TESTING HUMAN CAPITAL PROXIES IN THE SOLOW MODEL

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Testovanie proxy indikátorov ľudského kapitálu v Solowovom modeli

Abstract: *In their famous article, Mankiw, Romer and Weil (1992) concluded that estimates based on the augmented Solow model imply output elasticities of physical and human capital at about 0.3. When replicating the authors' methodological approach to our own data, there is a significant overestimation of the impact of physical capital in recent periods compared to the conclusions of Mankiw, Romer and Weil (1992). We consider the main determinant of this overestimation to be an imperfectly chosen proxy variable, which does not capture well the stock of human capital essential for the current economic growth. In this paper, we tested four different proxy variables for human capital in the augmented Solow model. We found that the proportion of people with at least some tertiary education is the best variable in analyzing data between 1960 – 2000. When examining recent periods, the better proxy variable is the average length of schooling.*

Keywords: *Solow model, Human capital, Cross-sectional data*

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1 Introduction

Mankiw, Romer and Weil (hereinafter referred to as 'MRW') *"show that an augmented Solow model that includes accumulation of human as well as physical capital provides an excellent description of the cross-country data"* (Mankiw, Romer and Weil, 1992). In this paper, we have estimated the basic Solow model based on the MRW approach over a moving 25-year period between 1960 ─ 2017. We have found that the impact of physical capital is significantly overestimated and increases over time.

MRW dealt with the problem of overestimated impact of physical capital by incorporating human capital, which they identified with an education measured by the share of enrolled students in secondary school in the working age population (Mankiw, Romer and Weil, 1992). This choice of a proxy variable for human capital has been criticized by several authors (Gemmell, 1996; Nonneman and Vanhoudt, 1996). For the basic replication of the model, we therefore chose data on the proportion of people older than fifteen years who completed at least some education at a secondary school. We estimated the augmented Solow model on a moving 25-year period in the years 1960 – 2015. The output elasticity of human capital oscillates around the predicted value of 0.3 during all periods. The impact of physical capital is slightly lower in the first half of the period compared to the predicted values and it is slightly overestimated in both samples of countries[2] in the second half. We also identified an imperfect choice of a proxy variable for human capital as a potential source of overestimation of the effect of physical capital. It is possible that with the increase in automation of many activities in the last two decades, the share of the secondary school population no longer captures a significant part of the human capital used in production. Based on this hypothesis, we estimated the augmented Solow model in the period 1990 – 2015 with various proxy variables for education. We have come to a conclusion that our estimates are closest to the MRW predictions using the proportion of people over the age of fifteen with at least some tertiary education and the average length of schooling. We also performed a robustness test at different time periods, which confirms these conclusions.

[2] We use two samples of countries, which are compiled on the basis of the MRW paper. A description of the sample can be found in the methodology chapter and a list of countries is in the appendix.

2 Review of Literature

In 1956, Robert Solow introduced his theoretical model of long-term economic growth (Solow, 1956). According to the Solow model, whether a country is rich or poor depends on its savings rate and population growth. The accumulation of household savings creates investments that result in new physical capital. Solow presented several possible extensions of the model, one of which was exogenous technological progress, which multiplies the influence of production factors on the output of the economy.

Mankiw, Romer and Weil took Solow's work seriously and derived testable hypotheses from the Solow's "textbook" model, which they verified by using standard econometric methods (Mankiw, Romer and Weil, 1992). After the incorporation of human capital, they found out that the extended Solow model well describes the cross-sectional data spanning the years 1960 – 1985.

The MRW paper provoked a lot of discussion and was criticized mainly for the chosen econometric framework. According to Islam, the chosen approach based on cross-sectional data is inappropriate due to an omitted variable bias and due to a non-control for country specific shocks (Islam, 1995). He dealt with these problems using dynamic panel data models but did not experience similarly convincing results as MRW. The issue with the endogeneity of explanatory variables was addressed by Caselli, Esquivel and Lefort (1996). Based on the GMM estimator, they estimated a "textbook" and an augmented Solow model. Likewise, as with Islam, the resulting estimates did not agree with the basic predictions of the Solow model.

Several authors have investigated the robustness of the Solow model using various samples of countries divided into groups by per capita income (Brumm, 1996; Temple, 1998). Brumm focused exclusively on the analysis of cross-sectional data and did not confirm the robustness of the augmented Solow model. Similar conclusions were reached by Temple, who analyzed panel data in addition to cross-sectional data and showed that *"estimated technology parameters and convergence rates are highly sensitive to measurement error"* (Temple, 1998).

Although MRW showed that the extended Solow model describes data well for large samples of countries, the results for the OECD group were not so convincing. According to MRW, this implies a greater distance from the steady state in OECD countries (Mankiw, Romer and Weil, 1992). This problem was addressed in more detail by Nonneman and Vanhoudt (1996), who saw the reasons for these shortcomings in the excessive similarity of the countries, or in the possible non-inclusion of an important variable in the model. Based on this observation, authors added an endogenous accumulation of technological know-how to the augmented Solow model, which was then able to explain up to 3/4 of the total differences in per capita income. Another approach was taken by Canarella and Pollard (2003). For their estimates, they used a newer version of the Penn World Table database, which has undergone several methodological adjustments. They found that, compared to MRW estimates, the explanatory power of the Solow model has increased significantly in OECD countries.

The literature on the selection of a proxy variable for human capital is not as broad as the one on testing the Solow model. Knowles and Owen (1995) have shown in a wide sample of countries that human capital in the form of health has a greater impact on per capita income than human capital in the form of education. In cross-sectional data from fifty countries, Hanushek and Woessmann (2012) pointed out that the impact of quality of education (measured by international student tests) has a significantly greater impact on economic growth than variables reflecting the quantity of education (average number of years of education).Breton (2015) criticized this approach and estimated the augmented dynamic Solow model on panel data with various proxy variables for human capital. The author focused mainly on comparing the variable on the quality of education from Hanushek and Woessmann's article with education expenditures. He found that improvements in student tests only increase GDP growth rates for countries with low average school attendance (less than 7.5 years) in contrast to spending on education, which, according to Breton, increases growth even in countries with longer average school attendance.

To summarize: using a cross-sectional approach, the results of the augmented Solow model are largely consistent with the basic predictions, with a significant impact of both physical and human capital. Using panel data, the results seem much more sensitive to the sample of countries used and to the econometric techniques chosen.

3 Methodology and Data

As already mentioned, analysis of the Solow model based on panel data does not provide results similar to the basic predictions, and the impact of human capital is rarely statistically significant. A panel approach in examining various proxy variables for human capital in the augmented Solow model has been applied in e.g. Hojdan (2019). The robust significant impact of human capital has not been confirmed in international PISA tests either.

Criticism of the MRW model estimates using OLS was largely associated with omitted variable bias. The omission of other variables is addressed by Breton (2011), who argues that other variables such as institutions, culture, or policy variables determine the amount of national income through the accumulation of physical and human capital. Several studies that have examined the robustness of determinants of economic growth confirm this hypothesis (Levine and Renelt, 1992; Ciccone and Jarociński, 2010). It is also important to note that this paper aims to test the assumptions of the Solow model in the MRW specification. If we wanted to address the problem of omitted variable bias by adding additional regressors to the model, the implied elasticities of the production factors would then not be comparable to the study of Mankiw, Romer and Weil (1992). Based on this, we think that the chosen model specification is appropriate for the purposes of this article. Authors such as Islam, using panel data and various estimators tried to deal with econometric issues such as assumption of homogeneity of production functions across countries or omitted variable bias (Islam, 1995). Although panel data models are better able to deal with econometric problems, it should be emphasized that the Solow model is a model of long-term economic growth. The selection of the length of periods when testing the Solow model is in our view essential. The discrepancy between estimates on different types of data may be the result of the rigidity of school systems, which can only change very slowly. Based on this consideration, we therefore chose to use the cross-sectional approach with OLS estimator for our analysis.

Data on the real GDP at chained PPPs (in 2011 US $) were obtained from the Penn World Table 9.1. For the share of investment in GDP, we used data from the United Nations on Gross fixed capital formation as % of GDP (the problem here is that they are available only since 1970). Like MRW, we divided the real GDP by data on the population aged 15 – 64, which we obtained from the World Development Indicators database. From these data, we also calculated a population growth. As a primary source of data on education, we used the Barro and Lee database from which we gathered data on the proportion of people older than fifteen years who completed at least some secondary and tertiary attendance (Barro and Lee, 2013). From the same dataset, we have drawn the data on the average length of education. The human capital index from Penn World Table 9.1 was chosen as another variable. This indicator is composed as the number of years of education and the estimates of returns for individual years of schooling.

In this paper, we used two samples of countries. Like MRW, we used groups of countries called non-oil and intermediate countries. The first sample is for countries where oil extraction is not the dominant sector. In the case of the intermediate group, countries with a population of less than 1 million were removed from the non-oil sample (referring to the period when the MRW paper was published). Some data were not available, especially for some African countries, resulting in an imperfect replication of samples from the MRW article. A list of countries in both samples can be found in the appendix.

4 Empirical Results

In the first part of this chapter, we tested the predictions of the Solow model about the output elasticities of production factors over a moving 25-year period from 1960 to the present. We find that the augmented Solow model with human capital coincides with the basic predictions during all periods. We have found that the augmented Solow model with human capital is relatively consistent with the fundamental prediction during all periods. In the second part, we tested various proxy variables for human capital. The human capital index has the largest estimated impact on GDP per worker. In contrast, models with a share of people with tertiary education and an average number of years of schooling are closest to the predictions of the Solow model. In the third part of this chapter, we tested the robustness of our findings at different time periods. We found that the proportion of people with at least some tertiary education is the best variable in analyzing data between 1960 – 2000. When examining recent periods, the better proxy variable is the average length of schooling.

4.1 Testing the Solow model over time

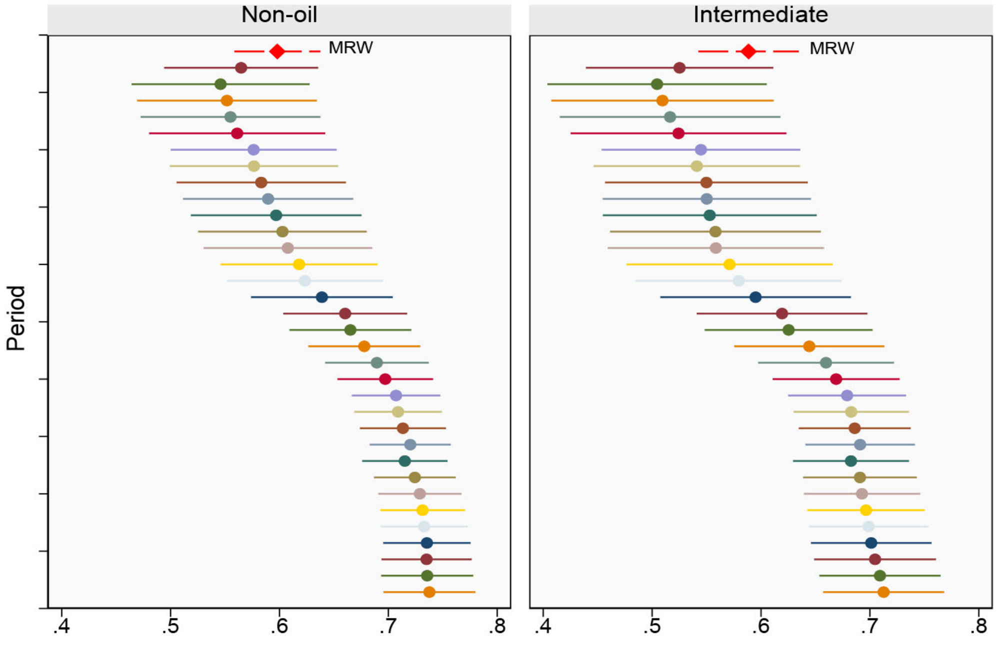
As a starting point for our analysis, we chose to test the basic Solow model without human capital. The main parameter on the basis of which we can verify the validity of the model is the so-called output elasticity of physical capital α. Essentially, it indicates how the output of the economy will increase if we involve another unit of physical capital in the production process. The general rule and also the MRW prediction for the Solow model is a value of α about 0.3.

To test the prediction of the model on real data, it is necessary to derive its econometric form according to the MRW model:

$$\ln\left(\frac{Y(t)}{L(t)}\right) = c + \frac{\alpha}{1-\alpha}\left(\ln(s_k) - \ln(n+g+\delta)\right) + \epsilon \qquad (1)$$

where *Y/L* is GDP per worker, s_k is the savings rate (in our case the average share of gross fixed capital formation in GDP), n is population growth (an average growth of the labor force), g expresses technological progress and δ is a depreciation of capital. Like MRW, we assume that $g + \delta = 0.05$.The constant c expresses the initial state of technology in the countries and ϵ expresses the random component.We estimated this econometric model on samples of two group of countries using constrained regression on cross-sectional data. We then calculated the average values of the parameter α and the corresponding confidence intervals. We repeated this process 34 times for both samples of countries and on all possible 25-year periods (the length of the periods was chosen according to MRW) between 1960 and 2017.The average elasticities are shown in Figure 1. First, we can notice that the estimated parameter α based on our data slightly differs from the parameter estimated by MRW (first and second observations from above). This is mainly due to the corrections that databases have undergone over the last few decades. Based on our results, we came to the same conclusion as MRW that the basic Solow model significantly overestimates the impact of physical capital. Furthermore, this overestimation increases over time to a level close to 0.8. This large difference from the predicted value implies omitting an important variable in the model.

Figure 1: Evolution of the estimated output elasticity of physical capital over time.



Note: The first point corresponds to the MRW estimates. Estimates are displayed from the top to the bottom in the chronological order.

Source: Author's calculations.

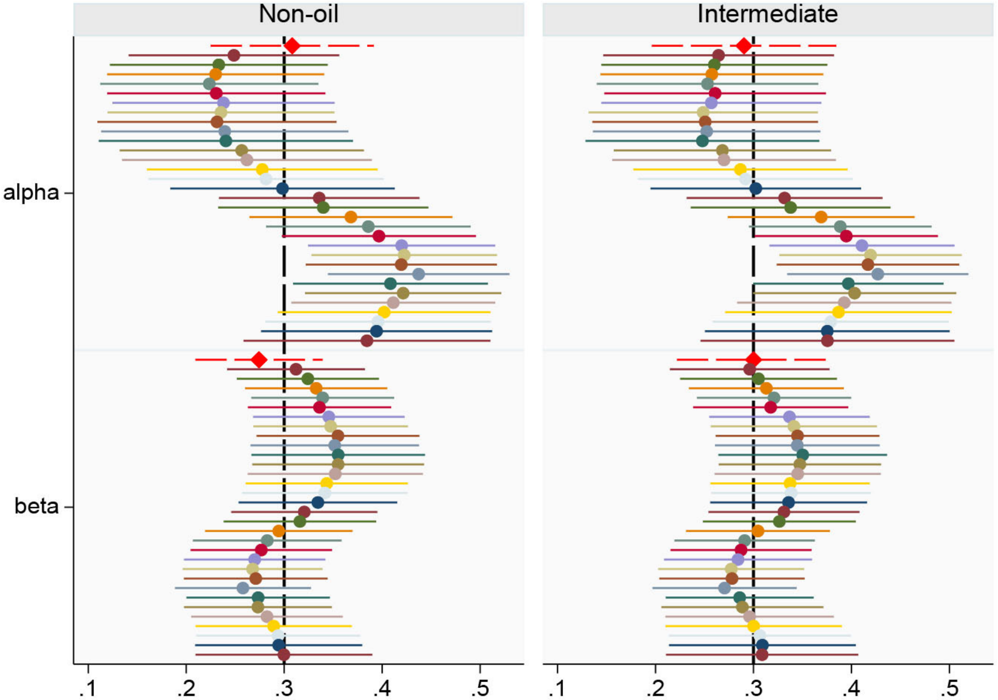
MRW have tackled this problem by extending the Solow model to another factor of production – human capital. As with the basic model, in this case we can derive an econometric equation for the extended Solow model in a form, where we can calculate the output elasticities after estimates:

$$\ln\left(\frac{Y(t)}{L(t)}\right) = c + \frac{\alpha}{1-\alpha-\beta}(ln(s_k) - \ln(n+g+\delta))$$

$$+\frac{\beta}{1-\alpha-\beta}(\ln(s_h) - \ln(n+g+\delta)) + \epsilon \qquad (2)$$

The parameter β symbolizes the output elasticity of human capital and the variable s_h shows the rate of investment in human capital according to the MRW model (in our case we used the share of the population older than fifteen years who completed at least some secondary school attendance). We estimated the effects of individual variables using constrained regression and then we calculated the average output elasticities α and β. In this case, we repeated this process 32 times on all possible 25-year periods between 1960 and 2015. The average elasticities and the corresponding 95% confidence intervals are shown in Figure 2. The average values of β oscillate very close to the value predicted by MRW in all time periods and in both samples of countries. With the output elasticity of physical capital, our estimates are slightly underestimated in the first half of the periods under review whereas in the second half we may observe a more significant overestimation.

Figure 2: Evolution of the estimated output elasticities of production factors over time



Note: The first period: 1960 – 1985 (top), the last period: 1990 – 2015. The reference line shows MRW predictions for elasticities of production factors.

Source: Author's calculations.

Based on these results, we conclude that the augmented Solow model relatively well describes real data during all the examined periods and on both samples of countries. Our main hypothesis is that the overvaluation of physical capital in the second half of the study period is caused by an imperfect proxy variable for human capital. It is possible that with the increase in automation of many activities in the last two decades, the share of the secondary school population no longer captures a significant part of human capital used in production. In light of this, we assume that by using other auxiliary indicators that reflect this trend, e.g higher education share over the population, we can explain part of the differences in GDP per worker attributed to physical capital (based on the standard assumption that physical and human capital are positively correlated).

4.2 Testing proxy variables for human capital

When testing proxy variables for human capital in the augmented Solow model, we chose a standard framework based on MRW which regresses real GDP per worker in 2015 over the average share of gross fixed capital in the country's GDP in the years 1990 – 2015 and the average growth rates of the population aged 15 – 64 in the same period (increased by $g + \delta = 0.05$).As a proxy for human capital, we tested 4 variables (all educational variables enter the model as averages in the period 1990 – 2015):

1. Share of the population older than fifteen years that completed at least some education at secondary school;
2. Share of the population older than fifteen years that completed at least some education at tertiary school;
3. Average length of schooling (in years);
4. Human capital index (based on years of schooling and returns to education).

We estimated the augmented Solow model on a non-oil sample using OLS without restriction (in the first part of Table 1) and with restriction (in the second part of Table 1). Models 1 to 4 differ only in the proxy variable used for human capital. The largest estimated impact of the proxy variable has an index of human capital from the Penn World Table database. In this case, the calculated output elasticity β with a value of 0.509 is significantly overestimated compared to the predictions. This overestimation may be due to the endogeneity of this explanatory variable. It is reasonable to assume that in countries with a better institutional environment, educational returns are significantly higher. Thus, this variable appears to be highly correlated with other growth determinants that are not included in the model, which overestimates the estimated effect. In models 2 and 3, which use tertiary school and average years of schooling variables as proxies, the calculated elasticities of physical and human capital are closest to the values predicted by the augmented Solow model. These results are in line with our hypothesis that human capital over the last years needs to be measured by indicators that also reflect higher education than secondary school.

In Table 2 we can see the estimates of the extended Solow model for countries from the intermediate group. At first glance, the results are very similar to those on a non-oil sample. The extended Solow model in this case explains the differences in GDP per worker (based on adjusted R-squared) worse than in the previous sample. In this group of countries, small countries with less than 1 million inhabitants are absent. The Solow model describes large differences in per capita income between countries sufficiently. However, if we choose a sample from countries with similar levels of GDP per capita, its success in fitting the data is less-than-stellar. As in the previous case, the output elasticities came closest to the predicted values in models 2 and 3 (we consider the approximation to the value of 0.3 for physical capital to be a more important factor, as we can also compare this value with national accounts).

Table 1: Estimates of the augmented Solow model for non-oil countries with different proxies for human capital (1990 – 2015)

Dep. var.: Real GDP p. c. 2015 (PPP)	(1) secondary	(2) tertiary	(3) years	(4) human
Observations	88	88	88	92
ln (*I/GDP*)	1.130***	0.823***	1.010***	0.928***
	(0.279)	(0.242)	(0.243)	(0.218)
ln (n+g+δ)	-3.207***	-2.475***	-2.431***	-1.532***
	(0.495)	(0.436)	(0.457)	(0.457)
ln (*school*)	0.808***	0.602***	1.329***	2.513***
	(0.126)	(0.063)	(0.148)	(0.234)
Constant	9.647***	10.796***	8.826***	7.803***
	(1.340)	(1.039)	(1.162)	(1.075)
Adjusted R-squared	0.733	0.809	0.797	0.832

Restricted regression:				
ln (*I/GDP*) − ln (*n*+*g*+*δ*)	1.302*** (0.273)	0.969*** (0.238)	1.019*** (0.236)	0.885*** (0.228)
ln (*school*) − ln (*n*+*g*+*δ*)	0.947*** (0.110)	0.667*** (0.057)	1.344*** (0.115)	1.952*** (0.153)
Constant	6.805*** (0.254)	8.615*** (0.273)	8.642*** (0.276)	10.893*** (0.395)
Implied α	0.401*** (0.060)	0.368*** (0.062)	0.303*** (0.056)	0.231*** (0.052)
Implied β	0.292*** (0.043)	0.253*** (0.035)	0.400*** (0.044)	0.509*** (0.045)
Adjusted R-squared	0.722	0.801	0.800	0.816

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Author's calculations

Table 2: Estimates of the augmented Solow model for intermediate countries with different proxies for human capital (1990 – 2015)

Dep. var.: Real GDP p. c. 2015 (PPP)	(5) secondary	(6) tertiary	(7) years	(8) human
Observations	70	70	70	73
ln (*I/GDP*)	1.091*** (0.299)	0.653** (0.264)	0.988*** (0.263)	0.874*** (0.227)
ln (*n*+*g*+*δ*)	-2.752*** (0.502)	-2.294*** (0.427)	-2.174*** (0.458)	-1.425*** (0.440)
ln (*school*)	0.854*** (0.166)	0.572*** (0.072)	1.345*** (0.183)	2.520*** (0.256)
Constant	8.824*** (1.551)	11.086*** (1.101)	8.427*** (1.300)	7.787*** (1.144)
Adjusted R-squared	0.674	0.767	0.749	0.818

Restricted regression:				
ln (*I/GDP*) − ln (n+g+δ)	1.230*** (0.278)	0.862*** (0.252)	0.966*** (0.248)	0.737*** (0.236)
ln (*school*) − ln (n+g+δ)	0.972*** (0.137)	0.637*** (0.067)	1.314*** (0.140)	1.910*** (0.167)
Constant	6.934*** (0.290)	8.795*** (0.289)	8.758*** (0.288)	11.063*** (0.407)
Implied α	0.384*** (0.064)	0.345*** (0.072)	0.295*** (0.061)	0.202*** (0.058)
Implied β	0.304*** (0.049)	0.255*** (0.041)	0.401*** (0.049)	0.524*** (0.050)
Adjusted R-squared	0.671	0.755	0.752	0.797

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.
Source: Author's calculations.

4.3 Testing proxy variables over time

In the previous section we tested four different proxy variables for human capital in the Solow model, but only during the period between 1990 and 2015. In this section, we test the robustness of our findings by analyzing the estimated elasticities using different proxy variables over multiple time periods. As in the previous parts of this paper, we used the basic MRW estimates as benchmark values, and thus the assumption that the output elasticities of physical and human capital are equal to 0.3. When testing the predictions, we used the same methodology as in Section 4.1. From data ranging from 1960 – 2015, we estimated 31 regressions over 25-year periods for each of the four proxy variables for human capital. We then calculated the implied elasticities of physical and human capital α and β based on our prior estimates. To express the prediction error, we calculated the root mean squared error (RMSE), which is commonly used in the literature and is calculated as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{N}}, \qquad (3)$$

where the variable x_i denotes the predicted value (estimates of elasticities α

and β) and N is the number of observations. The term $\hat{x}_i$, by which we denote the actual value, was in our case fixed at 0.3 in all examined periods. We aggregated the calculated RMSE values so that each of the eight clusters contained estimates for four consecutive 25-year periods (for example, in the first row of Table 3 are the RMSE values for the period 1960 – 1988, which refers to the average value for the periods: 1960 – 1985, 1961 – 1986, 1962 – 1987 and 1963 – 1988). The lowest errors of the elasticity estimates for the sample of non-oil countries are marked in red and the lowest errors in the given period for the intermediate countries are marked in green. The results can be seen in Table 3.

Based on our results, we can see that the choice of the most appropriate variable depends on both the time and the sample of countries studied. If we choose to minimize the deviation of α from the value of 0.3 as the main goal, then in the case of non-oil countries, the most successful variable in the first four periods is the proportion of people with at least some sort of tertiary education. In the second half of the period, average years of schooling are the most successful proxy variable. In the case of the elasticity of human capital β, in the Non-oil sample, except for two periods, the variable with the smallest deviations is the proportion of people with at least some secondary education.

For the countries in the Intermediate sample, which does not include countries with a population of less than 1 million, the proportion of people with at least some secondary education appears to be the most successful variable for the elasticity of human capital β over the entire horizon. With the elasticity of physical capital α, the picture is similar to the sample of Non-oil countries. In the first half, the variable with the smallest deviation is the share of people with some tertiary education, and in the second half, the best variable is the average length of education.

The success of individual proxy variables depends on the criteria according to which we will evaluate them. The only variable that has not been clearly shown to be suitable for use in the Solow model is the human capital index from the Penn World Table database. However, if we choose the minimization of deviations of elasticities β from the value of 0.3 as our main criterion, the most successful variable would be the share of people with some secondary education. However, as we explained above, the use of this criterion is associated with several weaknesses. A value of 0.3 is also an estimate of MRW based only on the selected proxy variable, and the definition of human capital is not unambiguously determined. On the other hand, physical capital has a precise definition and has its place in statistical reporting. The value of the elasticity of physical capital is thus associated with a much smaller degree of uncertainty, and at the same time there is a consensus on its value, which fluctuates over time and across countries at around 0.3. Hence, we decided to evaluate the overall success of proxy variables on the basis of approaching the elasticity of physical capital to the value of 0.3. In this respect, for both non-oil and intermediate countries, it is appropriate to use the proportion of people with some tertiary education in the 1960 ─ 2000 period, and the use of the average length of school seems to be a more appropriate option when analyzing recent data.

Table 3: RMSE of output elasticities of physical and human capital from 0.3 value in different time periods

	Share of people with some secondary education				**Share of people with some tertiary education**			
	Non-oil n = 87		*Intermediate* n = 70		*Non-oil* n = 87		*Intermediate* n = 70	
period	**α**	**β**	**α**	**β**	**α**	**β**	**α**	**β**
1960 ─ 1988	0.056	<u>0.021</u>	0.040	*0.011*	<u>0.013</u>	0.060	*0.038*	0.083
1964 ─ 1992	0.065	<u>0.042</u>	0.046	*0.033*	<u>0.004</u>	0.048	*0.035*	0.070
1968 ─ 1996	0.055	0.055	0.044	*0.050*	<u>0.013</u>	<u>0.030</u>	*0.022*	0.051
1972 ─ 2000	0.026	0.043	*0.018*	*0.041*	<u>0.012</u>	<u>0.025</u>	0.031	0.046
1976 ─ 2004	0.065	<u>0.015</u>	0.065	*0.018*	0.087	0.064	0.106	0.077
1980 ─ 2008	0.115	<u>0.028</u>	0.109	*0.017*	0.120	0.079	0.133	0.090
1984 ─ 2012	0.123	<u>0.029</u>	0.108	*0.018*	0.108	0.070	0.106	0.077
1988 ─ 2015	0.091	<u>0.003</u>	0.082	*0.006*	0.066	0.046	0.056	0.050
mean	0.074	0.030	0.064	0.024	0.053	0.053	0.066	0.068

Table. 3 (continued)

	Average length of schooling				Human capital index			
	Non-oil n = 87		*Intermediate* n = 70		*Non-oil* n = 91		*Intermediate* n = 72	
period	**α**	**β**	**α**	**β**	**α**	**β**	**α**	**β**
1960 – 1988	0.100	0.093	0.070	0.062	0.175	0.256	0.182	0.231
1964 – 1992	0.126	0.131	0.085	0.095	0.209	0.296	0.207	0.270
1968 – 1996	0.134	0.160	0.096	0.123	0.227	0.327	0.232	0.310
1972 – 2000	0.101	0.150	0.070	0.119	0.215	0.328	0.229	0.322
1976 – 2004	<u>0.031</u>	0.107	*0.023*	0.089	0.141	0.272	0.149	0.266
1980 – 2008	<u>0.022</u>	0.083	*0.038*	0.068	0.066	0.207	0.072	0.202
1984 – 2012	<u>0.029</u>	0.081	*0.034*	0.074	0.046	0.188	0.067	0.195
1988 – 2015	<u>0.008</u>	0.105	*0.005*	0.099	0.075	0.213	0.096	0.222
mean	0.069	0.114	0.053	0.091	0.144	0.261	0.154	0.252

Source: Author's calculations

Based on our results, we have come to the conclusion that the extended Solow model can still explain very large differences in income between countries, even after decades. In addition to this explanatory power, the output elasticities of physical and human capital are almost identical to the predictions of MRW's extended Solow model using proxy variables: the proportion of people over the age of fifteen with at least some tertiary education and the average length of schooling. Our robustness check confirmed these conclusions, showing that the average length of school attendance appears to be a slightly better proxy variable for human capital when examining recent data.

5 Conclusion

In this paper, we tested the augmented Solow model with human capital on cross-sectional data at different times and with different proxy variables for human capital. We found that MRW predictions of output elasticities of production factors coincide with real data in the period between 1960 – 2000. In later periods, the influence of physical capital is overestimated compared to the predictions of the Solow model. We have identified an imperfect choice of a proxy variable for human capital as a possible source of overestimation of this impact. It is possible that with the increase in automation of a large number of tasks in the last two decades, the share of the secondary school population no longer captures a significant part of the human capital used in production. Subsequently, we estimated the augmented Solow model with four proxy variables for human capital for the period 1990 – 2015.We found that using the proportion of people over the age of fifteen with at least some tertiary education and the average length of schooling, our estimates are very close to the predicted values from the MRW article. These results were supported by the robustness analyses at different time periods. The share of people with tertiary education has proven to be the most appropriate variable in the analysis of more historical data, while the average length of education appears to be the best proxy variable for human capital in the analysis of recent data.

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Appendix

Table 4: Samples of countries used in the study.

Non-oil **n = 93**	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Congo, Egypt, Ethiopia, Ghana, Côte d'Ivoire, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Togo, Tunisia, Uganda, Zambia, Zimbabwe, Bangladesh, Honk Kong, India, Israel, Japan, Jordan, Republic of Korea, Malaysia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Syria, Thailand, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, Canada, Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Trinidad a Tobago, United States, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Australia, Indonesia, New Zealand, Papua New Guinea
Intermediate **n = 73**	Algeria, Botswana, Cameroon, Ethiopia, Côte d'Ivoire, Kenya, Madagascar, Malawi, Mali, Morocco, Nigeria, Senegal, South Africa, Tunisia, Zambia, Zimbabwe, Bangladesh, Hong Kong, India, Israel, Japan, Jordan, Republic of Korea, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Syria, Thailand, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, Canada, Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Trinidad and Tobago, United States, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Australia, Indonesia, New Zealand