The induced innovation test (co-integration analysis) of Iranian agriculture

Test indukovaných inovací (kointegrační analýza) íránského zemědělství

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Abstract: Technological change is a determinant index for agriculture that can lead to the productivity growth by either increasing the total output or increasing the usage of relatively cheap inputs and reducing the relatively expensive inputs. The determination of the magnitude and the direction of technological change in agricultural production has attracted much attention and has become the focal point of intense research efforts over the last couple decades. This topic is frequently studied in two different ways. One is considering the efforts of investment in the research and development technological change. The other is explaining the technological change by testing induced innovation hypothesis that was first proposed by Hicks. Therefore, in this study, with the help of time series by using the cointegration analysis, the induced innovation hypothesis is tested and the effect of investment in agricultural research on technological changing is considered.

Key words: induced innovation, agriculture, cointegration analysis, Iran

Abstrakt: Technologické změny jsou základní determinantou pro zemědělství vedoucí k růstu produktivity buď zvyšováním celkového outputu, nebo zvyšováním využití relativně levnějších a omezováním relativně dražších inputů. Determinace velikosti a směru technologických změn v zemědělské produkci je předmětem pozornosti, stala se ústředním bodem intenzivního výzkumu v posledních desetiletích a je často zkoumána ze dvou hledisek. Jedno se zabývá investicemi do výzkumu a rozvoje technologií. Druhé hledisko vysvětluje technologické změny testováním indukovaných inovací na základě hypotézy, kterou poprvé navrhl Hicks. Ve studii se na základě kointegrační analýzy časových řad testuje hypotéza indukovaných inovací a hodnotí efekt investic do zemědělského výzkumu na technologické změny.

Klíčová slova: indukované inovace, zemědělství, kointegrační analýza, Írán

Technological change can lead to productivity growth by either expanding the total output or increasing application of the relatively cheap inputs and trimming down use of the more or less expensive inputs. The direction of technological change in agricultural production has been the subject of intense research efforts over the last thirty years (Huffman and Evenson 1993). This topic is frequently studied in two different ways. One is to consider the effects of investment in research and development on technological change (Evenson 1993; Alston et al. 1998; Evenson, Mckinsey 1991). The other is to explain technological change by testing the induced innovation hypothesis (Hicks 1932; Hayami, Ruttan 1970; Binswanger 1974; Lee 1983; Kawagoe et al. 1986; Clark, Youngblood 1992; Baldi, Casati 2005; Hockmann, Kopsidis 2005).

The theory of induced innovation was introduced in the early 1970s by Hayami and Ruttan (Hayami, Ruttan 1970). It stresses the significance of demand as the major source of research incentives. Ruttan (2001) admits that not all research should be considered as demand driven. Especially in basic research, the supply push component may be considerable. However, the induced innovation hypothesis concerns mainly applied research, and thus, research activities conducted by private companies which are mainly demand driven. Without an at least dormant demand for new products, firms could not put on their product in the market and no incentives for research exist. For example, if an imperfect factor and capital markets ground a decline in the effective demand, the investments in research remain too low.

Hayami and Ruttan in their Theory of Induced Innovation demonstrated that depending on the factors and products price relations, diverse kinds of technical change, technologies, and institutions are required to materialize agricultural growth in a most efficient way. There is no technology that fits every economy as the early development economics had assumed taking the USA and Europe as models for all developing economies completely ignoring the very different factor price relations (Hayami, Ruttan 1985).

Based on the hypothesis of Hayami and Ruttan (1970), when the relative factor prices change, a cost-minimizing producer will adopt a new technology which saves inputs which are relatively more expensive. So the technological change induced by input prices makes the isoquant shift along a long-run equilibrium path. Their basic model regressed the logarithms of the factor ratios on the logarithms of the factor price ratios using the aggregate data of the U.S. and Japan for 1880–1960. Hayami and Ruttan's tests were ad hoc, and the most important limitation was the failure to distinguish between the technological change effects and the effects of factor substitution under the given technology (Oniki 2000). In order to distinguish these two effects, Binswanger (1974) incorporated a time trend variable (proxy for technological change) in a translog cost function. Hayami & Ruttan (1970) and Binswanger (1974) found consistency with the induced innovation hypothesis. This approach has been applied in subsequent empirical studies with modest variation (e.g., Kawagoe et al. 1986; Kuroda 1987; Yuhn 1991; Lin 1991; Terrel 1993).

Clark and Youngblood (1992) proposed a time series approach to test the induced innovation. According to their method, if the co-integration exists among the non-stationary variables, there is no bias in the technological change since the residual of the translog share function is stationary. On the other hand, if there is no co-integration among the variables, the residual is non-stationary and the technological change effects are included in the residual. Clark and Youngblood proposed a more appropriate way to test the induced innovation hypothesis than the traditional model, the specifics of their ideas were questioned by Oniki (2000). Oniki argued that the residual of a co-integration part does not represent the technological change effects. Therefore, the long-run relationship does not imply a lack of technological change. He concluded that the induced innovation hypothesis is supported by the existence of a difference in the elasticities of factor substitution along the isoquant curve and the innovation possibility curve. The reason is that the relative price changes are only part of the explanation of the changes in input ratios. Research and extension (R&E) expenditures, an important determinant of productivity growth, should also be considered in the estimation of technical biases.

Ahmad (1966) pioneered the microeconomics of induced innovations. He introduced many of the concepts of an innovation possibility curve (IPC) which is also central in the Hayami and Ruttan frame-work. At a given time, the state of knowledge defines a set of production techniques latently available. However, before a special technique can be applied, it has to be designed, i.e. resources have to be devoted to the (applied) research and development (R&D). The IPC represents the envelope of these processes and thus is a presentation of production techniques which may be generated by R&D. Accordingly, the IPC shows larger possibilities of substitution among inputs than the individual techniques characterized by their isoquants. A change in the state of knowledge is equivalent to a shift in the IPC and the occurrence of new production possibilities. With the given factor prices, the increase of knowledge leads to the generation of production techniques along a given trajectory (for instance labor intensity). However, a change in factor prices does not only alter factor intensities along the production technique but will also lead to a change of the production process.[1]

This paper tests for the IIH (Induced Innovation Hypothesis) following the general logic of the Oniki's test procedure. The model used to conduct the induced innovation tests is specified in the next section. It is sequentially followed by testing methods, data description, and empirical results. The final section concludes.

MODEL

A translog, twice-differentiable cost function is used to estimate the factor bias in this work. The

[1] The micro-economics of the induced innovation hypothesis where also formulated in Binswanger (1978) and Hockmann (1992). Both approaches use deterministic research technologies. Stochastic research results are considered in Hockmann and Voight (2001).

dual cost function provides a useful summary of the behavioral responses to the changes in the relative input prices. Moreover, this model allows us to estimate the effects of research investment on input shares. We assume that producers minimize the static cost function, $C(y, w, R)$ by choosing input combinations that satisfy;

$$C(y, w, R) = \min x \{w'x : F(x, y, R) = 0\} \quad (1)$$

where:
y = output
w = the vector of input prices
R = R&E expenditure (treated as a fixed input)
$F(-)$ = the production function

Under the competitive, cost-minimizing behavior, $C(y, w, R)$ is non-decreasing in y and w, non-increasing in R, concave and homogeneous of degree one in w. Considering one output (aggregate of crop and livestock commodities) and two inputs (labor and capital), the variable cost function in (1) is approximated by the following translog function:

$$LnC = \alpha_i + \sum_{i=1}^{2} \alpha_i Lnw_i + \beta_1 Lny + \gamma_1 LnR + \\ + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2} \alpha_{ij} Lnw_i Lnw_j + \frac{1}{2}\beta_2 (Lny)^2 + \\ + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2} \alpha_{ij} Lnw_i Lnw_j + \frac{1}{2}\beta_2 (Lny)^2 \quad (2)$$

Homogeneity of degree one in variable input prices requires:

$$\sum_{i=1}^{2}\alpha_i = 1, \sum_{i=1}^{2}\alpha_{ij} + \sum_{i=1}^{2}\delta_i = \sum_{i=1}^{2}\theta_i = 0 \quad (3)$$

Using the Shephard' lemma, the i^{th} inputs cost share is given by:

$$\frac{\partial LnC}{\partial Lnw_i} = \frac{w_i}{C} = s_j \quad (4)$$

from which get the input share equation:

$$s_j = \alpha_i + \sum_{j=1}^{2}\alpha_{ij} Lnw_j + \delta_i Lny + \theta_i LNR \quad (5)$$

For the equation five, the symmetry constrains are:

$$\alpha_{ij} = \alpha_{ji}, \forall i, j \quad (6)$$

The Allen-Uzawa partial elasticities of substitution (σ_{ij}) for this cost function are given by:

$$\sigma_{ij} = \frac{\alpha_{ij} + S_i^2 - S_j}{S_i^2} \quad (7)$$

$$\sigma_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j} \quad (8)$$

Oniki's (2000) defy of the Clark and Youngblood's time series method for testing the induced innovation hypothesis rested on the argument that the residual of a co-integrated series does not symbolize the technological change effects. Instead, the short-run effects (represented by an isoquant) plus the technical change effects are equal to the long-run effects (represented by the IPC). Thus, Oniki mentioned that the existence of the IPC is an essential condition for induced innovation, which counters the Clark and Youngblood's (1992) assertion that the existence of the long-run relationship (co-integration) "entails that technical change is neutral"**.** In Oniki's study, the induced innovation hypothesis was tested by comparing the long-run Allen-Uzawa's partial elasticities of factor substitution (AUES) with the short-run AUES. If the long-run elasticity is greater than the short-run elasticity, the curvature of the isoquant is greater than the curvature of the IPC, which implies that the induced innovation exists in the production procedure. Although the Oniki's procedure for testing the induced innovation hypothesis is an important amendment to the Clark and Youngblood's (1992) time series method, his model did not contain technology variables. Technology variables, such as research and extension investments, could be indispensable for explaining some biases due to the technical change. Based on the Oniki's testing logic and explicitly incorporating the R&E investments in the model, we test the induced innovation hypothesis on domestic agriculture by the following procedures.

First, since the co-integration techniques are used to determine whether long-run relationships exist among the variables, stationary properties of the data series in equation (5) are checked to determine whether each of them is non-stationary and integrated of the same order. The augmented Dickey-Fuller (ADF) test is commonly used to test the unit root of the series.

Second, based on the outcome of the unit root tests, a co- integration test can be applied to determine whether there exists a linear combination of variables that are integrated to the same order. The Johansen's co-integration test (Johansen, Juselius 1990) is used to estimate all co-integrating relationships and to conduct tests for the number of co-integrating vectors under a multivariate framework. Let us consider a vector of n time-ordered variables X_i, where X_i follows an unrestricted vector auto-regression (VAR):

$$X_t = \pi_1 X_{t-1} + \pi_2 X_{t-2} + \ldots + \pi_p X_{t-p} + \mu + \varepsilon_t \quad (9)$$

where each of the π_i; is an nxn matrix of parameters, μ is a constant term and ε_t are identically and independently distributed with zero mean and contemporaneous covariance matrix Ω. The above VAR system can be written in the error correction form (ECM) as:

$$\Delta X_t = \mu + \Pi X_{t-p} + \Sigma\Gamma\Delta X_{t-1} + \varepsilon t \tag{10}$$

where $\Pi = I - \pi_1 - \pi_2 \ldots \pi_p$, and $\Gamma = [(I + \pi_1 + \pi_2), (I + \pi_1 + \pi_2 + \ldots \pi_p)]$, and P is chosen so that ε_t is a multivariate normal white noise process with mean 0 and finite covariance matrix. The rank of Π, r, can be used to investigate the cointegration relationship. If $r = n$, the variables in the level are stationary. If $r = 0$, none of the linear combinations is stationary When $0 < r < n$, there exist r co-integration vector so stationary linear combinations of X_t. The matrix Π can be factored as $n = \alpha\beta$, where both α and β are $n \times r$ matrices, and β may be interpreted as the matrix of co integrating vector representing the long-run relationship, and α is the matrix of adjustment parameter Johansen suggested two statistics to test the null hypothesis that there are the most cointegration vectors in the system. One is the maximal Eigen value and the other is the $r + 1$ cointegration vector for the former while there exist more than r co integration vectors for the latter. The statistic for each test follows a non-standard distribution. The critical values for the tests were emulated by Johansen and Joselius (1990). We apply both tests in this study.

Third, if there exists co-integration among the variables in the equation (5), the short-run and the long-run relationships of the variable can be estimated by the error correction model (EMC). If all variables are integrated to the order d, then p^{th} order of the vector EMC for the translog share input equations can be represented by the following equation:

$$\Delta S_t = \phi(L)\,\Delta s' - d + \Gamma_w(L)\Delta w, \;\; + \gamma_y(L)\Delta y, + \gamma_R(L)\Delta R, + A(S_t - d - \beta_0 - B_w w_t - p - \beta_y Y, - p - \beta_R R_{t-P}) + \varepsilon_t \tag{11}$$

where $\phi(L) = \Sigma(\Sigma\phi_j)\, L_i$ for $d > 1$, or null otherwise

$$\Gamma_w(L) = \sum_{i=1}^{P-1}(\sum_{j=1}^{i}\Gamma^*_{wj})L^i$$

$$\gamma_y(L) = \sum_{i=1}^{P-1}(\sum_{j=1}^{i}\gamma^*_{yj})L^i$$

$$\gamma_R(L) = \sum_{i=1}^{P-1}(\sum_{j=1}^{i}\gamma^*_{Rj})L^i \tag{12}$$

For $p > 0$, or null otherwise; and A is the loading matrix of adjustment parameters. Suppose all the variables are integrated to the first order and the lag order is 1, i.e., $d = p = 1$, the equation (12) can be rewritten in the following form

$$\Delta S_t = \Gamma_w \Delta w + \gamma_t \Delta t_t + \gamma_R \Delta R_t + A\Big(S_{t-1} - \beta_0 - - B_w w_{t-1} - \beta_y y_{t-1} - \beta_R R_{t-1}\Big) + \varepsilon_t \tag{13}$$

The differenced terms in the above model are stationary 1(0) and cover the short-run situation while the terms enclosed in parentheses are 1(1) and describe the long-run relationship. As the relative factor prices change, the input shares s will change immediately owing to the substitution effects (short-run effects), which are reflected by the matrix for w. According to Oniki (2000), the stochastic part, $\Delta = A(S_{t-1} - ß_0 - - B_w W_{t-1} - ß_y Y_t - J - ß_R R_{t-1})$, represents the technological change and its value tends to zero in the long-run equilibrium. In the short run, changes in the relative factor prices will make 8 non-zero, which shifts the short-run production process until the shares reach a new long-run equilibrium, where δ = 0. Therefore, the long-run effects of the relative factor price changes are B_w while the short-run effects are r_w.

The curvature of the isoquant and the IPC can be represented by the short-run AUES and the long-run AUES, respectively. From the equation (8), the short-run and long-run AUES, respectively, of factor i for factor j are estimated by:

$$\sigma_{ij}^{SR} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}$$

$$\sigma_{ij}^{lR} = \frac{\beta_{ij} + S_i S_j}{S_i S_j} \tag{14}$$

where Y_{ij} and /3; j are the ij^{th} element of the matrix r wand B_w, respectively, in the equation (14).

Following Oniki (2000), technological change is the difference between the long-run and the short-run production process. Therefore, the induced innovation exists if the estimated relationship. If $r = n$, the variables in levels are stationary. If $r = 0$, none of the linear long-run elasticities of substitution are significantly greater than the estimated short-run elasticities. Based on the equation (14), the biased technological change can be induced by changes in output levels and by R&E investments in addition to the changes in the relative factor prices. The possibility of the output- and R&E investment-induced technological change can be tested in a similar way to testing for price-induced innovation. If the long-run input-output elasticity is significantly greater than the short-run input-output elasticity, the output-induced technological change occurs. Similarly, the R&E investment-induced technological change exists when the long-run input-R&E investment elasticity is significantly greater than the short-run input-RE investment elasticity.

By the equation (14), it can be inferred that the biased technical change can be induced not only by changes in the relative factor prices but also by the changes in output level or R&E investments. The formulas for the short-run and long-run elasticities of the i^{th} factor with respect to output level y were derived by Oniki (2000):

$$\pi_i SR = (\gamma_i q/S_i) + \text{(short-run effect } \pi_i LR = (\beta_i q/S_i) + 1 \text{ (long-run effect)} \quad (15)$$

Similarly, the formulas for the elasticities of the i^{th} factor with respect to R&E investment R are:

$$\omega_i SR = (\gamma_i q/S_i) + 1 \text{ (short-run effect)}, \ \omega_i LR = (\beta_i q/S_i)+1 \text{ (long-run effect)} \quad (16)$$

Since all elasticity functions are nonlinear of parameter estimates, the Delta method was used to compute standard errors and confidence intervals for the short-run and long-run elasticities. This method is based on a first-order Taylor-series approximation to the statistic and was used to find standard errors of the nonlinear functions of parameter estimates. Confidence intervals were then derived based on the estimated parameters and estimated standard errors. Confidence intervals for the estimated elasticity of substitution, output elasticity, and R&E investment elasticity are presented in Table 5. Since the estimated AUES in the long-run was significantly greater than those in the short-run, we conclude that the induced innovation existed in their production processes.

RESULTS

The time series properties of the variables (labor cost share, capital share, output, R&E investments) were examined. The results of the unit root test are presented in Table 1. The results for each variable indicate that the null hypothesis of a unit root could not be rejected at the 10% significant level for any of variables. That is, the implications of these tests indicate that all of the variables are non-stationary. The unit root test for the first differences for each variable rejected the presence of the unit root (Table 2).

This means that all the data series are non-stationary in the levels and they are integrated to order one. Therefore, in the next stage, we adapt the Johansen's approach of co-integration tests to determine whether co-integrating vectors existed which would imply non-spurious long-run relationships among the variables. If we have N endogenous variables I (1), there can exist 0 to N–1 linearly independent cointegrating vectors that represent long-run equilibrium relationships. The number of these equations is called the

Table 1. Unit Root Tests for stationary of data series

Variable	ADF test statistic	Critical value (5%)
Labor share	–1/01	–3/58
Price	–3/46	–3/59
Output	–0/73	–3/58
R&E investment	–0/39	–1/95
Capital	–1/32	–3/59

Table 2. Unit Root Tests for stationary of the first difference of data series

Variable	ADF test statistic	Critical value (5%)
Labor share	–4.766475	–1.9552
Price	–4.832	–4.3921
Output	–6.171560	–3.6118
R&E investment	–4.950269	–3.6027
Capital	–5.154975	–3.5943

Table 3. Johansen's cointegration test

Hypothesized No. of CE (s)	Eigenvalue	Likelihood ratio	Critical value	
			5%	1%
None**	0.720824	59.43228	47.21	54.46
At most 1	0.547026	27.53447	29.68	35.65
At most 2	0.257709	7.736437	15.41	20.04
At most 3	0.011379	0.286096	3.76	6.65

*(**) denotes rejection of the hypothesis at 5 %(1%) significance level

L.R. test indicates 1 cointegrating equation(s) at 5% significance level

Table 4. Estimated error correction models

Variables	Coefficient
Constant	–0/82
Short-run effects	
Δw_t	0/04
Δq_t	0/02
ΔR_t	0/03
Long-run effects	
S_{t-1}	0/43
W_{t-1}	–0/07
q_{t-1}	0/03
R_{t-1}	0/01

"co-integrating rank" and the Johansen tests can determinate the number of co-integrating equations. The results of the co-integration examination are reported in Table 3.

Test statistics from the maximal Eigen value was consistent in suggesting that there are two integrating vectors among the variables. Thus, it is concluded that there existed long-run relationships among the labor cost share, capital share, output level, and R&E investments. The estimated co-integrating vectors were [1, 0, –0.73, 0.22], and [0, 1, 0.127, –0.193], accordingly, the long-run relationships among the four variables existed.

With estimating of the equation (14), it is determined that the variables are co-integrated, and this model allows us to scrutinize the short-run and long- run effects of changes in the relative input price, output level and R&E investments on the cost share. The result of the error correction model (ECM) estimation is presented in Table 4. Based on the AIC criterion, the "best" estimated lag length of the underlying vector auto-regression (VAR) was estimated to be two for each variable. In the equation (13), short-run effects represented by the difference terms and lagged terms represented the long-run effects. The results of the estimation represented are statistically significant at the 10% level except for the estimates of the short-run effects which were not significant.

In order to test the presence of the induced innovation, the short-run and long-run elasticities of substitution must be measured (see Oniki 2000). Therefore, we need to test whether the long-run elasticity of substitution is significantly greater than the short-run elasticity of substitution. Confidence intervals for the estimated elasticity of the substitution output elasticity and R&E investment elasticity are presented in Table 5. Since the estimated elasticities in the long-run were significantly greater than the estimated elasticities in the short-run, we can conclude that the induced innovation existed in their production process of the Iranian agricultural sector.

CONCLUSIONS

Induced innovation implies a long-run relationship between the technical change and the measure of factor scarcities. Cointegration is essentially based on the idea that there may be a long-run co-movement between the trended economic time series so that there is a common equilibrium relation which the time series have a tendency to revert to (Engle, Granger 1987). Therefore, this technique appears particularly suitable for modeling inducement hypothesis.

Testing for co-integration involves two steps. First, to determine the degree of integration in each of the series to verify if the variables are integrated of the same order. Second, to estimate the co-integration regression of which the error terms must be of a lower degree.

To test the degree of integration of the variables, we used two tests: the Phillips-Perron test (PP) and the Kwiatkowski test (KPSS) (Kwiatkowski et al. 1992). The first tests the null hypothesis that the series have a unit root, whereas the second one compares the null hypothesis of the stationary against the alternative

Table 5. Confidence intervals of the estimates of the AUES, output elasticity, and R&E investment elasticity along the isoquant and the innovation possibility curve

Curve	Confidence interval[1]		
	AUES	output elasticity	R&E investment
IQC	(0/274, 1/234)	(0/122, 1/428)	(0/750, 1/260)
IPC	(1/732, 2/052)	(0/673, 0/693)	(0/432, 0/543)

IQC is the isoquant and IPC is the innovation possibility curve

[1] Significant level is 5%

of a unit root. Schlitzer (1995) indeed demonstrated that a combined use of the unit root and stationary test would significantly reduce the number of the erroneous conclusions.

Table 1 shows the results of the two tests; both the level and first difference of each series were tested. The results of the PP test show that all variables are non-stationary in levels but stationary in first differences at 0.05 significance level. The KPSS procedure confirms that the series are unit root in level and stationary in first differences.

This paper tested for the IIH (Induced Innovation Hypothesis) following the general logic of the Oniki's (2000) recent time series test procedure with the augmentation that the research and extension (R&E) investments were included in the time series model. A translog, twice-differentiable cost function with one output and two inputs (labor and capital) was used to estimate factor biases. An error correction model was implemented to separate the short-run and long-run effects of the relative price changes as well as changes in output level and R&E investments. A significantly larger elasticity of factor substitution along the innovation possibility curve than along the iso-quant would imply the IIH. Significantly larger factor elasticities with respect to the output level or R&E investment along the IPC than along the iso-quant would imply that those respective variables also induce innovation. The mean values of the variables were used to calculate elasticities. Each variable was integrated of order 1 and the system of four variables was cointegrated. The latter implied that a long-run relationship and a corresponding IPC existed among these variables. The error correction model endogenized technical changes in terms of the relative factor prices, output, and R&E investments. The induced innovation hypotheses were tested by comparing the short-run and long-run elasticities of substitution, output elasticities, and R&E investment elasticities. The estimated results showed that the induced innovation hypothesis was supported. However, while the changes in the relative input prices induced innovation, the changes in the output level or the R&E investments did not. The empirical tests failed to find any significant impact of changes in the latter variables on agricultural technology.

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