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Article

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Revisiting the Mankiw et al. (1992) growth regressions

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Abstract

We revisit the highly cited Mankiw et al. 1992 (MRW) paper by updating the data for the periods 1960-2015, 1970-2015 and 1990-2015. We present results for the Solow model, the augmented Solow model and the conditional convergence on saving rates, population growth and human capital. The augmented model fits the data better. Human capital remains significant and its impact is higher than the MRW estimates for both the augmented model and the conditional convergence. The updated dataset highlights that the importance of human capital for growth is higher than MRW have demonstrated to be. The datasets for reproduction are also provided.

Keywords: Human Capital, Education, Neoclassical Model, Economic Growth
JEL Classification Codes: O47, F43

1. Introduction

Mankiw, Romer and Weil (1992) (henceforth MRW) has been one of the most influential contributions to the growth regressions literature with more than 24280 citations in Google Scholar at the time of the writing. They have contributed to the literature by providing evidence in favor of the augmented Solow model. They concluded that the existence of human capital in the regression improves their results and its omission leads to results that didn't fit with Solow's predictions.

MRW is a seminal paper and many studies build on this. For instance, Acemoglu (2009) using non-oil countries for the periods 1960-1985 and 1960-2000 rejects the Solow model too since physical capital share is bigger than 1/3. The augmented Solow model fits better in the data, although their adjusted R^2 is smaller than MRW. In this case, both capital shares, human and physical, are consistent with the Solow model. Bernanke and Gürkaynak (2001) using the same countries as MRW for the periods 1960-1985, 1960-1990 and 1960-1995 show that although the augmented model is more appropriate than the Solow, there are some issues like the rejection of coefficients' restrictions and the low values of capital share in some cases. They, also, find that the saving rates are correlated with long-run growth rates, which is inconsistent with the Solow model. Breton (2013) using micro and macro data indicates that the augmented

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model of MRW provides a good representation of the growth process. Campante et al. (2021), also, update the MRW data until 2017 (for non-oil countries only). They provide similar results to MRW: the Solow model is inconsistent because of the high capital shares while the augmented Solow model is consistent. Their updated estimates for human capital are higher than the MRW ones indicating the importance of human capital. Finally, Mello and Perrelli (2003) use quantile regressions only in the cases of convergence for the samples employed by MRW and Bernanke and Gürkaynak (2001). They reveal that when human capital is included in the conditional convergence, the model is better specified. They, also, show that human capital has a stronger impact on countries in the highest quintiles and conclude that in the model with human capital the slope of the coefficients is not constant.

This paper uses an updated dataset for the periods 1960-2015, 1970-2015 and 1990-2015 following the MRW approach. However, we do not find evidence to support the Solow, the augmented Solow model and the conditional convergence models given that the implied physical and human capital shares and implied convergence rate are not in line with the Solow predictions of 1/3, 1/3 and 2% respectively. Nevertheless, the augmented model provides a better fit and human capital remains significant.

This article proceeds as follows. Section 2 discusses the data. Section 3 provides the growth equations. Section 4 presents the empirical results and section 5 concludes.

2. Data

We employ data for Real GDP per worker (*Y/L*), investment share (*s*), population growth (*n*) and two indices for human capital (*ed*, *hc*). The following sources are used: the Penn Table version 10.0[1], the World Bank (WDI)[2] and the Barro-Lee dataset[3]. The data are annual and cover the periods 1960-2015, 1970-2015 and 1990-2015:

- *rgdpna* (Real GDP at constant 2017 national prices in million US$) from the Penn Table. This variable is multiplied by 1 million and then it is divided by the working age population (15-65) from the WDI resulting in the GDP per worker (*Y/L*),
- for the savings rate (*s*) which is (*I/Y*) in the investment equation, we use *rnna* (Capital stock at constant 2017 national prices in million US$) and *delta* (depreciation rate) from the Penn Table to create through the perpetual inventory method the value of investment[4]. Then we divide this variable with Real GDP at constant 2017 national prices in million US$,
- for the average working-age population growth (*n*), the working-age population from the WDI is used,
- finally, we use as a proxy for human capital: (a) the secondary educational attainment as a % of the population aged 15-64 (total) from the Barro-Lee dataset (Barro and Lee 2013) (*ed* and *lned* is the natural logarithm of *ed*), which is the same variable used in MRW; (b) the human capital index, based on years of schooling and returns to education from the Penn Table (*hc*).

Finally, the datasets are grouped as in MRW: the non-oil countries[5], the intermediate countries[6], and the OECD countries[7]. The number of countries varies and it depends on the dataset. Table D1 in the appendix provides a full list of the countries. The updated datasets are provided online in *EViews*, *gretl* and *Stata* format.

[1] https://www.rug.nl/ggdc/productivity/pwt/?lang=en
[2] https://databank.worldbank.org/source/world-development-indicators
[3] https://barrolee.github.io/BarroLeeDataSet/BLv3.html
[4] To create the value of investment we used $I_t = K_{t+1} - K_t\ (1-\delta_t)$.
[5] Non-Oil countries: countries whose production isn't based on oil industries.
[6] Intermediate countries: Non-oil countries as in the first sample but with a population greater than 1 million in the first year, i.e. 1960, 1970 or 1990.
[7] OECD countries: are only the OECD countries having a population of more than 1 million.

3. Methodology

This paper is based on the MRW cross-country growth regressions. Table 1 summarizes the equations that are estimated. For the Solow growth model, we use eq. (1), for the Augmented Solow model eq. (2) and for the conditional convergence on savings, population growth and education eq. (3). Moreover, in the case of the conditional convergence, we represent the restricted model with the restriction that the sum of the *lns* and *lned*'s coefficients is equal to the negative value of the *ln(s+g+δ)*'s coefficient[8]. The error term is denoted by ε_i. For the cross-country regressions, the average value of each variable is employed[9]. Note that in the steady state (y^*), a constant technological progress common to all countries is assumed[10]. We used the following time intervals: (1) 1960-2015 to employ the same period as in MRW, (2) 1970-2015 since the data for many countries start from 1970, and (3) 1990-2015 to include the post-Soviet states.

Table 1. Estimated equations

Estimated equation for the Solow model	
$ln\left(\frac{Y_{i,T}}{L_{i,T}}\right) = lnA(0) + gt + \frac{\alpha}{1-\alpha} ln(s_i) - \frac{\alpha}{1-\alpha} ln(n_i + g + \delta) + \varepsilon_i \rightarrow$ $\rightarrow ln\left(\frac{Y_{i,T}}{L_{i,T}}\right) = const + b_1 ln(s_i) + b_2 ln(n_i + g + \delta) + \varepsilon_i$	(1)
Estimated equation for the Augmented Solow model	
$ln\left(\frac{Y_{i,T}}{L_{i,T}}\right) = lnA(0) + gt + \frac{\alpha}{1-\alpha-\beta} ln(s_i) - \frac{\alpha}{1-\alpha-\beta} ln(n_i + g + \delta) + \frac{\beta}{1-\alpha-\beta} ln(ed_i) + \varepsilon_i \rightarrow$ $\rightarrow ln\left(\frac{Y_{i,T}}{L_{i,T}}\right) = const + b_1 ln(s_i) + b_2 ln(n_i + g + \delta) + b_3 ln(ed_i) + \varepsilon_i$	(2)
Estimated equation for the Conditional convergence on *lns*, *ln(n+g+δ)* and *lned*	
$lny_{i,T} - lny_{i,0} = \left(1 - e^{-\lambda t}\right)\frac{\alpha}{1-\alpha-\beta} ln(s_i) + \left(1 - e^{-\lambda t}\right)\frac{\beta}{1-\alpha-\beta} ln(ed_i) - \left(1 - e^{-\lambda t}\right)\frac{\alpha+\beta}{1-\alpha-\beta} ln(n_i + g + \delta) - (1 - e^{-\lambda t}) lny_{i,0} + \varepsilon_i \rightarrow$ $\rightarrow lny_{i,T} - lny_{i,0} = const + b_1 lny_{i,0} + b_2 ln(s_i) + b_3 ln(n_i + g + \delta) + b_4 ln(ed_i) + \varepsilon_i$	(3)

4. Empirical results

As noted, we employ alternative variables for human capital. The main results are qualitatively similar. In the next section, we represent only the results for samples and periods which are relative to Barro-Lee's human capital proxy.

4.1 Solow model

Figures 1 and 2 present the confidence intervals of the estimated coefficients (eq.1) of the savings and population growth. The savings' coefficients are smaller than the MRW coefficients,

[8] For the analytical derivation of the three estimated equations please follow the article of MRW. Moreover, as in MRW we have assumed $(g + \delta)$ to be 0.05 and common for all the countries, when it is used inside the variable $(n_i + g + \delta)$.

[9] For instance, the term $\frac{Y_{i,T}}{L_{i,T}}$ refers to Real GDP per worker for country *i* for the sample up to *T*. The Real GDP per worker can be written as $y_{i,T}$.

[10] The parameter λ shows the speed of convergcence and equals to $(1 - \alpha - \beta)(n_i + g + \delta)$.

especially for the 1990-2015 period. Moreover, *lns* for the OECD countries remains statistically insignificant but changes sign and becomes negative. The latter highlights the diminishing importance of savings (physical capital investment). This can be consistent with the lower degree of industrialization. The population growth's coefficients, except for the OECD countries in the period 1990-2015, are more negative than MRW's coefficients, especially for the intermediate sample in periods 1960-2015 and 1970-2015. Note here, that the *ln(n+g+δ)*'s coefficient is statistically insignificant for the MRW's OECD sample, whereas in the updated one this becomes statistically significant for the periods 1960-2015 and 1970-2015.

Figure 1. Solow model: eq. 1, confidence interval of the coefficient of savings (*lns*)

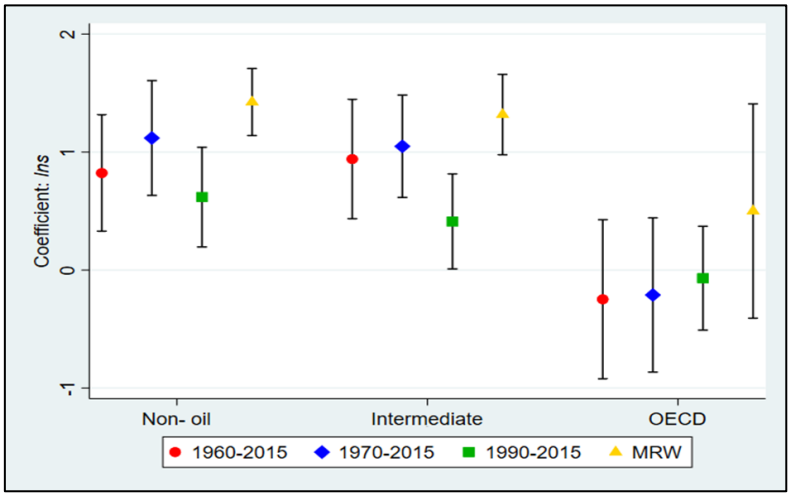
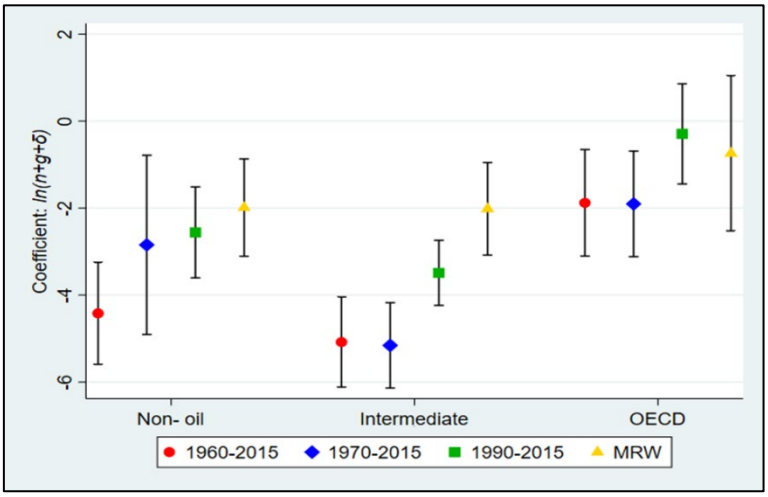


Figure 2. Solow model: eq. 1, confidence interval of the coefficient of population growth [*ln(n+g+δ)*]



4.2 The augmented Solow model

Figures 3-5 present the differences between MRW's coefficients and the updated ones in the augmented Solow growth model (eq.2). We can observe that all coefficients of savings (*lns*) are smaller than the MRW ones. In the period 1990-2015, the OECD's coefficients change sign, but they are insignificant while the Intermediate's coefficients become insignificant. With regard to the coefficient of population growth, *ln(n+g+δ)*, it is worth mentioning that the coefficients become insignificant (in MWR is significant) for non-oil countries in the periods 1970-2015 and 1990-2015, whereas the coefficients become significant (in MRW is insignificant) for the OECD countries in the periods 1960-2015 and 1970-2015. The coefficients of *lned* are higher than the MRW's ones, especially for the non-oil countries. Nevertheless, it becomes statistically insignificant for the OECD countries in the 1990-2015 period. That implies that

human capital becomes more important for economic growth over time, especially for the non-OECD countries. The diminishing importance of savings is confirmed. Human capital improves the explanatory power of the model.

Figure 3. Augmented Solow model: eq. 2, confidence interval of the coefficient of savings (*lns*)

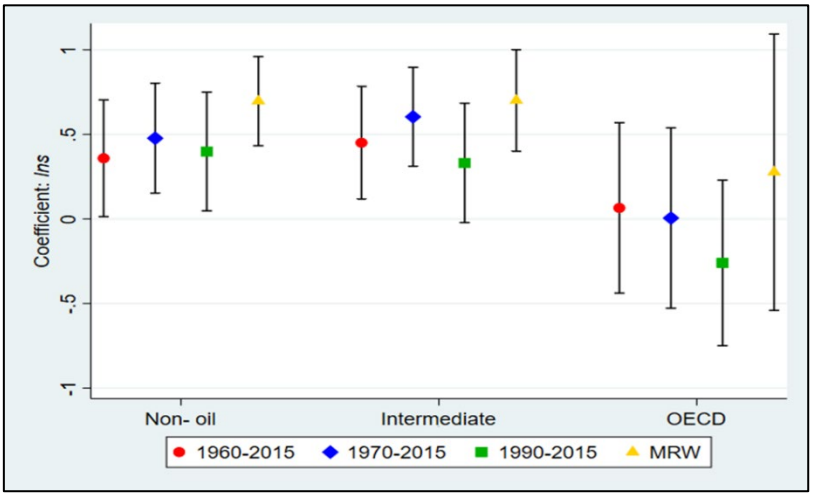


Figure 4. Augmented Solow model: eq. 2, confidence interval of the coefficient of population growth [$ln(n+g+\delta)$]

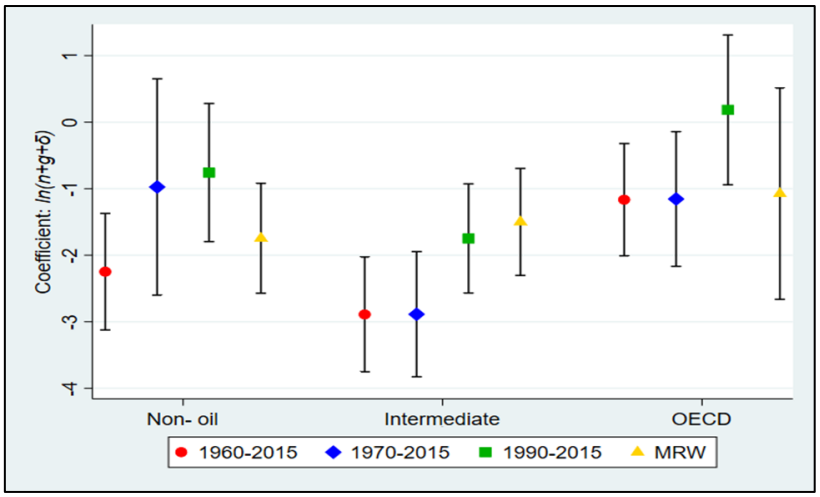
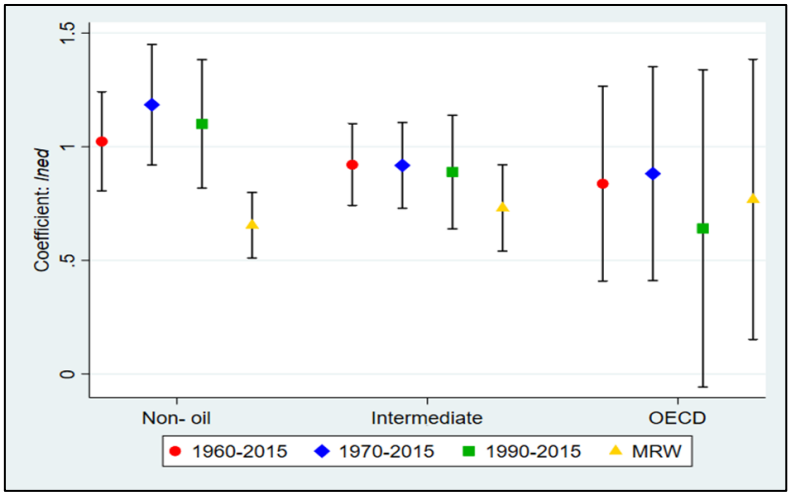


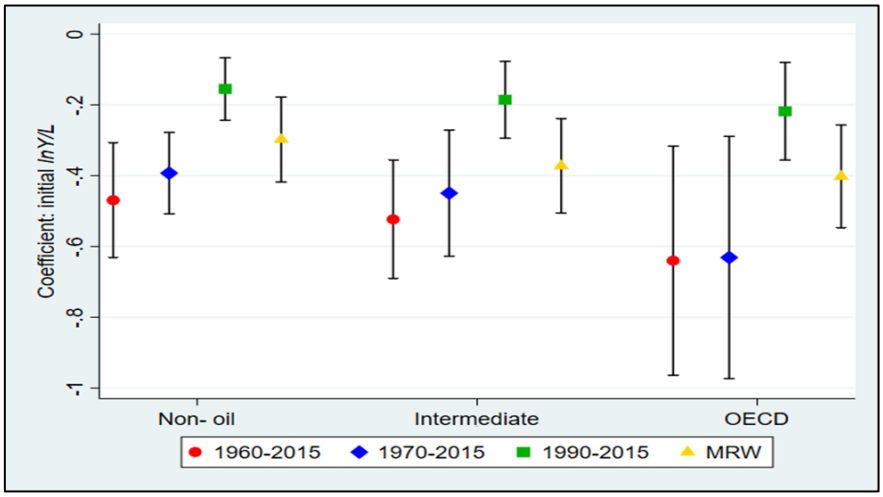
Figure 5. Augmented Solow model: eq. 2, confidence interval of the coefficient of education (*lned)*



4.3 Conditional Convergence

As noted, in the case of conditional convergence on savings, population growth and human capital (eq.3), the restricted model is used. In Figure 6 the restricted coefficients of initial GDP per working age population [*ln(Y/L)*] are displayed. They are negative and statistically significant in all samples. Specifically, they are lower than MRW for the periods 1960-2015 and 1970-2015 but higher for the 1990-2015 period.

Figure 6. Conditional convergence on *lns*, *ln(n+g+δ)* and *lned*: eq.3, confidence interval of the coefficient of initial GDP per working age population [*ln(Y/L)*]. Restricted model



5. Discussion and conclusions

This article revisits one of the most influential growth regression papers by using updated samples for the periods 1960-2015, 1970-2015 and 1990-2015. In the case of Solow model, the coefficients of the independent variables are statistically significant at the 5 percent level, and they have the expected signs for the non-oil and intermediate countries. The adjusted R^2 is, also, lower in the non-oil countries while for the intermediate and OECD countries is higher for the first two periods. Moreover, although the *implied* α's are lower than MRW in most cases, they remain higher than one-third that is predicted by the Solow model. Thus, we reject the Solow model in this sense. Similarly, in the augmented Solow model, our coefficients are statistically significant at the 5 percent level and with the expected signs in the first two country groups. The human capital index is statistically significant at the α=1% in all cases except the OECD countries for the period 1990-2015. Moreover, adjusted R^2 is lower than MRW in the non-oil countries but higher in the intermediate and OECD samples in the periods 1960-2015 and 1970-2015. In contrast to MRW, our implied α's are smaller than 0.25 and *implied* β's are about 0.40 indicating that we can't accept the augmented Solow model because the implied values are different from the Solow model's predictions. Finally, there is conditional convergence when controlling for the saving rate, population growth and human capital (see Tables A.7 to A.9 in the online supplementary materials). The coefficients of initial *ln(Y/L)*, also, are higher than MRW, in absolute terms, in the periods 1960-2015 and 1970-2015. Nevertheless, the *implied a* and *implied* β are between 0.2 and 0.3.

Thus, we find evidence that is not fully consistent with the models we examined above that rely on the Solow and the augmented Solow formulation; as implied physical and human capital share and implied convergence rate aren't consistent with the predictions of 1/3, 1/3 and 2% respectively. Nevertheless, the augmented model fits the data better and the coefficient of human capital is more important than in MRW (except for the OECD countries in the period 1990-2015). Overall, the updated dataset highlights that the importance of human capital for growth

is higher than the MRW estimates. The importance of physical capital investment is revealed to be diminishing.

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Supplementary materials

Additional materials are available online on the EBL website at the following link: https://re-unido.uniovi.es/index.php/EBL/article/view/19256/version/19750