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Immigrant Workers and Technological Change in U.S. Agriculture:

A Profit Maximization Approach of Induced Innovation

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Immigrant Workers and Technological Change in U.S. Agriculture:

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The international migration of labor for agriculture is a world-wide phenomenon, typically not sanctioned by the government of the host country. One of the recent controversial questions in U.S. agriculture is whether or not the recent slow pace of labor-saving innovation of new technology, specifically farm mechanization, is due to the availability of inexpensive foreign labor. An increasing flow of foreign workers, particularly unauthorized workers, can reduce farm wages below the level they would otherwise be. The National Agricultural Workers Survey (NAWS) reported that 53% of the hired crop labor force was unauthorized during 2001-2002 (U.S. Department of Labor, 2005). According to the induced innovation theory, the development of labor-saving technology would take place when the cost of labor becomes relatively more expensive than existing labor intensive technologies. There would be a diminished incentive to adopt and develop labor-saving technology while the supply of foreign workers remains abundant. Recognizing the effects of unauthorized workers on the welfare of the nation, the 1986 Immigration Reform and Control Act (IRCA) was passed in an effort to reduce the influx of unauthorized workers.

In this study we are interested in measuring the rate and bias of technological change in U.S. agriculture, particularly labor-saving technological change, and comparing them before and after the passage of IRCA. We emphasize the role of immigrant workers on innovations pertaining to farm mechanization. Hayami and Ruttan (1970) were the first to use the induced innovation theory in the study of agricultural development; however, their study was argued to lack a microeconomic foundation. Binswanger (1974a and 1974b) was the first to develop a microeconomic model based on the cost function approach. Following his work and to our knowledge, all previous empirical studies of technological change utilizing induced innovation

theory were based on a cost minimization model. Nevertheless, the cost minimization model has some limitations. First, agricultural output is assumed to be homogeneous and the production level is given. Second, it ignores changes in output combinations which become particularly important in the agricultural development process.

The following sections in this paper include the theoretical framework and the empirical profit maximization model of induced innovation. The empirical evidence of biased technological change in the U.S. is then shown for the 1960-1999 period.

Profit Maximization Model of Induced Innovation

The original cost function model of induced innovation does not permit an analysis of the effect of changes in output since it is assumed to remain constant. Thus, the profit maximization approach for the induced innovation model is a more appropriate alternative in the study of multi-input, multi-output technology. It recognizes the simultaneous determination of output mix and variable inputs for given prices. At a given time, the potential production processes are determined by the state of technology and the resource endowments. The *Innovation Production Possibility Frontier (IPPF)* is the envelope of all potential production processes that can be developed at a given time. Technological progress is defined as the upward shift of the IPPF, the envelope of production functions¹. Each potential production process is represented by a production function $f(x)$.

Figure 1 illustrates the concept of the IPPF and technological change in a simple case of a one output-one input technology. At time period 1, the innovation possibility frontier is represented by $IPPF_1$, the envelope of all less elastic production functions (e.g., $f_1(x)$) which are the potential technological processes at period 1. The isoprofit line, π , represents the profit for

¹ A change in technology in the cost minimization model of induced innovation is defined as the inward shift of the innovation possibility curve (IPC).

given input and output prices. Given that $\pi = py - wx$, the profit function defined in y - x space can be written as $y = \pi/p + (w/p)^*x$. The slope of the isoprofit line is equal to w/p , and a higher intercept implies higher profit. If given prices in period 1 represent π^* , the most profitable technology available under IPPF₁ is $Y_1 = f_1(x)$ where the slope of the isoprofit line coincides with the slope of the production function, the first order condition of profit maximization.

Assume that there is technological progress (an upward shift of IPPF) represented by IPPF₂ in period 2, but prices remain unchanged then the most profitable technological process in the second period is $Y_2 = f_2(x)$. The intercept of the new isoprofit line, π^{**} , is higher than that of π^* ; thus, the technological progress generates a higher profit at given prices. Figure 1 represents neutral technological progress (a parallel shift of IPPF); the new, most profitable technology produces more output and employs more input. An upward shift of IPPF results in higher profit and higher output, but the change in input is ambiguous depending on whether the shift is neutral or biased.

Figure 2 represents technological progress from IPPF₁ to IPPF₂, and an increase in price ratio $(w/p)^*$ to $(w/p)'$ for a one-output, one-input case. In period 1, π^* represents the profit given $(w/p)^*$, and the most profitable technological process is $Y_1 = f_1(x)$. After an increase in the price ratio to $(w/p)'$, the most profitable technological process is $Y_1' = f_1'(x)$. The increase in w/p resulted in reduced output and input levels. If there is technological innovation in period 2 resulting from the increase in w/p , output increases from Y_1' to Y_2 . In sum, an increase in w/p initially decreases the profit-maximizing output and input levels. However, if this price change induces a new set of potential technological processes that increase profit, the new technology will increase output, and may or may not change the input requirement. The combined effects of a change in price and technological progress on output and input levels are ambiguous.

In the case of more than one-input, one-output technology, it is unclear what a change in factor price or relative factor price would be on an output level. Recall that the uncompensated factor demand, $x_i^u(p, w)$, is the same as the compensated factor demand, $x_i^c(w, y^*)$, if the compensated factor demand is obtained from the cost minimization at the profit maximizing output level, y^* .

$$x_i^u(p, w) = x_i^c(w, y^*). \quad (1)$$

Suppose that there is a change in a factor price w_j . Taking the total derivative of (1) with respect to w_j ,

$$\frac{\partial x_i(p, w)}{\partial w_j} = \frac{\partial x_i(w, y^*)}{\partial w_j} + \frac{\partial x_i(w, y^*)}{\partial y} \frac{\partial y}{\partial w_j} \quad (2)$$

Factor demand changes may be decomposed into two effects: the *substitution effect*, represented by the first term on the right hand side, and the *output effect*, represented by the second term on the right hand side. If output does not change, the direction of a change in cost minimizing input requirements due to the substitution effect (*net effect*) can be determined by whether they are complements or substitutes. However, since there is an output effect which can counteract the substitution effect, the direction of change in profit maximizing inputs as a result of changes in factor prices (*gross effect*) becomes ambiguous.

Figure 3 illustrates changes in factor requirements as a result of substitution and output effects when there is a change in the factor price ratio in a profit maximization problem. As relative capital to labor prices increase from $(r/w)_1$ to $(r/w)_2$, a substitution effect will result in changes in compensated input demands due to cost minimization while holding output constant at Y_1 . This results in a movement along isoquant, Y_1 , from A to B which decreases the capital requirement from K_1 to K_1' and increases the labor requirement from L_1 to L_1' . When the increase in (r/w) is the result of an increase in r , for given w , it will increase marginal cost, and

consequently shift the isoquant inward (Y_2). When the increase in (r/w) is a result of a lower w , for given r , it will decrease marginal cost, and shift the isoquant outward (Y_3). Gross changes in input requirements are ambiguous.

As a result of the ambiguity of the impact of changes in input prices on the direction of input change, we will explain the profit maximization approach of induced innovation theory as an upward shift in the IPPF induced by changes in relative input prices. The result of *gross* biased input requirement changes determines the direction of biased technological change. Technological progress is defined as an increase in profit given that output and input prices remain unchanged:

$$\partial\pi/\partial t > 0 \text{ for given } p\text{'s and } w\text{'s} \quad (3)$$

An increase in profit could result from either, or both, an increase in output levels and a decrease in input requirements. Figure 4 gives an illustration of the profit maximized induced innovation model for a two-input, one-output technology. The IPC is used to demonstrate the concept of induced innovation analogously to IPPF.

An increase in relative factor prices from $(r/w)_1$ to $(r/w)_2$ results in a decrease in capital requirement and an increase in labor requirement by a substitution effect, a movement from A to B. A movement from technology at point A to point B does not require any innovation of new technology because they are both available under IPC_1 . IPC_1 could shift up IPC_1' or IPC_1'' via the output effect resulting in a different profit maximized production process. Holding the output level constant, an increase in relative capital to labor prices induces a new technological set IPC_2 which results in a further reduction of cost minimized input requirements. An increase in (r/w) could also induce a new set of technology that increases the output level, IPC_2' . The

gross effect of an increase in relative prices of capital to labor is ambiguous depending on how much IPC_2 and IPC_2' shift.

The example in Figure 4 is a neutral technological progress which means that holding factor price constant at $(r/w)_2$, the labor-capital ratio (L/K) remains constant as IPCs shift. Biased technological progress can be defined as a *gross* change in (L/K) given that output prices, input prices and fixed input quantities remain unchanged.

Rate of Technological Change and Biased Technological Change

A multi-output, multi-input variable profit function is defined as (Kohli, 1991):
 $\pi(Z, K, t) = \max_Q \{ZQ' | K, t\}$ for $Z > 0$ and $K \geq 0$, where Z is a given vector of N output and M input prices, and Q is a corresponding vector of quantities; K is a vector of L fixed inputs, R is a vector of fixed input prices, and t is a state of technology. Employing Euler's theorem, the linear homogeneity of the variable profit function in Z and K implies that

$$\frac{\partial \pi}{\partial t} = \sum_i Z_i \frac{\partial^2 \pi}{\partial t \partial Z_i} = \sum_j K_j \frac{\partial^2 \pi}{\partial t \partial K_j}. \quad (4)$$

Define the semielasticity of the supply of output and the demand of variable input with respect to the state of technology as:

$$\varepsilon_{it} \equiv \frac{\partial \ln Q_i}{\partial t}, \quad i = 1, \dots, N+M \quad (5)$$

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

$$\varepsilon_{jt} \equiv \frac{\partial \ln R_j}{\partial t} \quad j = 1, \dots, L \quad (6)$$

Dividing through by π , and using Hotelling's Lemma and the marginal revenue of fixed input condition, equation (4) can be written as:

$$\mu = \frac{\partial \ln \pi}{\partial t} = \sum_i \pi_i \varepsilon_{it} = \sum_j \pi_j \varepsilon_{jt}, \quad (7)$$

where μ is the *rate of technological change*, and π_i and π_j are profit shares of variable inputs and outputs, and those of fixed inputs, respectively. The rate of technological change is defined as the rate of growth in profit over time.

The *bias of technology* is defined as

$$B_i \equiv \varepsilon_{it} - \mu \quad i = 1, \dots, N+M \quad (8)$$

$$B_j \equiv \varepsilon_{jt} - \mu \quad j = 1, \dots, L \quad (9)$$

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. If technological change is unbiased or neutral, $B_i = B_j = 0$, and

$$\mu = \varepsilon_{it} = \varepsilon_{jt} \quad \forall i = 1, \dots, I; \forall j = 1, \dots, J \quad (10)$$

Data

It is important to use quality-adjusted price and quantity in the study of induced innovation because using indices unadjusted for quality will result in biased estimation of parameters in the induced innovation model. We obtained the quality-adjusted indices from Dr. Eldon Ball at Economic Research Service, USDA. The construction of this data set is similar to the ERS production account data (Ball, Butault, and Nehring 2001), but one difference is that contract labor is aggregated with hired labor instead of including it in the material inputs category in the published series. We use annual data from 1960 to 1999. There are four variable inputs - hired labor, self-employed labor, chemicals (fertilizers and pesticides), and materials

(feed, seed, and livestock purchases); two fixed inputs – capital (autos, trucks, tractors, other machinery, buildings, and inventories) and land; and two outputs - perishable crops (vegetables, fruits and nuts, and horticultural products) and all other outputs (livestock, cereals, forage, industrial crops, potatoes, household consumption crops, secondary products, and other crops).

Empirical Models

Assume that outputs $Y = (Y_1, Y_2)$ use variable inputs $X = (X_1, \dots, X_4)$ and fixed inputs $K = (K_1, K_2)$. The vectors of output prices, input prices and fixed input prices are denoted by $P = (P_1, P_2)$, $W = (W_1, \dots, W_4)$, and $R = (R_1, R_2)$, respectively. Let $Q = (Q_1, \dots, Q_6)$ be a vector of variable input and output quantities, and $Z = (Z_1, \dots, Z_6)$ be a corresponding price vector.

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

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

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. Utilizing Hotelling's Lemma and the result that the marginal revenue of a fixed input is equal to its cost under competitive conditions, share equations are derived as follows:

$$\pi_i = \alpha_i + \sum_{h=1}^5 \gamma_{ih} \ln \frac{Z_h}{Z_{matl}} + \delta_{ij} \ln \frac{K_j}{K_{capital}} + \delta_{it1} t + T_2 \delta_{it2} t + u_{it} \quad i = 1, \dots, 5 \quad (12)$$

$$\pi_j = \beta_j + \sum_{i=1}^5 \delta_{ij} \ln \frac{Z_i}{Z_{matl}} + \phi_{11} \ln \frac{K_{land}}{K_{capital}} + \phi_{1t1} t + T_2 \phi_{1t2} t + u_{jt} \quad j = 1 \quad (13)$$

We impose the restrictions for a well-behaved profit function as follows:

1. Homogeneity

$$\begin{aligned} \sum_{i=1}^5 \alpha_i &= 1; \quad \sum_{j=1}^2 \beta_j = 1 \\ \sum_{i=1}^5 \gamma_{ih} &= \sum_{h=1}^5 \gamma_{ih} = \sum_{j=1}^2 \phi_{jk} = \sum_{k=1}^2 \phi_{jk} = \sum_{i=1}^5 \delta_{ij} = \sum_{j=1}^2 \delta_{ij} = 0 \\ \sum_{i=1}^5 \delta_{it1} &= \sum_{i=1}^5 \delta_{it2} = \sum_{j=1}^2 \phi_{jt1} = \sum_{j=1}^2 \phi_{jt2} = 0 \end{aligned} \quad (14)$$

2. Symmetry

$$\gamma_{ih} = \gamma_{hi} ; \phi_{jk} = \phi_{kj} \quad (15)$$

3. Continuity

After introducing a dummy variable, the continuity at 1987 of the translog profit function requires that

$$\sum_{i=1}^5 \delta_{it2} \ln \frac{Z_i^{87}}{Z_{matl}^{87}} + \phi_{1t2} \ln \frac{K_{land}^{87}}{K_{capital}^{87}} + \beta_{t2} + \frac{1}{2} \phi_{tt2} t^{87} = 0 \quad (16)$$

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

4. Curvature

The profit function is convex with respect to variable input and output prices, and concave with respect to fixed input quantities. We imposed the curvature restrictions by using the Wiley-Schmidt-Bramble (W-S-B) reparameterization technique (Kohli, 1991, p.109-110). The W-S-B technique still does not guarantee global curvature, but by imposing the curvature at a particular point, we can assure that the curvature is satisfied locally. The curvature property of the profit function is first checked by Lau's Cholesky decomposition of the substitution matrix.

We found that the concavity was not violated at any observation, but the convexity was violated at all observations. We then imposed the convexity at the most violated point (the most negative Cholesky value of the substitution matrix of variable inputs and outputs) in 1983 following the W-S-B reparameterization technique.

The rate of technological change by the definition in Eq. (7) is written as

$$\mu = \beta_t + \beta_{t2} * T_2 + \sum_{i=1}^5 \delta_{it1} \ln \frac{Z_i}{Z_{mat1}} + T_2 \sum_{i=1}^5 \delta_{it2} \ln \frac{Z_i}{Z_{mat1}} + \phi_{t1} \ln \frac{K_{land}}{K_{capital}} + T_2 \phi_{t2} \ln \frac{K_{land}}{K_{capital}} + \phi_{tt} t + \phi_{tt2} t * T_2 \quad (17)$$

Following from Eq. (12),

$$\frac{\partial \pi_i}{\partial t} = \frac{Z_i}{\pi} \frac{\partial Q_i}{\partial t} - \frac{Q_i Z_i}{\pi^2} \frac{\partial \pi}{\partial t} = \delta_{it1} + T_2 \delta_{it2} \quad i = 1, \dots, 6 \quad (18)$$

solving for $\partial Q_i / \partial t$ from Eq. (18) and dividing by Q_i ,

$$\varepsilon_{it} \equiv \frac{1}{Q_i} \frac{\partial Q_i}{\partial t} = \frac{\delta_{it1} + T_2 \delta_{it2}}{\pi_i} + \frac{\partial \ln \pi}{\partial t} \quad (19)$$

$$\varepsilon_{it} = \frac{\delta_{it1} + T_2 \delta_{it2}}{\pi_i} + \mu \quad (20)$$

$$\text{Thus, } B_i = \frac{\delta_{it1} + T_2 \delta_{it2}}{\pi_i} \quad i = 1, \dots, 6 \quad (21)$$

Similarly, the technological change of fixed inputs is calculated as

$$B_j = \frac{\phi_{jt1} + T_2 \phi_{jt2}}{\pi_j} \quad j = 1, 2 \quad (22)$$

Results

The parameter estimates of the profit function are presented in Table 1. Figures 5 to 7 illustrate the rate and bias of technological change over time. Except for capital, technological change was biased against all outputs and inputs prior to 1986. After 1986, the technology became perishable crops-producing, less self-employed labor-saving, and more land-saving. Although insignificant, the technology was less hired labor-saving and less chemical-saving, and the biases against other outputs increased after 1986. After 1986, the technology was dramatically biased against materials until 1991 when it became materials-using.

Table 2 reports the average of U.S. biases before and after the passage of IRCA, and the differences between them. The technology was significantly biased against all outputs and inputs, except capital, before IRCA. After IRCA, the technology became significantly less hired and self-employed labor-saving; however, the use of capital was not significantly different. The technology became significantly more perishable crops-producing, but became significantly more other outputs-reducing. The technological bias shifted significantly in the direction of chemicals-using while there was no significant difference in the bias toward materials or land. The passage of IRCA coincided with a significant shift in technological bias toward employing more hired labor. Although the direction of bias toward land and capital did not change, it was significantly land-saving and capital-using in both periods.

IRCA coincided not only with U.S. producers failing to shift to a more labor-saving technology, but rather with a shift toward more labor-using technology at the same time that the presence of illegal foreign workers was increasing (Mehta et al. 2000). In addition, the change in the adoption of mechanized technology was insignificant in the post-IRCA period as compared to pre-IRCA. However, the passage of IRCA coincided with greater profitability in the production of perishable crops and reduced profitability in the production of the other outputs category. The production of perishable crops increasingly involved the employment of foreign workers (Mehta et al. 2000), and the bias in favor of these commodities suggested that producers utilized technologies favoring both perishable commodities and more hired labor. As the technology became more perishable crops-producing and more other outputs-reducing with IRCA, the technology became significantly more chemicals-using. The agricultural land-saving characteristic of technology did not significantly change with IRCA.

Rates of technological change were estimated both at observed prices and fixed input quantities, and holding both prices and fixed input quantities constant. The rate of technological change at observed prices and fixed input quantities was significantly different than zero at 5% significance level from 1960 to 1994; from 1995 to 1999 they were insignificant at greater than the 30% level. The rate of technological change at constant prices and fixed input quantities was significant at the 0.01% level from 1960 to 1990. It became significant at the 5% level for the remaining years, except for 1992 to 1994 when it was insignificant. Figure 9 shows that the rate of technological change at observed prices and observed fixed inputs declined from 16% to -0.9%. The rate of technological change at constant prices and constant fixed inputs (at 1983) declined from 21% to -7.8%; however, it declined more rapidly after 1986, with the implementation of IRCA.

Conclusion

This paper presents an alternative theoretical framework and an empirical model of induced innovation theory by applying a profit maximization model instead of the typical cost minimization model. The profit model adds information on the changes in output mixtures in addition to changes in input combinations when analyzing technological change. The technological change is defined as a shift in Innovation Production Possibility Frontier (increasing in profit). And the bias is defined as the difference between the rate of technological change and the semielasticity of the supply of output and the demand for variable inputs (or the semielasticity of the inverse fixed input demand) with respect to the state of technology.

We found that during 1960-1999, the technology was biased against perishable crops and other outputs before IRCA, but changed to produce more perishable crops and less other outputs after IRCA. Although the technology remained biased toward the use of capital throughout the

study period, IRCA did not have a significant impact on the adoption of mechanized technology. The technology was biased against the use of both hired and self-employed labor, and became significantly more hired labor-using after the passage of IRCA.

This suggests that even if the passage of IRCA to reduce the number of unauthorized foreign workers increased the risk adjusted cost of hiring illegal foreign labor, the incentives remained to use labor relative to the use of capital. Possible explanations for the increased use of hired labor are the increased availability of inexpensive undocumented immigrant workers, inadequate research investment from the private sector, and the lack of political interest to promote the development of a more affordable mechanized technology.

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U.S. Department of Labor, Office of the Assistant Secretary for Policy, 2005. Findings from the National Agricultural Workers Survey (NAWS) 2001 - 2002. A Demographic and Employment Profile of United States Farm Workers, Research Report No. 9.

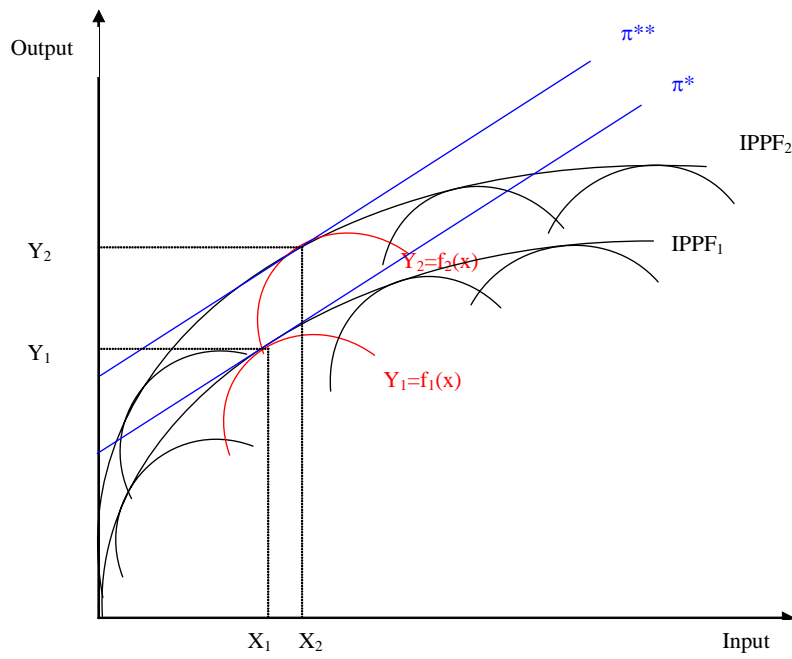


Figure 1. Innovation production possibility frontier and technological progress.

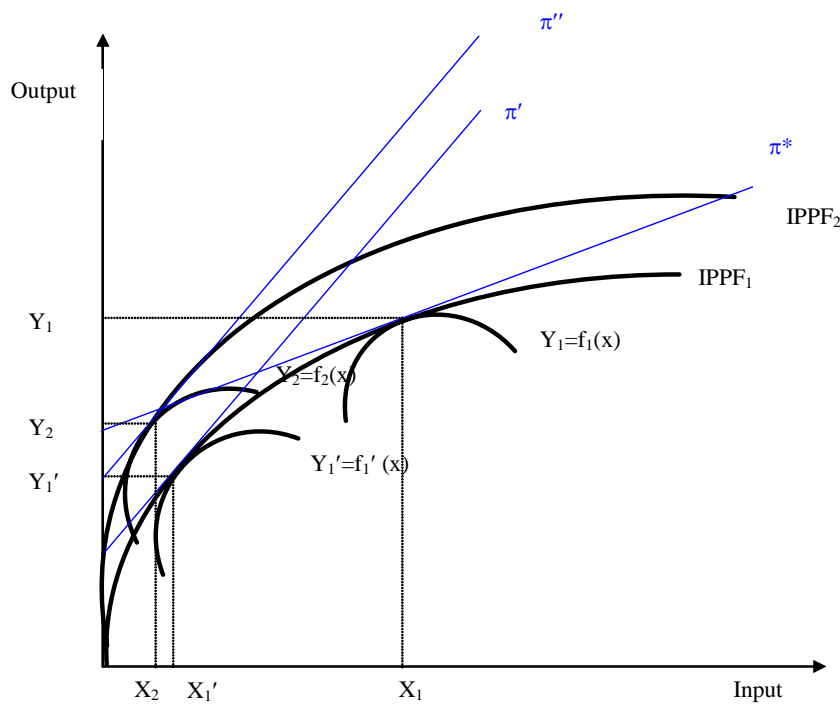


Figure 2. Technological progress and a change in prices.

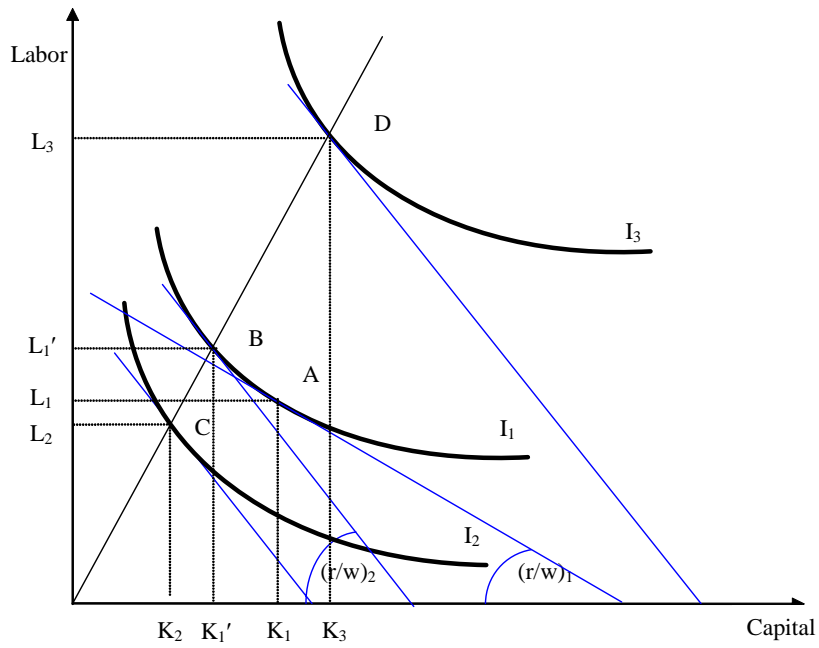


Figure 3. Substitution and output effects of profit maximization.

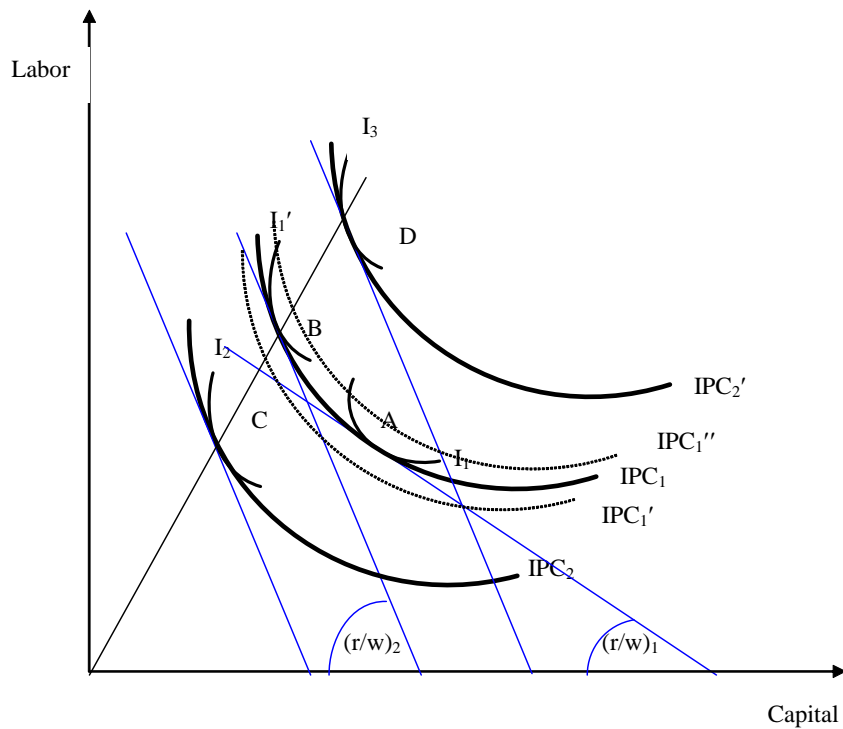


Figure 4. Induced innovation for profit maximizing technological change.

Table 1. Parameter estimates with homogeneity, symmetry, and convexity constraints.

Parameter	Estimate	Parameter	Estimate	Parameter	Estimate
α_0	10.8014* (0.0335)	γ_{hlc}	-0.0823* (0.0227)	δ_{pt1}	-0.0130* (0.0017)
α_{oout}	2.9035* (0.0676)	γ_{hlm}	-0.4311* (0.0573)	δ_{pt2}	0.0200* (0.0040)
α_{persh}	0.2969* (0.0107)	γ_{slsl}	-0.4318* (0.0849)	δ_{hlt1}	0.0187* (0.0014)
α_{hired}	-0.1732* (0.0085)	γ_{slc}	-0.1048* (0.0257)	δ_{hlt2}	-0.0154* (0.0031)
α_{self}	-0.3610* (0.0182)	γ_{slm}	-0.4249* (0.0687)	δ_{slt1}	0.0453* (0.0025)
α_{chem}	-0.2163* (0.0085)	γ_{cc}	-0.1204* (0.0283)	δ_{slt2}	-0.0254* (0.0065)
α_{matl}	-1.4499* (0.0495)	γ_{cm}	-0.3028* (0.0746)	δ_{ct1}	0.0153* (0.0015)
β_{land}	0.6213* (0.0345)	γ_{mm}	-3.3660* (0.2358)	δ_{ct2}	-0.0153* (0.0029)
$\beta_{capital}$	0.3787* (0.0345)	δ_{ol}	-2.4437* (0.3145)	δ_{mt1}	0.1042* (0.0064)
γ_{oo}	-5.2432* (0.3361)	δ_{pl}	-0.2692* (0.0745)	δ_{mt2}	0.1379* (0.0279)
γ_{op}	-0.9694* (0.0619)	δ_{hll}	0.1951* (0.0552)	ϕ_{ll}	-0.6090* (0.2563)
γ_{ohl}	0.6966* (0.0607)	δ_{sll}	0.1151 (0.1005)	ϕ_{lk}	0.6090* (0.2563)
γ_{osl}	0.9922* (0.0876)	δ_{cl}	0.4519* (0.0522)	ϕ_{kl}	0.6090* (0.2563)
γ_{oc}	0.4794* (0.0725)	δ_{ml}	1.9507* (0.2701)	ϕ_{kk}	-0.6090* (0.2563)
γ_{om}	4.0442* (0.2580)	δ_{ok}	2.4437* (0.3145)	ϕ_{lt1}	-0.0223* (0.0078)
γ_{pp}	0.2510* (0.0260)	δ_{pk}	0.2692* (0.0745)	ϕ_{lt2}	-0.0180 (0.0126)
γ_{phl}	-0.0127 (0.0382)	δ_{hlk}	-0.1951* (0.0552)	ϕ_{kt1}	0.0223* (0.0078)
γ_{psl}	0.1193* (0.0290)	δ_{slk}	-0.1151 (0.1005)	ϕ_{kt2}	0.0180 (0.0126)
γ_{pc}	0.1309* (0.0263)	δ_{ck}	-0.4519* (0.0522)	β_t	0.0924* (0.0057)
γ_{pm}	0.4809* (0.0560)	δ_{mk}	-1.9507* (0.2701)	β_{t2}	0.0208* (0.0052)
γ_{hlhl}	-0.0205 (0.1116)	δ_{ot1}	-0.1705* (0.0080)	ϕ_{tt}	-0.0053* (0.0007)
γ_{hlsl}	-0.1500 (0.0915)	δ_{ot2}	-0.1017* (0.0213)	ϕ_{tt2}	-0.0067* (0.0022)

Note: Estimated standard errors are in parentheses; convexity imposed in 1983.

o=other outputs, p=perishable crops, hl=hired labor, sl=self-employed labor, c=chemicals, m=materials, l=land, k=capital.

Table 2. U.S. biased technological change calculated at the means.

	Pre-IRCA	Post-IRCA	Difference
Other Outputs	-0.0466* (0.0019)	-0.2436* (0.1006)	-0.1970* (0.0988)
Persh Crops	-0.0362* (0.0044)	0.0128* (0.0051)	0.0490* (0.0086)
Hired Labor	-0.0659* (0.0042)	-0.0113 (0.0101)	0.0547* (0.0125)
Self-employed	-0.0628* (0.0031)	-0.0337* (0.0109)	0.0291* (0.0129)
Chemicals	-0.0662* (0.0055)	-0.0000 (0.0095)	0.0661* (0.0123)
Materials	-0.0584* (0.0033)	0.4999 (0.3260)	0.5583 (0.3231)
Land	-0.0426* (0.0147)	-0.0688* (0.0184)	-0.0262 (0.0230)
Capital	0.0466* (0.0168)	0.0969* (0.0239)	0.0503 (0.0290)

Note: Estimated standard errors are in parentheses.

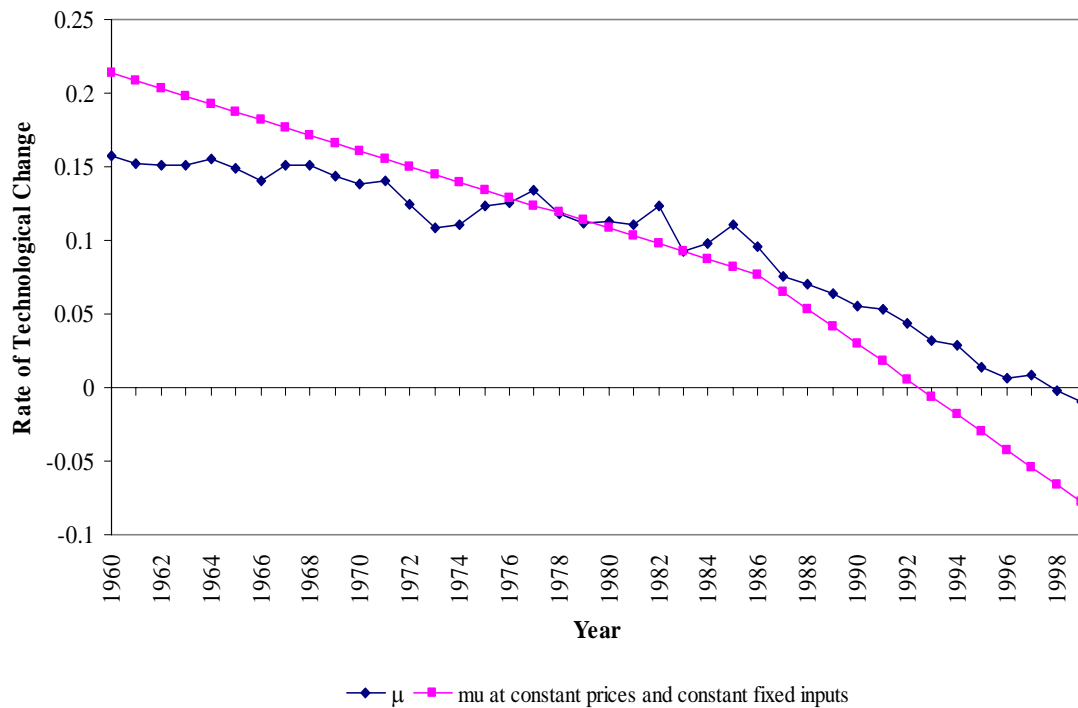


Figure 5. Rate of technological change.

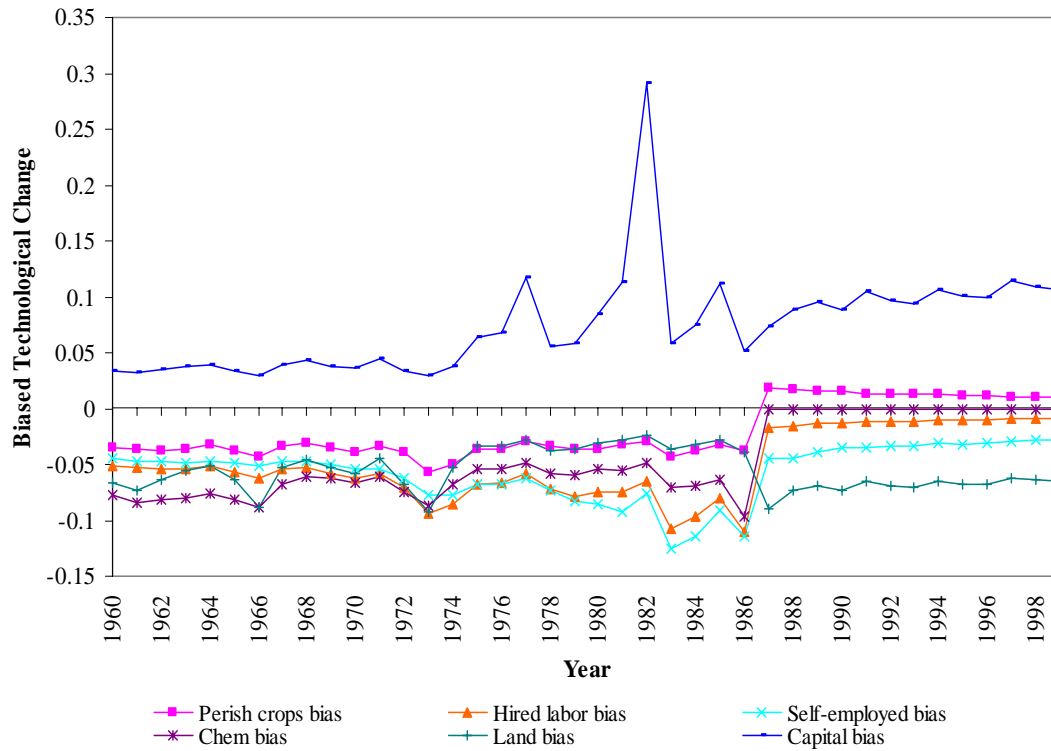


Figure 6. Biased technological change.

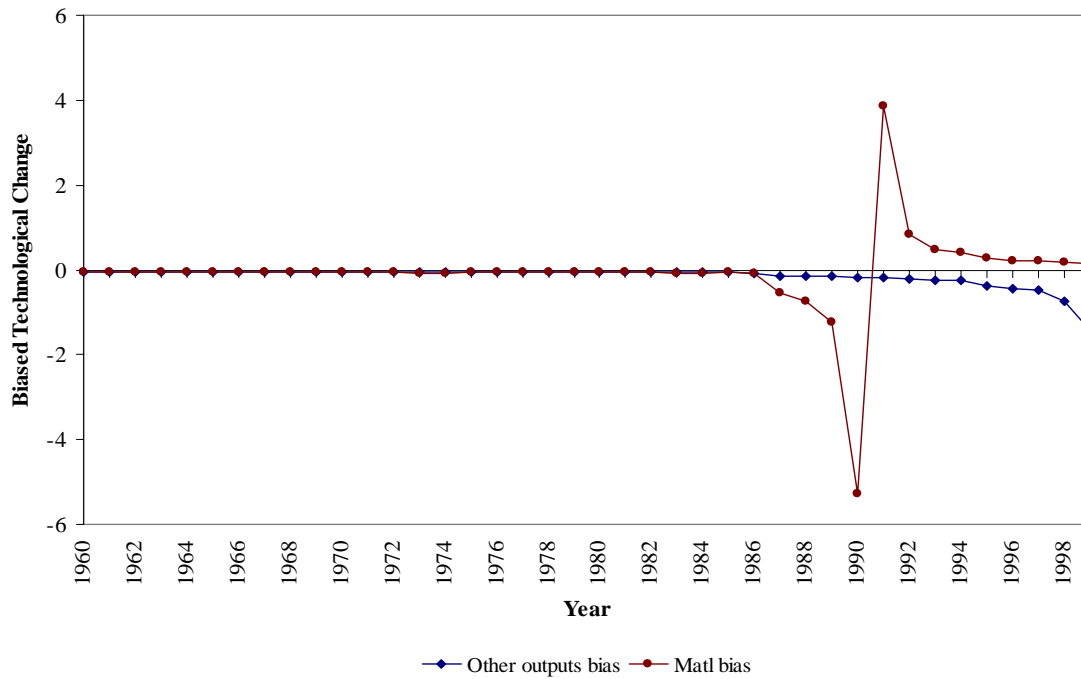


Figure 7. Biased technological change, other outputs and materials.