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ENDOGENOUS OUTPUT IN AN AGGREGATE MODEL OF THE LABOR MARKET

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ABSTRACT

A common feature to most aggregative studies of the labor market is a marginal productivity expression in which the quantity of labor appears on the left hand side of the equation, and the right hand side includes the real wage and output. A number of researchers have cautioned that if the output variable is treated as exogenous, serious econometric difficulties may result. However, the assumption that output is exogenous has not been tested. In this paper, we estimate an equilibrium model of the labor market, and use it to test the assumption of output exogeneity. We find that the assumption that output is exogenous cannot be rejected by the data.

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1. Introduction

A common feature of aggregative studies of the labor market is a labor demand equation based on the assumption that firms maximize profits conditional on the level of output. This leads to a marginal productivity expression in which the quantity of labor appears on the left hand side of the equation, and the right hand side includes the real wage and output.[1]

As long as firms maximize profits, the theoretical basis for this procedure is entirely solid. From a statistical point of view, however, there is a complication. Because firms make their output and factor demand decisions jointly, the output variable in a marginal productivity condition may be endogenous. It has long been recognized that this is a potential difficulty. For instance, Andrews and Nickell [1986] warn that ". . . if the output variable is treated as exogenous then there is a serious problem." (p. 387) The tendency has been for researchers to acknowledge the problem, hope that it is not too important, and then proceed on the assumption that output is exogenous.[2]

As a practical matter, the fact that an endogenous variable is (mistakenly) assumed to be exogenous does not necessarily mean that substantive econometric results will be wildly off the mark. The outcome depends on the specification of the rest of the model, the structure of the data, etc. One cannot know whether or how the substantive results change without actually estimating the model and treating the suspect variable as endogenous. The purpose of this paper is to estimate an aggregate labor market model with endogenous output, and to compare the results to those obtained under the more conventional assumption of exogeneity.

We discuss output endogeneity using Lucas and Rapping's [1970] equilibrium approach to the labor market. Although controversial, it is widely familiar and a useful starting point for examining the effects of output endogeneity. The model is presented in Section 2. Section 3 covers data and estimation issues. The results are presented in Section 4. They suggest that the assumption that output is exogenous cannot be rejected by the data. Further, models with exogenous output produce coefficients and forecasts that are virtually identical to those with endogenous output. Section 5 provides a summary and conclusion.

2. The Model

2.1 The Lucas-Rapping-Altonji Model

Our starting point is a variant of Altonji's [1982] version of Lucas and Rapping's [1970] equilibrium model of the labor market. This model consists of four equations, one each for labor demand, labor supply, the equilibrium condition, and the unemployment rate. Each period, the quantity of labor demanded equals the quantity supplied. Unemployment is a consequence of intertemporal labor supply substitution.

Demand for Labor. As noted in Section 1, profit maximizing behavior by firms conditional on output leads to a demand function for labor that depends on the real wage and output, *inter alia*. Let D_t = quantity of labor demanded, Q_t = real output, and (W_t/P_t) = real wage rate. The following approximation is employed:

$$(2.1) \quad \ln D_t = \alpha_0 + \alpha_1 \ln(W_t/P_t) + \alpha_2 \ln Q_t + \alpha_3 t + u_{1t} ,$$

where u_{1t} is a random error. The time trend t proxies for omitted variables that are correlated with time. These might include changes in the sex, age, and education composition of the labor force as well as technical progress.

Supply of Labor. The total number of hours people wish to supply in year t depends upon the real net wage (W_{nt}/P_t), the future expected real net wage $(W_n/P)^*_t$, the *ex ante* real interest rate, and a scale variable H_t to account for changes in the size of the population. If R_t is the nominal interest rate, P_t the current price level and P^*_t the anticipated future price level, then the real interest rate, r_t, is $R_t - (\ln P^*_t - \ln P_t)$. Again assuming a log-linear specification (except for r_t):

(2.2) $\ln S_t = \beta_0 + \beta_1 \ln(W_t/P_t) + \beta_2 \ln(W/P)^*_t + \beta_3 \ln H_t + \beta_4 r_t + u_{2t}$,

where u_{2t} is a random error.[3] Given intertemporal labor supply substitution, one expects $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_4 > 0$. We defer to Section 3 a discussion of how the expected wage and the *ex ante* real interest rate are measured.

Market Equilibrium. A key assumption of the model is that the labor market clears every period. Hence, the quantity of labor exchanged (L_t) is determined by the intersection of supply and demand:

(2.3) $L_t = D_t = S_t$.

Unemployment. Although the labor market clears at the current wage, there is unemployment because of the intertemporal labor supply substitution built into equation (2.2). Specifically, the amount of unemployment is a function of the difference between the labor supply at the current real wage and the supply that would prevail if wage expectations were correct. Altonji [1982, pp. 785-86] shows that assuming a linear approximation, the unemployment rate, U_t, can be written

(2.4) $U_t = \gamma_0 + \gamma_1[\ln(W/P)^*_t - \ln(W_t/P_t)] + \gamma_2 r_t + u_{3t}$.

One expects $\gamma_1 > 0$ (when the expected future wage is higher than the actual wage, workers choose unemployment) and $\gamma_2 < 0$ (when the real interest is high, workers supply more labor in the present and hence there is less unemployment).[4]

Substituting the equilibrium condition (2.3) into equations (2.1) and (2.2) gives us a three equation model with three endogenous variables: the quantity of labor exchanged, the nominal wage rate, and the rate of unemployment.

2.2 Making Output Endogenous

A natural way to allow output to be endogenously determined is to augment the system (2.1)-(2.4) with a production function whose arguments are the quantities of labor and capital services. The Cobb-Douglas form is convenient, and has done a good job of characterizing the data in some previous studies. (Hamermesh [1986].) Hence, we assume

$$\text{(2.5)} \quad \ln Q_t = \ln A + \Omega t + v_1 \ln L_t + v_2 \ln C_t + u_{4t} ,$$

where C_t is capital services and Ω is the coefficient on the time trend, which one might interpret as the rate of Hicks-neutral technological change.

Augmenting the model with equation (2.5) entails dealing with several issues. First, one must find a way to measure capital services, C_t. There exist time series data on the capital <u>stock</u>, but this is not the same as capital services because the utilization rate of the capital stock varies over time. This suggests that we write C_t as the capacity utilization rate, μ_t, times the capital stock, K_t: $C_t = \mu_t K_t$. Capacity utilization is notoriously difficult to measure.[5] In the empirical work reported below, we use two different measures. In order to avoid having to model the capital market, we assume that C_t is predetermined.

A second issue is what constraints, if any, the Cobb-Douglas production function (equation (2.5)) puts on the parameters of the labor demand equation (2.1). For a profit maximizing firm with a Cobb-Douglas technology, $\alpha_0 = \ln v_1$, $\alpha_1 = -1$, $\alpha_2 = 1$, and $\alpha_3 = 0$. If the economy acts as if it were maximizing profits with a Cobb-Douglas technology, then these constraints are also applicable to the aggregate marginal productivity condition. However, there are conditions under which a Cobb-Douglas production function is a correct characterization of the economy as a whole, but it is not appropriate to impose these constraints on the marginal productivity equation. For example, in a classic paper, Houthakker [1955-56] showed that if each firm has a fixed-coefficients technology and the distribution of the coefficients across firms is Pareto, then the aggregate production function is Cobb-Douglas. In this case, the elasticity of demand for a factor with respect to its own price is zero, not minus one.

The linkage between the production function and labor demand parameters is further weakened by Romer's [1987] suggestion that the true marginal productivities of various inputs need not be derivable from their relative shares of total income. He conjectures that if capital investment simultaneously leads to new knowledge that benefits other firms, then it is reasonable to expect that the coefficient of capital in a Cobb-Douglas production function (in our notation, v_2) will be greater than its share in output. Moreover, when the labor force increases, ". . . the implied decrease in the rate of growth of wages could cause a decrease in innovation" and hence lower output (p. 166). In short, the coefficient on labor (v_1) might be zero or even negative.

3. Data and Estimation Issues

3.1 Data

We describe here briefly the definitions of the variables. The sources and methods of construction are detailed in Quandt and Rosen [1988].

The data are annual observations on the U.S. economy for the years 1948 to 1982. L_t is total private hours worked per year expressed in billions.

The nominal gross hourly wage measured in dollars, W_t, is formed by dividing total civilian compensation by L_t. Q_t is gross national product measured in billions of 1972 dollars. P_t is the consumer price index, scaled so that the value in 1967 is 100.0. H_t, the potential labor force measured in billions, is constructed by taking the number of people between the ages of 16 and 65, and multiplying by the average number of hours worked per person.[6] The nominal interest rate, R_t, is the yield on Moody's corporate Aaa bonds.

The marginal net wage, W_{nt}, is the product of the gross wage W_t and a factor $(1-\Theta_t)$, where Θ_t is the average marginal federal income tax rate as computed by Barro and Sahasakul [1983]. U_t is the official unemployment rate as a fraction of the civilian labor force.

As noted earlier, the capacity utilization rate of capital is difficult to measure. A popular index in applied work is the one published by the Board of Governors of the Federal Reserve System, but it is better understood as the ratio of actual to potential output, not a measure of the intensity of capital use. Shapiro [1986] employs an econometric model of interrelated factor demand to produce a measure of capacity utilization, but as he notes, it suffers from several deficiencies. (For example, it does not account for temporary closings.) We estimate our model using both the Fed and Shapiro measures.[7] One expects that these will lead to different parameter estimates. From our point of view, however, the key question is whether the use of one measure or the other affects our substantive conclusions on whether output endogeneity "matters."

3.2 Econometric Issues

A number of econometric issues have to be addressed.

Stochastic Specification. The model with endogenous output consists of equations (2.1), (2.2), (2.3), and (2.5). We assume that the error terms

$u_{it}(i=1,\ldots,4)$ are distributed with mean zero. Further, we allow for the possibility of serially correlated errors by specifying that $u_{it} = \rho_i u_{it-1} + \varepsilon_{it}$, where ε_{it} is distributed as $N(0,\Sigma)$, with Σ not restricted to be diagonal.

Estimation Method. All estimation is by maximum likelihood; the relevant derivations are straightforward extensions of those in Chow [1983, Chapter 5].

Testing for Exogenous vs. Endogenous Output. Under the assumption that output is exogenous, labor (which is endogenous) cannot appear on the right hand side of equation (2.5). Hence, exogeneity of output implies that $v_1 = 0$. Moreover, if output is exogenous, the error term in the production function should be uncorrelated with the error terms of the other three equations--$\mathrm{cov}(\varepsilon_{4t}, \varepsilon_{1t}) = \mathrm{cov}(\varepsilon_{4t}, \varepsilon_{2t}) = \mathrm{cov}(\varepsilon_{4t}, \varepsilon_{3t}) = 0$. These considerations suggest a straightforward statistical test for whether output is exogenous. Estimate the model (by maximum likelihood) with these constraints imposed, and then do a likelihood ratio test to see if the constraints significantly lower the loglikelihood.

Generating Expectations of Variables. Anticipated values of variables play an important role in the equilibrium model. Lucas and Rapping assumed adaptive expectations. However, more recent treatments of the equilibrium model assume that expectations are formed rationally (see Altonji [1982]), and so do we.

Specifically, we estimate second order univariate autoregressions for both $\ln(W_{nt}/P_t)$ and $\ln P_t$, and use the forecasts based on these regressions as our values for $\ln(W/P)_t^*$ and $\ln P_t^*$.[8] The regressions are estimated with a "rolling regression" method--separate equations for $\ln(W/P)_t$ and $\ln P_t$ are estimated each period, using only data available in year t. In this way, one never has to assume that people based their expectations on data that were unavailable to them. After some preliminary experimentation, we implemented a rolling regression procedure using 27 years' worth of data.[9]

4. Results

4.1 The Endogenous Output Model

The maximum likelihood estimates of system (2.1)-(2.3), (2.5) are in the first two columns of Table 1. Consider first column (1), based on the FRB measure of capacity utilization. The estimates seem quite reasonable. In the demand equation, the value of α_1 implies a demand elasticity with respect to the real wage of -0.52, an estimate within the range reported in Hamermesh's [1986] survey. Similarly, the output elasticity, 0.63, is in line with earlier estimates. The coefficient of t, 0.0051 suggests a very mild positive trend in the demand for labor.

Turning now to the supply equation, the signs of the coefficients are consistent with the intertemporal labor supply substitution hypothesis: β_1, the coefficient on the current wage, is positive; β_2 the effect of the anticipated wage, is negative; and β_4, the real interest rate effect, is positive. Moreover, β_1 and β_4 are significantly different from zero at conventional significance levels. The elasticity of labor supply with respect to the potential number of hours, β_3, is about 0.12, which is substantially lower than one would expect. The reason probably lies in the strong collinearity between H_t and (W_{nt}/P_t). (The simple correlation between the two variables exceeds 0.99.)

The unemployment rate equation is less consistent with the equilibrium hypothesis. The model predicts that γ_1, the coefficient on the difference between the anticipated and current wage rates, will be positive. This prediction holds, but the coefficient is not statistically different from zero. Moreover, contrary to the prediction of the model, γ_2, the coefficient on the real interest rate, is significantly positive.

Before considering the production function, let us examine how the coefficients of the first three equations change with an alternative measure of capacity utilization. The second column of Table 1 shows the results when we use Shapiro's measure of capacity utilization. Most of the coefficients do not change very much. The major exceptions are that with Shapiro's measure, the time trend in the demand equation (α_3) is a small negative rather than a small positive; and the effect of the current wage in labor supply (β_1) becomes implausibly high (but it is imprecisely estimated).

Finally, we turn to the production function. In both columns (1) and (2), the coefficient on capital (v_2) is about 0.36. Given a traditional view, this estimate seems a bit high but reasonable. The labor coefficient is -0.85 in column (1) and -0.32 in column (2), estimates that are incompatible with a traditional view. However, given Romer's reinterpretation of production function estimates, particularly his assertion that the marginal product of labor may be negative, they do not seem implausible.[10]

In any case, columns (1) and (2) taken together suggest that the equilibrium model produces reasonable results, although, as one would expect, they are somewhat sensitive to how capacity utilization is measured. The key question now is whether alternative definitions affect our conclusions with respect to output exogeneity. We now turn to that issue.

4.2 The Exogenous Output Model

The exogenous output model imposes the restrictions that the coefficient of labor in the production function is zero, as are the covariances between the error term in the production function and the errors in the other three equations. The results when these constraints are imposed are presented in columns (3) and (4) of Table 1 and should be compared to columns (1) and (2) respectively.

Perhaps the most remarkable result suggested by such comparisons is the robustness of the demand function parameters. Although output appears on the right hand side of the demand function, allowing it to be endogenous has little effect on the demand parameters. Several of the coefficients in the other equations are rather more sensitive to the correction for exogeneity, but the differences are not dramatic. This impression that correcting for endogeneity does not matter very much is confirmed by likelihood ratio tests of the constraints imposed by the exogeneity assumption. For the models in colunmns (1) and (3), the test statistic is 7.90; for the models in columns (2) and (4), it is 5.92. The critical value for $\chi^2(4)$ at a 0.05 significance level is 9.49. Hence, however capacity utilization is defined, the data do not reject the constraints associated with the assumption that output is exogenous.

4.3 Further Comparison of the Models

We have shown that the models with exogenous and endogenous output have roughly similar coefficients, and that the data do not reject the constraints implied by the assumption of exogeneity. Another important issue is whether the models with endogenous output produce better predictions of labor (L), the unemployment rate (U), the wage rate (W), and output (Q) than the models with exogenous output. To investigate this issue, for each model we compare the predicted and actual values of these variables using Theil's [1958, p. 32] measure of inequality, I.[11] When a model forecasts perfectly I = 0; when a model's forecasts are orthogonal to the actual values, I = 1. The higher the value of I, the worse the forecasts. Moreover, Theil shows how to compute the proportions of inequality due to: differences in the mean values of the actual and predicted series (I^M); differences in the variances of the actual and predicted series (I^S); and differences due to imperfect covariation between the two series (I^C).

The Theil inequality coefficients corresponding to the parameter estimates in Table 1 are presented in Table 2. The figures in Table 2 suggest the following thoughts:

a) For all specifications, the predictions for the unemployment rate are the worst. Loosely speaking, the equilibrium model has a relatively hard time explaining unemployment, which is consistent with our earlier observation that the coefficients in the unemployment equations are often statistically insignificant and/or of signs contrary to the theory.

b) Comparing column (1) to column (3), and column (2) to column (4), it appears that allowing for endogenous output does not do much to enhance the explanatory power of the model.

c) The values of I^M, I^S, and I^C indicate that for both the exogenous and endogenous output models, the means and the variances of the predicted series closely mimic those of actual series. The main source of inequality is imperfect covariance between the predicted and actual series.

5. Summary and Conclusions

Aggregate labor demand equations are typically estimated on the assumption that output is an exogenous variable. Investigators who have made this assumption--and their critics--have noted that theoretically, output should be treated endogenously, and failure to do so may lead to inconsistent estimates of labor demand parameters. We have estimated an equilibrium model of the U.S. labor market with both exogenous and endogenous output. We found that: a) individual parameter estimates do not change much when output is allowed to be endogenous; b) the data do not reject the hypothesis that output is exogenous; and c) models with exogenous and endogenous output produce equally accurate predictions. In short, although the endogenous output model is more complicated, it does not seem any better.

Of course, all of these conclusions are conditional on the validity of the underlying model. In this context it is particularly important to recall that the equilibrium model fails to provide a very good explanation of unemployment. Maybe in a disequilibrium model the assumption of endogenous output would make a difference. In the same way, maybe a more adequate measure of capital services would change our substantive results. There are always a lot of "maybe's" in work like this; only additional research can tell whether the doubts they raise are justified. In the meantime, we conclude that the convenient assumption that output is exogenous is likely to produce results that are just as good as those generated by the perhaps more theoretically attractive assumption of endogeneity. There is no need for researchers who rely on the assumption of exogenous output to be overly apologetic.

Table 1
Parameter Estimates*

	Endogenous Output		Exogenous Output	
	(1) μ_t = FRB Measure	(2) μ_t = Shapiro Measure	(3) μ_t = FRB Measure	(4) μ_t = Shapiro Measure
α_0	-1.404 (-11.50)	-3.866 (-85.01)	-1.410 (-14.94)	-3.717 (-104.2)
α_1	-0.5172 (-20.56)	-0.5947 (-55.56)	-0.4833 (-24.07)	-0.5452 (-64.30)
α_2	0.6345 (65.39)	1.016 (247.7)	0.6638 (100.5)	1.032 (343.1)
α_3	0.005085 (6.247)	-0.006166 (-14.27)	0.003168 (4.797)	-0.008187 (-21.30)
β_0	7.783 (8.666)	32.54 (0.7084)	1.730 (1.630)	55.72 (0.7952)
β_2	1.079 (4.025)	10.13 (0.5954)	5.248 (1.300)	19.83 (0.7297)
β_2	-0.01575 (-0.5574)	-0.08624 (-0.3112)	-0.03719 (-0.2750)	-0.3129 (-0.5177)
β_3	0.1212 (1.909)	0.2154 (0.3622)	0.2947 (0.9722)	0.8753 (0.5918)
β_4	0.01781 (3.498)	0.1283 (0.5890)	0.1028 (1.377)	0.1597 (0.7193)
γ_0	0.03568 (5.415)	0.04510 (5.660)	0.03948 (5.960)	0.06781 (5.262)
γ_1	0.01881 (1.127)	0.01312 (1.303)	0.02254 (1.242)	0.01219 (1.362)
γ_2	0.003650 (4.174)	0.002053 (1.952)	0.003114 (3.548)	-0.001140 (-0.8168)
$\ln A$	5.132 (42.62)	2.773 (27.83)	1.860 (18.68)	2.594 (32.63)
Ω	0.0327 (30.44)	0.02430 (34.18)	0.02208 (38.33)	0.02550 (35.06)

Table 1 (continued)

	Endogenous Output		Exogenous Output	
	(1) μ_t = FRB Measure	(2) μ_t = Shapiro Measure	(3) μ_t = FRB Measure	(4) μ_t = Shapiro Measure
v_1	-0.8549 (-30.17)	-0.3160 (-13.38)	-	-
v_2	0.3556 (35.94)	0.3550 (71.23)	0.3121 (37.43)	0.2466 (36.81)
ρ_1	0.4230 (3.536)	0.2529 (2.391)	0.3206 (3.141)	0.2771 (3.201)
ρ_2	0.9074 (4.703)	0.9565 (77.15)	0.9622 (105.3)	0.9600 (105.3)
ρ_3	0.4211 (3.391)	0.5363 (4.442)	0.3639 (2.825)	0.7093 (5.986)
ρ_4	0.6214 (10.63)	0.4146 (3.842)	0.5457 (3.733)	0.5904
lnL	448.00	447.11	444.05	444.15

*The numbers in parentheses are asymptotic t-ratios.

Table 2
Theil's Inequality Coefficients for the Models*
(I; I^M, I^S, I^C)

	Endogenous Output		Exogenous Output	
	(1) μ_t = FRB Measure	(2) μ_t = Shapiro Measure	(3) μ_t = FRB Measure	(4) μ_t = Shapiro Measure
lnL	0.0015	0.0014	0.0012	0.0014
	1.4×10^{-5}	1.1×10^{-6}	8.8×10^{-6}	1.3×10^{-7}
	5.9×10^{-5}	0.014	1.1×10^{-4}	0.11
	0.99	0.98	0.99	0.89
U	0.093	0.096	0.095	0.11
	2.4×10^{-7}	1.4×10^{-7}	6.6×10^{-8}	6.2×10^{-10}
	0.21	0.34	0.31	0.27
	0.79	0.65	0.69	0.73
lnW	0.0058	0.0056	0.0058	0.0056
	2.1×10^{-5}	1.7×10^{-6}	3.9×10^{-7}	6.3×10^{-7}
	1.2×10^{-3}	9.9×10^{-3}	7.0×10^{-3}	0.043
	0.99	0.99	0.99	0.96
lnQ	8.6×10^{-4}	0.0015	8.7×10^{-4}	0.0016
	7.3×10^{-6}	1.3×10^{-7}	2.5×10^{-5}	6.2×10^{-9}
	2.1×10^{-4}	0.020	8.0×10^{-4}	0.11
	0.99	0.98	0.99	0.89

*The first number in each cell is I, Theil's coefficient of inequality between the predicted and actual values of the variable. The next three numbers are I^M (the proportion of inequality due to differences in the mean values of the actual and predicted series); I^S (the proportion due to differences in the variances of the actual and predicted series); and I^C (the proportion due to imperfect covariance between the actual and predicted series); respectively. $I^M + I^S + I^C$ may not sum to 1.0 due to rounding errors.

FOOTNOTES

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[1]See, for example, Lucas and Rapping [1970], Altonji [1982], Sarantis [1981], and Quandt and Rosen [1986]. Hamermesh [1986] provides further details on the theory of factor demand.

[2]See Lucas and Rapping [1970, p. 272] and Altonji [1982, p. 786].

[3]We also estimated a version of equation (2.2) that included a measure of wealth on the right hand side. In all specifications it was statistically insignificant, and has been omitted.

[4]The derivation of equation (2.4) implies that $\gamma_1 = -\gamma_2$, but rather than impose this constraint, we allow the data to determine the magnitudes of the two coefficients.

[5]This is presumably why Symons and Layard [1984] choose to proxy capital services as a cubic time trend rather than measure it emplicitly.

[6]We also examined a specification in which H_t was simply the number of people between the ages 16 and 65; no major differences resulted.

[7]Shapiro produces quarterly estimates for 1952-1982. We take averages to form annual figures. For 1948-1951, we impute values of Shapiro's index by means of a least squares regression of his measure on the Federal Reserve Board Measure.

[8]Following Altonji [1985], we take the simple averages of the first and second period ahead forecasts.

[9]The statistical theory required to obtain correct standard errors in a "rolling regression" framework has not yet been developed. (See Pagan [1984].) Hence, the standard errors on the expectational variables must be regarded with special caution.

[10] However, our estimates do differ from those of Romer, who found a larger coefficient on capital, and a coefficient on labor smaller in absolute value and not significantly different from zero. When we estimated the production function using ordinary least squares (as Romer did), we obtained results quite similar to his.

[11] Let A_t be the actual value of observation t for a series and P_t the value predicted by the model. Then

$$I = \frac{\sqrt{(1/n)\Sigma(P_t - A_t)^2}}{\sqrt{(1/n)\Sigma P_t^2} + \sqrt{(1/n)\Sigma A_t^2}}$$

where n is the number of observations. Note that an alternative definition of I exists as well, and there has been some controversy about which is the proper one. We use the one employed by Pindyck and Rubinfeld [1981].

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