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Issues on the Measurement of the Solow Residual and the Testing of its Exogeneity: a Tale of Two Countries*

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ABSTRACT

Using aggregate US and Canadian data, this paper examines the implications for the empirical assessment of market structure and exogeneity of productivity shocks of correcting the Solow residual for variation in capacity utilization. In contrast to most studies, not accounting for capacity utilization, our results suggest that the US and Canadian market structures are well described by constant returns to scale and perfect competition. They also suggest that Canadian productivity shocks are exogenous to real and monetary variables, while US productivity shocks become exogenous to narrowly-defined monetary aggregates and monetary policy innovations when the capital stock is adjusted for variations in utilization rates.

RÉSUMÉ

À l'aide de données agrégées américaines et canadiennes, nous examinons les implications empiriques quant à la structure de marché et à l'exogénéité des chocs de productivité, suite à la correction de la mesure du résidu de Solow lorsqu'il y a utilisation variable du capital. Comparativement, à la plupart des études qui ont ignoré cette considération, nos résultats suggèrent qu'en agrégé, les structures de marché canadienne et américaine sont convenablement caractérisées par des rendements constants à l'échelle et la concurrence parfaite. Nous trouvons aussi qu'après ajustement pour un taux variable d'utilisation du stock de capital, la mesure corrigée des chocs de productivité canadiens est exogène aux variables monétaires et réelles, alors que celle des chocs de productivité américains devient exogène aux agrégats monétaires étroits et aux innovations monétaires.

1. Introduction

The Solow residual (SR) has been directly or indirectly at the center of many recent macroeconomic developments. In calculating the SR, full and constant utilization of both capital and labour inputs is often assumed. Since the utilization of capital is likely to be highly procyclical, we argue that this assumption could have important implications for the interpretation of the procyclical behaviour and exogeneity of productivity shocks, as well as the degree of increasing returns to scale and market power in the economy.

Following Kydland and Prescott's model and Prescott's (1986) suggestion that about 75 % of US postwar fluctuations might be related to technology shocks, much work in modern macroeconomics has focused on the analysis of the business cycle by extending the basic neo-classical growth model with exogenous productivity shocks.[1] In these models, productivity shocks have been typically measured by the Solow residual under the maintained assumptions of constant returns to scale, perfect competition and full and constant utilization of capital and labour inputs. Aiyagari (1994) showed that under these standard assumptions, the contribution of technology shocks to output fluctuations must be near Prescott's (1986) estimate for the prediction concerning the contemporaneous productivity/labour correlation and the variability of labour input relative to output to be correct. Aiyagari (1994) also emphasized that imperfect competition, external economies of scale and/or measurement errors in inputs may well imply a smaller role for technology shocks in explaining aggregate fluctuations.

In parallel, models embodying imperfect competition and increasing returns to scale have also been developed in the last decade to study business cycles.[2] In contrast to equilibrium dynamic business cycle models where exogenous productivity shocks are the main impulses to economic fluctuations, these models emphasize the role played by monetary shocks in driving cycles. In these models the procyclical behaviour of productivity can be rationalize by these

[1] In first-generation real business cycle models, in a closed economy without government sector and without money, a single real productivity impulse shifted the aggregate production function. Many other extensions have been considered since. For instance, some have included spending and/or tax shocks (e.g. Christiano and Eichenbaum, 1992, Braun, 1994, McGrattan, 1994, Ambler and Paquet, 1996). Others have introduced monetary shocks (e.g. Cooley and Hansen, 1989), even in artificial economies with nominal rigidities (e.g. Cho and Cooley, 1995, Cho and Phaneuf, 1993).

[2] Books edited by Mankiw and Romer (1991) contain many papers related to imperfect competition in the New Keynesian macroeconomic tradition.

demand shocks since the production structure is characterized by market power and increasing returns to scale.[3] Notice that all these models have assumed a constant and full utilization of inputs.

By studying the relation between the SR and combinations of input and output growth, Hall (1988, 1990) reports empirical evidence suggesting the significance of market power and increasing returns to scale in many US industries. Although Waldmann (1991) suggests that the large markups found by Hall (1988) in the non-manufacturing industries reflect probably data construction, he did not dispute the finding of significant markups in most US manufacturing industries. The framework developed by Hall has been extended by Shapiro (1987) and Roeger (1995) to exploit the dual productivity measure as well as the traditional primal measure suggested by Solow (1957). Their empirical results support the presence of significant markups in US industries found by Hall (1988). Finally, Caballerro and Lyons (1992) interpret Hall's (1990) results has external effects, such as thick-market externalities, since they estimate larger increasing returns to scale for the aggregate manufacturing sector than for two-digit manufacturing industries.

However, under the assumption of imperfect competition, markups and scale elasticity estimated from these studies are likely to be upward biased since they use value-added as measure of output rather than gross output data (Hall, 1986, Basu and Fernald, 1994, 1995). The results obtained first by Domowitz, Hubbard and Peterson (1988) show that this bias was not important enough to reduce substantially the market power evidence when one accounts for intermediate inputs. The results obtained by Norrbin (1993) using a more appropriate data set suggests, in contrast, that the evidence for market power in US data vanishes when gross output is used as measure of output. The empirical evidence presented in Basu and Fernald (1994) also suggests that the typical US manufacturing industry is characterized by constant returns to scale when they correct for the bias caused by using value-added data, or when gross output data is used. In a related paper, they also show that the evidence of increasing returns for the US

[3] More recently, the implications of imperfect competition in dynamic general equilibrium models has also been considered. Farmer (1993) discusses how self-fulfilling prophecies in economies with imperfect competition and multiple equilibria can generate the business cycle. See also Beaudry and Devereux (1993), Benhabib and Farmer (1994), Gali (1994), Farmer and Guo (1995), and Rotemberg and Woodford (1995).

manufacturing industry as a whole obtained by Caballero and Lyons (1992) disappears when the same correction is applied to their value-added framework (Basu and Fernald, 1995).

If inputs are not always fully used, as even casual observation would suggest with respect to unused equipment or idle plants, then one needs to use effective measures of inputs to construct appropriately the SR and to gather evidence about its exogeneity and the degree of returns to scale and competition in an economy. For instance, Burnside and Eichenbaum (1994) have developed an equilibrium business cycle model with variable capital utilization rate, which plays a distinct role in magnifying and propagating the impacts of shocks over the business cycle.[4] On the empirical front, Burnside, Eichenbaum and Rebelo (1995) conclude that US aggregate and industry data are well described by constant-returns-to-scale production functions when variations in capital utilization is taken into account.

Another important issue about the SR pertains to its exogeneity or lack thereof. Evans (1992) finds that changes in real and monetary variables Granger-cause the Solow residual in the US. Cozier and Gupta (1993) find similar results using Canadian data. If the SR fails Hall's invariance and Granger-causality tests, this undermines its use as a measure of exogenous productivity shocks that contribute to generate business cycles.

This paper addresses the measurement and endogeneity of the measured productivity shock (or Solow residual) using value-added data for both the US and the Canadian economy. First, we consider an adequate measure of effective capital input.[5] Second, we proceed with an econometric assessment of the degree of competition and of returns to scale. Finally, having argued for the construction of an appropriate measure of the SR, we reconsider exogeneity tests of the SR with respect to real and monetary shocks.

In contrast to most previous studies, we use aggregate data to know how important is the degree of imperfect competition the economy as a whole. In addition, this approach is arguably more appropriate than industry studies to calibrate markup and scale elasticity parameters in

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[4] Other papers have also considered varying capital utilization in business cycle models, including Greenwood, Hercowitcz and Huffman (1988), Finn (1991), Greenwood, Hercowitcz and Krussel (1994), Bils and Cho (1993), Cooley, Hansen and Prescott (1995).

[5] We abstract here from the labor hoarding issue because of the difficulty of having suitable data on work effort.

one-sector macroeconomic models. Although some sectors of the economy can be characterized by imperfect competition structure, what matter for macroeconomic models is to know if this set-up is appropriate for aggregate data, and thus compatible with the modeling adopted in most of the modern cycle literature.

The use of value-added data means, however, that our results should be interpreted as upper bound estimates of markup and returns to scale given the likely upward bias associated with the use of these data, as noted above.

Examining both the US and the Canadian economy permits cross-country comparisons and extend the usual sample limited to the US economy[6]. It is also easier to find good instruments to estimate markup and returns to scale in the Canadian case since US data are obvious candidates to instrument Canadian data because of their likely exogeneity.

Our results indicate that varying capital utilization rates are not innocuous to characterize correctly US and Canadian economies and to assess the statistical behaviour of their SR. Indeed, overall our results suggest that the US and Canadian market structures are well characterized by constant returns to scale and perfect competition. They also suggest that Canadian productivity shocks are exogenous to real and monetary variables, while US productivity shocks become exogenous to narrowly-defined monetary aggregates and monetary policy innovations when the capital stock is adjusted for variations in utilization rates.

The paper is structured as follows. In section 2, we formally discuss issues relevant for the measurement of the *SR* under different assumptions. Section 3 describes the data employed. In particular, we discuss the capacity utilization measures in both countries and we justify their use. The empirical evidence on the degree of competition and returns to scale in the aggregate US and Canadian economies is presented in section 4. Section 5 provides an empirical assessment of the exogeneity of the US and Canadian Solow residuals. Conclusions are drawn in section 6.

6 The only multi-country study that we are aware of is the one by Evans and Santos (1993) which examine the validity of the assumption of exogenous productivity shocks for the G-7 countries.

2. The Measurement of the Solow Residual

Let us consider the following aggregate homogeneous production function:

$$Y_t \,=\, Z_t\; F(N_t, K_t^*), \tag{1}$$

where Y_t is a measure of aggregate commercial or market output, N_t is the number of person-hours worked in period *t*, K_t^* is an effective measure of the capital stock employed in period *t*. The latter is equal either to the aggregate capital stock, K_t, if we assume a constant and full utilization of the capital stock, or to the period's capacity utilization rate times the capital stock, $\kappa_t\, K_t$. The variable Z_t is the so-called total factor productivity, that is a Hicks-neutral index of technical progress.

Taking the logarithm of both sides of equation (1), then totally differentiating, and rearranging, we obtain:

$$d\,\ln Z_t \,= d\,\ln Y_t \,-\, \left(\frac{N_t}{Y_t}\frac{\partial Y_t}{\partial N_t}\right) d\,\ln N_t \,-\, \left(\frac{K_t^*}{Y_t}\frac{\partial Y_t}{\partial K_t^*}\right) d\,\ln K_t^* \quad . \tag{2}$$

Let us assume that firms are price takers in input markets, and that w_t and r_t are the wage rate and the rental cost of capital, respectively. The corresponding total cost function is therefore given by:

$$C_t \,=\, w_t\, N_t \,+\, r_t\, K_t^*, \tag{3}$$

with C_t/Y_t and $\partial C_t/\partial Y_t$ being the average cost and the marginal cost, respectively. Moreover, defining the degree of returns to scale, γ, as the ratio of the average cost to the marginal cost, the total cost function is also equal to:[7]

$$C_t \,=\, \gamma \cdot \frac{\partial C_t}{\partial Y_t} \cdot Y_t. \tag{4}$$

Cost minimization subject to the production function (1) implies the following first-order conditions with respect to each factor:

$$\frac{\partial Y_t}{\partial N_t} \,=\, \frac{w_t}{\partial C_t/\partial Y_t}\,, \tag{5a}$$

[7] The degree of returns to scale is also equal to the sum of the output elasticities with respect to each factor, i.e. $\gamma \equiv (\partial Y_t/\partial N_t) \cdot (N_t/Y_t) + (\partial Y_t/\partial K_t^*) \cdot (K_t^*/Y_t)$.

and

$$\frac{\partial Y_t}{\partial K_t^*} = \frac{r_t}{\partial C_t / \partial Y_t}. \tag{5b}$$

Using equation (4) along with (5a) and (5b) yields:

$$\frac{\partial Y_t}{\partial N_t} = \theta_{N\,t}^{C} \cdot \frac{Y_t}{N_t} \cdot \gamma, \tag{6a}$$

and

$$\frac{\partial Y_t}{\partial K_t^*} = \theta_{K^*\,t}^{C} \cdot \frac{Y_t}{K_t^*} \cdot \gamma, \tag{6b}$$

where $\theta_{N\,t}^{C} \equiv w_t N_t / C_t$ and $\theta_{K^*\,t}^{C} \equiv r_t K_t^* / C_t$ are the cost shares of labor and capital, respectively. Notice that, by definition, $\theta^{C}_{Nt} + \theta^{C}_{K^*t} = 1$.

Substituting equations (6a) and (6b) into equation (2), we obtain:

$$SR_t \equiv d \ln Z_t = d \ln Y_t - \gamma \left[\theta_{Nt}^{C} \; d \ln N_t + \theta_{K^*t}^{C} \; d \ln K_t^* \right], \tag{7}$$

which is the measure of the Solow residual, or *percentage* change in total factor productivity. Notice that this general measure (expressed in terms of cost shares) is independent of any assumption regarding the degree of competition in the economy, and that it incorporates directly the effect of various degree of returns to scale.

An alternative formulation of the Solow residual can also be derived to reflect the possible degrees of imperfect competition in the goods market. Under imperfect competition, the price of goods does not equal the marginal cost, rather the price P_t is equal to the product of a markup rate, μ, and of the marginal cost, $\partial C_t / \partial Y_t$. Using equation (5a) with (6a), and equation (5b) with (6b), we can show how cost shares are related to value shares. Defining the value shares of labor and capital as $\theta_{N\,t}^{V} \equiv w_t N_t / P_t Y_t$ and $\theta_{K^*\,t}^{V} \equiv w_t K_t^* / P_t Y_t$, respectively, then:

$$\theta_{Nt}^{C} = \frac{\mu \; \theta_{N\,t}^{V}}{\gamma}, \tag{8a}$$

and

$$\theta_{K^*\,t}^{C} = \frac{\mu \; \theta_{K^*\,t}^{V}}{\gamma}. \tag{8b}$$

Equations (8a), (8b) and (7) imply that the Solow residual is also given by:

$$SR_t \equiv d\ \ln Z_t = d\ \ln Y_t - \mu \left[\theta^V_{Nt}\ d\ \ln N_t + \theta^V_{K^*t}\ d\ \ln K^*_t \right]. \tag{9}$$

From the equations above, each input's value share and cost share are equal only under the maintained joint hypotheses of constant returns to scale (i.e. γ =1) and perfect competition (i.e. μ =1). Also, with imperfect competition and non-constant returns to scale, the true value shares do not sum to unity, but rather sum to $\gamma\ /\ \mu$.

Equations (7) and (9) are general expressions for the Solow residual (SR). If the *SR* is an appropriate measure of aggregate productivity shocks, it should be independent from changes in variables known to be neither causes of productivity shifts nor to be caused by such shifts. In practice, most papers in the *RBC* tradition, have assumed a perfectly competitive economy (in all markets), so that factors are paid their marginal products and output price equals its marginal cost (i.e. a markup rate is equal to 1), along with constant returns to scale (*CRS*), so that γ = 1. Under perfect competition, the factor cost shares are also equal to the factor value shares. Hence, most *RBC* models and empirical papers by Evans (1992) for the US., and Cozier and Gupta (1993) for Canada have used value shares to compute *SR* with γ = 1. However, if the aggregate production function does not exhibit *CRS* and/or if the aggregate goods market is characterized by imperfect competition, the failure to use a value of γ different from one and/or to use θ^c_i in place of θ^v_i, for i=*N, K*, will lead to a faulty measure of *SR*, which may lead to the erroneous rejection of the exogeneity of the Solow residual. Section 4 will empirically assess the extent of departures from *CRS* and imperfect competition in the Canadian and US economies.

Another complication in measuring *SR* is that the inputs have to be properly measured. For instance, Burnside and Eichenbaum (1994) emphasize the importance of variable capital utilization rates in propagating shocks over the business cycle. By not properly taking into account the measurement problem, using the measured stock of capital implicitly assumes constant and full utilization rate of capital, which may bias the evidence on the values of the scale elasticity and of the markup, and which may lead to the rejection of the endogeneity of *SR*. Indeed, a varying rate of capital utilization is correctly accounted for in the definition of the *SR*. For instance, equation (7) can be rewritten as:

$$SR_t \equiv d\ln Y_t - \gamma\left[\theta^C_{Nt}\ d\ln N_t + \theta^C_{K^*t}\ d\ln \kappa_t + \theta^C_{K^*t}\ d\ln K_t\right] \qquad (10)$$

However, if we wrongly impose a constant 100 % rate of capital utilization, we would be using an ill-defined measure of the *SR*. This mismeasurement problem would compound problems related to the wrong assumptions of *CRS* and perfect competition.

3. *The Data*

3.1 *Sources and definitions*

US data were generally taken from Citibase, while Canadian data were taken from CANSIM. Some specific series (such as the user costs of capital) were computed by the Department of Finance Canada. The raw data consist in quarterly series from 1962Q1 to 1993Q4 for the US, and from 1970Q1 to 1993Q4 for Canada. Details regarding the source and definitions of the variables are provided in the data appendix.

Aggregate output is defined as the market (or commercial) sector real output. Series on fixed capital income and labour income were defined by using standard practices in reading National Income and Products Accounts.[8] The labor input series consists in total hours worked in the commercial sector. The capital stock input is defined as the sum of the stock of machinery and equipment plus the stock of non-residential structure. All the above variables have been defined in a fairly similar fashion for both countries.

A key variable in our empirical work is the use of capital utilization series, that weight the aggregate stock of capital, to construct a variable for the effective productive services of capital, denoted $K_t^* = \kappa_t K_t$ earlier. As we discuss further below, the US and Canadian official series of capacity utilization are constructed differently. The US series is the Federal Reserve measure for the US manufacturing industry, while the Canadian series is that of Statistics Canada.

Other series that were used to construct either econometric instruments, or variables needed to assess the exogeneity of the *SR* in the US and Canada, are presented in the data appendix.

3.2 *The capacity utilization series*

[8] For instance, Cooley and Prescott (1995, pp. 17-20) discuss a consistent treatment od NIPA data.

Shapiro (1989) describes and discusses how the Board of Governors of the Federal Reserve Bank constructs its measure for the US manufacturing industry using a mix of surveys and regression analysis. Shapiro's assessment of this measure is often reported as justifying one not to use the official US series.[9] His criticisms can be summarized as follow. First, the Federal Reserve measure is somewhat based on vague concepts and incoherent theory. Second, industries with high measured capacity utilization fail to behave as if they were constrained by capacity. Third, markups and inflation do not rise significantly when capacity utilization increases. This suggests limitations about the overheating model of inflation, for which high output growth rates generates inflation.

We argue that while these criticisms point out *caveats* for some specific uses, they do not invalidate the use of the Federal Reserve measure for our purpose hereby. The official measure may well be an imperfect cardinal measure. Yet, the official measure of capacity utilization may well be all right as an ordinal measure, i.e. to measure the relative use of capital over the business cycle, and hence a measure of the effective services of the aggregate capital stock. As shown in equation (10), it is the first-difference of κ_t, weighted by the share of capital that enters the definition of the *SR*.[10]

Furthermore, if the supply-constraint model of capacity were correct, then the Fed's measure is not successful at measuring capacity. But, if we were to assume that the Federal Reserve has a fairly good measure of capacity, then the evidence underlying the second and third criticisms may mean just as well that capacity is not a binding constraint.[11] Shapiro (1989) concludes from his analysis: "The results of the paper do not point strongly to either conclusion. I would, however, lean toward the latter." In any case, we think that it is better to adjust the capital stock with such a measure of capacity utilization than always assuming at the outset full utilization rate.

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[9] Burnside and Eichenbaum (1994) construct a capacity utilization series consistent with their theoretical model, as functions of observable variables and estimable parameters. Their "resulting measure of capacity utilization tracks the analog time series published by the Federal Reserve." (p. 2; see also p. 14).

[10] Burnside, Eichenbaum and Rebelo (1995) with a different approach to measure varying effective services of capital with more disaggregated data find results compatible with ours.

[11] For instance, Finn (1995) does not find a systematic effect of high capacity utilization on the inflation rate.

Wallace (1991), and Wallace and Dion (1993) explain how the new Canadian series on capacity utilization is constructed for non-farm good-producing industries. The values of this series for observations prior to 1987 are reckoned as a weighted index of the output-capital ratio deflated by the Hodrick-Prescott filtered output-capital ratio for each industry, with adjustments, if necessary, based on information about the industry. For instance, if the automatic filtering yielded a value that seems odd and incompatible with what was known about the industry, the Hodrick-Prescott series is forced to pass through a selected point. This point is set using information about investment behavior, the movements of industrial prices, and other factual knowledge. For values after 1987, the observations are constructed using a new question in the Capital and Repair Expenditures Survey conducted with thousands of establishments in the mining and manufacturing industries, twice a year.[12] The survey yields a preliminary estimate in February for the reference year, while a revised estimate is obtained in November. The quarterly observations between survey points are constructed by interpolating between the survey-based values. The Hodrick-Prescott filtering of the output-capital ratio is used for interpolation, but it is forced to pass through the survey-based values.

4. Empirical Aggregate Evidence on Returns to Scale and the Degree of Competition

As a first step in our empirical inquiry, we want to reassess the evidence regarding the extent of market power and non-constant returns to scale in the US and Canada. For this, we extend Hall's (1988, 1990) approach. Essentially, by using a potentially ill-defined measure of the Solow residual as dependent variable, we can derive empirical specifications that can be used to estimate the aggregate markup rate μ and the aggregate degree of returns to scale γ.

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[12] The question asks: "At what capacity, did this plant operate for the year 19XX ? (Capacity is defined as maximum production attainable under normal conditions.)" (See Wallace, 1991, p.4.3). Respondents are explained that the maximum attainable output is defined with respect to standard practices of each establishment with respect to overtime, vacations, work shifts, maintenance, etc. As argued by Wallace and Dion (1993), "Since the rates are based on capacity estimates made by the respondent, the results should embody any changes in production techniques such as technological change. This is what the Bank of Canada and Statistics Canada have sought to estimate through the trending." (p.6). Wallace (1991) also reports that a "follow-up survey confirms the accuracy of the reported rates of capacity utilization", and "that 70 % of firms (accounting for 81 % of fixed assets) report their capacity utilization rates using the same rates for monitoring and planning production, apportioning fixed costs, budgeting and long-term planning." (p.44).

The traditional measure of the Solow residual under perfect competition and constant returns to scale, using value shares of the input, is defined as:

$$TSRV_t \equiv d \ln Y_t - \theta^V_{Nt} \; d \ln N_t - (1-\theta^V_{N\,t}) \, d \ln(\kappa_t \; K^*_t), \tag{11}$$

with κ_t being often set to unity. Using $\theta^C_{K^*t} = 1-\theta^C_{Nt}$, substituting equation (8a) into equation (7), and subtracting [$d\ln K_t + \theta^V_{k^*t}$ ($d\ln K_t$- $d\ln N_t$)] from both sides of the equality, we obtain the following general expression for the $TSRV_t$ in presence of non-constant returns to scale and market power:

$$TSRV_t = SR_t + (\mu - 1)\,[\theta^V_{Nt}\,(d \ln N_t - d \ln(\kappa_t K_t))] + (\gamma - 1)\, d \ln(\kappa_t K_t). \tag{12}$$

Replacing SR_t by $\beta_0 + \varepsilon_t$, the above equation can be rewritten as an empirical specification that can be used for estimating the markup rate and the degrees of returns to scale. The likely correlation between ε_t and the regressors justifies also the use of a generalized instrumental variable (GIVE) technique. Furthermore, in practice, the negative and probably high correlation between the last two regressors would make it hard to get precise estimates of both μ and γ. This is why, following Hall (1988, 1990), we first impose the assumption of constant returns to scale, and we assess the extent of market power by estimating the next equation by GIVE:

$$TSRV_t = \beta_0 + \beta_1\,[\theta^V_{Nt}\,(d \ln N_t - d \ln(\kappa_t \; K_t))] + \varepsilon_t \,, \tag{13}$$

where $\beta_1 = \mu$ - 1. Notice that, for instance, under increasing returns to scale, omitting wrongly the last term of equation (12), by imposing $\gamma = 1$, will tend to bias downward our estimate of μ, because of the likely negative correlation between the omitted term and the regressor in equation (13).

In order to assess the degree of returns to scale, we rewrite equation (7) by subtracting [$\theta^C_{N\,t}$ $d\ln N_t + \theta^C_{k^*\,t}\, d\ln K_t$] from both sides:

$$TSRC_t = \lambda_0 + \lambda_1 \; [\theta^c_N \, \Delta \ln(N_t) + \theta^c_K \, \Delta \ln(\kappa_t K_t)] + \omega_t \tag{14}$$

where $TSRC_t \equiv [\Delta \ln Y_t - \theta^C_{Nt} \Delta \ln N_t - (1-\theta^C_{Nt}) \Delta \ln(\kappa_t K_t)]$, and $\lambda_1 = \gamma$ - 1. Equation (14) can be estimated by GIVE. Moreover, this specification does not rely on any maintained assumption regarding the value of the markup rate.

To proceed with the estimation, we have used the sample averages of observed value and cost shares of each input, and we have treated them as invariant.[13] The last, but nonetheless key issue that needs to be dealt with is the choice of satisfactory instruments. Good instruments should ideally have two properties. They should be as highly correlated as possible with the variable they are instrumenting, without being correlated with the error term of the regression. This is why we will pay a special attention to assess statistically the quality of our chosen instruments. Instruments for the Canadian specifications are the contemporaneous and lagged value of US GDP growth. Instruments for the US specification were chosen amongst the lagged growth rates of real government compensations, a non-oil commodity price index relative to the GDP deflator, the relative price of oil, government military expenditures, and Hall's political dummy variable.[14]

Table 2 presents the results of the GIVE estimation of equation (13) and (14) for the US, first by imposing a constant 100 % use of the capital stock, then for an adjusted measure of the capital stock using the official series on capacity utilization. Table 2 shows similar results for Canadian data. Typically, for each regressions, the adopted instruments are listed, along with the R^2 and the $\bar{R}^2$ from regression of the relevant explanatory variable of each specification on the instruments. The *p*-value of the over-identifying restrictions is also reported. In all cases, the results suggest that our selected instruments are adequate. Before entertaining any economic interpretation of the estimates obtained by GIVE, we have applied a battery of misspecification tests to assess the statistical adequacy of the empirical models. For each equation, a RESET test of omitted variable, a Bera-Jarque normality test, a White heteroskedasticity test, and LM tests of serial correlation at order 1 and 4 are performed. In most cases, these tests do not revealed any

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13 This could be relaxed, especially, since the derivation of the *SR* in section 2, is applicable for fairly general production functions. Notice that these shares did not vary much in our samples, with standard-deviations of about 0.015. For Canada, the average value share of labor is 0.635, and the average cost share of labor is 0.673. For the US sample, the counterparts of these quantities are 0.731 and 0.795, respectively. Finally, treating these coefficients as fixed makes our results comparable with what has been done in the existing empirical and theoretical literature.

14 Hall (1988, 1990), with US industry data, has used as instruments the contemporaneous values of the growth rate in nominal oil price, in military expenditures, and a dummy variable to reflect the political affiliation of the President in office. The data on nondurables published in Table 1 of Hall (1988) show that the R^2 ($\bar{R}^2$) of these instruments with the regressor to be instrumented is 0.019 (-0.005). He had found the markup rate for this industry to be 3.1. Similar results are found in Hall (1990), where he reports also a point estimate for the degree of returns to scale in the nondurables industry of 3.1. Problems with respect to the instruments used by Hall (1988, 1990) have also been documented by Shea (1993).

problems with the adopted specification. However, with the capacity utilization adjusted capital stock in the markup equation (13), there is evidence of conditional heteroskedasticity both in the Canadian and in the US equation. That is why we have reported White's heteroskedasticity consistent standard errors of the estimated coefficients for this equation. In such instances, the *p*-values of other misspecification tests have been also computed with statistical tests that use heteroskedasticity consistent standard errors.

For the US, both the point estimates of the markup rate (under the restriction of *CRS*) and of the returns to scale index change when allowing for varying capital utilization. The point estimate of the aggregate markup rate, imposing $\kappa_t = 1$ for all t, is 0.712. However, using the capital stock adjusted for varying utilization rate, the point estimate is equal to 1.303, which is not statistically different from one even at a 20% significance level. However, theses estimates are obtained under the maintained assumption that the aggregate production function exhibits constant returns to scale. As we have argued before, these estimates are likely to be overestimated, if the aggregate economy is characterized by decreasing returns to scale. Turning our attention to the returns to scale equation, we find that with the unadjusted capital stock, the point estimate of 0.66 is centered on decreasing returns to scale value, with a standard-error of 0.26. When using the adjusted capital stock, the estimated value of γ is centered on 0.75, with a standard-error of 0.21.[15] It is not possible however to reject the *CRS* hypothesis at the 23% significance level.

Estimation of equations (13) and (14) for the Canadian economy yield broadly similar results. The point estimate of the aggregate markup rate, imposing $\kappa_t = 1$ for all t, is 1.56. This is statistically different from 1 at the 6% significance level. However, using an adjusted capital stock, the markup estimate is equal to 1.38, which is not statistically different from one even at a 22% significance level. It is however likely to be upward biased. The estimation of the returns to scale equation yields an estimate of γ centered on increasing returns to scale, with a value of 1.55. Its marginal significance is 10.3%. However, when using the adjusted capital stock, the

[15] Notice that if we impose the value of 0.746 for γ, and if we estimate equation (12), we then obtain a point estimate of μ that is centered on unity.

estimated value of γ is centered on 0.80, with a standard-error of 0.12. We cannot reject the *CRS* hypothesis at a 8% significance level.

Hence, taking into account varying capital utilization matters for gathering evidence about market power and the degree of returns to scale. The evidence is rather against the hypotheses of increasing returns to scale and imperfect competition. In fact, the point estimates of the degree of returns to scale in both Canada and the US, even though they are not necessarily very tightly estimated, remains centered on a value less than unity. These results for the aggregate economies of both countries differ much from Hall's (1988, 1990) results. They are, however, compatible with results for disaggregated data in the US obtained by Basu and Fernald (1994), who, maintaining full utilization of capital, point out specification errors when using value-added data, and Burnside, Eichenbaum, and Rebelo (1995), who use electricity consumption as a direct measure of the varying services of capital.

Notice also that our point estimates of the degree of returns to scale, γ, remain much too small relatively to the kind of values that would be required by models with imperfect competition and multiple equilibria, in which business cycles are generated by self-fulfilling prophecies and endogenous monetary non-neutralities.[16]

5. Empirical Assessment of the Exogeneity of the Solow Residual

Given the evidence gathered in the previous section, because of the lack of evidence suggesting significant departures from constant returns to scale and perfect competition at the aggregate level in both US and Canada, we maintain these assumptions for the rest of the analysis. However, we find the argument compelling to introduce a varying rate of capital utilization to construct adequate measures of the Solow residual for both countries. Hence, we define the *SR* as:

$$SR_t \equiv d \ln Y_t - \theta_{Nt}^{V} \; d \ln N_t - \theta_{K^*t}^{V} \; d \ln(\kappa_t \; K_t). \qquad (15)$$

[16] Farmer (1993) uses a degree of returns to scale equal to 1.61. Salyer (1995) shows how small departures from this value, such as for $\gamma = 1.368$, "can imply either noncyclical dynamics or, more critically, determinate equilibrium." (p.239).

Previously, Evans (1992), and Cozier and Gupta (1993) had assumed a constant rate of capital utilization in their own empirical studies, and uncovered evidence of significant endogeneity of the Solow residual.[17] We consider below empirical specifications with $\kappa_t = 1$ for all t, and with κ_t being defined as the official series of capacity utilizations of each country.

We are basically assessing the evidence of exogeneity, or lack thereof, in two ways. First, we regress the *SR* on four lags of itself and various blocks of monetary and real variables of four lags. Hence, a typical equation such as:

$$SR_t = \phi_0 + \sum_{i=1}^{4} \phi_i \; SR_{t-i} + \sum_{i=1}^{4} \mathbf{X}_{t-i} \, \delta_i' + u_t \tag{16}$$

is estimated by OLS for alternative definitions of the $\mathbf{X}_{t-i}$-vector. The predictability, and therefore endogeneity, of the *SR* is assessed by testing the significance of each block of variables, and of some combinations of groups of variables. Tables 3 and 4 show the p-values of these tests for US data, respectively with the unadjusted *SR* (i.e. $\kappa_t = 1$), and with the varying capacity utilization adjusted *SR*. Tables 7 and 8 show similar statistics for Canadian data.

A second tool employed to evaluate the possible importance of endogeneity in the *SR* consists in estimating a VAR(4) model for the same variables included in equation (16), and in examining the percentage of the variance of the *SR* explained 8, and 6 quarters ahead, by the innovation in each component of the $\mathbf{X}_{t-i}$-vector. These exercises are conducted assuming a recursive causal contemporaneous structure between the model's variables. Since such identification scheme (that amounts to a Choleski decomposition of the variance-covariance matrix of the VAR residuals) may be sensitive to the ordering of the variables, we have adopted an ordering that we judged reasonable. For US data, the *SR* ranked first, followed by the growth rate in the relative oil price, the inflation rate, the effective marginal tax rates on labor income and on capital income, the growth rate of government spending, the growth rate of some monetary aggregates, and the change in the nominal interest rate. For Canadian data, the ordering was fairly similar, except that the US output growth ranked first, and that the percentage change in the terms of trade were put in place of the changes in effective marginal tax rates.

[17] Evans (1992) had briefly considered one very specific type of variable capital utilization that varied one for one with the labour input. But, this did not alter his results.

Tables 5, for the US, and Table 9, for Canada, show the results of these variance decomposition exercises.

Let us first discuss the results for the US data. Table 3 shows the results of the predictability of the unadjusted *SR*. Here, the first three specifications of equation (16) use respectively, the growth rate of *M1*, of the ratio of the noncurrency component of *M1* relative to *M1* (which is a rough measure of a currency multiplier), and of the monetary base. The last three specifications use various orthogonalized structural monetary innovations obtained from structural vector autoregressions of order 4, following the recent work by Christiano, Eichenbaum and Evans (1996), and by Strongin (1995). The variables *FFS*, *NBRS*, and *RESMIX* interpret respectively orthogonalized shocks either to the Federal Funds rate, or to non-borrowed reserves, or to the mix of non-borrowed reserves relative to total reserves as the exogenous monetary impulse.[18]

As found by Evans (1992), the evidence tends to suggest that the *M1* multiplier of currency, the change in 90-day Treasury bill rate, and various definitions of structural monetary shocks are statistically significant at least at the 10 % level (when not at the 5 % level) in predicting the unadjusted *SR*. The significance of these monetary variables appears to be even stronger (at least at the 4% level, when not at the 1% level) for the joint blocks of the monetary aggregate or the monetary shock with ΔR, or with both ΔR and $\Delta \ln(P)$. We also find that the change in the capital tax rate is always significant at the 6% significance level.

However, when conducting the same predictability tests with the capacity adjusted *SR*, there remains evidence of endogeneity of the *SR*, but not necessarily with respect to the same variables. The specifications with either *M1* or the *M1* multiplier of currency exhibit a monetary aggregate growth block that is significant at 11%, and at 2.5%, respectively. In these specifications, the ΔR block is also significant at a 2% level. All the other specifications have neither the monetary impulse block, nor the ΔR block, individually or jointly, statistically significant even as high as at the 18% level. However, in all specifications, the inflation rate

[18] Notice that the *p*-values reported in Tables 6 and 7 with respect to the coefficients of these generated regressors may, as shown by Pagan (1984), tend to exagerate their significance, and therefore the evidence of exogeneity of the *SR* with respect to these variables.

block is significant at least at the 3.5% level. Hence, it would appear that, when adjusting for varying rate of capital utilization, the *SR* is endogenous with respect to inflation. Table 5 suggests similar evidence as the percentage of the variance of the *SR* explained by the innovation on inflation tends to increase with the adjusted *SR*.

A final check on the importance of accounting for a varying rate of capital utilization to measure and to characterize the *SR* is provided by extending the structural vector autoregressions (*SVAR*) of Christiano, Eichenbaum and Evans (1996), and of Strongin (1995) used to generate monetary shocks by adding in the logarithm of total factor productivity amongst the variables of each system. Table 6 presents the variance decomposition exercises for these *SVAR*'s. Typically, when using the capacity adjusted measure of Z_t, the contribution of the innovation on total factor productivity to its own variance increases substantially, both 8 and 16 quarter ahead, while that of the innovation on the monetary policy instrument drops.

Thus, for US data, we conclude that adjusting for varying rate of capital utilization tends to decrease the importance of endogeneity in the US *SR*, while shifting the burden of endogeneity from the measures of monetary impulses to the inflation rate.

For the Canadian data, as shown in Table 7, when we ignore a varying rate of capital utilization, the evidence tends to suggest that whether we use the growth rate of *M1*, or that of the monetary base (excluding required reserves), the block of four lags of monetary aggregate growth alone is not significant at the 10% level. Only the monetary base alone is significant at a 12 % significance level. This might suggest some endogenous response of inside money. However, the change in the 90-day commercial paper rate is significant at least at a 3% level. The inflation rate block alone does not seem significant. Notice however that when testing jointly for the significance of the monetary aggregate, along with the interest rate block alone, or even with both the interest rate block and the inflation rate block, these variables are always significant at conventional levels (at least at 7%, and most often at 5% and less). Finally, none of the real variables considered seem significant. However, these results might be spurious, since the adopted measure of *SR* fails to account for a varying rate of capital utilization.

Table 8 shows the results for the statistical significance of the same block of variables, but when *SR* is constructed with a variable κ_t. The results are strikingly different from those of Table 7. None of the equations estimated show a significant effect at the 13% level, and in most cases the *p*-values are at least higher than 0.25. This is particularly the case when testing for the significance of the blocks of monetary variables. The variance decomposition estimates in Table 9 are compatible with the above results. In particular, when adjusting the *SR* for varying capacity utilization, the estimate of the contribution of the *SR* to its own variance increases, and that of the change in *R* to the variance of *SR* drops.[19]

Hence, we cannot reject the exogeneity of an adequate measure of the *SR*, adjusted for varying capacity utilization in Canada.

6. Conclusions

Productivity shocks play a central role in many modern business cycle models as a source of macroeconomic fluctuations. Many of them assume that productivity shocks are exogenous and not influenced by other economic factors. This is compatible with the computation of the Solow residual under the assumptions of perfect competition, constant returns to scale and full utilization of capital over the business cycle. Also, various econometric analyses have previously questioned the exogeneity of the *SR*. However, all these studies generally assume that the capital stock remains fully utilized over the business cycle.

If some of these standard underlying assumptions are not verified, it is therefore necessary to construct differently the measure of the Solow residual to take into account, if needed, the extent of market power, returns to scale, and to measure appropriately the inputs. We argue that all these are empirical issues that are worth investigating in a comprehensive manner. Indeed, these issues are most relevant for: (1) gathering correctly the evidence on the extent of non-constant returns to scale and imperfect competition; (2) the proper specification and calibration of macroeconomic models; (3) assessing the contribution of technology shocks to

[19] Even though the standard-errors of the variance decompositions are not provided in the current version of these tables, they are typically large in such exercises. Nonetheless, the direction of the changes in the point estimates of the variance decompositions can be taken as suggestive, especially since they are compatible with the results of the predictability tests.

output fluctuations; (4) testing the exogeneity property of the Solow residual. Our paper used many recent econometric techniques to study these issues.

First, we have examined for both US and Canadian aggregate data the impact of varying capital utilization on the evidence of market power and returns to scale. It was found that varying capital utilization matters for adequate characterization of the data. Indeed, with varying capital utilization and the use of econometrically adequate instruments, imperfect competition and non constant returns to scale do not seem to be very important in aggregate for either the US, or Canada. This is contrary to what was implied by Hall (1988, 1990). But, this is in accord with recent results obtained by Burnside, Eichenbaum and Rebelo (1995).

Second, in sharp contrast with the results previously documented in the literature (e.g. Evans, 1992, and Cozier and Gupta, 1993), when adjusting for varying capacity utilization, we are unable to reject the exogeneity of the Canadian Solow residual relatively to changes in the relative price of oil, the terms of trade, the price level, government expenditures, and various measures of monetary policy shocks. For US data, we find that the own contribution of the technology innovation increases after adjustment for varying capacity utilization. But, the US adjusted Solow residual remains endogenous with respect to the price level and shocks on capital tax rates even though various measures of past monetary innovations tend to be much less important.

Data appendix

US data were generally taken from Citibase, while Canadian data were taken from CANSIM. Some specific series were computed by the Department of Finance Canada. The raw data consist in quarterly series from 1962Q1 to 1993Q4 for the US, and from 1970Q1 to 1993Q4 for Canada.

Aggregate output, labor income, and capital income in current dollars were derived from the National Income and Products Accounts of both countries. Aggregate output is defined as the market (or commercial) sector real output. That is, GDP net of general government output, the output of paid employees of private households and non-profit organizations, the rental value of owner occupied dwellings and some published statistical discrepancy.

The factor income series were defined by using standard practices in reading National Income and Products Accounts. Fixed private capital income is the sum of unambiguous capital income, the value share of capital times ambiguous capital income, and consumption of fixed capital. Unambiguous capital income is itself defined as rental income plus corporate profits, plus net interest payments net of the rental value of owner occupied dwellings, plus the factor payments to the rest of the world net, minus the factor payments from the rest of the world. Ambiguous capital income is the sum proprietors' income plus net national product minus national income. Labor income is defined as the compensations of employees, minus the total of the compensations paid by general government and the compensations from households and non-profit institutions. Notice that, because of the attribution of each income component in the NIPA into capital or labor income, the measured value shares of labor and capital sum to unity by construction for these aggregate data. That is, if the aggregate economy is characterized by imperfect competition, any non-normal profit is implicitly distributed in the various components of the income accounts.

Series on user costs of capital for both countries are computed by the Department of Finance Canada, while aggregate series on the user cost of labor are inferred from the NIPA. The capital stock input is defined as the sum of the stock of machinery and equipment plus the stock of non-residential structure. All the above variables have been defined in a fairly similar fashion for both countries.

The US labor input series is an extended series of efficiency units of labor, following Hansen (1993), while the Canadian labor input consists in total hours worked in the commercial sector. The US capital utilization series is the Federal Reserve measure for the US manufacturing industry, while the Canadian series is that of Statistics Canada.

The other series used to construct either econometric instruments, or variables needed to assess the exogeneity of the *SR* in the US and Canada are generally obtained from Citibase and CANSIM, respectively. For the US, we use: *M1*, the base (*MBASE*), total reserves (*TR*), non-borrowed reserves (*NBR*), the 90-day Treasury bill rate, the Federal Funds rates (*FF*), the GDP deflator (*P*), total government expenditures (*G*), the relative price of oil (*RPOIL*), government compensations (*GCOMP*), a commodity price index (*CP*). Following Hall (1988, 1990), we also used government military spending (*GMIL*), and a dummy variable indicating whether the White House was occupied by a Democrat or a Republican. Effective marginal tax rates on labor income (τ^N) and capital income (τ^K) in the US were also used after extending the series used by McGrattan (1994).

For Canada, we employ three monetary aggregates (*M1*), the base (*MBASE*), the base excluding reserve requirements (*MBASEER*)), the 90-day commercial paper yield (*R*), the GDP deflator (*P*), total government expenditures (*G*), the relative price of oil (*RPOIL*), the US real GDP (*YUS*), the terms of trade (*TOT*), the effective personal income tax rate (*TRDIR*).

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Table 1 U.S.: 1962Q1 - 1993Q4.
GIVE Estimates of Markup and Returns to Scale.[1]

(13) $\left[\Delta \ln Y_t - \theta^{V}_{Nt}\Delta \ln N_t - (1-\theta^{V}_{Nt})\Delta \ln(\kappa_t K_t)\right] = \beta_0 + \beta_1 \; [\theta^{v}_{N}\,(\Delta \ln(N_t) - \Delta \ln(\kappa_t K_t))] + \varepsilon_t$

where $\theta^{v}_{N} = 0.7310$, based on NIPA data; $\mu = \beta_1 + 1$, under the maintained hypothesis that $\gamma = 1$.

(14) $\left[\Delta \ln Y_t - \theta^{C}_{Nt}\Delta \ln N_t - (1-\theta^{C}_{Nt})\Delta \ln(\kappa_t K_t)\right] = \lambda_0 + \lambda_1 \; [\theta^{c}_{N}\,\Delta \ln(N_t) + \theta^{c}_{K}\,\Delta \ln(\kappa_t K_t)] + \omega_t$

where $\theta^{c}_{N} = 0.7954$, based on NIPA and Canadian Department of Finance data; $\gamma = \lambda_1 + 1$.

Markup equation			Returns to scale equation		
	Unadjusted variables ($\kappa_t = 1$, for all t) [13a]	Adjusted variables [13b]		Unadjusted variables ($\kappa_t = 1$, for all t) [14a]	Adjusted variables [14b]
β_0	0.012 (0.001)	0.014 (0.001)	λ_0	0.015 (0.002) *hc*	0.015 (0.001)
H_0: $\beta_0 = 0$	*p-val*=0.000	*p-val*=0.000	H_0: $\beta_0 = 0$	*p-val*=0.000	*p-val*=0.000
μ	0.712 (0.259)	1.303 (0.207) *hc*	γ	0.662 (0.256) *hc*	0.746 (0.210)
H_0: $\mu = 1$	*p-val*=0.269	*p-val*=0.145	H_0: $\gamma = 1$	*p-val*=0.190	*p-val*=0.230
σ	0.0159	0.0139	σ	0.0162	0.0108
Statistical inadequacy tests: (p-value)			*Statistical inadequacy tests: (p-value)*		
RESET(3)	0.55	*(2)* 0.64 *hc*	*RESET(3)*	0.97	0.99
Normality(2)	0.10	0.54	*Normality(2)*	0.12	0.30
White het(2)	0.06	0.00	*White het(2)*	0.03	0.07
SC(1)	0.14	0.44 *hc*	*SC(1)*	0.17	0.52
SC(4)	0.12	0.61 *hc*	*SC(4)*	0.99	0.10
Instruments for regression [13a]: $\Delta\ln(GCOMP_{t-1})$, $\Delta\ln(GCOMP_{t-4})$, $\Delta\ln(RCP_{t-1})$, $\Delta\ln(RCP_{t-2})$, $\Delta\ln(ROILP_{t-1})$.			Instruments for regression [14a]: $\Delta\ln(GCOMP_{t-4})$, $\Delta\ln(RCP_{t-1})$, $\Delta\ln(RCP_{t-2})$, *DUMPRES*, $\Delta\ln(ROILP_{t-1})$.		
Instruments for regression [13b]: *DUMPRES*, $\Delta\ln(RCP_{t-1})$, $\Delta\ln(RCP_{t-3})$.			Instruments for regression [14b]: $\Delta\ln(GCOMP_{t-4})$, $\Delta\ln(RCP_{t-1})$, $\Delta\ln(RCP_{t-2})$, *DUMPRES*.		
R^2 from regression of explanatory variable on instruments:			R^2 from regression of explanatory variable on instruments:		
R^2	0.1533	0.1545	R^2	0.1268	0.1389
$\bar{R}^2$	0.1185	0.1340	$\bar{R}^2$	0.0910	0.1109
Overidentifying restrictions test:			Overidentifying restrictions test:		
p-value	0.24	0.62	*p-value*	0.14	0.70

[1] The statistical inadequacy tests are Ramsey RESET test for misspecification with the square of the fitted value, Bera-Jarque normality test, White heteroskedasticity test, and LM tests of serial correlation of order 1, and 4. When there was evidence of heteroskedasticity, White's asymptotically consistent standard-errors are reported and denoted by *hc*.

Table 2. Canada: 1970Q1 - 1993Q4.
GIVE Estimates of Markup and Returns to Scale.[1]

(13) $\left[\Delta \ln Y_t - \theta^V_{Nt} \Delta \ln N_t - (1-\theta^V_{Nt}) \Delta \ln(\kappa_t K_t)\right] = \beta_0 + \beta_1 \; [\theta^v_N \; (\Delta \ln(N_t) - \Delta \ln(\kappa_t K_t))] + \varepsilon_t$

where $\theta^v_N = 0.635$, based on NIA data; $\mu = \beta_1 + 1$, under the maintained hypothesis that $\gamma = 1$.

(14) $\left[\Delta \ln Y_t - \theta^C_{Nt} \Delta \ln N_t - (1-\theta^C_{Nt}) \Delta \ln(\kappa_t K_t)\right] = \lambda_0 + \lambda_1 \; [\theta^c_N \; \Delta \ln(N_t) + \theta^c_K \; \Delta \ln(\kappa_t K_t)] + \omega_t$

where $\theta^c_N = 0.673$, based on NIA and Canadian Department of Finance data; $\gamma = \lambda_1 + 1$.

Markup equation			Returns to scale equation		
	Unadjusted variables ($\kappa_t = 1$, for all *t*) [13a]	Adjusted variables [13b]		Unadjusted variables ($\kappa_t = 1$, for all *t*) [14a]	Adjusted variables [14b]
β_0	0.367 (0.183)	0.285 (0.168) *hc*	λ_0	-0.224 (0.250)	0.266 (0.117)
H_0: $\beta_0 = 0$	*p-val*=0.048	*p-val*=0.093	H_0: $\beta_0 = 0$	*p-val*=0.374	*p-val*=0.026
μ	1.555 (0.288)	1.377 (0.307) *hc*	γ	1.554 (0.337)	0.796 (0.119)
H_0: $\mu = 1$	*p-val*=0.052	*p-val*=0.223	H_0: $\gamma = 1$	*p-val*=0.103	*p-val*=0.090
σ	0.0121	0.0109	σ	0.0126	0.0891
Statistical inadequacy tests: (p-value)			*Statistical inadequacy tests: (p-value)*		
RESET(1)	0.46	0.49 *hc*	*RESET(1)*	0.44	0.58
Normality(2)	0.86	0.91	*Normality(2)*	0.90	0.77
White het(2)	0.43	0.01	*White het(2)*	0.19	0.57
SC(1)	0.42	0.44 *hc*	*SC(1)*	0.52	0.70
SC(4)	0.19	0.61 *hc*	*SC(4)*	0.15	0.39
Instruments for regressions [13a] & [13b]: $\Delta\ln(USGDP_t)$, $\Delta\ln(USGDP_{t-1})$			Instruments for regressions [14a] & [14b]: $\Delta\ln(USGDP_t)$, $\Delta\ln(USGDP_{t-1})$		
R^2 from regression of explanatory variable on instruments:			R^2 from regression of explanatory variable on instruments:		
R^2	0.2992	0.1341	R^2	0.2229	0.4051
$\bar{R}^2$	0.2846	0.1160	$\bar{R}^2$	0.2067	0.3957
Overidentifying restrictions test:			Overidentifying restrictions test:		
p-value	0.24	0.25	*p-value*	0.23	0.48

[1] See footnote to Table 1.

Table 3
U.S.: 1962Q1 - 1993Q4
The Predictability of the Productivity Impulse
Unadjusted Solow Residual
(p-values for significance tests on the block of variable(s))

$$SR_t = \phi_0 + \sum_{i=1}^{4} \phi_i \, SR_{t-i} + \sum_{i=1}^{4} \mathbf{X}_{t-i} \delta_i^{\prime} + u_t$$

Vector	[1]	[2]	[3]	[4]	[5]	[6]
SR	0.462	0.437	0.442	0.485	0.192	0.101
$\Delta\ln(M1)$	0.168					
$\Delta\ln((M1\text{-}CUR)/CUR)$		0.031				
$\Delta\ln(MBASE)$			0.756			
NBRS [1]					0.071	
RESMIXS [2]						0.003
$\Delta(R)$	0.003	0.000	0.043	0.102	0.008	0.006
FFS [2]				0.076		
$\Delta\ln(P)$	0.316	0.369	0.686	0.256	0.217	0.213
$\Delta\ln(G)$	0.619	0.715	0.518	0.360	0.462	0.458
$\Delta\ln(ROILP)$	0.668	0.701	0.578	0.671	0.706	0.735
$\Delta(\tau^K)$	0.046	0.038	0.049	0.055	0.025	0.016
$\Delta(\tau^N)$	0.578	0.427	0.447	0.485	0.392	0.418
$\Delta\ln(money)$, $\Delta(R)$	0.003	0.000	0.019	0.001	0.001	0.000
$\Delta\ln(money)$, $\Delta(R)$, $\Delta\ln(P)$	0.006	0.001	0.034	0.002	0.002	0.000
$\bar{R}^2$	0.160	0.194	0.120	0.177	0.179	0.237

[1] The variables *NBRS*, *RESMIXS*, and *FFS* are structural innovations on non-borrowed reserves, on the mix of non-borrowed reserves relative to total reserves, and on the Fed Funds rate, that were retrieved from various structural vector autoregression. See text for details.

Table 4
U.S.: 1962Q1 - 1993Q4
The Predictability of the Productivity Impulse
Capacity Adjusted Solow Residual
(p-values for significance tests on the block of variable(s))

$$SR_t = \phi_0 + \sum_{i=1}^{4} \phi_i \, SR_{t-i} + \sum_{i=1}^{4} \mathbf{X}_{t-i} \boldsymbol{\delta}_i' + u_t$$

Vector	[1]	[2]	[3]	[4]	[5]	[6]
SRV	0.081	0.109	0.105	0.101	0.043	0.035
$\Delta\ln(M1)$	0.106					
$\Delta\ln((M1\text{-}CUR)/CUR)$		0.021				
$\Delta\ln(MBASE)$			0.863			
NBRS [1]					0.458	
RESMIXS [2]						0.163
$\Delta(R)$	0.0153	0.005	0.340	0.390	0.236	0.206
FFS [2]				0.471		
$\Delta\ln(P)$	0.003	0.007	0.031	0.008	0.004	0.005
$\Delta\ln(G)$	0.665	0.740	0.459	0.409	0.569	0.565
$\Delta\ln(ROILP)$	0.484	0.604	0.493	0.539	0.503	0.519
$\Delta(\tau^K)$	0.103	0.078	0.115	0.100	0.064	0.041
$\Delta(\tau^N)$	0.515	0.374	0.631	0.602	0.512	0.431
$\Delta\ln(money)$, $\Delta(R)$	0.049	0.011	0.365	0.192	0.187	0.072
$\Delta\ln(money)$, $\Delta(R)$, $\Delta\ln(P)$	0.003	0.001	0.035	0.015	0.015	0.005
$\bar{R}^2$	0.255	0.283	0.205	0.224	0.224	0.247

[1] See footnote 1 in Table 3.

Table 5
U.S.: 1970Q1 - 1993Q4
Variance Decomposition: % of Variance in *SR* Explained by Innovations in *VAR*(4)
8 and 16 Quarters Ahead

Unadjusted Solow Residual						
Vector	[1a]		[2a]		[3a]	
	8-Q	*16-Q*	*8-Q*	*16-Q*	*8-Q*	*16-Q*
SR	70.3	67.8	67.7	65.3	69.8	67.8
$\Delta\ln(ROILP)$	2.6	2.7	3.1	3.4	2.6	2.7
$\Delta\ln(P)$	2.4	3.6	3.0	4.0	1.5	2.1
$\Delta\ln(\tau^N)$	4.2	4.9	4.0	4.6	4.2	4.6
$\Delta\ln(\tau^K)$	4.8	5.0	4.8	5.0	5.9	6.0
$\Delta\ln(G)$	5.1	5.5	5.1	5.5	4.8	5.2
$\Delta\ln(M1)$	4.5	4.6				
$\Delta\ln((M1\text{-}CUR)/CUR)$			6.0	5.9		
$\Delta\ln(MBASE)$					3.0	3.5
$\Delta(R)$	6.0	6.0	6.3	6.2	8.2	8.1

Capacity Adjusted Solow Residual						
Vector	[1b]		[2b]		[3b]	
	8-Q	*16-Q*	*8-Q*	*16-Q*	*8-Q*	*16-Q*
SRV	66.1	62.2	62.8	59.9	68.2	64.8
$\Delta\ln(ROILP)$	3.1	3.1	3.6	4.1	3.0	2.9
$\Delta\ln(P)$	8.5	10.0	9.7	11.1	7.7	9.1
$\Delta\ln(\tau^N)$	3.5	4.5	3.4	4.1	3.5	4.3
$\Delta\ln(\tau^K)$	3.9	3.8	4.0	4.2	4.4	4.3
$\Delta\ln(G)$	5.3	5.5	5.2	5.3	4.7	5.0
$\Delta\ln(M1)$	4.8	5.1				
$\Delta\ln((M1\text{-}CUR)/CUR)$			6.5	4.8		
$\Delta\ln(MBASE)$					2.9	4.0
$\Delta(R)$	5.0	5.8	6.3	5.1	5.6	5.7

[1] The order of orthogonalization is the order of the variables listed.

Table 6
U.S.: 1970Q1 - 1993Q4
Variance Decomposition: % of Variance in ln(*z*) Explained by Innovations in *SVAR*(4) Used to Generate Monetary Shock
8 and 16 Quarters Ahead

***SVAR*(4) à la Christiano, Eichenbaum & Evans (1994)**
M-policy shocks: Innovations in the Fed Funds rate

Vector	Unadjusted *Z*		Capacity Adjusted *Z*	
	8-Q	*16-Q*	*8-Q*	*16-Q*
$\ln(z_t)$	39.4 (37.2)	19.5 (21.7)	59.7 (48.2)	52.0 (45.4)
$\ln(Y_t)$	6.6 (8.1)	6.6 (9.3)	3.1 (3.9)	4.3 (6.0)
$\ln(P_t)$	20.1 (21.6)	19.5 (22.1)	18.3 (19.6)	10.3 (12.6)
$\ln(CP_t)$	7.3 (9.5)	12.5 (15.8)	8.1 (9.5)	14.6 (16.8)
FF_t	20.2 (21.6)	30.2 (31.0)	4.3 (5.5)	12.8 (15.0)
$-\ln(NBR_t)$	3.5 (4.6)	3.5 (4.8)	3.5 (4.6)	2.6 (3.9)
$\Delta\ln(TR_t)$	3.0 (3.9)	8.3 (10.8)	3.1 (4.2)	3.4 (4.8)

***SVAR*(4) à la Christiano, Eichenbaum & Evans (1994)**
M-policy shocks: Innovations in nonborrowed reserves

Vector	Unadjusted *Z*		Capacity Adjusted *Z*	
	8-Q	*16-Q*	*8-Q*	*16-Q*
$\ln(z_t)$	41.3 (38.4)	21.5 (23.2)	59.9 (48.3)	51.0 (44.9)
$\ln(Y_t)$	5.8 (7.2)	5.1 (7.1)	3.2 (4.3)	4.6 (7.0)
$\ln(P_t)$	18.9 (20.3)	18.8 (21.3)	17.9 (19.2)	10.0 (12.3)
$\ln(CP_t)$	7.4 (9.3)	12.3 (14.8)	8.3 (10.2)	14.9 (18.0)
$-\ln(NBR_t)$	11.1 (13.1)	9.1 (11.5)	5.4 (6.9)	4.7 (6.6)
FF_t	13.1 (14.9)	26.7 (28.2)	2.7 (3.9)	11.6 (14.5)
$\Delta\ln(TR_t)$	2.4 (3.0)	6.5 (8.6)	2.7 (3.7)	3.1 (4.4)

[1] The order of orthogonalization is the order of the variables listed.

Table 6 (Continued)
U.S.: 1970Q1 - 1993Q4
Variance Decomposition: % of Variance in ln(*z*) Explained by Innovations in *SVAR*(4) Used to Generate Monetary Shock
8 and 16 Quarters Ahead

***SVAR*(4) à la Strongin (1992)** *M-policy shocks: Innovations in the composition between nonborrowed reserves and total reserves*				
Vector	Unadjusted *Z*		Capacity Adjusted *Z*	
	8-Q	*16-Q*	*8-Q*	*16-Q*
$\ln(z_t)$	50.7 (44.3)	38.7 (37.3)	61.4 (48.7)	56.3 (47.2)
$\ln(Y_t)$	3.5 (5.5)	3.4 (6.2)	3.6 (4.9)	4.4 (6.1)
$\ln(P_t)$	17.2 (18.9)	16.3 (19.0)	12.9 (14.3)	6.3 (7.9)
$\ln(CP_t)$	5.2 (6.8)	8.8 (11.7)	8.4 (10.4)	14.7 (17.6)
(TR_t/TR_{t-1})	4.5 (5.8)	4.9 (7.0)	7.6 (9.4)	6.2 (8.6)
$-(NBR_t/TR_{t-1})$	13.2 (15.2)	17.4 (20.2)	3.7 (5.2)	5.3 (7.6)
FF_t	5.7 (7.6)	10.5 (13.9)	2.5 (3.5)	6.8 (9.2)

[1] The order of orthogonalization is in the order of the variables listed.

Table 7
Canada: 1970Q1 - 1993Q4
The Predictability of the Productivity Impulse
Unadjusted Solow Residual[1]
(p-values for significance tests on the block of variable(s))

$$SR_t = \phi_0 + \sum_{i=1}^{4} \phi_i \, SR_{t-i} + \sum_{i=1}^{4} \mathbf{X}_{t-i} \delta_i' + u_t$$

SR, **X**-*vector*	[1]	[2]	[3]	[4]
SR	0.417	0.435	0.392	0.339
Δln(*M1*)	0.247			
Δln(*MBASE*)		0.110		
Δln(*MBASEER*)			0.393	0.560
Δ(*R*)	0.026	0.011	0.006	0.010
Δln(*P*)	0.953	0.946	0.762	0.913
Δln(*G*)	0.355	0.217	0.332	0.232
Δln(*ROILP*)	0.364	0.142	0.192	
Δln(*YUS*)	0.584	0.437	0.552	0.134
Δln(*TOT*)				0.417
Δln(*money*), Δ(*R*)	0.020	0.004	0.019	0.043
Δln(*money*), Δ(*R*), Δln(*P*)	0.027	0.012	0.045	0.062
$\bar{R}^2$	0.098	0.0124	0.081	0.091

1 The variable *money* is a generic term to represent the monetary shock used in the regression.

Table 8
Canada: 1970Q1 - 1993Q4
The Predictability of the Productivity Impulse
Capacity Adjusted Solow Residual
(p-values for significance tests on the block of variable(s))

$$SR_t = \phi_0 + \sum_{i=1}^{4} \phi_i \, SR_{t-i} + \sum_{i=1}^{4} \mathbf{X}_{t-i} \boldsymbol{\delta}_i' + u_t$$

SR, **X**-*vector*	[1]	[2]	[3]	[4]
SR	0.293	0.317	0.191	0.206
Δln(*M1*)	0.896			
Δln(*MBASE*)		0.144		
Δln(*MBASEER*)			0.324	0.321
Δ(*R*)	0.393	0.394	0.252	0.321
Δln(*P*)	0.942	0.846	0.822	0.901
Δln(*G*)	0.382	0.289	0.489	0.545
Δln(*ROILP*)	0.358	0.137	0.168	0.257
Δln(*YUS*)	0.505	0.473	0.684	0.708
Δln(*TOT*)				0.993
Δln(*money*), Δ(*R*)	0.792	0.216	0.392	0.500
Δln(*money*), Δ(*R*), Δln(*P*)	0.808	0.267	0.448	0.598
$\bar{R}^2$	0.027	0.104	0.076	0.020

Table 9
Canada: 1970Q1 - 1993Q4
Variance Decomposition: % of Variance in *SR* Explained by Innovations in *VAR*(4)
8 and 16 Quarters Ahead

Unadjusted Solow Residual								
Vector	[1a]		[2a]		[3a]		[4a]	
	8-Q	*16-Q*	*8-Q*	*16-Q*	*8-Q*	*16-Q*	*8-Q*	*16-Q*
Δln(*YUS*)	3.6	3.7	3.9	4.3	4.9	5.1	4.5	4.6
SRV	68.2	67.3	67.0	64.6	68.7	68.0	64.6	63.1
Δln(*ROILP*)	2.8	2.8	4.5	4.7	4.6	4.8	4.1	4.4
Δln(*P*)	2.6	2.6	4.7	4.7	4.5	4.6	5.8	6.4
Δln(*TOT*)							5.1	5.1
Δln(*G*)	4.7	4.8	5.5	5.6	4.1	4.2	5.6	6.1
Δln(*M1*)	6.9	7.3						
Δln(*MBASE*)			2.0	2.5				
Δln(*MBASEER*)					0.4	0.5	0.5	0.5
Δ(*R*)	11.2	11.4	12.4	12.6	12.7	12.9	9.5	9.8

Capacity Adjusted Solow Residual								
Vector	[1b]		[2b]		[3b]		[4b]	
	8-Q	*16-Q*	*8-Q*	*16-Q*	*8-Q*	*16-Q*	*8-Q*	*16-Q*
Δln(*YUS*)	8.3	8.3	9.6	9.7	9.4	9.6	9.6	9.5
SRV	70.4	69.2	64.8	63.5	67.6	66.4	67.5	65.7
Δln(*ROILP*)	4.4	4.4	6.9	6.9	6.3	6.3	4.7	4.8
Δln(*P*)	3.8	4.4	5.6	5.9	5.4	6.1	5.6	6.8
Δln(*TOT*)							2.4	2.7
Δln(*G*)	5.9	5.9	6.4	6.5	5.4	5.4	5.7	5.6
Δln(*M1*)	3.3	3.7						
Δln(*MBASE*)			2.1	2.5				
Δln(*MBASEER*)					0.2	0.4	0.2	0.4
Δ(*R*)	3.9	4.1	4.7	5.0	5.6	5.9	4.3	4.6

[1] The order of orthogonalization is the order of the variables listed.