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Variable capital utilization and international business cycles

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Abstract

This paper develops a two-country international business-cycle model with variable capital utilization, using a standard depreciation-in-use technology. Variable capital utilization significantly reduces the required size of productivity shocks needed to replicate observed output volatility by 20–40%. Further, the model generates positive comovement across countries in wages, hours, and investment, while preserving empirically accurate predictions regarding the relative cross-country correlations of output and consumption and the countercyclical behavior of net exports. Finally, accounting for variable capital utilization reduces cross-country correlation of true productivity shocks relative to that of the standard Solow residual.

Keywords: International business cycles; Utilization; Transmission; Productivity; Neoclassical

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1. Introduction

When an economic boom produces high output, employment, and investment in the United States, there is usually a simultaneous boom in other industrialized countries. But,

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why? Answering this question is a central goal of international macroeconomics. The class of open-economy dynamic stochastic equilibrium models that have been developed to this point have had good success at explaining how business cycles can arise as an equilibrium response to "shocks" to productivity. However, multi-country models have struggled with two major problems. The first difficulty, which is a problem shared by closed-economy models, is that the productivity shocks required by the model are viewed as implausibly large and volatile.[1] Second, many open economy models have difficulty explaining why business cycles move together so closely across countries: realistic international comovement of business cycles frequently requires implausibly high cross-country correlations of the productivity shocks.

This paper shows that variable capital utilization overcomes both of these difficulties. Variable utilization of capital is widely believed to be of first-order importance to understanding business cycles.[2] However, international macroeconomic models have so far abstained from incorporating this important channel of response to macroeconomic shocks. In the closed-economy models that incorporate variable factor utilization, the response to exogenous shocks is enhanced. In these models, a productivity shock of a given size leads to a greater increase in output when producers can vary the utilization rate of capital and/or the intensity of labor effort. Thus, a model with variable capital utilization should also require less volatility in exogenous productivity shocks in order to generate realistic levels of output volatility.[3]

In a multi-sector or a multi-country setting, however, variable capital utilization may be even more important. One important problem with many models of inter-acting economies is their prediction of negative international comovement of factor inputs. For example, these models predict that a productivity boom in the US that leads to increases in US output, investment, and employment would be accompanied by declines in investment and employment in Europe. However, this is not what we see in the data: economic booms tend to occur in most developed countries at the same time. The model mechanism that leads to this counterfactual prediction of negative international comovement is the neoclassical investment accelerator, through which investment responds strongly to increases in productivity that are expected to be persistent. Thus, if productivity simultaneously rises in the US and in Europe, but the increase in the US is somewhat larger, the models predict a strong investment flow out of Europe and into the US. There is also an important role for interactions of labor and capital in these models. When capital leaves Europe, the labor that remains there becomes less productive. This will lead to declines in labor input in Europe, which will set off another round of investment outflows because the decrease in labor input reduces the productivity of the remaining capital. The

[1] Several contributions to the closed-economy literature have explored the role of variable capital utilization in reducing the required size of exogenous productivity shocks. This literature includes contributions by Burnside et al. (1993) and Burnside and Eichenbaum (1996).

[2] See, for example, the work of Bils and Cho (1994), Burnside and Eichenbaum (1996), and King and Rebelo (1999), as well as related empirical analyses by Shapiro (1996) and Basu and Kimball (1997).

[3] An earlier version of this paper, Baxter and Farr (2001), incorporated variable labor utilization along the lines of Bils and Cho (1994). That paper finds that variable labor utilization does not enhance factor comovement, nor does it reduce the required size of productivity shocks.

sensitivity of investment flows to small differences in the return to capital means that productivity shocks must be correlated in excess of 0.99 for the models to be able to generate positive international factor comovement. This correlation is, of course, absurdly high (a more realistic correlation is about 0.30). When firms can vary capital input via increased utilization rather than through an increase in investment, the tendency for investment goods to flow rapidly across countries should be greatly diminished. Of course, we are not the first to address this factor comovement problem. Several other recent papers have also outlined mechanisms that lead to positive international factor comovement.[4] While these are interesting and important contributions, we believe that variable capital utilization is important fact of life in the operation of actual economies, and is therefore an aspect of reality that should be incorporated into our models.

The paper is structured as follows. Section 2 presents our model of variable capital utilization and discusses the ways in which this departs from the prototype twocountry model. Section 3 investigates the business-cycle properties of the variable-utilization model. Section 4 concludes with a summary of our results.

2. A model of variable factor utilization

There are two countries which together make up the world economy; both countries produce the same good which may be used either for consumption or investment. There is frictionless trade in the final good. Trade in financial assets is limited to a non-contingent real bond.

2.1. Preferences

Preferences are time-separable and exhibit constant relative risk aversion. We assume that individuals residing in the home country maximize expected lifetime utility, given by the following:

$$\max E_t \sum_{j=0}^{\infty} \beta^{t+j} \frac{1}{1-\sigma} \left(C_{t+j}^{\alpha} L_{t+j}^{1-\alpha} \right)^{1-\sigma} \tag{1}$$

where C_t is consumption and L_t is leisure. Letting N_t denote labor effort, the individual's time constraint is:

$$1 \geq N_t - L_t. \tag{2}$$

There are similar expressions for the foreign country. Throughout, the functions governing preferences and technology and the parameters of these functions are assumed to be the same across countries. This underlying symmetry allows us to focus on the stochastic elements of themodel as the only reason for asymmetric choices across countries.

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4 The proposed mechanisms include trade in capital goods (Boileau, 2002), household production Boileau (1996) and Canova and Ubide (1998) human capital (Maffezzoli, 2000), market entry (Cook, 2002), increasing returns to scale (Head, 2002), and endogenous market incompleteness (Kehoe and Perri, in press).

2.2. Technology

Home country output, denoted Y_t, is produced using capital services, S_t, and labor, N_t:

$$Y_t = A_t S_t^{1-\alpha}(X_t N_t)^{\alpha}, \tag{3}$$

where A_t is the stochastic component of total factor productivity and X_t represents the level of labor-augmenting technical progress, assumed to grow at a constant, gross rate γ. Foreign country output is given by the following, where asterisks denote foreign-country variables:

$$Y_t^* = A_t^* S_t^{*(1-\alpha)}(X_t N_t^*)^{\alpha}. \tag{4}$$

Home-country capital services are the product of the capital stock, K_t, and the utilization rate, Z_t:

$$S_t = Z_t K_t \tag{5}$$

Similarly, foreign-country capital services are given by:

$$S_t^* = Z_t^* K_t^* \tag{6}$$

We assume that increases in the utilization rate of capital are costly because higher utilization rates imply faster depreciation rates; the depreciation function is $\delta(Z_t)$, with $\delta' > 0$ and $\delta'' > 0$.[5] The stock of capital in place in the home country evolves according to

$$K_{t+1} = [1 - \delta(Z_t)]K_t + \phi(I_t/K_t)K_t; \tag{7}$$

For the foreign country, we have:

$$K_{t+1}^* = [1 - \delta(Z_t^*)]K_t^* + \phi(I_t^*/K_t^*)K_t^*; \tag{8}$$

This specification incorporates capital adjustment costs as described by Hayashi (1982) and employed by Baxter and Crucini (1995). The adjustment cost function is strictly positive with $\phi' > 0$ and $\phi'' < 0$. Firms choose an optimal level of utilization, as well as labor and capital inputs. When selecting an optimal rate of utilization, firms must weigh the benefits of greater output against the costs of greater depreciation.

2.3. Financial market structure

International trade in financial assets is limited to one-period, real discount bonds. These bonds sell at price $P_t^{\mathrm{B}} = (1+r_t)^{-1}$, where r_t is the world interest rate. Letting B_{t+1}

[5] Our parameteriation of the depreciation function, which specifies only the steady state level, slope, and curvature of the depreciation function, is consistent with the following functional form:

$$\delta_t = \delta + \frac{b}{1+\zeta} Z_t^{(1+\zeta)},$$

with $b > 0$, $\delta > 0$, and $\zeta > 0$. The empirical estimates of Basu and Kimball (1997) support this type of convex depreciation function.

denote the quantity of bonds purchased by residents of the home country at date t, the asset-accumulation equation for the home country is:

$$B_t + Y_t \geq C_t + I_t + P_t^{\mathrm{B}} B_{t+1}. \tag{9}$$

The foreign country analogue is:

$$B_t^* + Y_t^* \geq C_t^* + I_t^* + P_t^{\mathrm{B}} B_{t+1}^*. \tag{10}$$

We assume that bonds are in zero net supply, so world bond market clearing satisfies

$$\pi B_t + (1-\pi) B_t^* = 0, \tag{11}$$

where π is the fraction of the world population residing in the home country.

2.4. Model calibration

This sub-section describes the calibration of our model.

2.4.1. Preferences

Our parameterization of the model is designed to make comparison with the existing literature straightforward. Thus, we choose standard parameters for our calibration. The time period is a quarter of a year. The individual's subjective discount factor is set equal to β=0.984. Consumption and leisure are assumed to be separable, σ=1, and we set α=1/3.

2.4.2. Technology

Labor's share is equal to α=0.58, and the gross growth rate of labor-augmenting technical change is γ_X=1.004. The adjustment cost function $\phi(i/k)$ is parameterized as follows. We set $\phi(i/k)$=1 and $\phi'(i/k)$=1 in order to ensure that the steady state of the model is unaffected by incorporating adjustment costs. Given $\phi(i/k)$=$\phi'(i/k)$=1, the elasticity of (i/k) with respect to movements in Tobin's q is governed by the curvature of the adjustment cost function, $\phi''(i/k)$. There are no micro-studies that can tell us the appropriate setting for this parameter. However, it has been noted in past research that this elasticity primarily affects the volatilities of investment (and, of course, consumption) relative to output. As in Baxter and Crucini (1993, 1995) and Baxter (1995), we can use information on the relative volatility of investment to restrict the value of this elasticity, setting η=15. As in prior studies, this value of the adjustment cost elasticity means that investment is about three times as volatile as output in the absence of variable factor utilization.

Incorporating variable utilization introduces a new parameter, ζ, which represents the elasticity of marginal depreciation with respect to the utilization rate:

$$\zeta = \frac{Z\delta''(Z)}{\delta'(Z)} > 0.$$

Our parameterization of ζ is guided by the empirical work of Basu and Kimball (1997), who estimate a log-linear production function incorporating variations in both capital utilization and effort for a panel of US firms from 21 manufacturing industries for the period 1949–1985. They estimate ζ to be approximately unity. They stress, however, that "the data are not very informative" about this parameter. The 95% confidence interval of $[-0.2, 2]$ indicates that the data cannot reject even infinitesimally small values of ζ, although the negative values should be eliminated on purely economic grounds. In our baseline model, we specify ζ=1. In our sensitivity analysis, we also investigate the effects of reducing the elasticity of marginal depreciation with respect to utilization, by studying the effects of ζ=0.10 and ζ=0.05.

2.4.3. Productivity

The exogenous process for de-meaned, detrended productivity is specified as a bivariate *VAR*(1):

$$\begin{bmatrix} \log A_t \\ \log A_t^* \end{bmatrix} = \begin{bmatrix} \rho & v^* \\ v & \rho^* \end{bmatrix} \begin{bmatrix} \log A_{t-1} \\ \log A_{t-1}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \varepsilon_t^* \end{bmatrix}. \tag{12}$$

Many researchers have attempted to estimate the parameters of this process; see, for example, the work of Backus et al. (1992), Reynolds (1993), and Baxter and Crucini (1995). It has proved impossible to estimate the parameters of Eq. (12) with much precision, even if one is willing to abstract from variable utilization, so that the standard "Solow residual" measure of productivity:

$$\log SR_t = \log Y_t - (1-\alpha)K_t - \alpha N_t \tag{13}$$

is also the correct measure of true productivity, A_t.

These prior studies have suggested several qualitative features of the standard "Solow residual" measure of the productivity shocks. First, the shock process is highly persistent; Baxter and Crucini (1995) show that one cannot reject the hypothesis that the productivity shocks follow a random walk processes. Second, the innovations to productivity are positively correlated: cov(ε_t, ε_t^*)>0. It is less clear whether there is transmission of shocks from one country to another over time (v>0 and/or v^*>0); while the point estimates of Backus et al. do suggest transmission, especially from the US to other countries, the results of Reynolds (1993) and Baxter and Crucini (1995) find that the transmission parameters are not statistically significant. In light of these results, we parameterize our productivity process as a near-unit-root process without spillovers, $\rho=\rho^*=0.999$; $v=v^*=0$. We specify that *corr*(ε_t, ε_t^*)=0.258, which is consistent with estimates obtained in the various empirical studies discussed above. This parameterization of the productivity process will be used for all of the model variants that we study.

It remains to specify the variances of the innovations, ε_t and ε_t^*. The usual procedure (see, for example, Backus et al., 1992 or Baxter, 1995) is to estimate the innovation variances and then calibrate the model using this estimate. In the present paper, however, we use a different approach. In each variant of the model that we study, we will calibrate the innovation variance of the productivity shocks so that the volatility of output in the model economy exactly matches the volatility of output observed in US data. This will allow us to easily evaluate how the required volatility of the productivity shocks changes as we incorporate variable capital utilization. Finally, the model is solved using the solution algorithm described in King and Watson (1998). More details on model solution are given by Baxter and Farr (2001).

3. Variable factor utilization and business cycle moments

This section explores how variable capital utilization affects the business-cycle moments generated by our two-country international business-cycle model. We begin by reviewing the properties of the data and the moments generated by the baseline model without variable capital utilization. We then explore how the model's predictions are altered when we allow variable capital utilization.

3.1. The data and the baseline model

Table 1 shows the business-cycle properties of the data together with the predictions of a baseline model that abstracts from variable factor utilization. The business-cycle components of the data are extracted using the $BP_{12}(6, 32)$ band-pass filter described by

Table 1
The baseline model

	Standard deviation		Standard deviation relative to output		First-order autocorrelation		Correlation with output	
	US data	Model	US data	Model	US data	Model	US data	Model
Output	1.69	1.69	1.00	1.00	0.89	0.91	1.00	1.00
Consumption	1.28	1.68	0.76	1.00	0.92	0.90	0.81	0.78
Investment	5.03	5.83	2.98	3.45	0.92	0.90	0.81	0.75
Total hours	1.69	0.89	1.00	0.53	0.88	0.90	0.89	0.34
Capital	0.32	0.68	0.19	0.40	0.97	0.97	−0.09	0.31
Real wages	0.90	1.63	0.53	0.96	0.92	0.91	0.21	0.86
Net exports	0.39	1.78	0.23	1.05	0.93	0.89	−0.31	−0.22
Solow residual	1.00	1.54	0.59	0.91	0.90	0.90	0.87	0.92
True productivity	n/a	1.54	n/a	0.91	n/a	0.90	n/a	0.92

Cross-country correlations (see note)

	Data			
	Min	Max	Median	Model
Output	−0.35	0.81	0.29	0.69
Consumption	−0.62	0.67	0.12	−0.34
Investment	−0.05	0.73	0.25	−0.33
Total hours	0.19	0.84	0.43	−0.37
Real wages	0.07	0.66	0.45	−0.12
Solow residual	−0.79	0.70	0.18	0.26
True productivity	n/a	n/a	n/a	0.26

Correlations were computed between the US and 10 other OECD countries. The min, max, and median of each of these correlations are reported in the table.

Baxter and King (1999). The business-cycle properties of US data are well-known, so we review these only briefly. Consumption is less volatile than output, while investment is approximately five times as volatile as output. Our model with variable capital utilization will have predictions for the behavior of the capital stock, the rate of capital utilization, and the rate of capital services. Unfortunately, none of these variables is measured well in the data. A measure of the utilization rate is published by the Board of Governors of the Federal Reserve System, but this is a measure of the "output gap" rather than being a direct measure of the services supplied by the capital stock. Consequently, an empirical measure of capital services is not available.

All the macro-aggregates that we consider are highly autocorrelated, with first-order autocorrelation coefficients ranging from 0.88 to 0.97. Consumption, investment, the labor variables, the utilization rate, and real wages are all positively correlated with output. The capital stock appears acyclical, while net exports are countercyclical.

Cross-country properties of the data are shown in the bottom panel of Table 1. The key stylized facts are as follows. Outputs are positively correlated across countries, as are consumptions, although cross-country consumption correlations are well-known to be smaller than corresponding cross-country output correlations in most cases. The cross-country correlation of investment tends to be positive, as does the cross-country correlation of hours and employment.

To construct moments for the baseline model without variable factor utilization, we choose the variability of the productivity shock process ($\text{var}(\varepsilon_t)$) so that the standard deviation of output in the model exactly matches the empirical standard deviation of output: 1.69% per quarter. In this model, this means that the (filtered) standard deviation of the productivity shock is 1.60% per quarter—the productivity shock is 0.94 times as volatile as output. The Solow residual is computed as in Eq. (13); this is equivalent to the true productivity shock when there is no variability in factor utilization.

In our baseline model, consumption is slightly more volatile than output, while relative consumption volatility is $0.7 in US data.[6] Investment in our model is about three times as volatile as output, which is less than the relative volatility exhibited by the data, although filtered investment volatility tends to be dependent on the sample period; other researchers using different time periods find that relative investment volatility is on the order of three to four. In the baseline model, all of the variation in total hours occurs through variation in hours per week. Compared with the data, the variation in hours per week is too high, while the variation in total hours is too low. Partly, the low variation in total hours reflects the absence of employment fluctuations in the model; partly, it reflects the fact that our baseline model has an elasticity of hours with respect to the real wage that is one-quarter of the size of the elasticity typically used in "real business-cycle" models.[7] Our model predicts a relatively low correlation of hours with output, compared with the data. At the same time, the predicted correlation of real wages with output is much too high, relative to

[6] However, the relative volatility of consumption is low in the US relative to other countries. In Japan, for example, consumption is about as volatile as output. See Baxter (1995) for more details.

[7] The model studied by Baxter and Farr (2001) permits variation in hours, employment, and effort.

the data. The model correctly predicts that net exports are negatively correlated with output, and the magnitude of this correlation is also approximately correct.

Looking at cross-country correlations, we find that the model correctly predicts that output correlations exceed consumption correlations. Further, both correlations are within the range of observations for OECD countries. However, the output correlation is on the high side of its range: the model predicts a cross-country output correlation of 0.72; the range of correlations in the data is [−0.35, 0.81] with a median of 0.29. The consumption correlation is on the low side of its range, with a model prediction of −0.44. In the data, consumption correlations are in the range [−0.62, 0.67] with a median of 0.12.

Strikingly, the model predicts that investment and labor input will be negatively correlated across countries: −0.28 for investment, −0.53 for hours. This pattern is a common feature of many international business-cycle models, yet it is not the pattern observed in the data. The median cross-country investment correlation in the data is 0.25; for employment, the median correlation is 0.26, and for hours, the median correlation is 0.43. Thus, one important goal of this research is to determine whether variable capital utilization can improve the predictions of our model for the cross-country comovement of factor inputs.

As noted earlier, the productivity shock must be 0.94 times as volatile as output in order for the model to match the observed volatility of output. This shock is highly persistent, with first-order autocorrelation of 0.90; it is also highly correlated with output, with a correlation coefficient of 0.92. The high volatility of the productivity shock is frequently viewed as a problem for this class of models, as it implies a significant probability of technical regress. Further, the very high required persistence of the shock is evidence of weak internal propagation mechanisms in these models. Thus, a second goal of this paper is to determine whether variable factor utilization can be successful in reducing the volatility and persistence of the productivity shock that is required for the model to mimic the salient business-cycle features of the data.

3.2. Variable capital utilization

This section explores the implications of variable capital utilization for the business-cycle properties of the model. We consider three cases, which correspond to different values of ζ, the parameter that governs the elasticity of the utilization response (lower values of ζ imply a more-elastic response). The first case sets ζ=1, which is the Basu and Kimball (1997) point estimate. We consider two additional cases, corresponding to higher utilization elasticities: ζ=0.10, and ζ=0.05. Given the imprecision in the Basu-Kimball estimates, both of these alternative values of ζ are within the 95% confidence interval. The results for these three cases are presented in Table 2.

A major finding is that the variable capital utilization model dramatically reduces the required volatility of productivity shocks. Recall that the baseline model (Table 1) required productivity shocks that were 94% as volatile as output. By contrast, Case 1 of the utilization model requires that productivity shocks are only 76% as volatile as output (the true productivity shocks are the last line in the table). With higher utilization elasticities, the required volatility of productivity shocks falls to 60% of output volatility (Case 2), and 57% (Case 3).

Table 2
Model with variable capital utilization

	Standard deviation				Standard deviation relative to output				First order autocorrelation				Correlation with output			
	US data	Case 1	Case 2	Case 3	US data	Case 1	Case 2	Case 3	US data	Case 1	Case 2	Case 3	US data	Case 1	Case 2	Case 3
Output	1.69	1.69	1.69	1.69	1.00	1.00	1.00	1.00	0.89	0.90	0.90	0.90	1.00	1.00	1.00	1.00
Consumption	1.28	1.50	1.41	1.41	0.76	0.89	0.83	0.83	0.92	0.90	0.90	0.90	0.81	0.86	0.96	0.99
Investment	5.03	5.05	3.96	3.40	2.98	2.99	2.34	2.01	0.92	0.90	0.90	0.90	0.81	0.84	0.95	0.98
Total hours	1.69	0.70	0.41	0.30	1.00	0.41	0.24	0.18	0.88	0.90	0.90	0.90	0.89	0.46	0.66	0.81
Capital stock	0.32	0.50	0.28	0.19	0.19	0.30	0.17	0.11	0.97	0.97	0.97	0.98	−0.09	0.20	0.08	0.02
Capital services	n/a	0.86	1.40	1.54	n/a	0.51	0.83	0.91	n/a	0.92	0.90	0.90	n/a	0.94	1.00	1.00
Real wages	0.90	1.50	1.45	1.46	0.53	0.89	0.86	0.86	0.92	0.90	0.90	0.90	0.21	0.91	0.98	0.99
Net exports	0.39	1.30	0.66	0.39	0.23	0.77	0.39	0.23	0.93	0.90	0.90	0.90	−0.31	−0.27	−0.41	−0.49
Solow residual	1.00	1.51	1.53	1.54	0.59	0.89	0.90	0.91	0.90	0.90	0.90	0.90	0.84	0.96	0.99	1.00
True productivity	n/a	1.27	1.04	0.99	n/a	0.75	0.61	0.59	n/a	0.90	0.90	0.90	n/a	0.94	0.98	0.99

	Cross-country correlations			
	Data: median	Case 1	Case 2	Case 3
Output	0.29	0.73	0.61	0.48
Consumption	0.12	−0.14	0.12	0.20
Investment	0.25	−0.12	0.07	0.11
Total hours	0.43	−0.04	0.65	0.96
Capital stock	n/a	−0.30	−0.42	−0.48
Capital services	n’a	0.51	0.65	0.51
Real wages	0.45	0.07	0.24	0.26
Solow residual	0.18	0.39	0.41	0.35
True productivity	n/a	0.26	0.26	0.26

Case 1 is the Basu-Kimball depreciation elasticity (ζ=1.00).
Case 2 is the King-Rebelo depreciation elasticity (ζ=0.10).
Case 3 is the extreme depreciation elasticity (ζ=0.01).

Although variable capital utilization is successful in reducing the required volatility of productivity shocks, there was no effect on the required persistence of the shock. Overall, we found that the autoregressive properties of the model were unchanged, relative to the benchmark model, by incorporating variable utilization. This means that variable capital utilization does not provide a channel by which shocks to the economy are propagated over time, in the sense of endogenously increasing the persistence of macro-variables.

Comparing Cases 1–3, we find that increasing the elasticity of the utilization response (i.e., decreasing ζ), affects the within-county characteristics of business cycles along several dimensions. First, the relative volatilities of consumption, the capital stock and net exports all decline to levels more consistent with the data. However, more-elastic capital utilization works to reduce investment volatility and hours volatility, which is not desirable as the model already underpredicted the volatility of these variables. The correlations of the macro-aggregates with output change with increases in the elasticity of utilization: increasing elasticity raises the correlation of output with consumption, investment, hours, and real wages. However, increasing the utilization elasticity reduces the correlation between output and the capital stock, which is a move in the right direction.

Introducing variable capital utilization leads to remarkable improvement in the cross-country correlations of consumption, investment, and labor input. Specifically, increases in the utilization elasticity lead to an increase in the cross-country consumption correlation, to the point where this correlation is now very consistent with the data. Output correlations decrease slightly as the utilization elasticity rises, but in all three cases, consumption correlations remain smaller than output correlations, as is true in the data.

The most important effect of allowing variable utilization is the effect on the cross-country correlations of factor inputs. Increasing the utilization elasticity increases the cross-country correlations of investment, hours, and real wages. In Cases 2 and 3, the cross-country correlations of investment and hours are positive, and are consistent with the range observed in the data. Specifically, Cases 2 and 3 predict the cross-country correlation of investment of about 0.15; the range observed in the data was [−0.05, 0.73]. For hours, Cases 2 and 3 predict cross-country correlations of 0.25 and 0.58, respectively; the range observed in the data is [0.19, 0.84].

The variable-utilization model provides a dramatic improvement in terms of predictions for the cross-country correlations of real wages. Recall that the cross-country correlation of real wages in the baseline model was −0.21, compared with 0.45 in the data. With variable utilization, the real wage correlation is positive, and rises with increases in the elasticity of capital utilization. In the least-elastic case (Case 1), the cross-country correlation of wages is 0.01; in Cases 2 and 3, the correlation exceeds 0.20, which is in line with the data.

Finally, we note that the cross-country correlation of the standard Solow residual is higher than the cross-country correlation of the true productivity shocks; this discrepancy is higher with more-elastic utilization. This finding reflects the fact that the capital services are positively correlated across countries when utilization is variable; these capital services are included in the standard Solow residual but not in the true productivity residual. Thus, we find that there is an upward bias in the estimates of the cross-country correlation of productivity shocks computed by Backus et al. (1992) and others who use the standard Solow residual as their measure of productivity.

To summarize, we find that the forces described in the introduction are economically important in this model. Variable capital utilization takes the place of cross-country investment flows and greatly improves the overall macroeconomic performance of the model. The intuition is as follows. When productivity is relatively higher in one country, capital utilization rises in that country encouraging a positive labor response. Because of the positive (but not perfect) cross-country correlation of shocks, positive shocks in one country are likely to be accompanied by positive shocks in other countries. Even with a modest shock correlation of 0 258, we observe positive comovement in labor inputs and investment across countries. Furthermore, and most importantly, this is accomplished while retaining several very important macroeconomic predictions: (1) outputs are correlated across countries; (2) consumptions are positively correlated but less so than outputs; (3) net exports are countercyclical; (4) the pattern of volatility, persistence, and relative volatility are all consistent with the data.

4. Summary and conclusion

This paper explores the importance of variable capital utilization of factor inputs for four central issues in international macroeconomics. Our starting point is the observation that variable capital utilization is the most natural, most relevant, and most important single feature that has been omitted by prior analyses. Variable capital utilization is introduced through a standard depreciation-in-use specification. We find that variable capital utilization improves the predictions of the model along two important dimensions. First, variable capital utilization reduces the required volatility of the productivity shock by a very significant 20−40%. Second, variable capital utilization is very effective in strengthening the model's predicted cross-country correlations between factor inputs. We also show that variable capital utilization does not provide an endogenous propagation mechanism in the sense of increasing the persistence of macro-aggregates. Finally, we show that failing to account for variable capital utilization leads to an upward bias in measures of the cross-country correlation of productivity shocks.

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