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Abstract

The hypothesis of induced innovation has been empirically tested in many ways, using a wide variety of data and test periods for many industries in many countries. However, each test has maintained the hypothesis that the relative marginal cost of developing and implementing technologies that save one input is the same as for any other input. Lacking data on development and implementation costs of input-saving technologies, we develop and use a nonparametric procedure to estimate relative differences required for technical change in U.S. agriculture to be consistent with the induced innovation hypothesis.

***Key words*:** induced innovation, marginal cost, nonparametric

JEL Classification Codes: O300, D240

Induced Innovation and Marginal Cost of New Technology

1. Introduction

One of the foundational economic theories of technical change is induced innovation. First proposed by Hicks in 1932, it asserts that changes in relative prices of factors are expected to induce development and implementation of new technology to save relatively more expensive factors. It explains the nature of technical change by justifying impacts of research investments and provides a systematic theoretical basis for productivity growth. Since empirical research on the induced innovation hypothesis (IIH) began (Hayami and Ruttan, 1970), it has been tested in many countries and industries.

U.S. agriculture has been the most tested. By 1990, a stylized fact emerged that technical change in U.S. agriculture was generally consistent with this hypothesis (e.g., Kawagoe *et al*., 1986). Using a broader array of testing procedures and data, recent empirical evidence has been mixed and suggests the need to reconsider its theoretical intuition.

However, only the demand side of the hypothesis has been tested. Although Binswanger (1974) and Olmstead and Rhode (1993) both acknowledged the demand-side nature of their hypothesis tests, most others have been silent about this important limitation. All tests have maintained the hypothesis that the marginal cost of developing and implementing technologies that save one input is the same as for saving an equal percent of another input. Since innovation possibilities are unlikely to be this neutral, the IIH could provide a valid explanation and yet producers could augment cheaper factors with cheaper marginal cost of augmentation.[1]

Unfortunately, data on augmentation costs for saving different inputs are lacking. In this paper, we approach the testing problem indirectly by asking which inputs must have higher

[1] Cheaper inputs could also be augmented if their partial elasticities of substitution are greater than |1.0|, but such high elasticity estimates are rare for aggregated input categories in agriculture.

marginal costs of developing and implementing input-saving technology for the observed evidence to be consistent with the IIH.

2. Methodology

Output (Y) is produced using land (*A*), materials (*M*), labor (*L*), and capital (*K*) inputs. Our nonparametric model builds on Varian (1984) and Chavas *et al*. (1997). We assume (a) profit maximizing behavior, (b) closed, convex, and monotonic technology set, and (c) factor augmentation. The actual netput vector at observation *t* is $\boldsymbol{X}_t = (Y_t,\ \text{-}X_{A,t},\ \text{-}X_{M,t},\ \text{-}X_{L,t},\ \text{-}X_{K,t})$, with associated price vector $\boldsymbol{P}_t = (P_{Y,t}, P_{A,t}, P_{M,t}, P_{L,t}, P_{K,t})'$. Feasible netput choices satisfy $\boldsymbol{X}_t \in \boldsymbol{F}$, where $\boldsymbol{F}$ is the feasible technology set.

The technology-constant "effective" netput vector is $\boldsymbol{x}_t = (x_{Y,t}, x_{A,t}, x_{M,t}, x_{L,t}, x_{K,t})'$, which is a function of actual netput levels and their augmentations, $B_{i,t}$:

(1) $$x_{i,t} = g(X_{i,t}, B_{i,t}), \quad i = Y, A, M, L, K, \quad t \in T\ .$$

We treat $g(X,\cdot)$ as a reversible function, specify augmentation following the translating hypothesis, i.e., $\boldsymbol{X}_i = \boldsymbol{x}_i + \boldsymbol{B}_i$, and maintain three augmentation restrictions to implement nonparametric testing of the IIH.

The first restriction specifies the relationship between innovation investments and input augmentation: [2]

(2) $$B_{i,t} = \alpha_{i,t} + \sum_{j=0}^{\mathbf{r}} \left\{ [\boldsymbol{\beta}_{i,j} + (p_{i,t-j} - 1)\boldsymbol{\gamma}_{i,j}]\boldsymbol{R}_{t-j} \right\},\ i = A, M, L, K, \quad t \in T\ ,$$

where $p_{i,t\text{-}j}$ is price of input *i* relative to a Tornqvist index of all input prices at time *t-j* (it equals 1.0 if its price moves in proportion to the index of all input prices); the vector $\boldsymbol{R}_{t\text{-}j}$ denotes

[2] Since we use an aggregate index for outputs, the following specification governs output augmentation: $B_{y,t} = \alpha_{y,t} + \sum_{j=0}^{r} \beta_{y,t} R_{t-j},\ t \in T$.

innovation investments including private research (R_{pri}), public research (R_{pub}), and public extension (*Ext*); parameter $\alpha_{i,t}$ measures impact of exogenous shocks on augmentation; $\boldsymbol{r}$ is a vector of the maximum number of lags on innovation investments; j is lag number; $\boldsymbol{\beta}_{i,j}$ is a parameter vector measuring the marginal effect of $\boldsymbol{R}_{t-j}$ in lagged period j on $B_{i,t}$ for constant relative prices; parameter vector $\boldsymbol{\gamma}_{i,j}$ measures interaction effect of $p_{i,t-j}$ and $\boldsymbol{R}_{t-j}$ on $B_{i,t}$. Maximum number of lags is 28 for public research, 21 for private research, and 10 for extension. The IIH requires that $\boldsymbol{\gamma}_{i,j} > 0$ for some j with no $\boldsymbol{\gamma}_{i,j} < 0$.

Parameter vector $\boldsymbol{\beta}_{i,j}$ in equation (2) is crucial for our purposes because it contains information on the marginal cost of augmenting inputs. It measures marginal effect of a unit investment in an innovation activity in lagged period j on current productivity of each input given constant relative input prices. Its inverse represents marginal cost of creating a 1% increase in productivity of each input given constant relative input prices. Their inverse ratios measure relative marginal costs of augmenting inputs under revealed consistency with the IIH.

The second restriction smoothes output augmentation variables when nonregressive technical change is subject to random weather effects:

(3) $$B_{y,t} \geq \left(\sum_{j=1}^{5} B_{y,t-j}\right)/c\,.$$

We require output augmentation to be at least as large as a 5-year moving average of previous values, so downward trending augmentation is not permitted.

The third restriction assures nonnegative marginal effect of innovation investments on augmentation indices:

(4) $$\partial B_{i,t}/\partial \boldsymbol{R}_{t-j} = \boldsymbol{\beta}_{i,j} + (p_{i,t-j} - 1)\boldsymbol{\gamma}_{i,j} \geq 0,\ \ i = A, M, L, K,\ \ j = 1, \cdots, r_i$$, and

(5) $$\partial B_{y,t}/\partial \boldsymbol{R}_{t-j} = \boldsymbol{\beta}_{y,j} \geq 0,\ \ j = 1, \cdots, r_y\,.$$

Using marginal cost information embodied in the inverse of the $\boldsymbol{\beta}$'s, we compute minimum differences in marginal costs of developing and implementing input-saving technology for each input by including one additional restriction, that actual observations are consistent with the IIH:

(6) $\quad \gamma_{i,j} \geq \varepsilon, \forall i \in N, \forall j \in r_i,$

where ε is an arbitrarily small positive number, 0.0000001.

Extending Chavas *et al*. (1997), we solve the quadratic programming problem:

$$\text{(7)} \quad \min_{B,\alpha,\boldsymbol{\beta},\gamma} \left[\sum_{i \in N} \left\{ \sum_{t \in T} w_1 \alpha_{i,t}^2 + \sum_j (w_2 \boldsymbol{\beta}_{i,j} \boldsymbol{\beta}'_{i,j} + w_3 \gamma_{i,j} \gamma'_{i,j}) \right\} : \begin{array}{l} (X_{i,t} - B_{i,t}) \geq 0,\ i = Y; \\ (X_{i,t} - B_{i,t}) \leq 0,\ i = A, M, L, K; \quad t \in T; \\ \text{WAPM; the five restrictions (2), (3), (4), (5) and (6)} \end{array} \right]$$

where w_1, w_2, w_3 are positive weights (1.0 to give equal weight to each augmentation index). Equation (7) minimizes the weighted sum of squared parameters measuring various sources of impact on technical change over time. The intuition is to make the augmentation indices "as close to the data as possible" by searching for the smallest absolute values of the α's, $\boldsymbol{\beta}$'s, and γ's that satisfy WAPM and the IIH. It provides a simple framework for investigating relative differences in the marginal costs of technology development and implementation for the IIH to have been the sole motivation for input-saving technologies in the U.S. farm sector.

To create summary marginal cost measures, the implied marginal cost for the i^{th} input at each lag is discounted to the current period (j = 0) using a real discount rate of 0.03 and summed across j for each innovation investment type. For computational economy, we conduct the analysis for only nine states. A broad cross-section of major agricultural states was selected. They represent all regions of the U.S. – FL, NC, NY in the east, TX, IA, KS, MI in the center, and CA, WA in the west.

3. Data

Our estimation period was 1960-1999. Panel input quantity and price data for the 48 contiguous states for this period came from Ball *et al*. (2004). This aggregate data set includes a comprehensive price and quantity inventory for farm outputs and four categories of farm inputs (capital, land, labor, and materials) compiled to preserve the integrity of national and state production accounts consistent with a gross output model of production. To capture induced effects of earlier innovation investments, input prices were needed prior to 1960. Lacking an existing series, state-level input prices for the period 1932-1959 were estimated by backward forecasting of regressions of Ball's state-level prices on U.S. prices.

Deflated annual state-level agricultural public research investment data for 1927-1995 were from Huffman (2005), and agricultural extension investments for 1951-1996 were from Huffman, Ahearn, and Yee (2005). Private research investments were proxied by private patent numbers for use in agriculture compiled by Johnson (2005).

4. Empirical Results

We calculated relative differences in the marginal costs of developing and implementing saving technologies for all inputs to be consistent with the IIH. Qualitative pairwise results of nonparametric computations are reported for each state in Table 1.

For differences in marginal costs of technology development and implementation to render data consistent with the IIH, the marginal cost of land- and capital-saving technologies must have been greater than the marginal cost of material-saving technologies in nearly all states.[3] This finding was robust across the various types of input-saving innovation investment (i.e., public research and extension and private research). If these marginal cost differences actually existed, then higher cost of developing and implementing land- or capital-saving technologies could have induced profit-maximizing technical change that was biased toward augmenting materials even when land and capital were more expensive.

The marginal cost of developing and implementing land-saving technology must also have been greater than for labor-saving technology in most states for all types of innovation investment. The marginal cost of land-saving technology must have been greater than for capital-saving technology in all states for research investments and in a majority of states for extension investments. This same observation also applies in nearly all states for labor vs. material-saving technologies. However, the order ranking of required marginal cost differences for labor and capital was less clear. For private research investments, 2/3 of the states required higher marginal costs for labor-saving technologies than for capital-saving technologies. Nearly the reverse was found for extension investments, and neither dominated for public research investments.

5. Conclusions

Although empirical tests of the induced innovation hypothesis have increasingly shown lack of support, all tests have been limited to innovation demand. It could be a valid hypothesis and yet fail these tests because the marginal cost of developing and implementing technology to save expensive inputs is so much higher than to save cheaper inputs.

Unfortunately, data do not exist for a comprehensive test. Instead, we proposed and applied a nonparametric procedure to determine differences in marginal cost of developing and implementing input-saving technology in U.S. agriculture if the hypothesis were valid. For

[3] This conclusion was not altered by adjusting implied marginal cost by the cost share of the input. The cost shares averaged across states and years for materials (45%) was greater than for labor (23%), which in turn was greater than for capital (19%) and land (13%).

consistency with the hypothesis, we estimated that the marginal cost of developing and implementing technology to save 1% of an input could be similar for labor and capital but must be greater for land and capital than for materials and greater for land than for labor.

References

Ball, V.E., Hallahan, C., and Nehring, R., 2004. Convergence of Productivity: An Analysis of the Catch-up Hypothesis within a Panel of States. *American Journal of Agricultural Economics* 86, 1315-1321.

Binswanger, H.P., 1974. The Measurement of Technical Change Biases with Many Factor of Production. *American Economic Review* 64, 964-967.

Chavas, Jean-Paul, Aliber, M., and Cox, T.L. "An Analysis of the Source and Nature of Technical Change: The Case of U.S. Agriculture. *Review of Economics and Statistics* 79, 482-492.

Hayami, Y. and Ruttan, V.W., 1970. Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960. *The Journal of Political Economy* 78, 1115-1141.

Hicks, J. R., 1932. *The Theory of Wages.* London: Macmillan.

Huffman, W.E., 2005. Agricultural Public Research Expenditure Data. Unpublished, Ames: Iowa State University.

Huffman, W.E., Ahearn, M., Yee, J., 2005. Agricultural Extension Expenditure Data. Unpublished, Ames: Iowa State University, and Washington: U.S. Department of Agriculture Economic Research Service.

Johnson, D.K.N., *USHiPS*: *The U.S. Historical Patent Set*, Retrieved from http://faculty1.coloradocollege.edu/~djohnson/uships/histstat.xls (2005).

Kawagoe, T., Otsuka, K., Hayami, Y., 1986. Induced Bias of Technical Change in Agriculture: the United States and Japan 1880-1980. *Journal of Political Economy* 94, 523-544.

Liu, Y. and Shumway, C. R., 2008. Induced Innovation in U.S. Agriculture: Time Series, Direct Econometric, and Nonparametric Tests. *American Journal of Agricultural Economics*, forthcoming.

Olmstead, A.L., Rhode, P.W., 1993. Induced Innovation in American Agriculture: A Reconsideration. *Journal of Political Economy* 101, 100-118.

Varian, H.R., 1984. The Nonparametric Approach to Production Analysis. *Econometrica* 52, 579-598.

Table 1. IIH-Consistent Marginal Costs of Input-Saving Technology

Input Pair	Marginal Cost Relationship	Input-Saving Innovation Investments		
		Private Research	Public Research	Extension
Land(A) vs. materials(M)	$MC_A > MC_M$	CA, FL, IA, KS, MI, NC, NY, TX, WA	CA, FL, IA, KS, MI, NC, NY, TX, WA	CA, FL, IA, KS, MI, NC, NY, TX, WA
Labor(L) vs. capital(K)	$MC_L > MC_K$	CA, FL, KS, NY, TX, WA	CA, FL, KS, TX, WA	CA, KS, WA
	$MC_L = MC_K$			FL
	$MC_L < MC_K$	IA, MI, NC	IA, MI, NC, NY	IA, MI, NC, NY, TX
Land vs. capital	$MC_A > MC_K$	CA, FL, IA, KS, MI, NC, NY, TX, WA	CA, FL, IA, KS, MI, NC, NY, TX, WA	CA, KS, NC, NY, WA
	$MC_A = MC_K$			FL, IA, MI,TX
Labor vs. materials	$MC_L > MC_M$	CA, FL, IA, KS, NC, NY, TX, WA	CA, FL, IA, KS, NC, TX, WA	CA, FL, IA, KS, WA
	$MC_L < MC_M$	MI	MC, NY	MI, NC, NY, TX
Land vs. labor	$MC_A > MC_L$	CA, IA, KS, MI, NC, NY, TX, WA	IA, MI, NC, NY, WA	IA, MI, NC, NY, TX, WA
	$MC_A = MC_L$	FL	FL	FL, KS
	$MC_A < MC_L$		CA, KS, TX	CA
Capital vs. materials	$MC_K > MC_M$	CA, FL, IA, KS, NC, TX, WA	CA, FL, IA, KS, MI, NC, NY, TX, WA	CA, FL, IS, KS, MI, NC, TX, WA
	$MC_K < MC_M$	MI, NY		NY