**Appendices**

**Non-Neutral Marginal Innovation Costs, Omitted Variables, and Induced Innovation**

Daegoon Lee

Benjamin W. Cowan

C. Richard Shumway

## Appendix I

We develop the two-stage optimization conditions in this appendix. A single output  in period 2 is produced by the following two-level CES production function as in equation (1):

,

where is the elasticity of substitution between input indices, and  is a share parameter. The input indices  and  are produced respectively by pairs of inputs that also follow a CES form:



as in equation (2), where  is input  used in production of input index *i*, and *a* is a factor-augmenting parameter that captures technical progress.

A static cost-minimization problem for period 2can be stated as:





where  is the price of input . This gives the Lagrangian:



where  is the Lagrangian multiplier. First-order conditions for  and  are:

(A-1) ,

(A-2) 

where  and  . We only derive the first-order conditions for the input pair,  and . The conditions for the other pair of inputs,  and , can be obtained analogously. Dividing (A-1) by (A-2), we obtain:

(A-3) .

 Solving for , we obtain the condition for the optimal ratio of inputs:

(A-4) 

which is equation (3).

Now, consider R&D opportunities in period 1. For a given R&D budget , the innovation function is given by equation (4):



Where  is expenditure on R&D to augment the *i*th input index, the total R&D budget is assumed to be exogenously given and is fully expended, i.e., ,  is the factor-augmentation parameter which is assumed to be nonregressive, i.e., if ;  denotes marginal R&D costs in period 1 for technology that is expected to augment  by one percent in period 2; and  is a concavity parameter.

In the two-stage optimization problem, the cost-minimization problem for the firm’s R&D resource allocation in period 1 can be expressed, as in equation (5), by:

|  |
| --- |
|  |
|  and , |

where , ,  denotes expectation for price of input  in period 2 given information available in period 1*,* and  is the expected factor augmentation parameter in period 2. A tilde is given to input levels to denote that they are period 2 values “*conceived*” in period 1 and thus are distinguished from the values that are actually chosen by the firm in period 2.

The Lagrangian is given by



where  and  are Lagrangian multipliers for the constraints on production and R&D budget, respectively. First order conditions for  and  are

(A-5) ,

(A-6) ,

where  and .

First order conditions for  and  are

(A-7) ,

(A-8) ,

where , ,  and . Dividing (A-5) by (A-6) yields

(A-9) .

Dividing (A-7) by (A-8) and rearranging yields

(A-10) .

Dividing (A-9) by (A-10) and solving for , we obtain

(A-11) .

Substituting (A-11) into (A-9) and solving for  we obtain

(A-12) ,

where . This is equation (6). Asterisks are given to the factor-augmenting parameters to denote that they are optimal values.

By substituting (A-12) into the optimal condition for period 2(A-4) with  replacing , and rearranging, we get

(A-13) ,

which is equation (7). The condition for  can be analogously found as (A-13):

(A-14) .

## Appendix II

In this appendix, we demonstrate that the condition  on the innovation function, equation (4), ensures a negatively sloped and concave innovation possibilities frontier, i.e., that  and :

,

for , , . At a given R&D budget, differentiating both sides of the innovation function with respect to  yields

.

Solving for  yields

.

Differentiating both sides of the innovation function’s first-derivative equation again with respect to  gives

.

Solving for  yields

.

## Appendix III

We develop the rational expectations forecasts of input prices in this appendix. To obtain forecasted future input prices that are consistent with rational expectations theory, we identified the autoregressive (AR) structure for each input price to ensure that the forecasted prices based on the AR model give zero expected errors. To identify the AR structure, we first used the Im-Pesaran-Shin (2003) test for nonstationarity of the panel price data. Test results for the prices of each input category are presented in Table III.1.[[1]](#footnote-1) Two Augmented Dickey-Fuller test statistics are provided – with and without a time trend.[[2]](#footnote-2) The null hypothesis of nonstationarity was not rejected for prices of three inputs (land, non-land capital, and intermediate inputs) by both tests. Labor was found to be stationary but only when a time trend was included. The null hypothesis of nonstationarity was rejected (at the 1% level) for the first differences in all inputs. Thus, we fit an AR model with level values for labor price and with first-differenced prices for the other three inputs.

The AR structure for each input price was identified using a panel fixed effects estimator and an Arellano-Bond estimator (Arellano and Bond 1991).[[3]](#footnote-3) AR order *q* for each input price was selected based on satisfying the following two conditions: (a) the *q*th lagged autoregressive term was statistically significant at the 5 percent level and the (*q*+1)th lagged term was not significant, and (b) the residuals from AR(*q*) estimates followed a white noise process with zero mean. Step (b) is important to ensure that our forecasts are produced consistently with rational expectation. The AR structure was identical and the estimated parameters were almost identical for both panel fixed effects and Arellano-Bond estimations. The identified AR orders were, respectively, AR(7), AR(3), and AR(2) for first-differenced land, capital, and intermediate prices and AR(2) for the level of labor price with a time trend. The results are presented in Table III.2. With the estimated results, the *k*-step-ahead forecasts at the forecast origin *t-k* with AR(*q*) were used as the expected input prices.

**References**

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**Table III.1. Im-Pesaran-Shin Statistics for Nonstationaritya**

|  |  |  |
| --- | --- | --- |
| Price series | Without time trendb | With time trendc |
| *Level* |  |  |
| Land price | -0.7760 | -1.4674 |
| Labor price | 0.0001 | -2.6834\*\*\* |
| Capital price | -0.4160 | -1.2717 |
| Intermediate inputs price | -0.5841 | -1.9525 |
| *First-Differenced* |
| Land price | -3.6542\*\*\* | -3.6165\*\*\* |
| Labor price | -8.3984\*\*\* |  |
| Capital price | -3.7324\*\*\* | -3.6815\*\*\* |
| Intermediate inputs price | -5.3272\*\*\* | -5.2745\*\*\* |

Notes: p-value of estimated parameters: \* *p* < 0.10, \*\* *p* < 0.05, \*\*\* *p* < 0.01.

a The null hypothesis of IPS test is that each price series contains a unit root.

b Critical values of the statistics without time trend for 10%, 5% and 1% level of significance are -1.68, -1.73, and -1.81, respectively.

c Critical values of the statistics with time trend for 10%, 5% and 1% level of significance are -2.32, -2.36, and -2.44, respectively.

**Table III.2. Autoregressive Model Statistical Estimates**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Lags | Land price | Labor price | Capital price | Intermediate inputs price |
| Arellano-Bond | Fixed effect | Arellano-Bond | Fixed effect | Arellano-Bond | Fixed effect | Arellano-Bond | Fixed effect |
| Lag1 | 0.683\*\*\*(0.024) | 0.686\*\*\*(0.024) | 0.581\*\*\*(0.023) | 0.586\*\*\*(0.022) | 0.620\*\*\*(0.021) | 0.620\*\*\*(0.022) | 0.217\*\*\*(0.022) | 0.219\*\*\*(0.021) |
| Lag2 | -0.387\*\*\*(0.028) | -0.386\*\*\*(0.028) | 0.256\*\*\*(0.024) | 0.256\*\*\*(0.024) | -0.342\*\*\*(0.024) | -0.342\*\*\*(0.025) | -0.279\*\*\*(0.022) | -0.277\*\*\*(0.021) |
| Lag3 | 0.257\*\*\*(0.028) | 0.259\*\*\*(0.028) |  |  | 0.253\*\*\*(0.022) | 0.253\*\*\*(0.023) |  |  |
| Lag4 | 0.003(0.029) | 0.004(0.029) |  |  |  |  |  |  |
| Lag5 | -0.529\*\*\*(0.029) | -0.528\*\*\*(0.029) |  |  |  |  |  |  |
| Lag6 | 0.357\*\*\*(0.030) | 0.358\*\*\*(0.030) |  |  |  |  |  |  |
| Lag7 | -0.247\*\*\*(0.026) | -0.245\*\*\*(0.026) |  |  |  |  |  |  |
| Time trend |  |  | 0.005\*\*\*(0.000) | 0.004\*\*\*(0.000) |  |  |  |  |
| Constant | 0.024\*\*\*(0.002) | 0.023\*\*\*(0.002) | -0.021\*\*\*(0.005) | -0.020\*\*\*(0.005) | 0.010\*\*\*(0.000) | 0.010\*\*\*(0.000) | 0.026\*\*\*(0.001) | 0.026\*\*\*(0.001) |

Notes: Standard errors are in parentheses; p-value of estimated parameters: \* *p* < 0.10, \*\* *p* < 0.05, \*\*\* *p* < 0.01.

1. Among several test procedures for nonstationarity with panel data e.g., LLC (Levin et al. 2002), HT (Harris and Tzavalis 1999), Breitung (Breitung 2000, Breitung and Das 2005) and Hadri (Hadri 2000), we chose the Im-Pesaran-Shin test due to the following advantages: (a) the test allows heterogeneous non-stationarity structures among cross-section units, and (b) they provide exact critical values that assume both cross-sectional units and the time series are fixed. The latter advantage is particularly important in our case considering our fixed cross-sections (states) and the limited time dimension of our dataset. [↑](#footnote-ref-1)
2. Test statistics also depend on whether the lagged terms are included in the specification. When the lag structure is specified, the test procedure assumes that the number of time and cross-section units sequentially go to infinity. Thus, with only 45 years and 48 states in our data set, we do not consider specifications with lags. [↑](#footnote-ref-2)
3. The panel fixed-effects estimator can be subject to an endogeneity problem in dynamic models since the within-estimator or first-difference estimator can be correlated with the error term. To overcome this problem, the Arellano-Bond estimator makes use of lagged dependent and independent variables as instruments. However, because our ultimate purpose is to forecast, endogeneity is not a major concern. [↑](#footnote-ref-3)