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## Testing growth theories: Time series evidence

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Testing Growth Theories:  
Time Series Evidence

by

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## Testing Growth Theories: Time Series Evidence

### Abstract

Recent time series studies reject the hypothesis of catching up in terms of international per capita incomes as derived from the traditional neoclassical growth model. In turn, they seem to support new theories of economic growth which are capable of explaining persistent international differences in per capita incomes. In this paper I show that this finding is derived under a very restrictive econometric framework. Using a more flexible specification that allows for conditional convergence in per capita incomes and a gradual adjustment over time I derive results that are more favorable for the traditional growth model.

JEL Classification: C32, O47

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## Testing Growth Theories: Time Series Evidence

### I. Growth Theory: Old and New

The traditional neoclassical growth model with two factors of production, diminishing marginal products, and a constant returns to scale technology implies that the per capita incomes in poor and rich economies eventually converge to a common level, given that these economies do not differ with respect to their parameters of preferences and technology. With different preferences and technology parameters the model predicts conditional convergence, i.e. each country will converge to its own steady state level of per capita income. This result follows from the assumptions of international factor mobility and flexible relative prices. Once the steady state is reached, growth is only due to exogenous technical progress in this model.

In the absence of country specific differences the model identifies a relative shortage of capital in the relatively poor country as the reason for different per capita incomes. But then the higher marginal product of capital in the poor country will attract investments from abroad, leading to an international equalization in capital intensities and thereby leading to an international equalization of per capita incomes. This simple framework delivers the theoretical foundation for most development policies. The basic message is to increase the incentives for physical capital accumulation; this would lead to a temporarily steeper growth path which means a catching up of per capita incomes in the developing countries compared to the industrialized countries.

Recent advances in growth theory cast some doubt on this paradigm. The outstanding feature of the new models is that growth is explained by some sort of externality, be it related, e. g., to production technologies, human capital accumulation, or

research and development activities.<sup>1</sup> These models exhibit constant marginal products to the input factor that can be accumulated, due to the particular externality. As a consequence, they can explain why the per capita incomes of relatively poor countries may not catch up even if capital is internationally mobile. Therefore, relative income differences may persist forever and absolute income differences may increase. This is not a very encouraging implication for economic development, especially with respect to the formerly socialist economies of Eastern Europe.

Thus, the question arises whether catching up and convergence as suggested by the traditional model, or persistent differences in per capita incomes as suggested by the new models, are adequate descriptions of the real world. One of the first attempts to empirically discriminate between the old and the new approach was made by P. Romer [1988], using cross section evidence based on the PWT5 dataset [Summers, Heston, 1991]. His findings in favor of the new approach were successfully rejected by Mankiw, D. Romer, Weil [1991], using the same set of data but an explicitly formulated traditional model with the additional input factor human capital. Their results and the results in Barro [1991] support the hypothesis of conditional convergence. That is, poor countries tend to grow faster than rich countries holding constant the determinants of the steady state.

A different picture emerges on the basis of the presently existing time series evidence. These analyses seem to support the new models, especially because they refer to a small number of industrialized countries which seem to be not too different with respect to their discount rates, their population growth, their production technologies, and their institutional framework. Therefore, here at least the traditional model should apply. E. g., De Long [1991] finds a strong association between

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<sup>1</sup> For short summaries of "new" growth models see Grossman, Helpman [1990], Lucas [1990], and P. Romer [1990].

machinery investment shares of GDP and GDP per capita growth over the past century for five industrialized countries. At first sight this result appears to be inconsistent with the steady state solution of the traditional model, but not with the new models; and Bernard, Durlauf [1991] find substantial persistence in the estimated time series representation of cross-country output deviations which implies no catching up and no convergence of per capita incomes. This finding, too, can be interpreted as corroborating the new models.

In this paper I argue that the time series evidence does not uniformly support the new models. Using alternative econometric models I show that it is impossible to empirically discriminate between the new and the traditional growth models with the data at hand. However, theoretical considerations suggest that the results which favor the acceptance of the new models may systematically suffer from a small sample bias, whereas the less restrictive alternative econometric specification leads to results that are more favorable for the traditional model.

## II. Alternative Econometric Approaches to Testing Growth Theories

### II.1. Theoretical Background

Consider a Cobb-Douglas production function with three input factors of the form [Mankiw, Romer, Weil, 1990]

$$(1) Y_t = K_t^\alpha H_t^\beta (A_t L_t)^{1-\alpha-\beta}$$

where  $Y$  is output,  $K$  physical capital,  $H$  the stock of human capital,  $L$  labor, and  $A$  the level of technology, with  $\alpha + \beta < 1$  which implies decreasing returns to all inputs and the existence of a steady state.  $L$  and  $A$  are assumed to grow exogenously at rates  $n$  and  $g$ , and the number of effective units of labor,  $A_t L_t$ , grows at rate  $n + g$ . A constant fraction of output,  $s$ , is



invested, and the rate of depreciation of both the physical and the human capital is  $\delta$ . For  $\beta = 0$  the above model reduces to the traditional two factor growth model. It becomes a "new" growth model for  $\alpha + \beta = 1$ , which implies that there is no steady state to which the model economy converges, since exogenous shocks have persistent effects within the latter model.

The non-steady state properties of the traditional model with constant returns to scale can be derived by approximating around the steady state level of output per effective worker,  $y^*$ . This leads to a formula for the speed of convergence to the steady state,  $\lambda$ , which is given by [Mankiw, Romer, Weil, 1990]

$$(2) \frac{d \ln y_t}{dt} = \lambda (\ln y^* - \ln y_t)$$

where  $\lambda = (n + g + \delta) (1 - \alpha - \beta)$ .

Now it is easy to see that the traditional two factor model predicts a faster speed of convergence than the extended three factor model. E.g., for  $\alpha = \beta = 1/3$  the two factor model without human capital ( $\beta = 0$ ) predicts a speed of convergence that is two times faster than in the extended model. Assume  $(n + g + \delta) = 0.06$  which amounts to a halfway time to steady state in about 35 years for the extended model,<sup>2</sup> and about 17 years for the two factor model. This somewhat arbitrary guesswork has an important consequence for empirical research: For testing the steady state prediction of the traditional model one has to consider very long time periods. E.g., with the two worldwide oil price-shocks, the time span since World War II may mainly reflect non-steady state behavior, and even the whole time span since the turn of the

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<sup>2</sup> This theoretically predicted speed of convergence is confirmed by cross-section analyses for international output movements [Mankiw, Romer, Weil, 1990], regional output movements within European economies [Barro, Sala-i-Martin, 1991], and regional output movements within the United States [Barro, Sala-i-Martin, 1992].

century may not provide sufficient steady state information, given the additional shocks of World War I and the Great Depression. However, this interpretation of the data is simply a consequence of the underlying traditional theoretical model.

Alternatively, with a "new" growth model as the underlying theoretical framework, one would ignore the distinction between steady state and non-steady state behavior and instead would ask whether permanent movements in the per capita income of a certain country are associated with permanent movements in the per capita incomes of other countries. That is, an empirical rejection of this hypothesis is evidence against the traditional model, since such a result would imply that the per capita incomes of different countries seem to follow independent random walks.

The recently introduced concept of cointegration analysis [Engle, Granger, 1987] provides a relatively simple time series framework for testing the hypothesis that there are stable long-run relationships between the per capita incomes of relatively poor and rich countries. The existence of such a relationship is a necessary, though not sufficient condition for a catching up process as predicted by the traditional model. However, cointegration tests will provide unbiased estimates for large samples only. To put it differently, since cointegration tests are designed to estimate stable long-run equilibria, the data at hand have to cover a time span long enough to provide sufficient long-run information.

With respect to testing alternative growth theories, the dilemma for empirical research is that a given set of data may either be interpreted as reflecting cointegrating relationships or non-steady state behavior. The former interpretation would follow from the new growth models, the latter from the traditional ones. However, these alternative interpretations lead to alternative econometric model specifications and testing procedures. The one thing that they have in common is the selection of an appropriate

functional form.

## II.2. Functional Form and Model Specification

Testing for stable long-run relationships between the per capita incomes of different countries requires a relatively flexible econometric specification. First of all, the functional form of the empirical model has to be considered. E.g., think of  $Y_t^p$  as representing the log of per capita income in a relatively poor country, and of  $Y_t^r$  as representing the log per capita income of a rich country (USA) to which the initially poor country is assumed to catch up and eventually to converge. Then, a linear regression of  $Y_t^p$  on  $Y_t^r$  and a constant is not an appropriate framework, since in this case the estimated parameter value of  $Y_t^r$  is a constant elasticity. This specification excludes convergence by definition, because it does not allow for a gradual adjustment process which may lead to common (conditional) steady state levels of per capita incomes.

A less restrictive specification which could be used for the convergence regression was first suggested by Working [1943] and popularized in applied demand analysis by Deaton, Muellbauer [1980]. This specification reads:

$$(3) \quad S_t^i = c + \theta Y_t^{us} + z_t$$

where  $S_t^i$  is the per capita GDP of the initially poor country divided by the per capita GDP of the initially rich country,  $Y_t^{us}$  is the log per capita income of the initially rich country,  $c$  and  $\theta$  are parameters, and  $z_t$  is an error term.<sup>3</sup>  $\theta$  is used to compute the "expenditure" elasticity  $\eta_i$ , the elasticity of per capita GDP in the relatively poor country with respect to the per capita GDP in the rich country:

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<sup>3</sup> In terms of demand analysis,  $S^i$  is the expenditure share of good  $i$ , and  $Y$  is the log of total consumption expenditures.

$$(4) \eta_i = 1 + \theta/\bar{S}_t^i$$

where  $\bar{S}_t^i$  equals  $1/T \sum S_t^i$ .

Equation 3 has a straightforward interpretation with respect to catching up and convergence. A statistically significant positive coefficient indicates that the relatively poor country is catching up. It follows from equation 4 that the implication of such a finding is a variable elasticity which asymptotically approaches 1 as the catching-up proceeds. If the regression constant  $c$  in equation 1 is found to be not statistically different from zero, then a variable elasticity approaching 1 means that the hypothesis of convergence in terms of a common per capita income can not be rejected. Alternatively, a statistically significant positive constant means a steady state level of per capita income in the poor country which is lower than in the rich country, and a statistically significant negative constant means a steady state level of per capita income which is higher than in the rich country (conditional convergence).

Estimation of equation 1 by OLS will deliver unbiased estimates of the parameters  $c$  and  $\theta$  as long as this equation forms a cointegrating relationship and no small sample bias is present. Testing whether equation 3 actually forms a cointegrating relationship by one of the procedures suggested by Phillips, Ouliaris [1990] or by the alternative procedure suggested by Schmidt, Phillips [1991] involves an analysis of the residual  $z_t$ . The hypothesis of cointegration is rejected if  $z_t$  contains a unit root, which is observationally equivalent to a high degree of autocorrelation [Cochrane, 1991]. But autocorrelated errors also may indicate a misspecified functional form or a dynamic misspecification. Therefore, a misspecified functional form as well as a dynamic misspecification may lead to an unjustified rejection of a cointegrating relationship. The alternative to the cointegration approach is to begin the analysis with a general dynamic model, to employ some diagnostic checks, and then to

proceed with parameter estimation.

Consider the Autoregressive-Distributed lag model (AD 1,1) of the form

$$(5) \quad S_t^i = \beta_0 + \beta_1 Y_t^{us} + \beta_2 Y_{t-1}^{us} + \beta_3 S_{t-1}^i + e_t$$

where  $e_t$  is an independent error term with mean zero and common variance.

This model is fairly general in that it encompasses nine alternative dynamic models as special cases [Hendry, Pagan, Sargan, 1984]. If it is not rejected by a misspecification test, one can be reasonably confident that the long-run parameters have good statistical properties. That is, for the present analysis it is unnecessary to achieve parsimony in the short-run dynamics by subsequent re-estimation, since the focus here is on the long-run parameters.

Wickens, Breusch [1988] suggest that equation 5 should be transformed in such a way that it allows point estimates of the long run parameters and their standard errors. This specification reads<sup>4</sup>:

$$(6) \quad S_t^i = \delta - \alpha \Delta S_t^i + \gamma \Delta Y_t^{us} + \theta Y_{t-1}^{us} + v_t$$

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<sup>4</sup> See Kennedy [1992, p. 264] for a hint how to derive equation 6 from equation 5.

with the long-run parameters

$$\delta = \beta_0 / (1 - \beta_3)$$

$$\alpha = \beta_3 / (1 - \beta_3)$$

$$\gamma = \beta_1 / (1 - \beta_3)$$

$$\theta = (\beta_1 + \beta_2) / (1 - \beta_3)$$

and  $v_t = e_t / (1 - \beta_3)$

where  $\Delta$  is the first difference operator, and  $v_t$  is an error term. The major drawback of equation 6 is that it can not be estimated by OLS, since the first difference of the LHS-variable will be correlated with the error term  $v_t$ . Therefore, the appropriate estimation technique is by instrumental variables (IV).

### III. Empirical results

I confine the analysis to a small set of industrialized countries which are large and of comparable size with respect to their population. The reason is that an empirical test of the convergence hypothesis is appropriate only for countries with a similar institutional framework and without geographical peculiarities. Here it is hoped that particular regional effects may cancel out on average. These countries are Germany, France, Italy, the United Kingdom, and Japan, which are analysed with respect to their catching up in terms of per capita incomes relative to the United States.

The data for the empirical analysis come from the PWT5 dataset<sup>5</sup> which provides entries for the period 1950-88. This is roughly the time span for which early proponents of the traditional growth model claim to provide an explanation of economic development [Solow, 1991]. For testing the convergence hypothesis

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<sup>5</sup> This set of data is available on personal computer diskettes and through BITNET.

derived from this model I use the time series for real GDP per capita in current international prices<sup>6</sup>, which is the appropriate measure for an international comparison of standards of living since it allows for deviations in international purchasing power. That is, for each year, this GDP measure is directly comparable across countries.

The empirical analysis starts with testing whether equation 3 forms a cointegrating relationship. I use three alternative test procedures to check whether the residual  $z_t$  contains a unit root: the augmented Dickey-Fuller test (ADF) [Said, Dickey, 1984], the  $Z_\alpha$  test [Phillips, 1987], and the Schmidt-Phillips test (SP) [Schmidt, Phillips, 1991]. The latter two are less restrictive since they allow for non-i.i.d. errors in the data generating process of  $z_t$  ( $Z_\alpha$  test) and for a deterministic misspecification of equation 3 (SP test). Table 1 contains the results.

All test procedures indicate that the residual  $z_t$  of equation 3 contains a unit root, since the estimated t-ratios are not smaller than the appropriate critical values. This finding holds true even if the level of statistical significance is reduced from 5 per cent to 15 per cent. Therefore, the per capita incomes of the US and the other countries seem to follow independent random walks. To put it differently, no stable long-run equilibrium relationship between the per capita incomes of these countries seems to exist. Thus, equation 3 could be considered as representing an entirely spurious regression, pointing to the non-existence of a catching up process. This result is compatible with the new growth models, but not with the traditional model. However, as was noted in the previous section, reasonable parameterizations for the traditional model suggest that the cointegration approach may be inappropriate when applied to the post World War II era. Hence, equation 5 is used as an alternative empirical model for testing the catching up

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<sup>6</sup> Compare column 9 in the PWT5 tables [Summers, Heston, 1991] which is labelled CGDP.

hypothesis.

This alternative empirical analysis starts with diagnostic checking of equation 5. I test the possible misspecification of equation 5 by the Plosser-Schwert-White differencing test (PSW), which needs a minor modification to be applicable for regression equations with lagged dependent variables<sup>7</sup>; and I use the Breusch-Godfrey LM-test<sup>8</sup> (BG) to check for serial correlation in the errors. Table 2 contains the results. The equation for France is rejected by the PSW test. However, this rejection does not necessarily mean that the cointegration approach (equation 3) represents the relevant empirical model. The rejection may also be due to an implicit higher order dynamic model. Given the relatively small sample size testing for higher order dynamic models is somewhat restricted. Therefore, the equation for France is not considered for further analysis. Here it is sufficient to show that a relatively simple dynamic model (AD 1,1) provides a reasonable alternative to the cointegration approach, which uniformly rejected the equations for all countries. That is, the equations for Germany, Italy, Japan, and the UK pass the PSW test, at least at the 1 per cent level of statistical significance. Furthermore, all equations pass the BG test at the 1 per cent level of statistical significance. Evaluated at the 5 per cent level, however, the results point to first order autocorrelation in the case of Germany and third order autocorrelation in the case of the UK, but the estimated F-values do not exceed the critical F-values by far. Hence, equation 5 can be considered as a reasonable alternative to equation 3, except for the case of France.

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<sup>7</sup> See Maddala [1992] for a textbook exposition.

<sup>8</sup> For a textbook exposition, see, e.g., Johnston [1984] or Maddala [1992].



The next step in the analysis is to check whether equation 5 actually describes an AD(1, 1) model or a serial correlation model of the form

$$(7) \quad S_t^i = c + \theta Y_t^{us} + u_t \quad \text{with } u_t = \rho u_{t-1} + e_t$$

Hendry, Mizon [1978] show that this model can be rewritten as

$$(8) \quad S_t^i = (1 - \rho)c + \theta Y_t^{us} - \theta \rho Y_{t-1}^{us} + \rho S_{t-1}^i + e_t$$

which is equivalent to equation 5 except for the parameters. That is, if the restriction

$$(9) \quad \beta_3 \beta_1 + \beta_2 = 0$$

holds, then equation 5 actually describes the serial correlation model of equation 7. Such a model can be estimated by the Cochrane-Orcutt or the Hildreth-Lu procedure, whereas the AD(1,1) model can be estimated by OLS or IV.

I use the likelihood ratio (LR), the Wald (W), and the Lagrangian multiplier (LM) test<sup>9</sup> to check restriction 9, which discriminates between the models. For linear regression models the LR, W, and LM test are related in such a way that it is generally possible to reject restriction 9 by the W test but not by the LM test. Table 3 shows, however, that for all countries restriction 7 is rejected even by the LM test at the 5 p. c. level of statistical significance; restriction 9 is rejected at the 1 p. c. level of statistical significance by the W test. Thus the data can be adequately described by an AD(1,1) model, not by a serial correlation model. Then, point estimates of the long-run parameters may be derived from an IV-estimation of equation 6.

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<sup>9</sup> For a textbook exposition, see, e.g., Maddala [1992].

Obviously the results of an IV-estimation critically depend on the properties of the selected instruments. E. g., a low or a negativ  $R^2$  from an IV regression indicates that something is wrong with the specification of the model or with the selection of the instrument. Therefore, I use two different instruments to estimate equation 6 to check the robustness of the results. The upper part of Table 4 contains the resulting parameter estimates when  $\Delta Y_{t-1}$  is chosen as an instrument for  $\Delta S_t^i$ . Apparently, this is not a good choice for the UK equation. The lower part of Table 4 contains the parameter estimates when the sum of the differenced LHS-variables absent from the equation under consideration ( $\sum_{i=1}^n \Delta S_t^i$ ) is chosen as an instrument for  $\Delta S_t^i$ . This instrument yields a significant  $R^2$  for the UK equation, but otherwise lower  $R^2$ s except for the case of Italy. The results for Germany should be interpreted cautiously, because of the relatively low  $R^2$ .

Turning to the long-run parameter estimates one finds that all countries are catching up to the US, since  $\theta$  is positiv in all equations. With this result the non-cointegration finding of Table 1 may be reinterpreted as the acceptance of a possibly false hypothesis. E.g., testing for cointegration by an analysis of the residual  $z_t$  of the static model of equation 3 may involve a relatively high probability of committing a type II error when the time span under consideration actually reflects non-steady state behavior. Then, it will be impossible to statistically discriminate between the hypothesis of a non-stationary residual (no cointegration) and a serially correlated residual (wrong functional form, misspecified dynamics, or serial correlation model). However, a discrimination between these conflicting hypotheses is necessary for a discrimination between the traditional and the new growth models.

A unit root in the residuals and a high degree of autocorrelation are observationally equivalent for reasonable sample sizes. While the former is consistent with the new growth models, the latter is inconsistent with the traditional growth model only if this model predicts a high speed of convergence to the steady state path after an exogenous shock. However, theoretical considerations and empirical results based on cross section studies<sup>10</sup> point to a relatively slow rate of convergence: A fair guess is that an average economy will reach halfway to steady state in about 35 years. Thus the data used in this paper may mainly reflect non-steady state behavior. The implication for an empirical analysis of this time span, then, is to begin with a general dynamic model, and not to give too much weight to the results of cointegration tests which are valid for large samples only. Therefore, the failure to find a cointegrating relationship between the per capita incomes of the US and other countries does not necessarily support the new growth theories.

The estimates for the regression constant ( $\delta$ ), also presented in Table 4, can be interpreted in terms of the steady state levels of per capita incomes. The statistically significant negative constants for Italy and Japan indicate a higher steady state level of per capita income in these countries relative to the US, and the positive constant for the UK indicates a steady state level of per capita income below that of the US. The results for Germany depend on the instrument being chosen; a statistically insignificant constant indicates a convergence to the US level of per capita income. Taken together, these results confirm the hypothesis of conditional convergence.

Of course these results should not be misinterpreted as a forecast for country specific growth rates. They merely reflect an apparently reasonable account of the economic development of this group of countries since World War II, and they are in line with the predictions of the traditional growth model: The relatively

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<sup>10</sup>See footnote 2.

poor countries are catching up, which is a necessary though not sufficient condition for convergence; whether finally a common steady state level of per capita incomes will be reached is a question that can not be answered with the data at hand.

This interpretation of the empirical results corroborates the cross section results of Mankiw, D. Romer, Weil [1991], and Barro, Sala-i-Martin [1991, 1992]. It contradicts the time series evidence presented by Bernard, Durlauf [1991], which is based on cointegration analysis only. Therefore, it helps to put the traditional growth model back on the stage. The identification of differences between the countries that were selected for the analysis in this paper, e. g. in the saving behavior or in the rate of human capital accumulation, as well as a broadening of the empirical base, should further improve the empirical power of the traditional model.

#### IV. Conclusion

The basic message of the traditional model of economic growth is that market forces will ensure a catching up of per capita incomes between rich and poor countries, given that the countries under consideration do not differ too much with respect to their institutional arrangements and time preferences. This message is not necessarily confirmed by the new growth models. They can explain why international differences in terms of per capita incomes may persist, even if the countries under consideration are quite similar. Thus the new models predict that market forces alone might not be sufficient to ensure a catching up process, not to mention a convergence in terms of per capita incomes.

The empirical evidence based on the newly introduced concept of cointegration analysis seems to support the new models. However, these results are based on a very restrictive econometric framework. Less restrictive model specifications and estimation

techniques used in this paper produce results, at least for some countries, that are more favorable for the traditional model. The catching up hypothesis can not be rejected for a number of countries when the econometric model allows for conditional convergence of per capita incomes over time, due to the selection of an appropriate functional form and an explicit modeling of dynamic adjustment processes. This finding shows that the application of an inappropriate econometric approach may easily lead to the acceptance of a probably false hypothesis. Therefore, the empirical evidence does not support the recommendation of interventionist economic policies to achieve a catching up process, which is tempting to be derived from the new growth models.

Table 1 - Testing for Cointegration

	ADFa	$Z_{\alpha}^b$	SP <sup>c</sup>
France	-1.16	-2.33	-1.35
Germany	-2.79	-5.11	-1.17
Italy	-2.37	-5.86	-1.82
Japan	-1.26	-1.97	-1.12
UK	-2.76	-12.92	-2.45

ADF : Augmented Dickey-Fuller test

$Z_{\alpha}$  : Phillips- $Z_{\alpha}$ -test

SP : Schmidt-Philipps test

<sup>a</sup> Test equation:  $\Delta z_t = \alpha_0 z_{t-1} + \alpha_1 \Delta z_{t-1} + e_t$  ;  $H_0: \alpha_0 = 0$

Critical value [Phillips, Ouliaris, 1990, p.190]: -2.86 (5 p.c.)

<sup>b</sup> Test equation: See Phillips, Ouliaris [1990, p. 171]

Critical value [Phillips, Ouliaris, 1990, p.189]: -20.49 (5 p.c.)

<sup>c</sup> Test equations: See Schmidt, Phillips [1991, pp. 9-11]

Critical values are available for unit root tests only:  
approx. -3.15 (5 p.c.); critical values are necessarily  
higher for cointegration tests.

Table 2 - Testing for Misspecification and Autocorrelation

	Plosser-Schwert- White test <sup>a, c</sup>	Breusch-Godfrey test <sup>b, d</sup>		
		AR(1)	AR(2)	AR(3)
France	6.11	2.70	2.88	1.54
Germany	2.64	4.91	0.44	0.61
Italy	3.72	3.73	0.24	0.13
Japan	1.68	1.82	1.42	1.00
UK	2.43	0.69	0.67	4.43

<sup>a</sup> Test equations (PSW test):

$$S_t^i = \beta_0 + \beta_1 Y_t^{us} + \beta_2 Y_{t-1}^{us} + \beta_3 S_{t-1}^i + u_t$$

$$S_t^i = \beta_0^* + \beta_1^* Y_t^{us} + \beta_2^* Y_{t-1}^{us} + \beta_3^* S_{t-1}^i + \beta_4^* S_{t-2}^i + \beta_5^* (Y_{t+1}^{us} + Y_{t-1}^{us}) + \beta_6^* (Y_t^{us} + Y_{t-2}^{us}) + u_t^*$$

$$H_0: \beta_4^* = \beta_5^* = \beta_6^* = 0$$

<sup>b</sup> Test equations (BG test):

$$S_t^i = \beta_0 + \beta_1 Y_t^{us} + \beta_2 Y_{t-1}^{us} + \beta_3 S_{t-1}^i + u_t$$

$$u_t = \beta_0 + \beta_1 Y_t^{us} + \beta_2 Y_{t-1}^{us} + \beta_3 S_{t-1}^i + \sum_{j=1}^3 \rho_j u_{t-1} + e_t$$

$$H_0: \rho_j = 0$$

<sup>c</sup> Critical values:  $F(3, 29) = 2.93$  (5 p. c.) and 4.54 (1 p.c.)

<sup>d</sup> Critical values:  $\text{Chi}^2(1) = 3.84$  (5 p. c.) and 6.63 (1 p.c.)

Table 3 - Testing Serial Correlation vs. Misspecified Dynamics

	LR	W	LM
Germany	6.42	6.99	5.91
Italy	6.57	7.17	6.03
Japan	7.52	8.32	6.83
UK	18.24	23.41	14.49

Test equations:  $LR = n \log_e (RRSS/URSS)$

$$W = n (RRSS-URSS)/URSS$$

$$LM = n (RRSS-URSS)/RRSS$$

where  $n$  is the number of observations,  $RRSS$  is the sum of squared residuals from equation 5 (estimated by Cochrane-Orcutt), and  $URSS$  is the sum of squared residuals from equation 3 (estimated by OLS).

Critical value:  $\text{Chi}^2(1) = 3.84$  (5 p. c.)



Table 4 - Point Estimates for the Long-run Parameters<sup>a</sup>

Equation 4	$\delta$	$\theta$	R2
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1. IV: $\Delta Y_{t-1}^{us}$			
Germany	-0.044 (0.203)	0.082 (0,019)	0.581
Italy	-0.545 (0.084)	0.125 (0.010)	0.852
Japan	-1.431 (0.168)	0.207 (0.015)	0.917
UK	0.291 (0.098)	0.046 (0.016)	-0.878
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2. IV: $\sum_{i \neq j} \Delta S_t^i$			
France	-0.375 (0.106)	0.112 (0.012)	0.745
Germany	-0.398 (0.164)	0.119 (0.018)	0.552
Italy	-0.633 (0.079)	0.135 (0.009)	0.863
Japan	-1.611 (0.131)	0.230 (0.015)	0.885
UK	0.354 (0.034)	0.032 (0.004)	0.618

<sup>a</sup> Standard errors in parentheses.

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