Problem Set #7: Updating Mankiw, Romer, and Weil (1992) Using API Packages in R

In this problem set, I focus on updating the Mankiw, Romer, and Weil (MRW) paper with the most recent data. Their findings in favor of the Solow model have been enormously influential in the growth literature. The data they use covers the period 1960-1985. Hence their results from their analyses are bounded by this time range. A natural question to ask is, will these results still hold true with the updated data? MRW use the steady-state solution in the Solow model

$$k^* = \left(\frac{s}{n+g+\delta}\right)^{\frac{1}{1-\alpha}} \tag{1}$$

then plugging it to the production function and taking logs

$$ln\left(\frac{Y}{L}\right) = a + \frac{\alpha}{1-\alpha}\, ln(s) - \frac{\alpha}{1-\alpha}\, ln(n+g+\delta) + \epsilon \tag{2}$$

is their main empirical specification where Y/L is real ouput per worker, s is savings in physical capital, n is population growth, g is technological growth, and δ is depreciation. They use PWT 4.0 to measure the real output per worker in 1985 and the average saving rate in the 1960-1985 period. They obtain data on the average growth rate of the working age population, n, from World Development Indicators (WDI) from the World Bank which similarly covers the 1960-1985 period. They assume (g+δ) to be constant and equal to 0.05. I extend the period covered in MRW to 1960-2014 by using PWT 9.0.

I run the same analysis on MRW Section II with the "augmented" version of the textbook Solow model. The main empirical specification in this section is

$$ln\left(\frac{Y}{L}\right) = a + \frac{\alpha}{1-\alpha-\beta}\, ln(s_k) + \frac{\beta}{1-\alpha-\beta}\, ln(s_h) - \frac{\alpha+\beta}{1-\alpha-\beta}\, ln(n+g+\delta) + \epsilon \tag{3}$$

where s_h is human capital investment. To measure s_h, they obtain data from UNESCO and create a variable, SCHOOL, which is the multiplication of secondary school enrollment rate and fraction of the working age population that is of school age. Instead of this variable, I use the human capital index provided by PWT 9.0, which is an improved version of the human capital index proposed by Barro and Lee (2013). Lastly I check the MRW predictions on unconditional and conditional convergence by running

$$\begin{aligned} ln(y_t) - ln(y_0) \quad = \quad & a + \phi \frac{\alpha}{1-\alpha-\beta} ln(s_k) + \phi \frac{\beta}{1-\alpha-\beta} ln(s_h) \\ & - \phi \frac{\alpha+\beta}{1-\alpha-\beta} ln(n+g+\delta) - \phi \, ln(y_0) + \epsilon \end{aligned} \quad (4)$$

where $\phi = 1 - e^{-\lambda t}$ and $\lambda = (n+g+\delta)(1-\alpha-\beta)$. Once we run the model, a negative coefficient on $ln(y_0)$ with no controls would imply unconditional convergence while a negative coefficient controlling for savings and population growth would suggest conditional convergence.

Results & Discussion

Table 1 summarizes the baseline regression where the textbook Solow model is estimated. For Solow model's predictions to be consistent with data, coefficients on ln(I/GDP) and ln(n+g+δ) must be 0.5 and -0.5 respectively. First column shows the results for the non-oil countries that consists of 93 countries. We can see that the signs of the coefficients are correct as we have the coefficient on ln(I/GDP) being positive and on ln(n+g+δ) negative. However, their magnitudes are too strong. This results in an implied α that is too large, since α is empirically established to be $1/3$. For both non-oil and intermediate countries, implied α is almost twice as big as it's stylized value. Implied α for OECD countries sample performs better, yet it is 0.46, hence still bigger than $1/3$. Since the coefficients on

ln(I/GDP) and ln(n+g+δ) must be 0.5 and -0.5, we can test if our estimated coefficients are the same with opposite signs. This is done in the restricted regression. For non-oil and intermediate countries, we reject the null hypothesis that these two coefficients are same in magnitude with opposite signs. For OECD countries we do not reject this hypothesis.

Table 1: Estimation of the Textbook Solow Model

Sample:	Non-oil	Intermediate	OECD
Observations:	93	74	22
CONSTANT	-17.78^{***}	-16.13^{***}	-5.50^{*}
	(1.55)	(1.23)	(2.51)
ln(I/GDP)	1.45^{***}	1.64^{***}	0.89
	(0.21)	(0.21)	(0.64)
ln(n+g+δ)	-3.51^{***}	-2.74^{***}	0.09
	(0.64)	(0.52)	(0.85)
Adj. R^2	0.58	0.69	0.01
RMSE	0.78	0.58	0.32
Restricted regression:			
CONSTANT	-9.90^{***}	-10.36^{***}	-5.67^{**}
	(0.65)	(0.65)	(1.91)
ln(I/GDP) $-$ ln(n+g+δ)	1.94^{***}	2.15^{***}	0.86
	(0.22)	(0.21)	(0.58)
Adj. R^2	0.45	0.58	0.06
RMSE	0.89	0.68	0.31
Test of restriction:			
p-value	< 0.01	< 0.01	0.91
Implied α	0.66	0.68	0.46

Dependent variable is the log GDP per working age person in 2014. Standard errors are shown in parentheses. (g+δ) is assumed to be 0.05.

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 2 shows the results for the Augmented Solow model where human capital enters into the production function. We can see that the human capital investment is a strong predictor of real GDP, as was found in MRW. Different from their estimates, implied betas are quite larger than implied alphas. This reveals that over the past two decades, share of

Table 2: Estimation of the Augmented Solow Model

Sample:	Non-oil	Intermediate	OECD
Observations:	93	74	22
CONSTANT	-9.07^{***}	-10.44^{***}	-4.82^{*}
	(1.38)	(1.23)	(1.70)
ln(I/GDP)	0.53^{**}	0.87^{***}	0.33
	(0.17)	(0.19)	(0.45)
ln(H)	2.66^{***}	2.02^{***}	1.32^{***}
	(0.27)	(0.28)	(0.27)
ln(n+g+δ)	-0.61	-0.92	0.16
	(0.53)	(0.47)	(0.57)
Adj. R^2	0.80	0.82	0.55
RMSE	0.54	0.45	0.22
Restricted regression:			
CONSTANT	-7.57^{***}	-8.23^{***}	-5.12^{***}
	(0.43)	(0.49)	(1.29)
ln(I/GDP) $-$ ln(n+g+δ)	0.53^{**}	0.88^{***}	0.28
	(0.17)	(0.20)	(0.41)
ln(H) $-$ ln(n+g+δ)	2.83^{***}	2.32^{***}	1.32^{***}
	(0.22)	(0.24)	(0.27)
Adj. R^2	0.45	0.58	0.06
RMSE	0.54	0.46	0.21
Test of restriction:			
p-value	0.25	0.05	0.78
Implied α	0.12	0.21	0.11
Implied β	0.65	0.55	0.51

Dependent variable is the log GDP per working age person in 2014. Standard errors are shown in parentheses. (g+δ) is assumed to be 0.05.

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

human capital investment in real GDP has been increasing, even surpassing the share of

savings, compared to the 1960-1985 period. One supportive finding for the Solow model is that for all samples, test of restriction gives p-value>0.05. Thus the null hypothesis that the coefficients are same in magnitude but with opposite signs is not rejected.

Table 3 presents the results for testing unconditional convergence. We have insignificant coefficients in first two samples which reveals that over the period of 1960-2014, there has not been unconditional convergence where poor countries are catching up with the rich countries. This is in parallel to what MRW found for the years 1960-1985. Their results show unconditional convergence only for OECD countries as in Table 3. These results are very interesting as they show that there still is no significant tendency towards convergence for a sample of countries that includes almost every country in the world.

Table 3: Tests for unconditional convergence

	Non-oil	Intermediate	OECD
Observations:	89	74	22
CONSTANT	0.62	1.46	5.33^{***}
	(0.66)	(0.77)	(0.93)
ln(Y60)	0.03	-0.06	-0.42^{***}
	(0.08)	(0.09)	(0.09)
Adj. R^2	-0.01	-0.01	0.48
RMSE	0.68	0.65	0.19

Dependent variable is the log difference GDP per working age person 1960-2014.
Standard errors are shown in parentheses. Y60 is GDP per working age person in 1960.
$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 4 shows the findings for testing conditional convergence. Here, we still see conditional convergence for every sample. This is also very interesting as MRW find similar results for the years 1960-1985. These findings show that if there was no variation throughout countries in terms of savings and population growth, then the poor countries would catch up with rich countries.

Table 4: Tests for conditional convergence

	Non-oil	Intermediate	OECD
Observations:	89	74	22
CONSTANT	-3.17^{**}	-2.25^{*}	2.34
	(1.17)	(0.98)	(1.73)
ln(Y60)	-0.32^{***}	-0.47^{***}	-0.42^{***}
	(0.09)	(0.08)	(0.09)
ln(I/GDP)	0.94^{***}	1.22^{***}	0.41
	(0.20)	(0.18)	(0.38)
ln(n+g+δ)	-1.54^{**}	-1.41^{**}	-0.56
	(0.54)	(0.46)	(0.50)
Adj. R^2	0.28	0.48	0.53
RMSE	0.58	0.46	0.18

Dependent variable is the log difference GDP per working age person 1960-2014.
Standard errors are shown in parentheses. Y60 is GDP per working age person in 1960.
$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 5 summarizes the tests for unconditional convergence controlling for human capital investment. We see that the convergence gets even stronger holding human capital constant along with other explanatory variables. This is also not unexpected as human capital indeed has some explanatory power over growth hence controlling for it would unravel the convergence effect even further.

Figure 1 shows the relationship between log savings and income. We can see that there is positive association even when considering the GDP size of each country. The association seems to be even too strong, hence we get very large implied alphas in the first set of regressions for the textbook Solow model. The importance of savings on income is most likely over-estimated. Figure 2 presents the relationship between income in 1960 and growth rate for the period 1960-2014, first not controlling for any variables, then controlling for savings rate and population growth and finally human capital investment. We can see that the negative association, which implies convergence, gets more clear as we control for savings, population growth and human capital investment.

Table 5: Tests for conditional convergence with human capital

	Non-oil	Intermediate	OECD
Observations:	89	74	22
CONSTANT	2.85^{*}	1.60	3.89
	(1.38)	(1.25)	(2.34)
ln(Y60)	-0.71^{***}	-0.69^{***}	-0.55^{**}
	(0.10)	(0.09)	(0.16)
ln(I/GDP)	0.53^{**}	0.87^{***}	0.35
	(0.18)	(0.18)	(0.38)
ln(H)	2.04^{***}	1.38^{***}	0.40
	(0.33)	(0.32)	(0.41)
ln(n+g+δ)	-0.50	-0.72	-0.40
	(0.48)	(0.44)	(0.53)
Adj. R^2	0.50	0.59	0.53
RMSE	0.48	0.42	0.18

Dependent variable is the log difference GDP per working age person 1960-2014.
Standard errors are shown in parentheses. Y60 is GDP per working age person in 1960.
$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Overall, results are not so different than MRW estimates. Textbook Solow model performs poorly with the updated data while the results are improved with the Augmented Solow model. The results show that between 1985-2014, the share of human capital in real gdp has increased relative to other factors of production. There is still no unconditional convergence, however there indeed is conditional convergence for almost all countries in the world. This shows that savings, population growth, and human capital investment differences throughout countries in the world might explain why we observe different growth rates empirically. In other words, because countries have different levels of factors of production and population growth rates, they converge to different steady states, yet if they are below steady state, their growth rates are more positive compared to the case where they are above steady state. Lastly, human capital has become even more influential in explaining the income differences throughout countries relative to the period 1960-1985.

Figure 1: Scatterplot of Log Savings and Income by GDP size (trillion $)

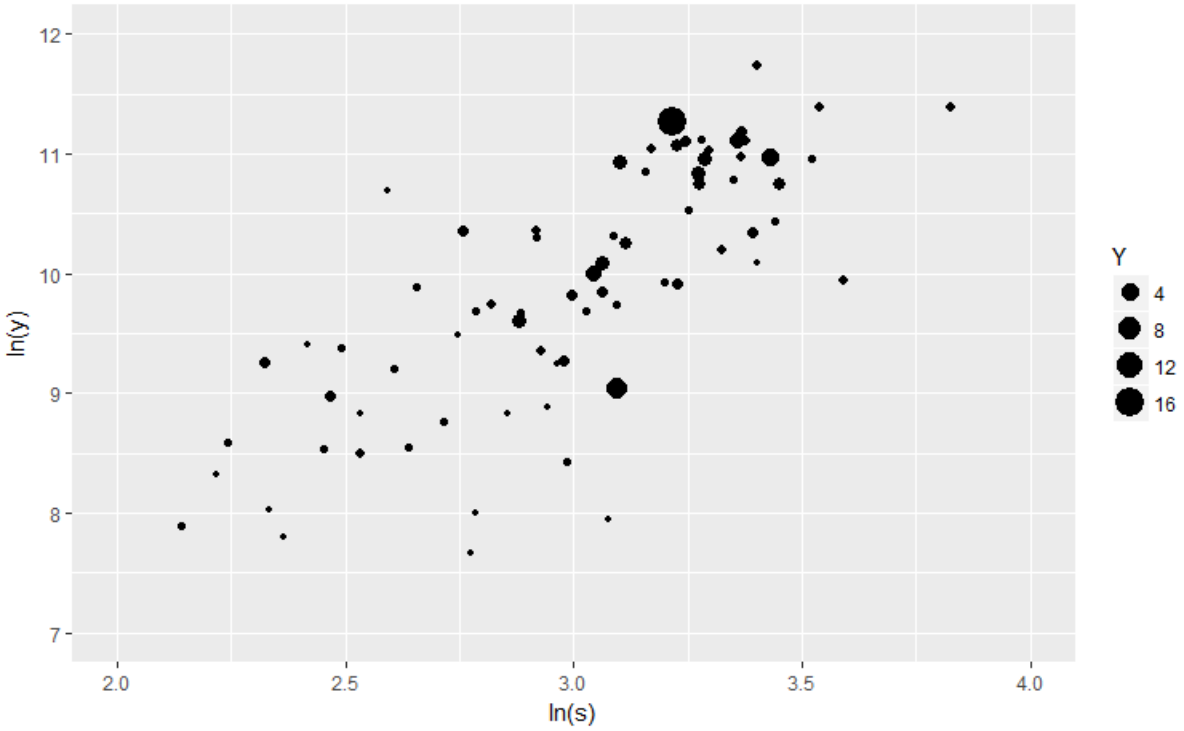

Figure 2: Scatterplots for convergence