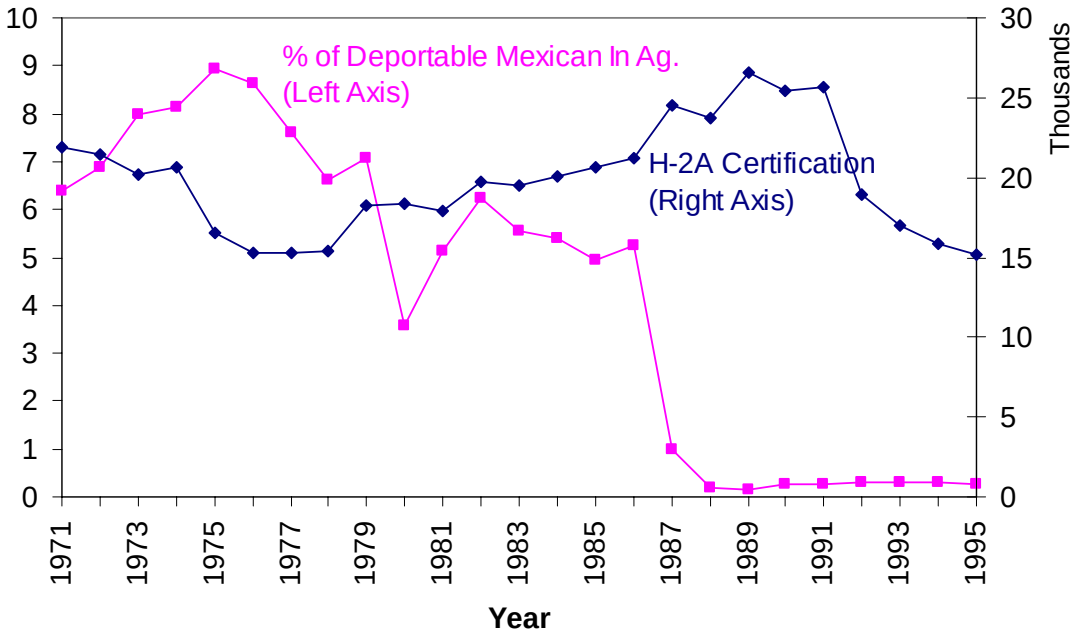
## Conclusions

This is our second paper to capture the impact of socioeconomic variables and institutional factors on the changes in U.S. agricultural technology. Unlike our first paper in 2003, we use the multi-product cost function in this paper instead of a single output cost function so the potential effects of the socioeconomic variables on the output prices can be estimated. We use the factors that are a more direct result of political market pressure by using the research and investment of public and private expenditure in agricultural technology. The plant variety protection certificates also represent intellectual property rights in agricultural research which is evidence of how transaction costs may be altered by the government. The two factors regarding immigration policy are the number of unauthorized farm workers and the number of guest workers. Incorporating these factors in our empirical study of biased technological change added

new information on the mechanism of the change in agricultural technology in addition to the factors in our previous study.

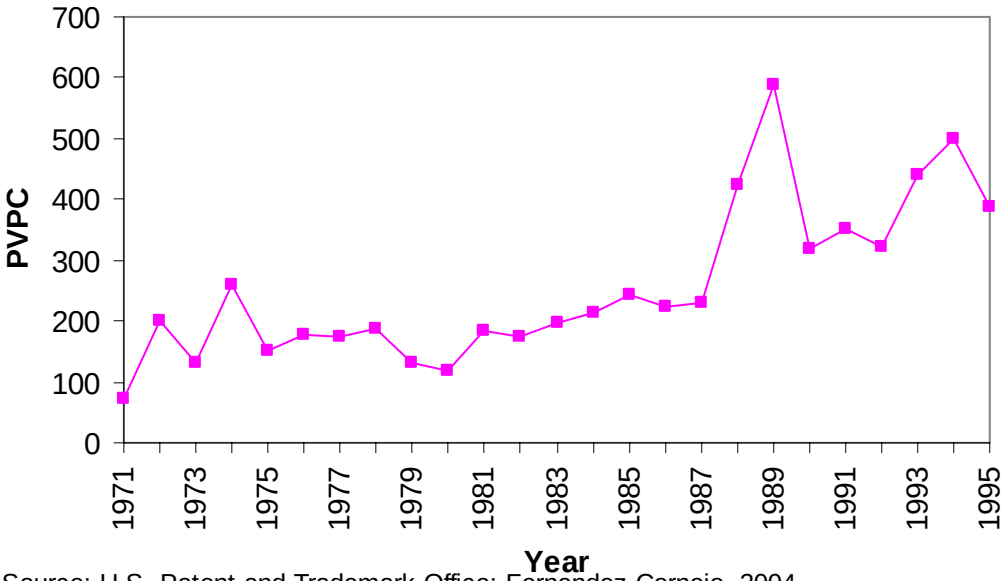
We found that the public expenditure on mechanization has a significant impact on reducing the cost share of capital. However, the private expenditure on machinery increases the cost share of capital. Public expenditure on mechanization increases the revenue share of cereal, but decreases the revenue share of perishable crops and other outputs.

The combined effects of the socioeconomic variables on the direction of technological change show that the technology was biased toward labor-saving, and neutral in capital. Their effects increase the rate of labor-saving technological change after the passage of IRCA, but have no significant impact on capital. The combined effects of the socioeconomic variables also raise the price of perishable crops, but decrease the price of cereal, and at higher rates following IRCA.



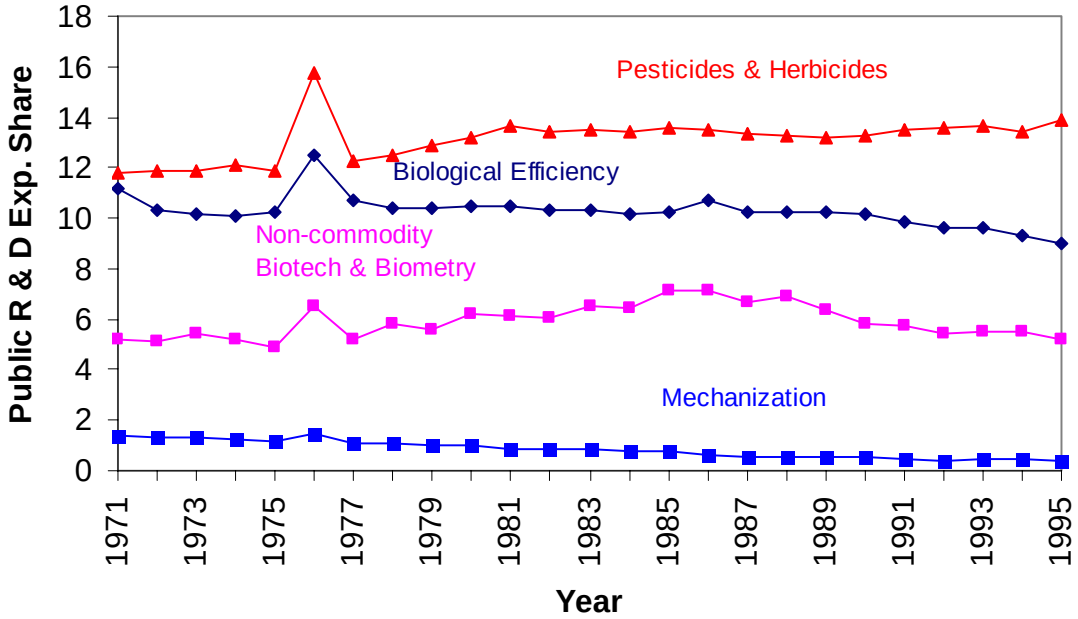

Source: USCIS for Deportable Mexicans, and Emerson (1988) & Martin (2002) for H-2A

**Figure1.** Percentage of deportable Mexican aliens working in agriculture and number of H-2A certifications



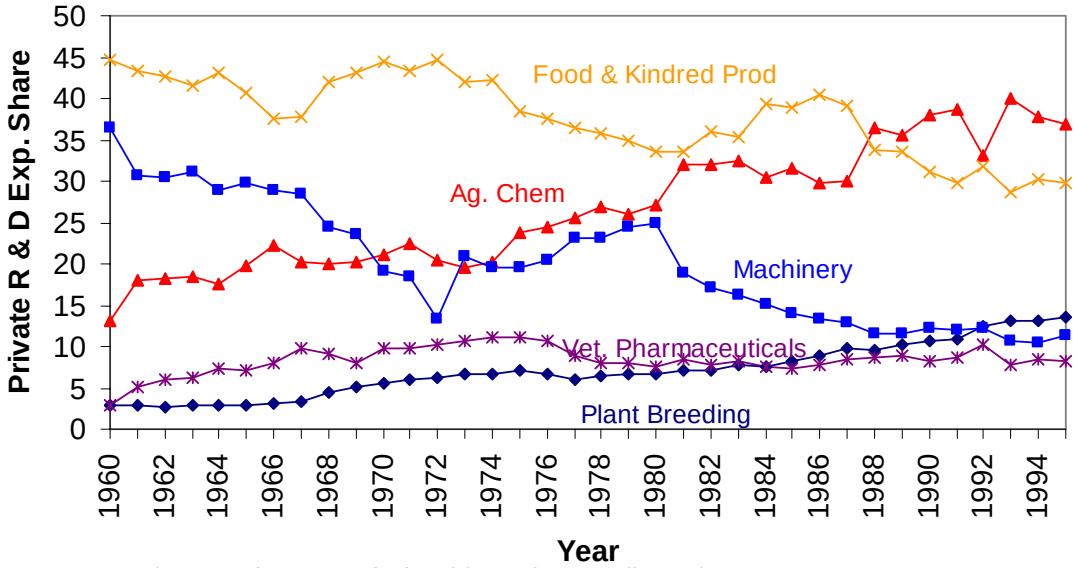

Source: U.S. Patent and Trademark Office; Fernandez-Cornejo, 2004

**Figure 2.** Plant variety protection certificates




Source:Fernandez-Cornejo, 2004 calculated from CRIS, CSREES

**Figure 3.** Shares of public expenditures in agricultural research and development




Source: Fernandez-Cornejo, 2004 calculated from Klotz, Fuglie, and Pray 1995, 1998

**Figure 4**. Shares of private expenditures in agricultural research and development

**Table 1.** Parameter Estimates of the Translog Cost Function, 1971-1995

| Variable | Cost Share of | | | | Revenue Share of | | |
|---|---|---|---|---|---|---|---|
| | Capital | Labor | Chemicals | Materials | Other Outputs | Cereal | Perishable Crops |
| **Intercept** | 18.0441* | 11.2240 | 1.0199 | -29.2880* | 9.3484 | 9.8868 | 0.8792 |
| | (4.5247) | (5.8823) | (5.3693) | (10.9533) | (14.5522) | (5.6485) | (6.4164) |
| **Input Price of** | | | | | | | |
| Capital | 0.1249* | | Symmetric | | -0.1923* | -0.0014 | -0.0376* |
| | (0.0098) | | | | (0.0480) | (0.0218) | (0.0109) |
| Labor | -0.0631* | 0.1721* | | | 0.0280 | -0.1993* | 0.0830* |
| | (0.0078) | (0.0126) | | | (0.0626) | (0.0215) | (0.0132) |
| Chemicals | 0.0150 | 0.0340* | -0.0175 | | -0.2815* | 0.0584 * | -0.0515* |
| | (0.0091) | (0.0118) | (0.0158) | | (0.0738) | (0.0263) | (0.0157) |
| Materials | -0.0768* | -0.1430* | -0.0316 * | 0.2515* | | | |
| | (0.0104) | (0.0123) | (0.0112) | (0.0236) | | | |
| **Quantity of Land** | -1.3897* | -1.1348* | 0.1041 | 2.4203* | -0.6968 | -1.1821* | 0.1888 |
| | (0.3868) | (0.4977) | (0.4535) | (0.9320) | (1.2828) | (0.5293) | (0.5407) |
| **Output Quantity of** | | | | | | | |
| Other Outputs | -0.2131* | 0.1164 | -0.2258* | 0.3225* | -0.0055 | | Symmetric |
| | (0.0047) | (0.0608) | (0.0612) | (0.0950) | (0.2770) | | |
| Cereal | 0.0721* | -0.0027 | 0.0147 | -0.0842* | 0.1161* | 0.1094* | |
| | (0.0107) | (0.0128) | (0.0120) | (0.0236) | (0.0449) | (0.0160) | |
| Perishable Crops | -0.1553 * | -0.0212 | 0.0439 | 0.1326 | -0.2596* | 0.0252 | -0.0026 |
| | (0.0388) | (0.0526) | (0.0451) | (0.0984) | (0.0687) | (0.0145) | (0.0566) |
| **Socioeconomic Variables*ln(t)** | | | | | | | |
| Intercept | 0.0331 | -0.0525* | 0.0314 | -0.0120 | 0.3352 * | -0.1540* | 0.1245 * |
| | (0.0216) | (0.0259) | (0.0247) | (0.0440) | (0.1136) | (0.0402) | (0.0284) |
| Deportable Mexicans | 0.0012 | -0.0009 | 0.00009 | -0.0003 | 0.0064* | 0.0034* | 0.0012 |
| | (0.0006) | (0.0008) | (0.0008) | (0.0015) | (0.0028) | (0.0011) | (0.0009) |
| H-2A | -0.000001* | -0.0000004 | 0.00000003 | 0.000002* | -0.0000009 | 0.000001* | -0.0000006 |
| | (0.0000002) | (0.0000004) | (0.0000003) | (0.0000006) | (0.000001) | (0.0000004) | (0.0000004) |
| PVPC | 0.000002 | -0.000002 | 0.000008 | -0.000007 | 0.00006* | -0.00003* | 0.00001* |
| | (0.000005) | (0.000006) | (0.000006) | (0.00001) | (0.00002) | (0.000009) | (0.000007) |
| Public Biological Efficiency | -0.0028 | 0.0066* | -0.0046 | 0.0007 | -0.0117 | 0.0074* | -0.0088* |
| | (0.0018) | (0.0024) | (0.0024) | (0.0034) | (0.0119) | (0.0033) | (0.0027) |
| Public Non-Commodity Biotech | 0.0092* | -0.0013 | -0.0044* | -0.0035 | -0.0002 | 0.0064* | 0.0017 |
| | (0.0017) | (0.0021) | (0.0019) | (0.0038) | (0.0068) | (0.0029) | (0.0023) |
| Public Chemicals | 0.0007 | -0.0026* | 0.0033 * | -0.0014 | -0.0005 | -0.0103* | 0.0047* |
| | (0.0010) | (0.0013) | (0.0013) | (0.0020) | (0.0062) | (0.0019) | (0.0015) |
| Public Mechanization | -0.0348* | 0.0114 | -0.0012 | 0.0246 | -0.0663* | 0.0383* | -0.0430* |
| | (0.0086) | (0.0111) | (0.0103) | (0.0205) | (0.0312) | (0.0101) | (0.0123) |
| Private Plant Breeding | -0.0051* | -0.0029 | -0.0006 | 0.0086* | -0.0095 | 0.0097* | -0.0035* |
| | (0.0012) | (0.0015) | (0.0014) | (0.0025) | (0.0060) | (0.0022) | (0.0017) |
| Private Chemicals | 0.0003 | -0.0002 | -0.00002 | -0.0001 | -0.0013 | -0.0005 | -0.0004 |
| | (0.0002) | (0.0002) | (0.0002) | (0.0004) | (0.0008) | (0.0004) | (0.0003) |
| Private Machinery | 0.0017* | -0.00006 | 0.0001 | -0.0018 | -0.0012 | -0.0002 | -0.0004 |
| | (0.0006) | (0.0008) | (0.0007) | (0.0015) | (0.0019) | (0.0008) | (0.0009) |
| Private Vet Pharmaceuticals | -0.0016* | 0.0006 | 0.0011 | -0.0002 | -0.0034 | 0.0015 | 0.0005 |
| | (0.0005) | (0.0006) | (0.0006) | (0.0012) | (0.0026) | (0.0011) | (0.0007) |
| Dummy for t>1986 | 0.0217* | 0.0010 | -0.0012 | -0.0215 | 0.0774* | -0.0073 | 0.0173* |
| | (0.0058) | (0.0075) | (0.0070) | (0.0138) | (0.0208) | (0.0070) | (0.0083) |

* Significant at 95% confidence level

**Table 2.** Estimates of Rate of Bias Technological Change/Rate of Output Price Alteration

| | Bias | | | | Alteration | | |
|---|---|---|---|---|---|---|---|
| | Capital | Labor | Chemicals | Materials | Other Outputs | Cereals | Perishable Crops |
| **Before IRCA** | 0.0059<br>(0.0052) | -0.0470*<br>(0.0062) | 0.0097<br>(0.0059) | 0.0313*<br>(0.0114) | 0.0146<br>(0.0250) | -0.0254*<br>(0.0107) | 0.0192*<br>(0.0070) |
| **After IRCA** | 0.0112<br>(0.0088) | -0.0683*<br>(0.0106) | 0.0102<br>(0.0100) | 0.0469*<br>(0.0197) | 0.0681<br>(0.0413) | -0.0487*<br>(0.0167) | 0.0476*<br>(0.0119) |

* Significant at 95% confidence level

**Table 3.** Estimates of Price Elasticity of Input Demand

| | Factor Price of | | | |
|---|---|---|---|---|
| **Demand for** | Capital | Labor | Chemicals | Materials |
| Capital | -0.1762*<br>(0.0490) | -0.0661<br>(0.0390) | 0.1543*<br>(0.0455) | -1.0624*<br>(0.0519) |
| Labor | -0.0531<br>(0.0314) | -0.0598<br>(0.0507) | 0.2160*<br>(0.0475) | -1.2534*<br>(0.0492) |
| Chemicals | 0.3901*<br>(0.1150) | 0.6787*<br>(0.1494) | -1.1413*<br>(0.1994) | -1.0779*<br>(0.1418) |
| Materials | 0.3134*<br>(0.0153) | 0.4597*<br>(0.0181) | 0.1258*<br>(0.0166) | -2.0493*<br>(0.0347) |

* Significant at 95% confidence level

**Table 4.** Estimates of Morishima Elasticity of Substitution

| **MESij** | Factor Price of j | | | |
|---|---|---|---|---|
| **Input Factor i** | Capital | Labor | Chemicals | Materials |
| Capital | N/A | -0.0063<br>(0.0617) | 1.2956*<br>(0.2276) | 0.9869*<br>(0.040) |
| Labor | 0.1231*<br>(0.0582) | N/A | 1.3572*<br>(0.2332) | 0.7960*<br>(0.0308) |
| Chemicals | 0.5664*<br>(0.1444) | 0.7385*<br>(0.1817) | N/A | 0.9714*<br>(0.1220) |
| Materials | 0.4896*<br>(0.0428) | 0.5195*<br>(0.0433) | 1.2670*<br>(0.1955) | N/A |

* Significant at 95% confidence level

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