The Behaviour of Productivity Growth Rates and Composition Bias in the Labour Input

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Abstract: *The conventionally calculated Solow residual has been used as a measure of exogenous productivity shocks that contribute to the business cycle. However recently this residual has been shown to be endogenous and has led to the conclusion that the aggregate economy is characterized by increasing returns to scale and imperfect competition. Another hypothesis is that the Solow residual may fail to be exogenous due to measurement errors in labour and capital. Using an efficiency hours series corrected for the composition bias in the labour force and a capital series adjusted for capacity utilization for Canada, we find that adjusting the Solow residual for cyclical variations in labour and capital inputs over the business cycle re-establishes exogeneity of productivity shocks.*

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I. INTRODUCTION

The Solow residual plays an important role in growth accounting and neoclassical growth theory. Best known as a measure of total factor productivity growth rates, the residual, calculated under the assumptions of constant returns to scale, perfect competition and constant utilization of labour and capital inputs, was thought to be exogenous. However, Evan (1992) found that changes in real and monetary aggregates Granger-caused the Solow residual in the US and Cozier and Gupta (1993) found similar results for Canada. Hall (1986, 1988, 1990) has contended that the failure of the Solow residual to be invariant with respect to nominal variables indicates that the economy is best described as being characterized by increasing returns to scale and monopolistic competition. Another hypothesis, however, is that the failure of the exogeneity test may be due to measurement errors in inputs. In fact, several more recent papers (e.g., Paquet and Robidoux (1997), Burnside, Eichenbaum and Rebelo (1996)) have found that incorporating variations in the utilization of the capital stock changes the properties of the calculated Solow residual and, in particular, the endogeneity of the conventionally measured Solow residual is due to measurement errors in capital.

In addition, in a separate branch of the literature Hulten (1986), among others, has argued that the average quality of the labour input changes over the business cycle. If so, then failure to take this into account would also result in a biassed measure of the Solow residual Together these arguments indicate that the appropriate method for testing the properties of the Solow residual is to calculate the residual taking into account cyclical variations in bothb capital utilization and labour quality and then to test this for exogeneity.

Accordingly, this paper demonstrates the importance of adjusting the Solow residual for both cyclical variations in capital utilization and quality of labour. To this end, an efficiency hours series based on formal education is computed using Canadian data from 1976 to 1989 and is used to determine if composition bias in the labour force affects the properties of the Solow residual. The impact of adjusting for variations in capital input on the productivity residual is also analysed. This study is unique in its use of formal education as the basis for cyclical adjustment and is the first attempt to construct an efficiency hours series for Canada.[1] It also contributes by being the first to examine for Canada the impact on the Solow residual of adjusting for both labour and capital. Only one other study for the U.S., by Paquet and Robidoux (1997), has attempted to adjusting both inputs.[2]

The results indicate that adjusting productivity growth rates for both utilization of the capital stock and quality of the labour force has a significant impact on the exogeneity of the Solow residual. Unadjusted we find the Solow residual, at the 10 percent level of significance, is endogenous with respect to the 90-day commercial paper rate and a vector of monetary variables. However when adjusting for capacity utilization, we are unable to reject the exogeneity of the Solow residual with respect to these variables, although the residual does become endogenous to the terms of trade at the 10% level of significance. Moreover, when adjusting for changes in the composition of the labour force only, we are unable to reject, at the 10 percent level, the exogeneity of the Solow residual with respect to all variables selected for the exogeneity test. Finally, when the Solow residual is adjusted for both capital and labour inputs, we find that this increases the degree of exogeneity of the residual with respect to these variables. This suggests that the previous failure of exogeneity tests may be due to measurement errors in the capital and labour inputs rather than to evidence of non-constant returns to scale and imperfect competition in the aggregate economy.

In addition, although our principal concern is the exogeneity of the Solow residual, an important ancillary result is that failure to adjust for labour force quality has systematically biased upward the secular rate of the total factor productivity growth.

The paper is organized as follows. Section 2 outlines the assumptions and derivation of the Solow residual. It also explores the potential bias in the conventionally calculated Solow residual that are caused by cyclical variation in capacity utilization and cyclical changes in the average quality of the labour input. Section 3 introduces data and the calculation of an efficiency labour series for Canada which adjusts for the changing quality of the labour force. The efficiency labour series, along with the varying capacity utilization series, is then used to calculate several adjusted Solow residuals which are used to examine the variation in the Solow residual caused by measurement errors in the labour and capital inputs. Section 4 presents the results of the exogeneity tests on both the unadjusted and adjusted Solow residuals. Finally, section 5 ends with conclusions.

II. MEASURING PRODUCTIVITY SHOCKS

Solow (1957) assumed that the economy could be approximated by an aggregate neoclassical production function:

$$Y_t = A(t)\ F(K_t, L_t) \qquad (1$$

where Y_t is output and L_t and K_t can be interpreted either as vectors of inputs or, for simplicity, as two composite inputs of labour and capital expressed in terms of time t.

Under the assumptions of perfect competition and constant returns to scale, the Solow residual derived from expression (1) is:

$$SR = \frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - W_K \frac{\dot{K}}{K} - W_L \frac{\dot{L}}{L} \qquad (2)$$

where W_K and W_L are the factor shares of output and can be calculated directly from the national income accounts. Equation (2) shows that the Solow residual is the part of output growth not explained by the contribution of the growth in inputs. Thus if capital and labour inputs are correctly measured, the Solow residual should be exogenous with respect to variables that are known not to affect technological change in the short run.

Traditionally, the capital input has been measured by a constant proportion of the capital stock and labour input by total hours worked. However, it is generally accepted that the utilization of capital is not constant over the business cycle and tends to be high in expansions and low in recessions. Thus, using constant capacity utilization in capital will bias the Solow residual.

As mentioned above, the impact of correcting for capacity utilization has been investigated in recent research. Paquet and Robidoux (1997), in a study of the U.S. and

Canada, adjusted their capital series by using measures of the rate of utilization calculated by Statistics Canada and the Federal Reserve Board and found for Canada, that productivity shocks were exogenous to real and nominal variables while for the US, productivity shocks were exogenous to narrowly-defined monetary aggregates. For comparison purposes, we follow Paquet and Robidoux and adopt the Statistics Canada series for our capital adjustment.

For the labour input the use of total hours worked implicitly assumes that the "efficiency" value of each hour is identical. However, recent evidence of composition bias in the labour force suggests that the average quality of labour changes over the business cycle. For instance, Topel (1993) tracked the number of weeks that individuals were unemployed using American data for the 1968-1990 period and found that high wage wokers exhibited little variation in their employment prospects over the business cycle compared to low wage workers. This implies that the average quality of the labour input is higher during recessions than expansions and the unadjusted Solow residual will be biassed.

One way to address this problem is to calculate an "efficiency" labour units series in place of total hours. This approach assumes that workers are paid their marginal product and therefore relative wages for workers with different characteristics reflect the relative productivity of these workers. Generally, differing productivity across workers is thought to reflect differing quantities of human capital.

Examples of constructing efficiency labour series include Hansen (1993) who computed a monthly efficiency hours series using US data from July 1955 to June 1988. Hours worked by different age-sex subgroups were weighted by the relative average hourly earnings of each group. Hansen calculated the weights as equal to the ratio of the average hourly earnings of workers in a given classification divided by the average hourly wage of all workers. Kydeland and Prescott (1993) also constructed an efficiency hours series using a longitudinal US data set from 1969 to 1982. By comparing the calculated efficiency labour series to the total hours series , Kydeland and Prescott found that the adjusted series was one third less volatile over the business cycle then the unadjusted series. Though none of these authors were concerned specifically with bias in the Solow residual, their findings indicate that composition bias could lead to substantial cyclical bias in the calculation of the Solow residual.[3]

III. DATA AND ADJUSTMENTS

To help us examine the variation in the Solow residual caused by measurement error in labour, we construct an efficiency hours series based on formal education. The choice of formal education is based on Presad (1993) who argue that variation of employment prospects over the business cycle is largely due to differences in level of education, rather than experience or tenure on the current job. The data used are from the Labour Force Survey which has collected monthly employment statistics disaggregated by educational attainment since 1976. Prior to 1990, individuals were classified as belonging to one of five education classes: 0-8 years, (some) high school, some post-secondary, post secondary certificate, and university degree.[4]

To assess the cyclical variability of the total number employed by education class, the number of individuals employed in each education class was seasonally adjusted and detrended. Visual inspections of these series indicate that the lower educated groups are more sensitive to cyclical fluctuations than are the more educated groups. The recessions in the early 1980's have had the greatest impact upon the least educated groups.

The efficiency hours series is constructed as follows:

$$E_t = \Sigma_i \alpha_i S_{it} L_t \tag{3}$$

In (3), the efficiency hour series is denoted by E_t, the total number employed by L_t, the relative earnings by α_i, and the share of total employment of each group i at time t by S_{it}. The relative weights used to calculate the efficiency labour series use the annual earnings of workers with less than eight years education as the numeraire.[5] The weight used to construct the efficiency hours series is:

$$\alpha_i = \frac{ave.\ annual\ earnings\ of\ group\ i}{ave.\ annual\ earnings\ with < 8\ Yrs.Educ.} \tag{4}$$

These weights are arguably better then the use of relative average hourly earnings for this data set. Annual earnings will differ across groups both because of different average hourly wages and different average hours worked in each time period. On average, we expect that more educated workers will work longer hours than less educated workers. Therefore, using relative average hour earnings to construct α_i, means the calculated efficiency hours series underestimates the true efficiency hours input. The use of average relative earnings alleviates this problem by capturing differences in average hours worked by different education categories.

The procedure followed here differs substantially from previous work in several ways. First, unlike Kydeland and Prescott (1993), aggregate data using the total number of individuals employed is used instead of longitudinal data. Although our data is similar to that of Hansen, the series calculated in this paper disaggregates along educational classes rather than the age-sex classifications employed by Hansen. Furthermore our weights are defined differently than in the previous two papers. Hansen constructed his weights by dividing the average hourly earning of each class of workers by the average hourly wage of all workers while Kydeland and Prescott use the real hourly wage of each individual as weights. In contrast, for reasons already explained, the series calculated here uses average annual earnings of workers classified by formal education and uses the 0-8 year education group as the numeraire.

Using equation (4) and data on annual earnings of workers classified by formal education, Riddell (1995) calculated the weights as shown in Table 1. Based on these weights and total hours worked, the efficiency hours series is then calculated to replace the total hours series.

Figure 1 shows the calculated efficiency hours series and the total hours series. The two series track each other closely before diverging in the early 1980's and growing further apart after that. This seems to indicate that a secular increase in the average quality of the labour force occurred during the 1980's. This implies that the increase in the labour input over the 1980's was greater than that measured by unadjusted total hours, and therefore that a Solow residual calculated using total hours would overestimate the true rate of total factor productivity growth.

To determine whether the efficiency hours series exhibits less cyclical volatility than the total hours series, we follow Hansen (1993) and Kydeland and Prescott (1993) and estimate the percent standard deviation of the detrended series. As in Kydeland and Prescott, the cyclical component of a time series is defined as the deviations from the time trend. This is calculated by regressing the natural log of each series on a constant and a linear time trend. The estimated percentage standard deviations were 2.781 for the total hours series and 2.642 for the efficiency hours series. As expected, the efficiency hours series is slightly less variable than the total hours series, although the difference is small. The ratio of the two standard deviations is 1.05, which is the same ratio as that of the two series calculated by Hansen.[6] This result is significantly less than that reported by Kydeland and Prescott (1993), who found that the ratio of the two series they calculated was 1.39. However, since each individual in their sample was weighted according to their average earnings, it is not surprising that their efficiency hours series is less variable than ours which uses aggregate data.

Next, using four different combinations of the input measures and gross domestic product (in 1986 dollars) at factor cost, we calculate four versions of the Solow residual. Labour's share of income is set equal to 0.66 (consistent with the average share in the data). The first measure of the Solow residual, denoted by SR1, is the unadjusted residual calculated using the growth rates of total hours and the unadjusted capital stock. The second Solow residual (SR2) is calculated using total hours worked and the product of the capital stock and the capacity utilization rate published by Statistics Canada. The third, SR3, is calculated using the efficiency hours series and the unadjusted capital stock. The fourth, our preferred Solow residual (SR4), is calculated using both the efficiency hours series and the capital stock adjusted for variations in capacity utilization.

The impacts of the adjustments are displayed in Figures 2 and 3 with Figure 2 showing the effect of adjusting for one input only and Figure 3 for both. Panel (a) of Figure 1 shows that the Solow residual calculated using the efficiency hours series has, as expected, shifted downwards during the recession of the early 1980's. During the mid to late 1980's, the secular trend in the average quality of the labour force dominates, and the adjusted residual tends to be less than that of the residual calculated using total hours. This suggests that the reported productivity growth rates of the 1980's may be biassed upwards due to a failure to account for changes in the quality of the labour force.

Panel (b) of Figure 2 shows that correcting for capacity utilization appears to have a greater impact than adjusting the labour series. The capacity adjusted residual tends to be greater than the unadjusted measure during the recession of 1981-82 and less than the unadjusted residual during the1983 recovery.

Finally, Figure 3 compares the unadjusted residual (SR1) with the residual adjusted for both labour and capital inputs. The difference between these two series appears to be larger than for any of our other comparisons. This indicates that correcting for both capital utilization and quality of labour has important implications for the behaviour of productivity growth rates. Interestingly, we can also observe from Figures 2 and 3, that while productivity growth is procyclical, the effect on the Solow residual of adjusting capital or labour or, both, is asymmetric over the business cycle.[7] The divergence between the adjusted and unadjusted residuals is noticeably larger during the recessions of the early 1980's than that in the rest of the sample period.

IV. EXOGENEITY TESTS

To assess the impact of the adjustments to inputs on productivity shocks, we conduct exogeneity tests on the residual using a vector of nominal variables similar to those employed by Cozier and Gupta (1993) and Paquet and Robidoux (1997). The appendix contains a detailed description of the data used. The four measures of the Solow residual were tested to determine if they were exogenous. Exogeneity is tested by regressing the Solow residual on a vector of nominal variables and its own lagged values. Granger causality tests are then conducted to determine if the Solow residual is Granger-caused by one or more of the nominal variables. As discussed earlier, Evans (1992), using US data, and Cozier and Gupta (1993), using Canadian data, both found that the unadjusted Solow residual was Granger-caused by nominal variables. Paquet and Robidoux found that correcting for variations in capacity utilization allowed one to reject the hypothesis that the Solow residual was Granger caused by nominal variables for Canada and to reduce the endogeneity of the Solow residual calculated using US data.

The variables used in conducting these tests have been constructed to correspond to those used by Cozier and Gupta. The vector of nominal variables used is the 90-day commercial paper rate (R90), Gross M1 (DLM1), the GDP deflator (DLGDP), the terms of trade

(DLTOT), U.S. real GDP (DUSGDP), a fuel oil price index (DFOIL), and real total government spending (DLGOVS). All variables are the first difference of the natural log, with the exception of the commercial paper rate which is the first difference of the levels of the series. The number of lags for each variable included in the Granger causality tests were determined using the Akaike and Schwarz criterion.

The results of the Granger causality tests are summarized in Table 2, where the marginal significance of each variable is reported. The results for the basic residual, SR1, indicate that the unadjusted Solow residual is Granger caused by the 90-day commercial paper rate at the 6% level and by the vector of monetary variables (R90 and M1) at the 9% level. These results are weaker but consistent with those of Cozier and Gupta. Unlike Cozier and Gupta, USGDP is not found to Granger cause the Solow residual. The inclusion of the capacity utilization series in the calculation of the Solow residual, SR2, yields results similar to Paquet and Robidoux since the interest rate and monetary variables are insignificant. However, they differ in that the terms of trade variable is now significant at the 10% level.

The fourth column of Table 2 reports the results for the Solow residual calculated using the efficiency hours series and the unadjusted capital stock, SR3. Interestingly, adjusting for changes only in the composition of the labour force effects the Granger causality results in a manner similar to but not identical to adjusting only for capital utilization. In particular, none of the nominal variables are significant at the 10% level. But the terms of trade variable is now insignificant.

The final column reports the results for the Solow residual calculated using the efficiency hours series and the capital stock adjusted for variations in capacity utilization. For this, our preferred Solow residual, for all variables we cannot reject the exogeneity of the Solow residual at the 10% level. The net effect of adjusting for capital and labour inputs, based on the marginal significance level in Table 2, is to increase the degree of exogeneity of the Solow residual.

V. CONCLUSION

This paper has examined the impact of cyclical variations in labour quality and capital utilization on the Solow residual. One of the key arguments outlined in this paper is that the failure to correct the Solow residual for variations in the utilization of the capital stock and the average quality of the labour input can lead to misleading results. Moreover, although this study has focussed on applications relating to the structure of the economy and business cycle fluctuations, the results also suggest that there may well be secular trends, particularly in the quality of the labour force, that could result in a systematic bias of the measured rate of total factor productivity growth. The study follows recent literature which questioned Hall's conclusion that the failure of the Solow residual to be invariant to nominal shocks is evidence that the economy is characterized by increasing returns and monopolistic competition. It has found that adjusting the Solow residual for cyclical variations in inputs over the business cycle re-establishes exogeneity of the Solow residual.

An efficiency labours series using Canadian data has been constructed to adjust for variations in the average quality of the labour input. The cyclical composition bias was found to be comparable to that estimated by Hansen (1993) using US data. Interestingly, there also appears to a large secular trend in the efficiency labour series over the sample period studied. This reflects the large decline in the demand for low skilled (educated) workers over the sample period that has been documented elsewhere (Riddell (1995)).

The exogeneity tests indicate that adjusting the Solow residual for utilization of the capital stock and for the level of human capital of the labour force re-establishes the exogeneity of the Solow residual. The results suggest that models based on perfect competition and constant returns to scale provide a good approximation to the "real world"; they also indicate the importance of building models that allow for varying utilization of the capital stock and heterogeneity of the work force.

Data Appendix

Sample Period 1976 - 1989

GDP	I35026	GDP at Factor Cost, 1986 Prices, QT., S.A.
Labour	D778711	Total Hours Worked, Monthly, S.A. Converted to Quarterly by summing.
Capital	13-568	Fixed Capital Flows and Stocks (Catalogue)Total End Year Net Stock, Geometric Depreciation, Millions of 1986 Dollars
Employed by Education		Labour Force Survey, Monthly Data, Converted to quarterly by averaging and then seasonally adjusted using four constants and a time trend (polynomial).
Govt Spending	D20013	Government Current Expenditure on Goods & Services Dollars, (SAAR), GDP Expenditure Based QT.
GDP Deflator	D20556	Impl. Price Index GDP (1986=100) SAAR by QT. Gross Domestic Product
M1	B1642	Cht'd Banks - Sel. S.A. Series / Statement Gross M1 Dollars
Price Oil		Prices: Petroleum, Nat. Gas, Electricity Crude Prices by period of loading Exch.Rate
Interest Rate	B14001	91 Day TBill
US GNP	D360013	Real US GNP, 1982 Constant Dollars
Terms of Trade	D395030 D448933 D75000 D398534 D395030 D448933 Defined to be the ratio of the paasche export and import price deflators. The total series is based on combining the different deflators, as well the export price index's. The TOT was then defined to be the ratio of the two indices.	
Capacity Utilization.		Statistics Canada

NOTES

1. For the US, Hansen (1993) has constructed an efficiency hours series using aggregated data disaggregated by age and sex, while Kydeland and Prescott (1993) have also constructed an efficiency hours series using a longitudinal data set.

2. Paquet and Robidoux (1997) also examined Canadian productivity shocks but adjusted only the capital input because an adjusted labour series was not readily available.

3. Although Hansen (1993) and Kydeland and Prescott (1993) both constructed a labour efficiency series, neither used it to calculate the Solow residual. Their main purpose was to examine the cyclical behaviour of the labour input. Evans (1992) and Paquet and Robidoux (1997), however, have used Hansen's efficiency hours series to calculate US productivity shocks. Using Hansen's labour series and an unadjusted capital series, Evans found that US productivity shocks did not behave as an exogenous impulse. When adjusting for both the labour and capital inputs, Paquet and Robidoux found that US productivity shocks were endogenous with respect to only narrowly-defined monetary aggregates, while the unadjusted residual was endogenous with M1, the 90-day Treasury bill rate, and various definitions of monetary shocks.

4. In 1990, a sixth category was added: graduated from high school. For simplicity, data after 1989 are not included in this paper.

5. The weights used, however, are sensitive to variations in the average quality of the workers in the 0-8 class. For example, if the decline in employment for this group during the past twenty years has resulted in the exit of the least productive members of this group, the efficiency hours series would underestimate the true increase in the labour input.

6. The two results are not directly comparable, however, as Hansen used the Hodrick-Prescott filter do detrend the series. For a recent critique of the H-P filter, see Cooley and Nason (1995).

7. Interestingly, Ryan (1997) in a study of U.S. productivity shocks and price-cost margins during contractions and expansions found that both the unadjusted productivity growth rates and price-cost ratio are asymmetric over business cycles. This led the author to conclude "These characteristics are consistent with labour hoarding" (pp.889).

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Table 1: Relative returns to education

Year	0 -8 Years	Some High School	Some Post Secondary	Post Secondary Cert.	Univ. Degree
76 -81	1.0	1.0	1.01	1.28	2
82	1.0	1.0	1.01	1.26	2.01
83[a]	1.0	1.0	1.0	1.25	2.0
84	1.0	1.0	.99	1.26	1.98
85	1.0	1.02	1.02	1.3	2.02
86	1.0	1.01	1.02	1.25	1.96
87	1.0	1.02	1.01	1.25	1.97
88	1.0	1.06	1.03	1.34	1.97
89	1.0	1.04	1.02	1.35	2.19
Avg. 82 - 89	1.0	1.02	1.01	1.28	2.0

a No value was reported for this, so the values reported above are based upon the regression lines from Ridell.

Table 2: Granger causality tests

Variable	Marginal Signif. SR1[a]	Marginal Signif. SR2[b]	Marginal Signif. SR3[c]	Marginal Signif. SR4[b]
SR	0.049	0.307	0.076	0.349
R90	0.057	0.4	0.119	0.547
DLM1	0.997	0.748	0.895	0.347
DLGDP	0.492	0.882	0.52	0.785
DLGOVS	0.781	0.554	0.528	0.756
DUSGDP	0.679	0.554	0.775	0.627
DLTOT	0.237	0.091	0.386	0.104
DFOIL	0.984	0.498	0.675	0.531
R90, DLM1	0.081	0.514	0.157	0.555
R90, DLM1, DLGDP	0.123	0.71	0.187	0.75

a One lag of all the variables was used with the exception of R90 which had 5.
b One lag of all the variables was used, except for DLTOT which had 4 lags and DFOIL which had 2
c One lag of all of the variables was used, except for R90 which had 5 and DLGDP which had 2.

Figure 1: Efficiency hours and total hours worked

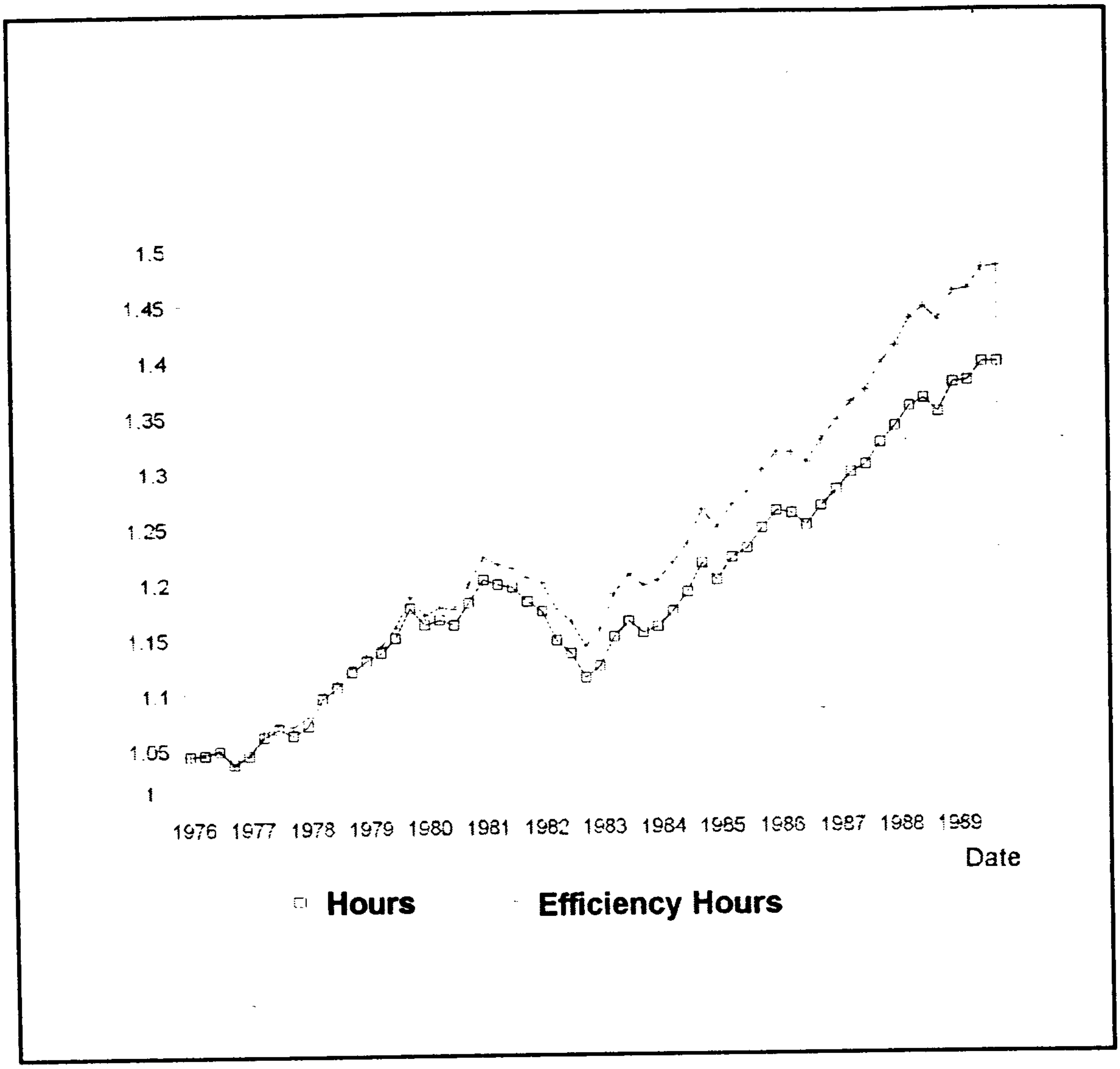
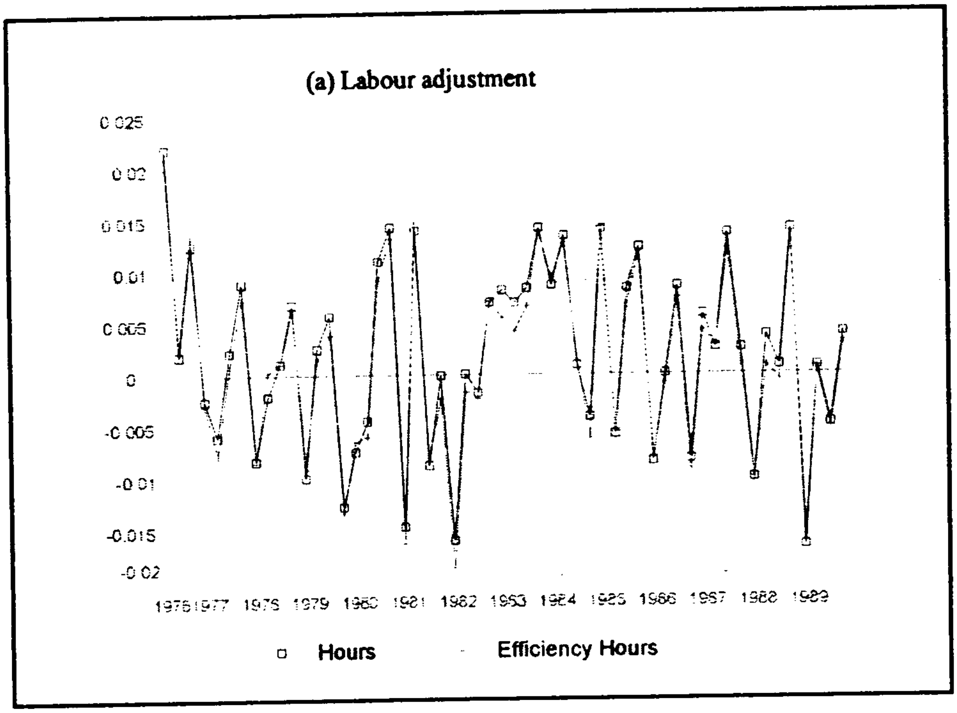


Figure 2: Impact of adjusting one input on the residual



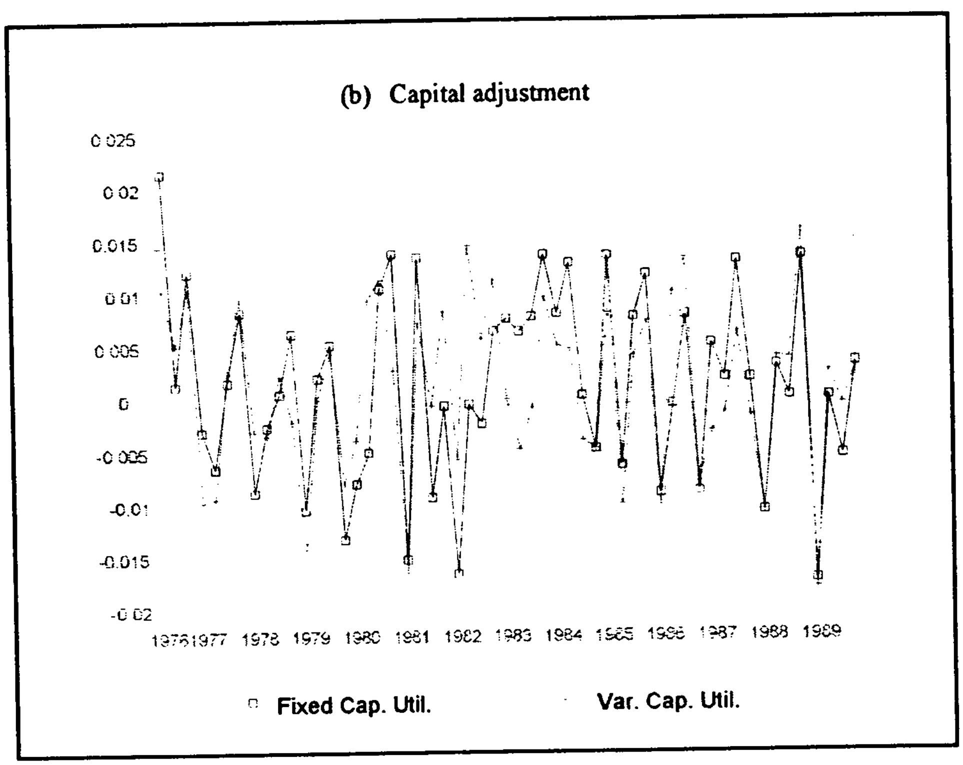


Figure 3: Comparing the adjusted and unadjusted Solow residuals