Technology, Growth and the Business Cycle[*]

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Abstract

Using a partial equilibrium model that allows for factor hoarding, I construct series on input utilization rates for ten OECD countries. These series are used in growth accounting computations of total factor productivity which filter out cyclical variations in input utilization rates. The main findings are as follows: (i) adjusted Solow residuals grow consistently faster than standard measures, (ii) the variability of the adjusted Solow residual is in some cases smaller than the standard residual's, (iii) adjusted Solow residuals are less procyclical than standard residuals, and fare better at usual exogeneity tests, (iv) supply shocks are no more symmetric between European countries than elsewhere, (v) observed increased output symmetry in Europe is due to demand factors.

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1 Introduction

The standard practice of identifying technological progress to the Solow residual, a measure of the changes in output not accounted for by changes in inputs, is what led Abramovitz (1956) to call technology a "measure of our ignorance". However, this measure is central to a wide range of empirical analyses both in a closed and open economy context. In particular, the growth rate of the Solow residual is often taken to be indicative of the extent of technological progress. In the Real Business Cycle literature, the residual is commonly taken as the empirical counterpart to the exogenous technology shocks assumed to drive the fluctuations of the economy. Starting with Hall (1990) and Gordon (1990), the observed procyclicality of the Solow residual has been argued to stem either from the presence of increasing returns to scale in aggregate production[1], or from procyclical measurement error, exemplified by the failure to correct for inputs utilization in the computation of Solow residuals[2]. In open economy models, bilateral correlations of productivity measures indicate how structurally synchronized two economies are, and thus help identifying the driving forces to the international business cycle.

The purpose of this paper is to cast new evidence on these issues by improving on the standard computations of the Solow residual. These typically assume production to be derived from measured inputs, namely capital stock and hours worked, rather than from input services, for which no direct data is available. Implicit in this procedure is the assumption that measured inputs vary proportionately with input services. There is however clear evidence against this: keeping in mind that they probably contain measurement error[3], it is possible to use the series on capital utilization provided by the OECD to approximate capital services by the capital stock multiplied by its utilization rate. With this proxy, the correlation between growth in capital services and in capital stock is 0.12 in the US. Similarly the correlation between labor services, proxied by measures of overtime, and employment is 0.48. While the fact that these approximations are inaccurate is indisputable, it is hard to see how the assumption that input services are proportional to input stocks can be reconciled with the low observed correlation. Input utilization seems to behave independently of standard measures of input stocks, and standard computations of the Solow residual fail to filter this independent behavior, assigning it to fluctuations in technology. Hence the need for adjusted Solow residuals.

This paper constructs adjusted residuals for ten OECD countries using a partial equilibrium version of Burnside and Eichenbaum (1996) and new quarterly

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[1] As well as from the exercise of market power by firms, commonly associated with increasing returns to scale in production to prevent pure profits.

[2] This has been the object of intense debate. See for instance Basu and Fernald (1995), Basu and Kimball (1995), Burnside, Eichenbaum and Rebelo (1995) or Sbordone (1995).

[3] See Shapiro (1989)

data on hours worked. In the model, because of costs specific to each margin of adjustment, the utilization rates of inputs –capital utilization and labor effort– are chosen optimally by the representative firm in a way that gives rise to restrictions relating unobservable input utilization to observable variables. The cost of capital utilization is modeled as faster depreciation, and increasing labor effort requires the payment of a higher wage to compensate workers for the disutility of harder work. Since the key issue is to come up with series on capital utilization and labor effort, all that is needed from the model are restrictions sufficient to back out utilization rates as functions of other observable variables and certain estimable parameters. While general equilibrium models akin to Burnside and Eichenbaum (1996) give rise to such restrictions, they are closed economy models. Extending them to a multi-country general equilibrium framework as would be necessary for the present cross-country study, would require taking a stance on the economic linkages between countries, which may influence the resulting measures of technology. The partial equilibrium strategy permits to bypass this issue as well as other details of a general equilibrium model that are not important for the issue at stake.

Partial equilibrium models have been used extensively in the literature on productivity measurement, and have focused on industry level analyses. Basu and Kimball (1995) construct a cost-minimization model with increasing returns to scale to generate adjusted Solow residuals at the industry level, and find that observed procyclicality of productivity is an artifact of cyclical utilization of inputs rather than of increasing returns. Burnside, Eichenbaum and Rebelo (1995) implement a similar framework, using industry electricity consumption and data on the workweek of capital as proxies for capital utilization, and establish the importance of cyclical variations in capital utilization in explaining procyclical productivity. Sbordone (1995) models labor hoarding with convex costs of adjusting labor, and stresses variations in labor effort as the culprit for the observed cyclical behavior of total factor productivity at the industry level. Finally, in one of the few cross-country analyses of the issue, Costello (1993) approximates capital utilization by electricity consumption for a subset of OECD countries and finds that industrial technological progress is more correlated across industries within one country than across countries for one industry.

The main results of the paper can be summarized as follows. First, in nine out of ten countries growth rates of technological progress are larger once input utilization rates are controlled for. There is no common culprit for this result: in some countries, capital services appear to grow slower than measured capital stocks, whereas in others it is labor effort that displays a downward trend. Second, in half the countries the adjusted Solow residual is less volatile than the standard measure. Consistent with this is the finding that correlations between productivity growth and employment growth decrease substantially -and are negative- when factor hoarding is accounted for. Models with monopolistic competition, labor hoarding and nominal rigidities, where technological progress actually drives employment down[4] find support in this negative correlation. Third, in all ten countries adjusted residuals are found to be substantially less procyclical than standard series. Moreover, while usual technology measures are significantly Granger-caused by monetary, price and government spending variables, adjusted series are found to be Granger-caused merely by monetary variables, which arguably could obtain even with a true measure of exogenous technological change. Finally, bilateral correlations of adjusted residuals do not come out any higher between European countries than elsewhere. Thus, the observed increase in bilateral output correlations in Europe is due mainly to demand factors.

The paper is organized as follows. Section 2 presents the model and methodology. Section 3 discusses the closed economy results and section 4 presents the cross-country results. Section 5 argues that the results are robust to alternative specifications. Section 6 concludes. The appendix describes data sources.

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[4] See Gali (1996)

2 Model and Methodology

2.1 Model

The model is a partial equilibrium version of Burnside and Eichenbaum (1996). It is assumed that the aggregate technology for producing goods is a constant returns to scale function of effective capital and labor services, as in the following:

$$Y_t = X_t \left(K_t u_t\right)^{1-\alpha} \left(N_t e_t\right)^{\alpha}$$

where Y_t is the aggregate output, K_t the aggregate capital stock and N_t employment or hours worked, depending on data availability. Effective labor input is defined as labor effort e_t times total hours of work, and effective capital services are defined as the capital utilization rate u_t times the stock of capital. X_t is total factor productivity corrected for inputs utilization, the adjusted Solow residual. Following Burnside and Eichenbaum (1996), the rate δ_t at which capital depreciates is assumed to be a function of the capital utilization rate:

$$\delta_t = \delta\, u_t^{\chi} \tag{1}$$

where $\chi > 1$. Thus, the utilization rate of capital becomes a choice variable in the firm's problem[5]. Following Jorgenson (1963), firms rent capital at a rate that includes both the interest rate r_t and the depreciation δ_t induced by its use. Here, depreciation is variable, so that we assume the existence of contracts between firms and capital owners with the rental cost contingent on the utilization rate, observable to capital owners.

Turning to effective labor input, the presence of both labor effort and hours worked in the production function demands that they be differentiated in terms of the costs they entail. This is done by assuming as in Burnside, Eichenbaum and Rebelo (1993) that effort can be adjusted instantaneously against payment of a higher wage, whereas employment is set one period ahead and cannot vary within the period. In effect, employment is predetermined, and firms choose a level of effort taking as given a wage schedule relating labor cost to effort. It is the empirical purpose of this theoretical construct that makes the assumption extreme. In theory, all that is needed are labor contracts and periods short enough to make it infinitely more costly to adjust employment than to adjust effort within the period. Here, the empirical analysis is quarterly, and so should the contracts be. Section 5 presents results using alternative specifications and argues that relaxing this assumption does not improve the results.

When entering a period, firms choose how much labor N_t they want to hire, keeping in mind that they will be able to adjust instantaneously labor effort

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[5] This is consistent with Greenwood, Hercowitz and Huffman (1988) among others. See Bils and Cho (1993) for alternative ways of introducing optimal underutilization of capital.

e_t, utilization u_t and capital stock K_t in response to shocks. Thus, the firm's optimization problem can be written:

$$\underset{e_t;\,u_t;\,K_t}{\mathrm{Max}}\ X_t\,(K_t\,u_t)^{1-\alpha}\,(N_t\,e_t)^{\alpha} - w(e_t)\,N_t - (r_t + \delta_t)\,K_t$$

which yields the following necessary first-order conditions:

$$\alpha\frac{Y_t}{e_t} = w'(e_t)\,N_t \tag{2}$$

$$(1-\alpha)\frac{Y_t}{u_t} = \delta\phi u_t^{\phi-1}\,K_t \tag{3}$$

$$(1-\alpha)\frac{Y_t}{K_t} = r_t + \delta_t \tag{4}$$

where $w(e_t)$ denotes the wage schedule, reflecting agents' disutility of increased effort. As in Basu and Kimball (1995) the focus is on the intra-temporal conditions associated with minimizing costs. Inter-temporal profit maximization is irrelevant to the purpose of backing out restrictions on inputs utilization[6]. Given a wage schedule $w(e_t)$ and a value for α, equation (2) gives a relation between unobservable effort and observable variables. Given a value for δ and ϕ, equation (3) similarly gives a way of constructing series on capital utilization.

2.2 Capital Utilization

Official series on capital stocks are typically constructed by assuming the following capital accumulation rule:

$$K_{t+1} = (1-\delta_t)\,K_t + I_t$$

The initial capital stock is often determined using the perpetual inventory method, and depreciation is assumed constant[7]. This is a problem when modeling capital underutilization as resulting from increased depreciation, since then depreciation cannot be assumed constant anymore. The issue is tackled as in Burnside and Eichenbaum (1996).

Combining (3) and (4) yields $(1-\alpha)\frac{Y_t}{K_t} = \phi\delta_t = r_t + \delta_t$. Assuming r_t and δ_t stationary and taking expectations, $\phi = 1 + \frac{\bar{r}}{\bar{\delta}}$, where $\bar{r} \equiv E(r_t)$ and $\bar{\delta} \equiv E(\delta_t)$. Note that $\phi > 1$, so that depreciation is a convex function of utilization. Under the additional assumption that factor shares are constant,

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[6] In particular, assuming predetermined capital, though more plausible, would complicate simulation substantially, and somewhat undesirably given the empirical purpose of the study.

[7] Official capital data actually do imply a time-varying depreciation rate. This is however an artefact of aggregation across different types of capital.

(4) implies that $\alpha = 1 - \frac{K}{Y}\left(\rho + \bar{\delta}\right)$. Finally, since the present analysis involves growth rates only, u_t may be normalized so that $E\left(u_t^{\phi}\right) = 1$, and thus $\delta = \bar{\delta}$. Rearranging (3) then yields

$$u_t = \left(\frac{Y_t/K_t}{Y/K}\right)^{\frac{\bar{\delta}}{\rho+\bar{\delta}}} \tag{5}$$

where $\frac{Y}{K}$ is the average output-capital ratio. Thus, capital utilization is high when the output-capital ratio is higher than its average value[8]. Given the official data on capital stock and output, and values for ρ and $\bar{\delta}$, it is possible to construct a series $\{u_t\}$. Using (1) and an initial value for $\bar{\delta}$, this series gives rise to a simulated variable depreciation series $\{\delta_t\}$, which can be used recursively along with official investment data to construct an alternative capital stock series allowing for variable depreciation[9]. This alternative capital series can in turn be used to generate a value for $\bar{\delta}$, thereby initiating an iterating procedure. The true capital series is reached when two successive values for $\bar{\delta}$ cease to differ[10]. It is then used in (5) along with the corresponding value for $\bar{\delta}$ to compute series on capital utilization. The benchmark case corresponds to ρ = 4% p.a., and is subjected to a sensitivity analysis in section 5.

2.3 Labor Effort

Equation (2) can be used to construct labor effort. However, (2) involves the wage schedule $w(e_t)$, which must be determined by a utility maximization problem. The household's objective function ought to differentiate the disutility of working harder from the disutility of working more hours, so that the two margins should not become observationally equivalent from the household's perspective[11]. In fact, using observations on the responses of output per shift to changes in the wage rate among a group of British nineteenth century miners, Treble (1996) provides evidence that effort adjustments actually dominated hours responses. Insofar as the two margins appear to entail different costs, it seems reasonably plausible to assume preferences additively separable in labor and effort, and the representative households is then faced with the following problem:

$$\underset{C_t;\, N_t;\, e_t}{\text{Max}}\; E \sum_{j=0}^{\infty} {}^{-t} \left\{ \ln C_t - \frac{N_t^{1+\theta}}{1+\theta} - \frac{e_t^{1+\psi}}{1+\psi} \right\}$$

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[8] This is precisely how some Central Banks compute their official series on capital utilization. See Paquet and Robidoux (1997)

[9] An initial level for the simulated capital stock is also needed. I follow Burnside and Eichenbaum (1996) in choosing it so that the simulated capital series imply the same output-capital average ratio as in the data.

[10] This happens typically after few iterations on capital series, as in Burnside and Eichenbaum (1996). Initial values for $\bar{\delta}$ were taken from Nehru and Dhareshwar (1993).

[11] If utility is assumed convex in the product $N_t e_t$, one can show that $w(e_t)$ is linear in effort.

subject to $q_t s_t + C_t < w(e_t) N_t + (q_t + d_t) s_{t-1}$, where s_t is the household's assets holdings at time t, q_t is the assets price and d_t is the dividend paid at the end of period t. Maximizing utility with respect to effort yields

$$w'(e_t) = \frac{e_t^{\psi} C_t}{N_t} \tag{6}$$

A positive value for ψ implies that hourly wage is a convex function of effort. Using this expression back in (2) gives:

$$e_t = \left(\alpha \frac{Y_t}{C_t} \right)^{\frac{1}{1+\psi}} \tag{7}$$

Given a value for ψ, (7) gives a relation that determines labor effort from observables. Assuming that zero effort implies zero wage, integrating (6) yields $e_t = \left[(1+\psi) w(e_t) \frac{N_t}{C_t} \right]^{\frac{1}{1+\psi}}$, which combined with (7), requires that:

$$\psi = \frac{\alpha}{w(e_t) N_t / Y_t} - 1$$

Given α, and assuming that $w(e_t)$ is observed at least on average, this can be used to estimate ψ and therefore completes the determination of inputs utilization series.

3 Utilization Rates and Adjusted Solow Residuals

Table 1 reports summary statistics corresponding to $\rho = 4\%$ p.a. Section 5 discusses the robustness of the results to alternative values of ρ. [TABLE 1 APPROXIMATELY HERE] ψ is found to be positive in all countries, and thus the wage schedule is always convex in effort. Moreover, a low value for ψ implies that the effort margin is relatively cheap, and should therefore be associated with high volatility of effort and low volatility of capital utilization, as is the case for Italy, Germany or the UK. The labor elasticities of output α are estimated within the usual interval. In most cases, both input utilization growth rates are more volatile than changes in input stocks[12]. When the labor stock is measured using a measure of hours worked where available, labor effort is hardly ever more volatile that labor stock, an encouraging result given the treatment imposed on the theoretical firm, assumed unable to choose how many hours to employ within the period and thus likely to have implausible recourse to the intensive margin[13].

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[12] In Italy, capital utilization is less volatile than capital stock, because of the unusually smooth capital-output ratio in this country.

[13] Measures of hours worked include overtime or part-time labor. There is no *a priori* reason why effort ought to be more volatile than these.

However, when a measure of employment is used instead, effort comes out more volatile in all but two countries, a sign that adjusting effort remains cheaper than hiring or firing.

The last two columns report the correlations between simulated and official capital utilizations series, and between simulated utilization and effort series, respectively. Simulated capital utilization is everywhere positively correlated with official computations, with coefficients ranging from 0.18 in Australia to 0.65 in Canada and 0.75 in the US. This last result was to be expected given that both the Bank of Canada and the Fed include deviations of the output-capital ratio from its average value in their computations of the official utilization rates[14]. Finally, correlations between simulated capital utilization and effort series are found to be systematically positive, which insures that the results generated by the present model will not contradict models where capital utilization is fully determined by the available labor input, as in Bils and Cho (1994).

3.1 Growth and Volatility

Surprising though it may seem, on average capital utilization as reported by the OECD for the US displays a mild downward trend of 0.03% per quarter[15]. While this evidence is subject to already mentioned data related reservations, it implies that the growth rate of technology as measured by the standard Solow residual is understated, for it includes the decreased use of capital -and potentially of labor- and labels it productivity slowdown. The model supports this surprising feature of the data: Table 2 presents a comparison between growth rates of technology over 1970:1 - 1993:4 as implied by standard Total Factor Productivity (TFP) computations and by Adjusted Solow Residuals. Except for Spain, adjusted measures grow substantially faster. This points to measurement error as one of the potential explanations for the sudden decrease in measured productivity that developed countries are argued to have experienced in the last two decades. Furthermore, Table 2 presents a decomposition of $g_X - g_{TFP}$ into the contribution of a -trend- diminishing capital utilization rate and of a -trend- diminishing labor effort rate. The results are mixed: while technology in Australia, Japan and the US unambiguously grow faster because of diminished capital utilization, the culprit in Italy, France and to a lesser extent Switzerland, is diminished labor effort. For the rest of the sample, both utilization rates have diminished through the period and contributed equally to higher technology growth. [TABLE 2 APPROXIMATELY HERE]

To the extent that it is purged from the volatility in input utilization, one would expect an adjusted Solow residual to display a lower volatility than the standard residual. The second half of Table 2 reports both volatilities. While the

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[14] See Shapiro (1989) or Paquet and Robidoux (1997)

[15] A downward trend can also be observed in the data for Germany, Canada and Australia.

volatility of TFP growth is in the vicinity of 1% per quarter for all countries, as in the literature, correcting for input utilization does not result systematically in a lower volatility. In half the countries, adjusted Solow residuals are more volatile than TFP. This points to a robust negative correlation between measured inputs N and K and their respective utilization rates[16]. The last two columns in Table 2 confirm however that input utilization as a whole is procyclical, since $\rho(dTFP, dN)$ is almost always larger than $\rho(dX, dN)$. True technology is thus less correlated -indeed, negatively- with employment, a finding consistent with general equilibrium models with monopolistic competition, labor hoarding and nominal rigidities, as Gali (1996), where positive technology shocks lead to decreases in employment[17].

3.2 Exogenous Technology

Gordon (1990) shows that the measurement error required to explain all of the observed procyclicality of the standard Solow residual needs not be substantial, and an obvious candidate is unaccounted procyclicality in factor utilization. Starting with Hall (1990), an alternative explanation for the apparent procyclicality of Solow residuals has been the existence of increasing returns to scale in production, in which case the economy becomes endogenously more productive by moving to higher levels of activity. In Hall's view, adjusted Solow residuals should remain significantly procyclical. Table 3 reports contemporaneous correlations of the two residuals with output growth. Procyclicality of productivity measured by these correlations unambiguously decreases in all countries when correcting for input utilization. On average, the measure halves; it falls by 70% in the US and by a third in the United Kingdom. Thus, inputs utilization is indeed an important contributor to the observed procyclicality of standard TFP; however, adjusted residuals remain procyclical, if mildly, potentially a result of increasing returns in production. [TABLE 3 APPROXIMATELY HERE]

Hall (1990) proposes an exogeneity test that regresses technological innovations on various demand variables, and proceeds to argue that the significant coefficient estimates he obtains show that technology is not exogenous. However, the apparent response of technology to shocks that would be innocuous under constant returns to scale could stem from the response of inputs utilization. The question is whether technology continues to be affected by demand variables once utilization rates are eliminated from the residual, and it is addressed in the second half of Table 3. The following regressions are estimated

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[16] Computations show that capital utilization is robustly negatively correlated with capital stock, both using the simulated and official series. This is not true of labor effort and employment.

[17] The mostly negative values for $\rho(TFP, N)$ may be an artefact of the use of a fixed labor share α to compute TFP, while studies that use time-varying –and countercyclical– labor shares typically find a positive correlation. Then, an increase in N may be accompanied by an increase in TFP, since the negative impact of higher labor input on the residual is mitigated by a lower α.

for each country i:

$$dX_t^i = \sum_{j \neq i} \alpha_j (L)\, dX_t^j + \beta_1 dM_{t-1}^i + \beta_2 dR_{t-1}^i + \gamma_1 dP_{t-1}^i + \gamma_2 dG_{t-1}^i + \varepsilon_t \tag{8}$$

where the α_j's are meant to correct for international technology transmission, and the β's and γ's investigate if technology is Granger-caused by monetary variables, and price and government spending, respectively. As expected, in all countries -except Canada- TFP is Granger-caused by at least one demand variable[18]. Adjusting for utilization rates, the picture becomes more complex: coefficients remain insignificant in Canada, but now this is also the case in Germany, Spain, Switzerland, and almost Japan. More importantly, the null hypothesis that $\gamma_1 = \gamma_2 = 0$ can hardly ever be rejected with adjusted measures, and the weight of causality seems to have shifted on monetary variables, as is particularly striking in the US. Whereas it is hard to see how an exogenous technology could be influenced by price changes or government spending, the task becomes somewhat easier when monetary variables come out significantly. In light of the high serial correlation in technology shocks, an inflation-targeting Central Bank would indeed ease the money as soon as signs of a productivity boom start to appear, leading to the -observed- result that $\beta_1 > 0$ and $\beta_2 < 0$. Note that this happens particularly in inflation-targeting countries, such as the US, Japan and Germany[19]. Thus the estimates are not inconsistent with an exogenous technological process.

4 Evidence across countries

Table 4 reports average bilateral correlations of the residuals and of output over different time periods and for various subsets of countries. Several observations are in order. First, on average adjusted residuals are less correlated than TFP between European countries, where input utilization rates are therefore synchronized. The opposite is true between non-European countries, where utilization is therefore idiosyncratic. Thus, it is outside of Europe that international co-fluctuations are best explained by technological co-movements, for it is there that the discrepancy is smallest[20]. Moreover, TFP correlations point to highest symmetry of supply shocks within a European core[21], and lowest between non-European countries. The opposite is true once utilization rates are purged of the residual: shocks in countries of a European core then become least symmetric; symmetry of shocks was merely symmetry in utilization rates. [TABLE 4 APPROXIMATELY HERE]

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[18] Significance is at the 5% level throughout. The α's are found highly significant in all instances.

[19] See Clarida, Gali and Gertler (1997)

[20] In particular, highly correlated supply shocks help explain correlation of domestic savings with domestic investment. See Baxter and Crucini (1993).

[21] Composed of the UK, France, Germany and Italy.

Second, correlations of supply shocks in the whole sample of the G10 decrease over time regardless of the measure chosen. In Europe (and outside Europe), average correlations are hump-shaped over time, highest in the early eighties and lowest in the most recent period. In Europe, correlations of outputs are actually U-shaped and highest in the most recent period, an indication that output symmetry in Europe is not due to a structural synchronization of the economies, but to other -demand- factors.

5 Sensitivity Analysis

5.1 Predetermined Labor

The cost minimization problem faced by the firm assumed that the stock of labor is predetermined within the period, which would happen if employment decisions were hindered by the presence of labor contracts preventing immediate adjustment of hours hired. Using a measure of overtime as a proxy for labor services to compute adjusted residuals, this section argues that this is not too extreme an assumption: if it were, simulated effort would come out more volatile than its proxy, since it is the only margin available to the theoretical firm to adjust labor input within the period. In the US[22], simulated labor services remain roughly four times less volatile than overtime, and the two variables are positively correlated (½ = 0:45). In spite of the higher volatility of overtime, the adjusted residual computed using the proxy is actually much more volatile than TFP (3.30% vs. 0.78% per quarter), quite implausibly so. It is also significantly correlated contemporaneously with output (½ = ¡0:40), and remains Granger-caused by price level and government spending. Thus, assuming rigid labor contracts generates a measure of technology whose properties are more plausible than using available proxy; moreover, the simulated effort series remains reasonably smooth.

5.2 Choice of ¹

This section explores the robustness of the previous results to alternative values of ¹, a parameter that governs the relative costs of the two intensive margins, and argues that the main results carry through for ¹ = 6% and ¹ = 2%. Table 5 presents those results and it is easy to see that adjusted Solow residuals keep similar properties for alternative values of ¹. [TABLE 5 APPROXIMATELY HERE]

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[22] Unfortunately, overtime measures are only available for the US. Arguably it is however the country where the assumption of labor contracts is *a priori* the least plausible.

6 Conclusion

This paper uses a simple cost-minimization problem to generate series on intensive use of inputs, which are included in a standard growth accounting exercise to generate measures of technology corrected for inputs utilization. A number of standard results are substantially modified when investigated using adjusted technology measures: adjusted Solow residuals grow faster and behave more as an exogenous process ought to. They become less volatile in half the cases, and their correlation with employment becomes highly negative. Adjusted residuals are not more correlated in Europe than elsewhere, thus pointing to demand factors as the culprits for increased output symmetry in Europe. These modifications are robust to alternative specifications.

Appendix

All series for the US come from Citibase and cover 1960:1-1993:4. For the other countries, the sample covers 1970:1-1993:4, and quarterly data come from the OECD Main Economic Indicators (MEI), except for nominal interest rates, taken from the IMF International Financial Statistics. Real wages are computed by deflating nominal wages series on CPI. Data on capital stocks are constructed using the perpetual inventory method and taking the depreciation rates from Nehru and Dhareshwar (1993). In Australia, Spain and Switzerland, no measures of hours worked are available, and employment was used instead.

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Table 1: Summary Statistics

	j	a	s_{du}/s_{dK}	s_{de}/s_{dH}	s_{de}/s_{dN}	$r(du, du_{off})$	$r(de, du)$
Australia	0.096	0.821	3.308	-	2.811	0.183	0.835
Canada	0.007	0.847	2.914	0.477	1.459	0.651	0.425
France	0.121	0.706	2.717	1.159	1.676	0.307	0.355
Germany	0.023	0.738	3.768	2.555	6.883	0.192	0.209
Italy	0.003	0.728	0.191	0.986	1.041	0.462	0.725
Japan	0.177	0.842	2.380	0.629	1.971	0.338	0.288
Spain	0.058	0.712	1.481	-	0.673	0.229	0.041
Switzerland	0.008	0.661	2.396	-	0.648	0.262	0.480
UK	0.231	0.793	2.851	1.115	1.504	0.454	0.266
US	0.161	0.832	2.901	0.674	1.195	0.749	0.634

dX denotes the growth rate of X, H is hours worked, whereas N is employment. $r(.)$ is the coefficient of correlation and u_{off} the official series on capital utilization.

Table 2: Growth and Volatility

	g_{TFP}	g_X	CTR u_t	CTR e_t	s_{dTFP}	s_{dX}	$r(dTFP, dN)$	$r(dX, dN)$
Australia	15.85	23.01	104	-4	1.480	0.800	-0.196	-0.456
Canada	22.28	30.98	43	57	1.800	1.884	-0.838	-0.872
France	48.55	54.62	22	78	0.602	0.635	-0.239	-0.522
Germany	41.85	49.73	40	60	0.813	1.482	-0.431	-0.340
Italy	30.74	39.22	3	97	0.963	0.740	-0.368	-0.535
Japan	32.22	66.26	111	-11	0.998	1.270	-0.577	-0.705
Spain	54.92	53.28	48	52	0.554	0.679	-0.353	-0.459
Switzerland	18.96	23.38	33	67	0.941	0.818	-0.508	-0.700
UK	31.17	50.17	53	47	1.010	0.952	0.121	-0.085
US	8.27	17.84	100	0	0.815	0.754	-0.207	-0.630

TFP is the standard measure of Total Factor Productivity.

CTR u_t (e_t) is the proportion of $g_X - g_{TFP}$ due to a decrease in u_t (e_t).

Table 3: Procyclicality and Granger-Causality

	$r\left(dTFP, dY\right)$	$r\left(dX, dY\right)$	$b^{TFP}=0$	$g^{TFP}=0$	$b^{X}=0$	$g^{X}=0$
Australia	0.966	0.406	0.009	0.146	0.006	0.222
Canada	0.347	0.123	0.260	0.563	0.257	0.944
France	0.847	0.379	0.001	0.725	0.004	0.562
Germany	0.606	0.267	0.645	0.002	0.623	0.321
Italy	0.818	0.529	0.001	0.008	0.001	0.020
Japan	0.553	0.242	0.834	0.059	0.043	0.659
Spain	0.548	0.300	0.044	0.948	0.152	0.640
Switzerland	0.682	0.300	0.256	0.135	0.565	0.083
UK	0.913	0.618	0.831	0.109	0.014	0.593
US	0.745	0.214	0.029	0.007	0.000	0.918

$b=0$ reports the p value associated with the hypothesis that $b_1=b_2=0$;
$g=0$ reports the p value associated with the hypothesis that $g_1=g_2=0$.
Superscripts indicate the left-hand side variable.

Table 4: Average Bilateral Correlations

	All Pairs			European Pairs			Non-European Pairs		
TFP Correlations		0.089			0.217			0.126	
Sub-Periods	0.122	0.098	0.020	0.203	0.284	0.053	0.111	0.224	0.075
X Correlations		0.077			0.108			0.182	
Sub-Periods	0.112	0.089	-0.008	0.008	0.157	0.061	0.193	0.275	0.089
Y Correlations		0.176			0.320			0.229	
Sub-Periods	0.192	0.151	0.263	0.322	0.286	0.345	0.291	0.270	0.079

European pairs contain France, Germany, Italy and the UK. Non-European pairs contain Australia, Canada, Japan and the US. The three sub-periods are 1970.1-78.3, 1978.4-86.2 and 1986.3-93.4.

Table 5: Sensitivity Analysis

$\bar{r} = 2\%$	$s_{TFP} - s_X$	$g_X - g_{TFP}$	$r_{TFP,Y} - r_{X,Y}$	Monetary Variables	Price and Government	Bilateral Correlations
Australia	45.5	35.8	58.5	0.009	0.248	
Canada	-	33.9	68.1	0.242	0.946	
France	-	16.5	58.3	0.005	0.582	
Germany	-	22.4	58.0	0.647	0.328	
Italy	25.4	26.2	38.6	0.002	0.017	
Japan	-	61.1	72.8	0.043	0.456	
Spain	-	3.0	54.4	0.178	0.738	
Switzerland	7.0	28.2	62.6	0.616	0.085	
UK	5.0	41.7	34.2	0.015	0.634	
US	4.5	59.4	91.9	0.001	0.967	
All Pairs						0.073
European Pairs						0.104
Non-European Pairs						0.178

$\bar{r} = 6\%$	$s_{TFP} - s_X$	$g_X - g_{TFP}$	$r_{TFP,Y} - r_{X,Y}$	Monetary Variables	Price and Government	Bilateral Correlations
Australia	46.6	25.8	57.5	0.004	0.197	
Canada	-	21.7	60.9	0.283	0.937	
France	-	5.2	52.3	0.003	0.560	
Germany	-	8.3	53.9	0.600	0.354	
Italy	25.7	16.5	31.9	0.001	0.015	
Japan	-	43.7	49.0	0.047	0.661	
Spain	-	-	35.8	0.130	0.509	
Switzerland	18.5	7.9	49.0	0.540	0.097	
UK	5.5	33.6	30.3	0.015	0.534	
US	5.0	52.8	83.7	0.001	0.822	
All Pairs						0.081
European Pairs						0.112
Non-European Pairs						0.184

All differences are in percentage.