Effects of the Level and Structure of Taxes on Long-Run Economic Growth: What Can We Learn from Panel Time-Series Techniques?

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We estimate how the level and structure of taxes affect long run economic growth, using a panel of 79 countries from 1980 through 2010. First, we replicate and extend the cross-country panel study of Lee and Gordon (2005), which attempts to distinguish short-run from long-run effects of taxes on growth by collapsing the data into a series of successive five-year averages. This exercise confirms Lee and Gordon's finding of a significant negative relationship between the statutory corporate tax rates and growth in real GDP per person. Second, we estimate a similar model using panel time series techniques, including unit root and cointegration tests, while explaining and comparing these tests to other methods. Based on these panel time series tests, which surmount significant methodological shortcomings in the previous literature, we fail to detect evidence of a significant long run equilibrium relationship between the level or structure of taxes, and the growth in or the level of real GDP per person. This suggests that findings in the previous literature about the association between taxes and growth may be more about short-run co-movement of taxes and GDP over the business cycle, where temporarily low taxes are associated with GDP returning to its long-run trend more quickly, as opposed to permanent changes in taxes affecting the long-run trend of GDP per person.

KEYWORDS: Tax structure, Economic growth, Time series tests, Cointegration, Tax Policy, Cross-country regressions

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Introduction

In this paper, we investigate the effect of the level and structure of taxes on the long run rate of economic growth. First, we first replicate and extend the cross-country panel study of Lee and Gordon (2005), which attempts to distinguish short-run from long-run effects of taxes on growth by collapsing the data into a series of successive five-year averages. Next, we study the relationship between taxes and the level and growth of real GDP per person in the same data using panel time series techniques, including panel unit root tests and panel cointegration techniques. While our extension of Lee and Gordon's methodology corroborates their finding of a statistically and economically significant negative effect of statutory corporate tax rates on growth of real GDP per capita, the panel time series estimates suggest no evidence of a long-run equilibrium relationship between taxes and the growth or level of real GDP per capita. This suggests that findings in the previous literature about the association between taxes and growth may be more about short-run co-movement of taxes and GDP over the business cycle, where temporarily low taxes are associated with GDP returning to its long-run trend more quickly, as opposed to permanent changes in taxes affecting the long-term trend of GDP per person.

Theory on the Relationship between Taxes and Growth

The relation between taxation and growth is well understood in short run theoretical models: taxation distorts decisions, creates misallocations of resources, and results in deadweight loss to the economy. The effects of taxation in the long run are less certain. The neoclassical Solow-Swan growth model predicts that taxation (and government policy as a whole) plays no role in determining the steady state growth rate in the long run, though it may have short run effects on the growth rate, and long run effects on the *level* of real GDP per person, as the economy transitions to the steady state equilibrium. Economists later developed theories which suggest that taxation may, in fact, influence the rate of technological progress – for example, it might influence the incentive to innovate or become an entrepreneur. Alternatively, government expenditures financed through taxation such as investments in education or basic science could also affect the long run growth rate[1]. Thus it is conceivable that taxation could have either positive or negative long run growth effects unconditional on government spending.

Lee and Gordon (2005)

Our first step is to replicate and extend Lee and Gordon's 2005 study, "Tax Structure and Economic Growth." Lee and Gordon (henceforth "LG") investigate the effects of tax structure on economic growth. Specifically, they test the effects of the corporate tax rate and the personal tax rate on growth while controlling for various other determinants of growth and employing several strategies to account for problems of omitted variable bias and endogeneity. We focus here on their relatively more convincing panel regressions.

LG use panel data but collapse the growth data into three five-year periods and one three-year period: 1980-1984, 1985-1989, 1990-1994, and 1995-1997. For each period, the dependent variable is the annualized growth rate of real GDP per capita and the main explanatory variable is the corporate tax rate in the initial year of each period. For example, for the first period, the dependent variable is the growth rate from 1980 to 1984 and the key explanatory variable of interest is the corporate tax rate in 1980. Thus, each panel regression has four constituent time periods covering a total of 18 years (inclusive). All of the regressions in the panel data set use the same set of control variables: an average composite of the International Country Risk Guide

[1] E.g. Robert Lucas' model of human capital accumulation.

(ICRG)'s measures of corruption and bureaucratic quality over the period, GDP per capita in the initial year of each period, average trade openness over each period as measured by the Sachs and Warner index, the annual population growth rate over each period, primary school enrollment in the initial year of each period, and the annual rate of inflation over each period. In an OLS regression controlling for country fixed effects but not year fixed effects, they find that the coefficient on the corporate tax rate is -0.082, which implies that that a ten percentage point decrease in the statutory corporate tax rate is associated with a 0.82 percentage point increase in the annual growth rate. This coefficient is significant at the 1% level. LG also estimate a specification with country fixed effects where they instrument for statutory corporate and personal income tax rates with an inverse-of-distance weighted average tax rates in other countries, and find an even larger negative effect of corporate tax rates, implying a ten percentage point increase in the statutory corporate tax rate is associated with a 1.82 percentage point decline in the growth rate of real GDP per person; their estimated coefficient on the statutory personal tax rate is just 0.001 and statistically insignificant.

The LG analysis raises a number of questions. One is whether their instrumental variables are valid. There are many reasons to use an IV in this context, including omitted variable bias, measurement error, and reverse causality. The last of these, reverse causality, is particularly germane to LG's investigation as there a number of plausible explanations which draw a causal link from growth to tax rates. As LG suggest, countries with higher growth rates may raise tax rates to finance new infrastructure investment or expenditures. Alternatively, if a country is suffering a low economic growth rate due to a scarcity of foreign investment or a recession, that might cause it to decide to reduce its corporate tax rates in a bid to attract international firms, or as a Keynesian stimulus. LG used the inverse-of-distance-weighted average of corporate and personal tax rates in other countries as instruments for own-country corporate and personal tax rates to try and remove the endogenous variation in those tax rates, and show that the IV is strongly positively correlated with own country tax rate. One potential problem with this is that economic growth is spatially correlated – negative economic shocks in neighboring countries tend to be correlated with each other, and this may feed back into the neighboring countries' tax rates, in which case the IV would not solve the reverse causality problems, although it might at least reduce them. Another problem is that the exclusion restriction may be invalid. A reduction in a neighboring country's tax rate may affect own country economic growth directly. The bias from that could go either way. For example, if a reduction in neighboring country corporate tax rate attracts capital away from own country, that induces a positive correlation between neighboring country tax rate and own country growth. However, in Lee and Gordon's paper, the coefficient on the corporate tax rate becomes more negative when they move from OLS to IV. On the other hand, if a reduction in a neighboring country's corporate tax rate has a positive short-run effect on economic growth through an aggregate demand channel, that might help boost economic growth in own country because the neighboring country is an important trading partner. That would induce a spurious negative correlation between corporate tax rate and growth in the IV specification that has nothing to do with the long-run effects of corporate tax rate on growth.

Another question is raised by the fact that LG do not control for year fixed effects in any of their regressions. As a result, they are not controlling for any unobserved variables whose effect on growth varies across time but not across countries. In their sample period, statutory corporate tax rates are on average are experiencing a secular downward trend, so global shocks to oil prices, financial crises, or long-term secular trends in global economic performance that could be coincidentally correlated with changes in statutory tax rates could be creating a spurious relationship between corporate taxes and growth, and controlling for year fixed effects would help control for that.

A third question raised by LG's methodology is that it is unclear whether collapsing the data into successive five-year averages does enough to distinguish short-run co-movement of taxes and growth over the business cycle from the effects of permanent changes in tax rates on long-run growth. While collapsing the data into 5-year averages probably helps remove *some* of the business cycle effects, there's no guarantee that this is going to purge the estimates entirely of short-run business cycle effects. For example, if the beginning of a five-year period happens to coincide with the bottom of a recession and a corporate tax rate cut that was enacted in response, the rapid recovery from the recession that typically ensues, due to putting unused capacity back to work, will contribute to a large negative estimated effect of corporate tax rates on growth, but that coefficient might actually tell us nothing at all about the effects of the corporate tax rate on the long run trend or rate of growth of GDP per person. Collapsing the data into 5-year averages also sacrifices useful information about the exact timing of changes in tax rates, GDP per person, and control variables and how they relate to each other. One of our main contributions is to use panel unit root and cointegration tests that are much better suited to uncovering long-run equilibrium relationships in the data.

Lastly, it is important to note that a majority of LG's specifications do not actually investigate the effect of the tax structure on growth, but rather the effect of the *corporate tax rate* on growth unconditional on most other aspects of the tax system or the size of government.[2] This

[2] The one exception is in their set of "cross-sectional" regressions, where they estimate the effect of corporate tax rates circa 1980 on the growth rate in real GDP per person from 1970 to 1995, while controlling for a measure of overall government size. In that case, they've collapsed the data into a single long-run average growth rate and

is important because their panel specifications do not control for the size of government expenditure or the overall tax level. Therefore they do not disentangle effect of the tax structure on growth from the effect of the overall size of government on growth. We might expect the corporate tax rate to be positively correlated with either overall government revenues or expenditures, while increases in either revenue or expenditure could drive growth rates down. Thus, it is at least possible LG's results may reflect a spuriously significant negative correlation between the corporate tax rate and growth when, in fact, the real driver of growth may be an unobserved third variable, government size, which happens to be correlated with the corporate tax rate.

Lee and Gordon's paper is groundbreaking but leaves room for improvement. Comparing LG's results to economic theory and setting aside methodological issues, they support the prediction from endogenous growth theory that higher corporate tax rates have a negative effect on economic growth. The findings from the panel regression with fixed effects but without instrumental variables, the most convincing of LG's specifications, suggest that lowering the corporate tax rate by 10 percentage points would boost the growth rate of GDP per capita by 0.82 percentage points each year – an economically significant result. For example, if we assume that the growth rate of real GDP per capita would otherwise have been 1.7% a year, which was the average in the sample, a ten percentage point cut in the corporate tax rate would cause real GDP per person to be 17.4 percent larger after 20 years than it would have been in the absence of the tax cut. However, the problems discussed above raise questions about the reliability of such an

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cannot control for country fixed effects, which opens up more opportunities for omitted variable bias. In that specification, they do find that the negative effect of the statutory corporate tax rate on growth persists when they control for measures of overall government size. They find no effect of overall government size on growth, but they control for multiple highly collinear measures of government size at the same time, so that the regression is not informative about how the overall size of government affects growth.

inference. In particular, it is unclear whether we can really extrapolate from the correlation between corporate tax rates and relative changes in growth rates across five-year periods to learn the effect of persistent changes in corporate tax rates on long-run economic growth. In the next section, we replicate and extend LG's methodology and test the sensitivity of the estimates to addressing some of the problems mentioned above, and then in the following section we switch to using panel time-series techniques which are more appropriate for uncovering long-run equilibrium relationships in the data.

Replication and Extension of Lee and Gordon

Data

For our replication and extension of LG, we assemble panel data on 79 countries from the years 1980 through 2010, extending the period of analysis from the 17 years used in LG to 31 years.[3] To roughly match their approach for smoothing out business-cycle fluctuations, we initially divide our data into six time periods, composed of five five-year periods and one six-year period: 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, and 2005-2010. Table 1 lists the variables used in our analysis and the sources for each. In some rare cases, there were small gaps in the time series for certain variables which we filled in with linear interpolation; variables where we did this are marked with an asterisk in Table 1. For a more detailed discussion of how we constructed the data, including the full list of countries we used in the panel, please refer to the Web Appendix (also included at the end of this document).

[3] LG only named 70 of the 77 countries they used in their panel analysis in their paper. We used those 70 countries plus 9 other countries for which data was available for much or all of 1980 through 2010.

Table 1: Variables and Sources for Lee and Gordon – Panel Replication and Update

Variable	Sources	Years Available	Mean	Minimum	Maximum
Top Statutory Corporate Tax Rate, Central Government*	OTPR's World Tax Database Pricewaterhouse Coopers USAID KPMG Ernst & Young	1980-2002 2003-2004 2004, 2007-10 2005-07, 2009-10 2006-2006	34.7	0	75
Top Statutory Personal Tax Rate, Central Government*	OTPR's World Tax Database Peter *et al* Pricewaterhouse Coopers USAID's KPMG	1980-1999 1981-2005 2003 2004, 2007-10 2005-2010	38.1	0	85
GDP per capita (constant 2000 US$)	World Development Indicators (WDI) Penn World Tables	1980-2010 1980-2010	12910	82	136248
Inflation (GDP Deflator measure)	WDI	1980-2010	125.2	0	4976
Population (growth rate)	WDI	1980-2010	1.78	-0.79	16.45
ICRG Index (average)	ICRG	1984-2010	2.86	0	5
Trade Openness Index*	Sachs and Warner Index Wacziarg and Welch Index	1980-1992 1980-2001	0.48	0	1
Absence of Trade Restrictions Index	KOF Index	1980-2010	56.7	9.3	98.3
Primary School Enrollment*	WDI	1980-2009	101	43.3	161.9
Average years of schooling	Barro and Lee	1980-2005	6.8	1.0	13.27
Government Total Revenue (% of GDP)[+]	OECD Tax Statistics and Mauro *et al* (2013)	1980-2010	27.2	3.6	52.2
General government consumption expenditure (% of GDP)	WDI	1980-2010	15.8	2.0	76.2

*Data for this variable involved some linear interpolation or extrapolation to fill in gaps.
+ This variable represents general government tax revenue as a percentage of GDP for most countries, but we use general government revenue or central government revenue as a percentage of GDP for a few countries where general government tax revenue data was not available. We use a consistent measure (either general government or central government) in all years for any given country.

Estimates

Table 2 shows estimates from our replication and extension of Lee and Gordon. First, we attempt to approximately replicate LG's OLS fixed effects panel specification from column (4) of Table 4 of their paper, using data from the same sample period (1980 through 1997) as they used. We then make a series of changes to either the covariates, the data, or the specification, showing the effect of each change *ceteris paribus*.

As shown in column 1 of table 2, like LG, we find an economically and statistically significant negative coefficient on the top statutory corporate tax rate – though our estimate is slightly smaller in magnitude (-0.078 as opposed to -0.082). The small difference is probably attributable to small differences in the data used, including the fact that we are using a more recent series of revised GDP data, and a different inflation measure (if LG used CPI as opposed to GDP deflator), and a slightly different set of countries (we use 79 countries whereas they use 77, and we only know for sure that 70 of these countries are in both data sets because they did not name their other 7). Because of the 2 extra countries and the fact that we were able to collect data on the full set of variables for a somewhat larger number of years during 1980-1997 than they were, our specification (1) in table 2 has larger sample than LG did (306 observations as opposed to 270). In column (2), we add year fixed effects to the specification, to control for any unobserved influences on growth that are changing in the same way over time in different countries. This reduces the magnitude of the corporate tax rate's coefficient to -0.055, statistically significant at the 10% level. Switching to robust clustered standard errors, with clustering by country, in column (3), does not change the statistical significance of the corporate tax rate's coefficient.

The rest of the specifications discussed in this section all use robust clustered standard errors. In column (4), we switch from using the indices of trade openness that LG used, which were from

Table 2: Replication and Extension of Lee and Gordon

VARIABLES	(1) LG Baseline	(2) Add Year Effects	(3) Clustered Standard Errors	(4) Replace Trade Variable	(5) Extend to 2010	(6) Add PIT Rate	(7) Replace Education Variable
Corporate Top Tax Rate+	-0.0776***	-0.0545*	-0.0545*	-0.0599*	-0.0564***	-0.0545**	-0.0543**
	(0.0287)	(0.0300)	(0.0289)	(0.0303)	(0.0203)	(0.0208)	(0.0206)
Personal Top Tax Rate+						-0.00899	-0.00940
						(0.0128)	(0.0129)
Log of initial GDP per capita	-4.359***	-5.413***	-5.413***	-5.890***	-5.614***	-5.656***	-5.625***
	(0.909)	(0.989)	(1.611)	(1.514)	(1.089)	(1.130)	(1.143)
Primary School enrollment (WDI)+	0.000618	-0.00853	-0.00853	-0.00649	0.0117	0.0116	
	(0.0182)	(0.0178)	(0.0251)	(0.0261)	(0.0154)	(0.0152)	
Average years of schooling (BL)							-0.103
							(0.202)
Average openness (SW/WW)+	2.426***	1.724***	1.724**				
	(0.584)	(0.650)	(0.788)				
KOF absence of trade restrictions				0.0412	0.0810***	0.0790***	0.0776***
				(0.0318)	(0.0181)	(0.0186)	(0.0188)
Average ICRG Index	0.380	0.221	0.221	0.509	0.354	0.339	0.342
	(0.420)	(0.411)	(0.474)	(0.498)	(0.260)	(0.255)	(0.260)
Average population Growth	-0.612**	-0.293	-0.293	0.0251	-0.237	-0.239	-0.245
	(0.285)	(0.300)	(0.371)	(0.354)	(0.286)	(0.285)	(0.282)
Average inflation (GDP deflator)	-0.0022***	-0.0024***	-0.0024***	-0.0025***	-0.002***	-0.002***	-0.0021***
	(0.00058)	(0.00057)	(0.0003)	(0.00032)	(0.00021)	(0.00021)	(0.00021)
Years included	1980-1997	1980-1997	1980-1997	1980-1997	1980-2010	1980-2010	1980-2010
Fixed Effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects?	No	Yes	Yes	Yes	Yes	Yes	Yes
Observations	306	306	306	294	443	443	443
R-squared	0.308	0.359	0.359	0.325	0.348	0.349	0.347
Number of countries	78	78	78	75	76	76	76

+ Data for this variable involved some linear interpolation to fill in gaps (by country, by five-year period)
Standard errors in parentheses (columns 3 through 7 use robust clustered standard errors).
*** p<0.01, ** p<0.05, * p<0.10

Sachs and Warner and Wacziarg and Welch but which have not been updated in recent years, to a KOF absence of trade restrictions index (where a higher number means fewer trade restrictions). In this specification, the corporate tax rate's effect remains statistically significant with a coefficient of -0.060 and is statistically significant at the 10% level.[4]

In column (5), we expand the sample size to include 13 additional years (holding all other aspects of the specification constant) so that the time period now spans 1980 to 2010. This change makes the estimated effect of the corporate tax rate more statistically significant, which could be because number of observations increased from 306 to 443 and so the standard errors correspondingly decreased. In column (6), we add the personal tax rate as a covariate; this has a negligible effect on the estimate of the corporate tax rate, while, much like in LG's estimates, the personal tax rate itself has a statistically and economically insignificant coefficient. Nevertheless, we maintain the personal tax rate as a covariate for the remainder of the specifications. Column (7) introduces Barro and Lee's average years of schooling variable as a substitute for WDI's primary school enrollment variable, since it makes more sense that average years of schooling in the adult population would affect economic growth, compared to primary school enrollment. This change has a negligible effect on the other estimates.

In order to maximize comparability between the specifications that replicate and extend Lee and Gordon, and the specifications using panel time series techniques that are presented later in the paper, we use as many of the same covariates in both approaches as possible. However, for reasons explained later, the panel time series techniques require continuous time series on each variable. Moreover, using interpolation or extrapolation to fill in missing values can be problematic in either approach. Two of the covariates used in this section would require

[4] Note that the number of countries went down by three due to the inclusion of the KOF Index since it is missing data for three countries in the sample.

especially large amounts of interpolation and extrapolation if we wanted to include them in the panel time series specifications: the ICRG Index (its time series starts in 1984 and was extrapolated back to 1980 in the LG regressions and our replication) and the Barro and Lee education variable (only available at five-year intervals). Thus, here we experiment with removing either and then both of these covariates from the panel regression, in order to test whether the Lee and Gordon style estimates are sensitive to inclusion or exclusion of these variables. As shown in Table A6 of the Web Appendix, these changes have little effect on the coefficients for the corporate or personal tax rates. As a result, we exclude these covariates for the remainder of the regressions in this section.[5]

As discussed earlier, LG failed to control for one of the most important sources of omitted variable bias: overall government size. We correct for this in separate specifications by including, in each one, a different measure of government size: first, a measure of government revenue as a percentage of GDP, and second a measure of government consumption expenditure. In Table 3 below, we first include a baseline estimation without any government size variables. Because the government revenue variable has a smaller sample size of only 50 countries, column (2) includes only those observations which have data for the government revenue variable; this will give us a better sense of the *ceteris paribus* impact of controlling for government revenue. Reducing the sample to 50 countries causes the coefficient on the corporate tax rate to become slightly smaller in absolute value, at around -0.04, while remaining statistically significant at the 10 percent level. The smaller sample also causes the coefficient on the personal tax rate to become a small but statistically significant positive 0.03. When we do add the control for government revenue as a percentage of GDP in column (3), we see that it has a negligible impact on the coefficient either tax rate relative to column (2).

[5] Note that column 1 of table A6 is identical to column 6 of table 2 in this paper for ease of comparability.

Table 3: Lee and Gordon Panel Regressions Update, 1980-2010
With Government Size Controls

VARIABLES	(1) Baseline	(2) Remove countries missing revenue variable	(3) Add government revenue variable	(4) Replace gov't revenue with gov't consumption
Corporate Top Tax rate+	-0.0520**	-0.0396*	-0.0393*	-0.0365*
	(0.0209)	(0.0210)	(0.0219)	(0.0208)
Personal Top Tax rate+	-0.0106	0.0282*	0.0281*	-0.0106
	(0.0129)	(0.0159)	(0.0157)	(0.0130)
Log of GDP per capita	-5.657***	-5.441***	-5.456***	-5.423***
	(1.109)	(1.595)	(1.553)	(1.147)
KOF absence of trade restrictions	0.0839***	0.0649***	0.0650***	0.0803***
	(0.0200)	(0.0170)	(0.0173)	(0.0199)
Average population growth	-0.238	-0.801**	-0.800**	-0.127
	(0.293)	(0.397)	(0.397)	(0.381)
Average inflation (GDP deflator)	-0.00207***	-0.000569	-0.000574	-0.00197***
	(0.000216)	(0.00106)	(0.00106)	(0.000254)
Government Revenue+			-0.00185	
(% of GDP)			(0.0336)	
Government Consumption				-0.0393
(% of GDP)				(0.0314)
Constant	44.83***	46.31***	46.97***	43.09***
	(9.498)	(14.11)	(13.77)	(9.749)
Fixed Effects?	Yes	Yes	Yes	Yes
Year Effects?	Yes	Yes	Yes	Yes
Observations	443	268	268	430
R-squared	0.344	0.342	0.342	0.324
Number of countries	76	50	50	75

+ Some linear interpolation was used to fill in gaps for this variable.
Robust clustered standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.10

In column (4), when we use government consumption expenditure as a control, the corporate tax rate diminishes in magnitude and statistical significance (though it is still significant at the 10% level). Meanwhile, the personal tax rate's coefficient stayed negative and statistically insignificant.

The main finding from the replication, update, and extension of Lee and Gordon's paper is that the corporate tax rate has an economically and statistically significant negative association with the economic growth rate that is fairly robust to adding many additional years of data and making various changes and improvements to the specification. The estimated effect of the corporate tax rate does become a bit smaller relative to what Lee and Gordon found, with the addition of year fixed effects, and this is mostly due the inclusion of year fixed effects and controlling for government consumption expenditure. Also, throughout almost all of these specifications, the coefficient on the personal tax rate either remained economically and statistically insignificant, or switched to having a counter-intuitive positive (but small) and statistically significant effect. The most important finding from this section was that, by making reasonable changes to the basic OLS framework used by Lee and Gordon, it is difficult to disprove the connection (though not necessarily causal link) between the corporate tax rate and growth, even after controlling for measures government size and year fixed effects. The next section will discuss more sophisticated methods to determine if a long run equilibrium relationship exists between economic growth and tax structure; we can then compare the results of these alternative methods to Lee and Gordon's findings that tax structure plays a key role in shaping growth.

Literature Review: Recent Research Using Panel Time Series Techniques

Time series econometrics has developed powerful tools for investigating long run relationships in data. Several papers on the effects of tax structure on economic growth in recent years have used a technique called an "error correction model." This technique is closely related to the panel cointegration techniques which we use later in the paper, and so before we discuss these papers, we will outline the theories underlying both of these techniques – specifically, stationarity and cointegration.

Stationarity

Stationarity is one of the key concepts in time series econometrics. Briefly, a variable is stationary if it is mean-reverting in the long run; shocks to the variable may disturb it in the short run, but in the long run, there is some equilibrium value to which it will return. To be more precise, a stationary variable has both a constant mean and variance over time. If a variable is nonstationary, then it is not mean-reverting in the long run and shocks to the variable can disturb it from its previous level in a permanent way. If, by differencing a nonstationary variable, we obtain a stationary process, then we refer to the original variable as having a “unit root.”

For the LG approach to estimating “long-run” effects of policy variables on growth rates to make sense, the growth rate would have to be non-stationary. Whereas a stationary variable’s long run value cannot change in response to shocks (such as a shock to the corporate tax rate), a nonstationary variable can have persistent, long run effects from shocks; therefore, LG implicitly assume that the growth rate of GDP per capita is a nonstationary variable whose long run value is altered by shocks from the corporate tax rate. We will test this assumption in the next section using a panel unit root test.

Cointegration

Assume that we have two variables, y_t and x_t, where both variables are nonstationary and integrated of order one, meaning that if we first-difference the variable it becomes stationary.[6] Using conventional time series notation, this is denoted as:

[6] Note that this is equivalent to stating that both variables are unit root processes.

$$y_t \sim I(1), \;\; x_t \sim I(1) \tag{1}$$

Where I(1) denotes "integrated of order one."

The best approach for uncovering long-run equilibrium relationships in time-series data is to work with non-stationary variables and test them for "cointegration." Suppose we can write the relationship between two variables y_t and x_t as follows:

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon_t \tag{2}$$

Where β_0 is the intercept of the linear equation, β_1 is the coefficient on x_t. The variables y_t and x_t in equation (2) are *cointegrated* if they are each non-stationary and integrated of order one, *and* most importantly if ε_t is stationary (i.e., mean-reverting in the long-run). In that case, we can interpret β_1 as the long-run equilibrium relationship between x_t and y_t such that a permanent one unit increase in x_t leads in the long run to a β_1 unit increase in y_t. If these conditions are all true, it means that x_t and y_t tend to "move together" in a long-run sense. When x_t and y_t are cointegrated, shocks to ε_t can cause x_t and y_t to move away from their long-run equilibrium relationship temporarily, but if ε_t is stationary, that means that x_t and y_t gradually adjust over time to restore that long-run equilibrium relationship. If statistical tests fail to reject the null-hypothesis that ε_t is non-stationary, then the two series are not cointegrated. That suggests either that the apparent relationship between x_t and y_t is spurious, or that there is some other non-stationary variable that we have not taken into account that is causing them to diverge permanently from their long-run equilibrium relationship. If we could identify and measure that other variable, we could solve the problem by adding it as a second *X* variable to the equation that we use to test for cointegration. The logic of a test for cointegration carries over in a relatively straightforward fashion to panel data as well, and can also be extended to allow for other non-stationary variables in the cointegrating relationship, country-specific fixed effects and time trends, and year fixed effects.[7]

Single Equation Error Correction Models

Much of the recent literature investigating how tax structure affects economic growth uses what is known as an Error Correction Model (ECM) to test the link between tax structure and growth. ECMs constitute a class of techniques used in time series econometrics to model and explore the movement and behavior of multiple variables, and to determine or not these variables share a long run relationship. This approach was developed for use with nonstationary cointegrated variables, but in the literature on how taxes affect growth it has been applied to non-stationary data, which is controversial because it infers the "long-run" effect of one variable on another by extrapolating it from the relationship between variables that are stationary, and thus do not actually exhibit any long-run changes.

The single-equation ECM uses a restatement of this relationship to estimate the long run relationship of two variables. Using lags of y_t and x_t (y_{t-1} and x_{t-1} respectively) and rearranging terms, we can re-write equation (2) into a form which allows us to estimate the long run effect of x_t on y_t:

$$\Delta y_t = y_t - y_{t-1} = \alpha + \theta_0 * \Delta x_t - \theta_1 * (y_{t-1} - \theta_2 * x_{t-1}) + \epsilon_t \qquad (3)$$

The term within parentheses represents the error-correction component and θ_2 represents the long run effect of x_t on y_t. If there is a long run relationship between y_t and x_t, then the coefficient on the error-correction term, θ_1, will be between -1 and 0.

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[7] For further information on cointegration, see a time series econometrics textbook such as Enders (2009).

Recent Literature

Arnold *et al* (2011), Xing (2012), Acosta-Ormaechea and Yoo (2012), Gemmell, Kneller, and Sanz (2011 and 2015) all use a version of the single-equation ECM developed by Pesaran *et al* (1999) called the Pooled Mean-Group (PMG) Estimator. This essentially applies the methodology of a single equation ECM to a panel. Arnold *et al*, using a dataset of 21 OECD countries from 1971 through 2004, find that lowering the corporate (and to a lesser extent, the personal) income tax and replacing the lost revenue with an equivalent amount of consumption or property taxes would significantly augment growth. Xing, using similar data, finds that Arnold *et al*'s results are not robust to reasonable changes in the specifications, such as including different covariates or deterministic controls or controlling for cross-sectional dependence. Finally, Acosta-Ormaechea and Yoo also use the PMG Estimator but with an expanded dataset of 69 countries from 1970 through 2009. Their results support Arnold *et al*'s findings that increasing income taxes while reducing consumption and property taxes leads to slower growth. But within income taxes, they find that personal income taxes are more harmful to growth than corporate income taxes. Both papers by Gemmell, Kneller, and Sanz find that an increase in income taxes, holding government revenue and expenditure as a percentage of GDP constant, has a negative effect on the growth rate of real GDP per capita.

One concern with all of these papers is that they tend to use data from time periods and sets of countries where both the growth rate in real GDP per person and tax rates are stationary (this is true in both Gemmell, Kneller, and Sanz studies, for example). In such data, there are no permanent changes in either tax rates or growth rates – rather, changes in both variables tend to reverse themselves over time. Attempting to estimate a "long-run" effect of taxes on growth rates in such data necessarily involves a great deal of extrapolation that may not be externally valid.

We cannot necessarily infer what the long-run effect on economic growth of a permanent change in tax rates would be from data where there are no permanent changes in either economic growth rates or tax rates.

A second problem is that the PMG Estimator, like all single equation ECM's, makes a critical assumption which casts doubt on the validity of the results: they assume weak exogeneity (Pesaran *et al* 1999). If we were *a priori* confident that causality ran from tax rates to growth or income, then this would not be a problem; however, there is reason to believe, based on theory, that growth may also affect tax rates in the long run. For example, Wagner's Law proposes that demand for government services has an income elasticity greater than one, so that rich countries demand proportionally more government services (and presumably face higher tax rates) than poor countries (Slemrod *et al* 1995). So the assumption of weak exogeneity may be invalid – and if that is the case, then the PMG Estimator yields inconsistent estimation of parameters. Thus the significant relationships found by Arnold *et al* could well reflect causality flowing from growth rates to tax rates. Acosta-Ormaechea and Yoo account for endogeneity by performing checks for endogeneity between growth and taxes on each country and then excluding from their sample countries where such endogeneity might be present. Though their results are robust to these exclusions, it would be preferable to use a method where we do not have to make such a strong assumption in the first place. The estimates derived from the panel cointegration techniques we describe in the next section are robust to endogeneity, in the sense of providing a consistent estimate of the long-run equilibrium relationship between two variables in the presence of cointergration. This does not necessarily settle the direction of causality, but it does at least consistently estimate the (possibly bi-directional) long-run equilibrium relationship, and the single equation error correction approach does not even do that if there is endogeneity.

Panel Time Series Tests

Cointegration tests, like ECM tests, constitute a class of powerful time series tests. However, the latter are robust to many of the statistical problems that prevent accurate estimation of long run relationships. Some cointegration tests have been adapted for panel settings. We will first explain the details of two such tests, the Im, Pesaran, and Shin Panel Unit Root Test and the Group Mean Parametric Residual Based Test, and then apply these tests to the tax variables described above in order to uncover any long run relationships in the data between tax structure and economic growth.

Data

The data we use to carry out the panel cointegration tests is derived from the data we gathered to carry out the Lee and Gordon replications. As noted above, for our panel cointegration tests, we limit the sample and the set of variables so that we can have a continuous time-series for each variable, but as we showed above, limiting the sample and set of variables in this way does not significantly change the estimated coefficients on the corporate tax rate. For each variable, we used only those countries for which 15 or more years of continuous data was available and discard any observations in those countries which were not in the continuous series. For every variable used in each unit root test described below, we use every country for which a continuous time series of at least 15 years was available. For the cointegrated tests, we select only those countries for which at least a 15-year continuous overlap in observations between all variables in that particular analysis was available. So if, for example, a country had continuous data on the corporate tax rate from 1980 through 2000, and continuous growth data from 1985 through 2010, then it was included in the cointegration test because it has 16 years (inclusive) of overlap between those variables. On the other hand, if it only had growth data from 1995 through 2010, then it would not have been included since it would only have six years (inclusive) of overlap.

Panel Unit Root Test Estimation Method

Unlike the PMG Estimator described above, the panel cointegration test used below requires all of the tested variables to be nonstationary. In order to ensure that all of the variables used are nonstationary we turn to the the Im, Pesaran, and Shin (IPS) panel unit root test, which is analogous to the Augmented Dicky-Fuller (ADF) test. The IPS test is a group mean test, so it allows the parameter of interest to vary heterogeneously across countries rather than assuming that all of the countries share a common long run value for the parameter.

The first step in the test is, if warranted by the model, to extract time effects in order to control for cross-sectional dependence (in other words, to control for any unobserved influences on the dependent variable that are changing in the same way over time across all countries).[8] This entails performing the following demeaning of the data by year:

$$\tilde{y}_{it} = y_{it} - \bar{y}_t \, where \, \bar{y}_t = \frac{1}{N}\sum_{i=1}^{N} y_{it} \quad (4)$$

$$\tilde{x}_{it} = x_{it} - x_t \, where \, \bar{x}_t = \frac{1}{N}\sum_{i=1}^{N} x_{it} \quad (5)$$

The second step is to estimate the ADF regression individually for each country by OLS using the demeaned data. Note that this specification can, if desired, include member-specific controls such as country fixed effects (these are signified by the $\tilde{\alpha}_l$ term) and deterministic time trends ($\delta_i t$), where *t* is time, and δ_i is a parameter that allows the effect of time to be heterogeneous across countries.[9]

[8] Note that this step is conceptually equivalent to including year fixed effects in the specification.

[9] For the remainder of this paper, “time trends” refers specifically to linear time trends.

$$\Delta\tilde{y}_{i,t} = \tilde{\alpha}_i + \delta_i t + \rho_i \tilde{y}_{i,t-1} + \sum_{k=1}^{K_i} \varphi_{i,k} \Delta\tilde{y}_{i,t-k} + e_{i,t} \quad (6)$$

In equation 1, K_i must be chosen to ensure that $e_{i,t}$ is white noise. Next, we compute the t-statistic t_{ρ_i} for the null hypothesis of H_0: $\rho_i = 0$ for each country. If $\rho_i = 0$, that implies that the variable $y_{i,t}$ is nonstationary. Intuitively, if a variable $y_{i,t}$ were stationary, then periods of time when $y_{i,t}$ was unusually high would be associated with subsequent negative movements in the value of $y_{i,t}$ as it reverts towards its mean. If we cannot reject the hypothesis that $\rho_i = 0$, that implies that there is no evidence that the variable $y_{i,t}$ is in fact mean-reverting over the long-run. If, by contrast, ρ_i is negative and statistically significant, that suggests that $y_{i,t}$ is indeed mean-reverting in the long-run and thus stationary.

Once we estimate this ADF regression separately for each country, the group mean t-statistic, $\overline{t_\rho}$, can be calculated using the average of the individual t-statistics:

$$\overline{t_\rho} = N^{-1} \sum_{i=1}^{N} t_{\rho_i} \quad (7)$$

Finally, we construct the group mean panel unit root test statistic:

$$Z_{NT} = \sqrt{\frac{N}{var(t_{\rho_i})}} \left(\overline{t_\rho} - E[t_{\rho_i}]\right) \quad (8)$$

Where N is the number of countries in the panel and $E[t_{\rho_i}]$ is the mean of t_{ρ_i}. Under the null hypothesis of $\rho_i = 0$, the distribution of Z_{NT} converges to a standard normal distribution as the sample size increases, while under the alternative hypothesis of stationarity, where $\rho_i < 0$, Z_{NT} goes to negative infinity as the sample size increases. Therefore, we compare Z_{NT} to the critical values of the left tail of a standard normal distribution (e.g. -1.28 for a 10% confidence level, -1.64 for a 5% confidence level, etc.). The null hypothesis being tested is that a unit root is present across *all* the panel members, and so failure to reject the null hypothesis implies *all* of the panel members are nonstationary. Since the IPS test allows the long run relationship to vary across panel members, the alternative hypothesis is that at least *some* of the panel members fail to show a unit root and therefore some nonzero number of them is stationary. Test statistics more negative than the critical values for a standard normal distribution imply rejection of the null hypothesis of a unit root and suggest that the variable is stationary. Conversely, test statistics more positive than the critical values imply failure to reject the null hypothesis of a unit root and suggest that the variable is nonstationary.

IPS Test Results

We first give a sense of what economic theory and intuition would predict for the stationarity or nonstationarity of each variable so that we have a point of comparison for the results. GDP per capita is, with any consistently nonzero amount of output growth, a nonstationary process; on the other hand, we might expect the change in log GDP per capita over time to be a stationary process. Indeed, Jones (1995) shows that growth rates of real per capita GDP have been stationary in almost all industrialized nations since the late 1800s, and argues that this calls into question any theory which suggests that any policy variables that experience permanent changes (such as taxes relative to GDP, which did indeed experience large permanent changes during the middle part of the 20^{th} century) could be having any permanent effects on the rate of economic growth. Similar to GDP per capita, we would expect the level of population to be a nonstationary process. Tax rates and government spending relative to GDP can in principle be nonstationary, since once changed, there is no necessary reason for them to revert to their former values. Indeed, it seems clear that taxes and government spending as a percentage of GDP and tax rates have been non-stationary in rich countries over the very long run, as they increased greatly during the mid-20th century and there is no prospect of those increases being permanently reversed. However, as noted above Gemmell *et al.* find, in a small sample of rich countries, that taxes as a percentage of GDP have been non-stationary during more recent times (since the mid-1970s), since most of the big permanent changes in that variable occurred prior to the mid-1970s. However, extending the sample to a much wider range of countries, as we do here, could change the conclusion that tax rates or taxes as a percentage of GDP are stationary, even when restricting attention to recent periods. Finally, the KOF "absence of trade restrictions" index is also derived from exogenous policy decisions and there is no obvious reason to expect mean reversion, so it might plausibly be nonstationary.

The intuition on most of these variables is borne out by the results of the IPS tests, reported in Tables A8a and A8b of the Web Appendix. As expected, the first-difference of log of real GDP per capita (which is equivalent to the growth rate of real GDP per capita) from 1980 through 2010 displays stationary behavior, while all of the non-GDP variables display nonstationary behavior. However, the first-difference in log of GDP per capita form 1980 through 1997 was found to be non-stationary.

Failure to reject the null hypothesis of non-stationarity in the economic growth rate in the 1980 – 1997 period should be taken with a grain of salt, given the low power of this test in a relatively short time series. But it is at least plausible that the growth rate would be non-stationary during this period given that we have a wide sample of both rich and poor countries, and stationarity of growth rates has only been consistently established for rich countries over longer time periods. The failure to reject non-stationarity of the growth rate over the 1980 to 1997 period raises the possibility that Lee and Gordon's approach *could* be identifying a long-run causal effect on the economic growth rate. However, this finding also raises the possibility (though not the certainty) that Lee and Gordon's finding of a significant relationship between the corporate tax rate and GDP per capita could be the result of a spurious correlation. As discussed by many authors (e.g. Granger and Newbold (1973)), spurious correlations arise when two nonstationary variables are regressed on each other, yet they are not cointegrated. The resulting OLS coefficient may be significant even though the two underlying data generating processes having nothing to do with each other. This is a common problem in using OLS and other cross-sectional techniques in a dynamic framework, and is one reason to prefer time series tests to such techniques.

Broadening our sample to thirty-one years, we derive a different result: that the growth rate of GDP per capita is stationary, meaning that while a shock could disturb its short run value, over the long run it will be mean-reverting, with no evidence of permanent changes. This is a more convincing result than the unit root test on the growth rate for 1980-1997 since the sample size is larger and it throws into question Lee and Gordon's finding that the tax rate has a persistent long run effect on the growth rate; if the growth rate is stationary, it is *impossible* for a permanent shock in a policy variable to cause a shift the long run value of the growth rate, unless by some unlikely coincidence permanent shocks to the policy variable are always exactly counteracted by permanent shocks to some other nonstationary variable that influences the growth rate in exactly the opposite direction and by the same magnitude.[10]

Given that in the longer 1980-2010 panel, the growth rate is stationary, a next step is to test whether the *level* of log real GDP per capita and tax rates share a long run, cointegrating relationship. Even if the long run *growth rate* of GDP per capita (the steady state rate of growth)

[10] See Jones (1995) for elaboration on this point.

is stationary, it is still possible for the *level* of GDP per capita and tax rates to have a long run equilibrium relationship if, say, tax rates affect the level of income. We also test for a cointegrating relationship between the level of log real GDP per capita and tax rates controlling for country-specific time trends. In those particular specifications, we ask a particularly sensible question: when taxes as a percentage of GDP rise above their historical trend in a persistent way, does that lead log real GDP per person to drop below its historical trend in a persistent way as well, and does that relationship persist over the long-run?

To summarize what we know so far: all of the variables of interest except for the growth rate of GDP per capita from 1980 through 2010 are nonstationary and therefore could well be cointegrated with one another. With this in mind, we turn to estimation of cointegrating relationships in order to find proof of long run relationships.

Theory behind Robustness of Cointegration Tests

Before we examine the details of the panel cointegration test, it is important to understand why evidence of cointegration would suggest that we have consistent estimates of a long-run equilibrium relationship, in a way that the techniques used in the previous literature on tax structure and economic growth do not.[11] If two variables are cointegrated, that means that the error term in the relationship between them is stationary. The effects of any omitted variables that influence the dependent variable will be in the error term. But only non-stationary variables can have long-run impacts on the dependent variable, or long-run correlation with the explanatory variable. In the long-run, the effects of any stationary variables on the non-stationary dependent variable, and any relationship between any stationary variables and the non-stationary

[11] It is important to note that when we state the evidence of cointegration is evidence of a long-run equilibrium relationship, we do not mean that it allows researchers to infer one-way causality in the presence of reverse causality. Rather, this test is a consistent estimator of whether or not a relationship exists in the presence of endogeneity; this this is explained in more detail later in this section.

explanatory variable, will die out. Evidence that the error term in the relationship is stationary, or in other words evidence that we have cointegration, is also evidence that there are no non-stationary omitted variables that are influencing the dependent variable in the relationship. In that case, it is still possible we could have bi-directional causality between the dependent variable and the explanatory variable, but the coefficient on the explanatory variable estimated by OLS will still be a consistent estimator of the long-run relationship between the variables.

By contrast, if we do not find evidence of cointegration, that is not necessarily dispositive, because then it could be the case that there are omitted non-stationary variables that influence the dependent variable and are correlated with the explanatory variables. If we could have included those other variables in the analysis, then we might have found evidence of cointegration. However, failure to find evidence for cointegration means that we cannot be confident that any long-run equilibrium relationship exists among the variables we've included in the analysis.

More formally, suppose that the relationship we investigating is as follows (abstracting from the intercept, other variables in the cointegration relationship, etc., which can easily be accommodated):

$$y_t = \beta x_t + \mu_t \tag{9}$$

$$y_t \sim I(1),\ \ x_t \sim I(1),\ \ \mu_t \sim I(0) \tag{10}$$

Many statistical problems might bias the estimated parameter, $\hat{\beta}$, and arise from covariance between the independent variable, x, and the residuals, μ. This can be seen from the following (where y is the dependent variable):

$$\hat{\beta} = \frac{\sum xy}{\sum x^2} \tag{11}$$

$$\hat{\beta} - \beta = \frac{\sum x\mu}{\sum x^2} \tag{12}$$

$$\hat{\beta} - \beta = \frac{\frac{1}{T}\sum x\mu}{\frac{1}{T}\sum x^2} \tag{13}$$

If both variables x and y are stationary, such that $x, y \sim I(0)$, then the residuals will also be stationary. Then in this case, both the numerator and the denominator of Equation (1) will go to constant values as we let T, the number of observations, increase indefinitely. Specifically, equation (1) will approach the following value:

$$\hat{\beta} - \beta \rightarrow \frac{\sigma_{x\mu}}{\sigma_{x^2}} \tag{14}$$

where $\sigma_{x\mu}$ is the covariance between the independent variable and the residuals, and σ_{x^2} is the variance of the independent variable. Thus if $\sigma_{x\mu}$ is nonzero (i.e. if the independent variable and the residuals are correlated) then the difference between $\hat{\beta}$ and β does not approach zero and the OLS estimator is inconsistent.

However, if x and y are cointegrated, such that $x, y \sim I(1)$ but $\mu \sim I(0)$ (as per the definition of cointegration) then we find a different result. We will examine the following equation:

$$\hat{\beta} - \beta = \frac{\frac{1}{T^2}\sum x\mu}{\frac{1}{T^2}\sum x^2} \tag{15}$$

As we let T^2 go to infinity, the term in the denominator approaches a stable distribution around a nonzero value. On the other hand, the term in the numerator goes to zero as we let T^2 go to infinity. Intuitively, this occurs because μ is stationary and x is non-stationary, so as T gets large the correlation between them in the data approaches zero. Thus, as we let T^2 go to infinity, $\hat{\beta}$ approaches β regardless of the covariance between the residuals and the independent variable and we have a consistent estimator (Pedroni 2012).[12]

Panel Cointegration Estimation Method

The estimation method we selected for the cointegration test is the Group Mean Parametric Residual Based Test developed in Pedroni (1999) and Pedroni (2004). Overall, the test is analogous to the Augmented Dicky-Fuller (ADF) test for a unit root process: the basic idea is to regress one nonstationary variable on another nonstationary variable and then test the residuals for stationarity. However, whereas time series estimators such as the ADF test require a very long time dimension of several hundred or more observations in order to have consistent estimation, Pedroni's Group Mean Parametric Residual Based test (henceforth, referred to simply as the panel cointegration test for brevity) uses the member dimension of panel tests to overcome the problem of short time dimensions. We describe here exactly how the test functions.

The first step, if we want to control for time fixed effects, is to take each variable, and subtract its mean value across countries in each year. For countries $i = 1, \dots, N$ and time periods $t = 1, \dots, T$, this implies performing the following operation:

$$\tilde{y}_{it} = y_{it} - \bar{y}_t \; where \; \bar{y}_t = N^{-1} \textstyle\sum_{i=1}^{N} y_{it} \qquad (16)$$

[12] Cointegration is thus a powerful tool to uncover long run relationships. However, while the cointegration test outlined below allows one to uncover such a relationship, it does not allow the researcher to infer anything about one-way causality once such a relationship is uncovered. Thus, if the tax rate and GDP per capita were found to be cointegrated, then one would need to use other tests to uncover information about the nature of the causal relationship between the two variables (e.g. Canning and Pedroni (2008)). We do not pursue such a test because we find no evidence of cointegration.

$$\tilde{x}_{it} = x_{it} - x_t \, where \, \bar{x}_t = N^{-1} \sum_{i=1}^{N} x_{it} \tag{17}$$

Where $\tilde{y}_{it}$ and $\tilde{x}_{it}$ are the cross-sectionally demeaned data series for the original variables, which as noted above is effectively similar to controlling for time fixed effects.

The second step is to estimate the panel cointegration regression by OLS for each country individually. In the bivariate case, this estimation is:

$$\tilde{y}_{i,t} = \alpha_i + \delta_i t + \beta_i \tilde{x}_{it} + e_{i,t} \tag{18}$$

We are simply regressing the demeaned data from one variable on the demeaned data of the other variable. The inclusion of the α_i term takes fixed effects into account; this means that the regression controls for unobserved factors which influence the variables and whose effects vary across countries but not over time. The $\delta_i t$ term can be included if heterogeneous time trends should be taken into account, meaning that the panel cointegration regression takes into account trends within the left hand side variable that may cause it to increase or decrease over time independently of the right hand side variables. This is an important consideration for the question at hand since, for the majority of countries, real GDP per capita does increase over time regardless of movement in the tax rates. A major driver of growth in real GDP per capita over the long-run is technological change, which is unobserved, but these tests will control for that to the extent that it is evolving similarly over time across countries in the sample, or to the extent that it follows a steady linear time trend in each country.

The third step is to estimate the ADF regression for each country individually. This regression takes the following form:

$$\Delta \hat{e}_{it} = \rho_i \hat{e}_{i,t-1} + \sum_{k=1}^{K_i} \gamma_{it} \, \Delta \hat{e}_{i,t-k} + u_{it} \tag{19}$$

In this estimation, we regress the first-differences of the residuals from the regression in equation (18) on the one-period lag levels of the residuals as well as the lagged differences of the residuals. Note that the length of the lag varies by country; a “step-down procedure” is used to choose the lag length for each country. The step-down procedure entails estimating equation (19) for each country with a large number of lags. If the coefficient on the last lag is significant according to a two-tailed T-test, then that specification is used to estimate equation (19) for that country. If not, the number of lags is reduced by one and the estimation is repeated until a statistically significant lag is obtained. The motivation is to choose a value for K_i which is large enough to ensure that u_{it} is white noise without also obtaining a large loss in efficiency.

The fourth step is to compute the t-statistic for the coefficient ρ_i ($H_0\colon \rho_i = 0$) from equation (2) for each country. Then the individual t-statistics are used to compute the restandardized Group Mean t-statistic value for the panel:

$$N^{-1/2}\tilde{Z}_{t_{N,T}} = N^{-1/2}\sum_{i=1}^{N} t_{\rho_i} \qquad (20)$$

Using this restandardized Group Mean t-statistic, we can then construct the panel group mean test statistic, which is represented by the formula:

$$\frac{x_{N,T} - \tau\sqrt{N}}{\sqrt{v}} \qquad (22)$$

Where τ and v are values that can be computed appropriately using the values described in Corollary 1 of Pedroni (2004) (or Table 2 of Pedroni (1999) when there is more than one regressor); the values depend on the inclusion or exclusion of year and country fixed effects. This panel group mean test statistic goes to a standard normal distribution under the null hypothesis of no cointegration, while under the alternative hypothesis of cointegration it goes to negative infinity. Therefore, as with the IPS test employed earlier, we compare the panel group mean statistic to the critical values of the left tail of a standard normal distribution. Results less negative than these critical values indicate a failure to reject the null of no cointegration, as none of the members in the panel are cointegrated, so we can say that the variable is not cointegrated. Results more negative than these critical values indicate rejection of the null of no cointegration, suggesting that at least some of the members in the panel are cointegrated.

Panel Cointegration Test Results

We begin by estimating a pairwise panel cointegration test on the growth rate in GDP per capita and the statutory corporate tax rate from 1980 to 1997. As noted above, it makes sense to do this because we could not reject the null hypothesis of non-stationarity for either of these variables during the 1980 to 1997 period, although we did reject non-stationarity for the economic growth rate from 1980 through 2010. All of the tests control for country fixed effects, and we show results of the tests with and without controlling for time fixed effects (implemented by cross-sectional demeaning) and country-specific time trends). The results, presented in Table 4, reject cointegration between the growth rate of GDP per capita and the corporate tax rate, regardless of whether we control for time fixed effects or country-specific time trends or not. Recall that evidence for cointegration would require a group mean ADF statistic that is more *negative* than the critical value, as this would be evidence that the error term in the relationship is stationary. But all of the group mean ADF statistics are positive, suggesting there is no evidence of mean reversion in the error term. This suggests that Lee and Gordon's evidence of a negative effect of the corporate tax rate and the growth rate of GDP per capita could be spurious – both variables are nonstationary and are correlated with each other, but there is no compelling evidence of a long-run equilibrium relationship between them. This is not a definitive rejection of LG's results because of the possibility of an omitted, confounding non-stationary variable that could be driving economic growth and could be correlated with the statutory corporate tax rate, such as technological change, to the extent that such variables are not adequately controlled for by the country fixed effects, time fixed effects, and country-specific time trends. The tests also reject cointegration between the economic growth rate and the top personal income tax rate.

Table 4: Pairwise Cointegration Results, Taxes and growth in GDP per capita, 1980-97

Right-Hand Side Variable	Time fixed effects?	Country-specific time trends?	Group Mean ADF statistic	Number of countries
Corporate Tax Rate	No	No	3.49	68
	Yes	No	2.99	68
	No	Yes	7.14	68
	Yes	Yes	7.96	68
Personal Tax Rate	No	No	3.18	69
	Yes	No	3.44	69
	No	Yes	7.22	69
	Yes	Yes	6.26	69

Change in log of real GDP per capita is the left-hand side variable in all of the tests in this table. All tests control for country fixed effects.

We next estimate analogous pairwise cointegration tests on the full time period from 1980 to 2010, except that in this time period, we switch to looking at the relationship between tax variables and the *level* of log real GDP per capita, since we reject the null hypothesis that the economic growth rate is non-stationary during this period. The results of these tests are presented in Table 5. In all cases the group mean ADF statistic is once again positive, so all of these tests fail to reject the null hypothesis of no cointegration. In other words, there is no evidence of cointegration between the corporate tax rate or personal tax rate and log of GDP per capita in pairwise tests. So for example, the test which controls for country fixed effects, time fixed effects, and country specific time trends means that when the corporate tax rate rises above its long-run historical trend in a persistent way, there is no evidence that log real GDP per capita dips below its long-run historical trend in a persistent way. This is sharply at odds with the implication from the Lee and Gordon paper that a permanent increase in the corporate tax rate would have a large permanent negative effect on the growth rate and level of real GDP per capita.

Table 5: Pairwise Cointegration Results, CIT or PIT and GDP per capita, 1980-2010

Right-Hand Side Variable	Time fixed effects?	Trends?	Group Mean ADF-statistic	Number of countries
Corporate Tax Rate*	No	No	4.38	70
	Yes	No	4.95	70
	No	Yes	4.12	70
	Yes	Yes	6.06	70
Personal Tax Rate*	No	No	8.15	76
	Yes	No	6.99	76
	No	Yes	4.36	76
	Yes	Yes	4.29	76

Log of GDP per capita is the left-hand side variable in all of the tests in this table.
All tests control for country fixed effects.

In table 6, we report tests for pairwise cointegration between each of our measures of the overall size of government relative to GDP and the level of log real GDP per capita in the 1980 – 2010 data. Once again, the Group mean ADF tests are all positive, suggesting no evidence of cointegration.

Table 6: Pairwise Results, Government Size and GDP per capita, 1980-2010

Right-Hand Side Variable	Time fixed effects?	Country-specific time-trends?	Group Mean ADF-statistic	Number of countries
Gov't tax revenue as a percentage of GDP	No	No	3.53	41
	Yes	No	2.22	41
	No	Yes	3.42	41
	Yes	Yes	2.49	41
Gov't Consumption expenditure as a percentage of GDP	No	No	5.52	50
	Yes	No	3.59	50
	No	Yes	5.39	50
	Yes	Yes	4.52	50
Log of real GDP per capita is the left-hand side variable in all of the tests in this table. All tests control for country fixed effects.				

Finally, we run three-way tests to determine if the corporate tax rate and government size (or the personal tax rate and government size) are jointly cointegrated with log of GDP per capita. That is, there is a possibility that while individual variables are not cointegrated with GDP per capita, two or more variables may jointly share a long run relationship with GDP per capita. To this end, we run two sets of tests each comprised of four tests; each of these four tests investigates joint cointegration between the corporate tax rate, log of GDP per capita, and one of each measure of government size. Similarly, we also run four three-way tests using the same variables but substituting the personal tax rate for the corporate tax rate. Thus we end up running eight three-way tests in total. These eight tests all reject joint cointegration between each type of tax, each measure of government size, and log of GDP per capita. These results are shown in the Web Appendix. These results suggest, in contrast to Tables 2 and 3 of Section 4, that neither taxes, government size, nor some combination of the two have a significant long run equilibrium relationship with the level of real income per capita.

The final set of panel cointegration tests also include control variables that we used in the regressions back in table 3 that are available for long continuous time series, and which were found to be non-stationary, including KOF “absence of trade restrictions” index and the total population. Running joint cointegration tests including these controls with the corporate tax rate, the personal tax rate, both tax rates, and both tax rates with each control for government size yielded no evidence of cointegration between these variables and the level of log real GDP per capita. These results are shown in Table A10 of the Web Appendix.[13]

Discussion of Results

One of the most important findings of this section is that the growth rate of GDP per capita is stationary rather than nonstationary for the period from 1980 through 2010. This finding suggests that there is no evidence of long-run changes in the economic to the growth rate for this sample of countries during the period in question. Since changes to the corporate tax rate are persistent (because the corporate tax rate is nonstationary), we would expect such changes to have persistent effects on the growth rate according to Lee and Gordon’s results; however, this is impossible if the growth rate is stationary. Therefore, the panel unit root test provides a strong counterpoint to Lee and Gordon’s main conclusions. While a test on a panel of countries similar to the one Lee and Gordon used for the 1980 to 1997 period does yield evidence of nonstationarity in the economic growth rate, we found that the growth rate and the tax rate variables were not pairwise cointegrated, indicating that Lee and Gordon’s results possibly

[13] Note that in this preliminary draft of the paper, we estimate the cointegration tests with the full set of control variables, reported in tables A9 and A10, only for a smaller sub-set of countries for which the Mauro *et al* provide data on revenues and government expenditure as a percentage of GDP for long time series – it is possible to increase the sample size considerably by adding the OECD data on tax revenues as a percentage of GDP, but tables A9 and A10 do not yet reflect this.

reflected a spurious correlation rather than a real long run relationship. In the 1980 to 2010 data, we tested whether tax rates have a long run relationship with the level of GDP per capita – that is, whether they were linked with income levels (rather than growth in income) over the long run. We failed to find any support for this hypothesis. The presence of cointegration was also rejected when we broadened the set of variables to include the non-stationary and continuously available controls from the Lee and Gordon specifications.

As discussed earlier, it is still at least possible that there is in fact a long-run relationship between tax rates and the level of log real GDP per capita, but that this relationship is obscured by some omitted variable that is non-stationary and is causing log real GDP. Technological change could be an example of such a variable. But even then, it would have to be technological change that is not adequately controlled for by country fixed effects, time fixed effects, and country-specific linear time trends. While these panel cointegration results are not the final word on the matter of tax structure and long run growth, they should reduce confidence that there is a long run equilibrium relationship between tax structure and the level of real GDP per capita.

Conclusion and directions for future research

The panel cointegration tests in this paper provide no evidence that tax structure has any long run effect on the level or growth rate of real GDP per capita across countries, which is at odds which much of the previous literature. The difference probably arises from the fact that the previous literature used techniques that could not convincingly distinguish short-run co-movements of taxes and economic growth over the business cycle from the effects of persistent shocks to taxes on long-run economic outcomes. Due to the potential presence of unobserved non-stationary variables which might confound the cointegration test, such as possibly a country-specific and time-varying rate of technological change, we cannot state unequivocally that the answer to this question is settled, but such omitted variables would be a problem for every other study that has been done on this question as well. In ongoing work, we are constructing a much longer and wider panel of cross-country data on fiscal and economic variables, with improved and more consistent measures of tax rates and the size of government and additional control variables, in order to investigate these questions further.

References

Acosta-Ormaechea, S. & Yoo, J. 2012. “Tax Composition and Growth: A Broad Cross-Country Perspective”. IMF Working Paper WP/12/257.

“Americans for Fair Taxation”. FairTax.org. http://www.fairtax.org

Barro, R., & Lee, J. 2011. “A New Data Set of Educational Attainment in the World, 1950-2010”. NBER Working Paper No. 15902.

Canning, D. & Pedroni, P. 2008. “Infrastructure, Long-Run Economic Growth and Causality Tests for Cointegrated Panels”. *Manchester School* 76 (5): 504-527.

Dreher, A. 2006. “Does Globalization Affect Growth? Evidence from a new Index of Globalization”. *Applied Economics 38*, 10: 1091-1110.

Enders, Walter. 2009. *Applied Econometric Time Series, 3rd edition*. Wiley.

Ernst & Young. *Worldwide Corporate Tax Guide* (2005 and 2006 issues).

Gemmell, N., Kneller, R., & Sanz, I.. 2011. "The Timing and Persistence of Fiscal Policy Impacts on Growth: Evidence from OECD Countries." *Economic Journal.* 121 (550): F33-58.

Gemmell, Norman, Richard Kneller, and Ismael Sanz. 2015. “The Growth Effects of Tax Rates in the OECD.” *Canadian Journal of Economics*. Forthcoming. <http://dx.doi.org/10.1111/caje.12105>.

Gentry, W. & Hubbard, R. 2004. "'Success Taxes,' Entrepreneurial Entry, and Innovation." NBER Chapters, in: Innovation Policy and the Economy. Vol. 5: 87-108.

Granger, C.W.J. & Newbold, P. 1974. “Spurious Regressions in Econometrics”. *Journal of Econometrics*. 2 (2): 111-120.

Heston, A., Summers, R., & Aten, B. 2012. Penn World Table Version 7.1, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.

Im, K., Pesaran, M., & Shin, Y. 2003. “Testing for Unit Roots in Heterogeneous Panels”. *Journal of Econometrics*. 115 (1): 53-74.

Jens, A., Brys, B., Heady, C., Johansson, A., Schwellnus, C., & Vartia, L. 2011. “Tax Policy for Economic Recovery and Growth”. *The Economic Journal*. 121 (February): F59-F80.

Jones, Charles I. 1995. “Time Series Tests of Endogenous Growth Models.” *Quarterly Journal of Economics*. Vol. 110, No. 2, pp. 495–525.

KPMG. “Corporate tax rates table”. Accessed January 2013. http://www.kpmg.com/global/en/services/tax/tax-tools-and-resources/pages/corporate-tax-rates-table.aspx

Lee, Y., & Gordon, R.H.. 2005. "Tax Structure and Economic Growth." *Journal of Public Economics*. 89 (5-6): 1027-43.

Mauro, P., Romeu, R., Binder, A., & Zaman, A. 2013. “A Modern History of Fiscal Prudence and Profligacy”. IMF Working Paper. http://www.imf.org/external/pubs/cat/longres.aspx?sk=40222.0

OECD. 2010. "Revenue Statistics: Comparative tables", *OECD Tax Statistics* (database). Accessed on April 5 2013. http://www.oecd-ilibrary.org/taxation/data/revenue-statistics/comparative-tables_data-00262-en?isPartOf=/content/datacollection/ctpa-rev-data-en

Office of Tax Policy Research. *World Tax Database*. Accessed November 2012 and March 2013. http://www.bus.umich.edu/otpr/otpr/default.asp

Pedroni, P. 2012. Class Lecture: Advanced Econometrics, Time Series. Williams College, Williamstown, MA..

Pedroni, P. 1999. “Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors”. *Oxford Bulletin of Economics and Statistics*. Vol. 61 (S1): 653-70.

Pedroni, P. 2004. “Panel Cointegration: Asymptotic and Finite Sample Properties of Pooled Time Series Tests with an Application to the PPP Hypothesis”. *Econometric Theory*. 20 (3): 597-625.

Pesaran, H., Shin, Y., & Smith, R.P. 1999. "Pooled Mean Group Estimation of Dynamic Heterogeneous Panels." *Journal of the American Statistical Association* 94 (446): 621-634.

Peter, K.S., Buttrick, S., & Duncan, D. 2010. “Global Reform of Personal Income Taxation, 1981-2005: Evidence from 189 Countries.” *National Tax Journal*. 6(3).

Political Risk Services Group. “International Country Risk Guide”. Accessed July 2012. http://www.prsgroup.com/ICRG_methodology.aspx

Pricewaterhouse Coopers. *Corporate Taxes: A Worldwide Summary* (2003 and 2004 issues).

Sachs, J. & Warner, A. 1995. “Economic Reform and the Process of Global Integration”. *Brookings Papers on Economic Activity*. 26 (1): 1-118.

USAID. *Collecting Taxes*. Accessed January 2013. http://www.fiscalreform.net/index.php?option=com_frontpage&Itemid=1

Slemrod, J., Gale W., Easterly, W. 1995. "What Do Cross-Country Studies Teach about Government Involvement, Prosperity, and Economic Growth?" *Brookings Papers on Economic Activity*. 1995 (2): 373-431.

Wacziarg, R., & Welch, K. 2008. "Trade Liberalization and Growth: New Evidence." *The World Bank Economic Review*. 22 (2): 187-231.

World Bank. 2012. World Development Indicators 2012. © Washington, DC. https://openknowledge.worldbank.org/handle/10986/6014 License: CC BY 3.0 Unported. Accessed March 30, 2013

Xing, J. 2012. "Tax Structure and Growth: How robust is the empirical evidence?" *Economics Letters*. 117 (1): 379-382.

Web Appendix to "Effects of the Level and Structure of Taxes on Long-Run Economic Growth: What Can We Learn from Panel Time-Series Techniques?" by Jon Bakija and Tarun Narasimhan

Further Details on Data Construction

Lee and Gordon named 70 countries in table 1 of their paper, but used 77 countries in their panel analysis. As noted in the text, we use the same 70 countries that they named, plus 9 other countries for which the variables in our analysis were available. Then we constructed a test of the OTPR data to determine which additional seven countries they might have selected based on which countries had the most tax data observations from the OTPR dataset. Table A2 in this appendix contains a list of the full 79 country sample with the nine candidates in bold.

Data on statutory top corporate and personal tax rates came from many sources. For replicating Lee and Gordon's panel regressions from 1980-1997, the sole source was the OTPR dataset. However, the OTPR stopped updating this database in 2003, so 2002 was the latest year for which data was available from this source. Using the various tax sources as described in Table 1, we accordingly updated the data on corporate and personal tax rates for the 79 country sample and constructed new, updated tax variables. Comparing our raw OTPR data to LG's raw data, there were significant discrepancies for two countries, Switzerland and Norway. Using the OTPR's footnotes, we altered our raw data to match the changes LG had presumably made. The top statutory corporate tax rate for Norway was listed as 50.8 from 1980 through 1991; reviewing the OTPR footnotes, this was most likely done to combine state and municipal aggregate tax rates. The unaltered OTPR data had only the central tax rate of 27.8 percent, while the municipal rate was listed as 23 percent. We accordingly changed our raw data. A similar change was made for Switzerland. The unaltered OTPR data showed a rate of only 11.5 percent from 1980 through 1989 and 9.8 percent from 1990 through 1997 (in line with the federal tax rate). LG's raw data showed an average rate of 29 percent from 1980 to 1989 and an average rate of 45 percent from 1990 to 1997. Their methodology appears to be inconsistent: from 1980 to 1989, they summed the federal tax rate and an average of OTPR's stated range of estimates for the cantonal corporate taxes, whereas from 1990 to 1997, they simply chose a top rate of 45 percent (the actual top rate, according to OTPR, was 46.65 percent; we are uncertain how LG obtained the value of 45 percent). In order to maintain methodological consistency, we altered Switzerland's rates from 1990 through 1998 to be an average of the stated range of estimates of the top combined federal, cantonal, and communal taxes, which came out to 34.175 percent. We also made similar changes to the data after 1998 to maintain consistency when performing the updates – specifically, we altered Switzerland's rates for 2001 and 2002. A summary of all these changes is listed in Table A1.

For the corporate tax rate, Table A3 in this appendix shows exactly how we used our various data sources to construct the variable used. If we relied on a single source, then that variable is only listed in the "1st priority column". If we used one source but augmented it with observations from another source, then those sources are shown in the "1st priority" and "2nd priority" columns respectively. Table A4 shows the same information for the personal tax rate.

Table A1: Summary of Alterations to OTPR Dataset

Country	Years	Original Rate (%)	Altered Rate (%)
Norway	1980-1991	27.8	50.8
Switzerland	1980-1989	11.5	29
	1990-1998	9.8	34.175
	2001-2002	8.5	21

Table A3: Constructing the Corporate Tax Rate Variable

Years	1st priority	2nd priority
1980 – 2002	OTPR's World Tax Database	
2003	Pricewaterhouse Coopers (PwC)	
2004	PwC	USAID's FiscalReform.net
2005	KPMG	Ernst & Young
2006	KPMG	Ernst & Young
2007	USAID's FiscalReform.net	KPMG
2008	USAID's FiscalReform.net	
2009	USAID's FiscalReform.net	KPMG
2010	USAID's FiscalReform.net	

Table A4: Constructing the Personal Tax Rate Variable

Years	1st priority	2nd priority
1980	OTPR's World Tax Database	
1981 – 1999	OTPR's World Tax Database	AYS Tax Indicators
2000 – 2003	AYS Tax Indicators	
2004	AYS Tax Indicators	USAID's FiscalReform.net
2005	KPMG	
2006	KPMG	
2007 – 2010	USAID's FiscalReform.net	KPMG

Table A2: List of countries in our 79 country sample

Argentina	Kenya
Australia	Korea, Rep.
Austria	**Kuwait**
Bahrain	**Luxembourg**
Belgium	Malawi
Bolivia	Malaysia
Botswana	Mexico
Brazil	Morocco
Cameroon	Netherlands
Canada	New Zealand
Chile	Nicaragua
China	Nigeria
Colombia	Norway
Congo, Dem. Rep.	**Oman**
Congo, Rep.	Pakistan
Costa Rica	Paraguay
Cote d'Ivoire	Peru
Denmark	Philippines
Dominican Republic	Portugal
Ecuador	**Qatar**
Egypt, Arab Rep.	**Saudi Arabia**
El Salvador	Senegal
Finland	Sierra Leone
France	Singapore
Germany	South Africa
Ghana	Spain
Greece	Sri Lanka
Guatemala	Sweden
Guyana	Switzerland
Haiti	Thailand
Honduras	Trinidad and Tobago
Hong Kong	Turkey
India	**United Arab Emirates**
Indonesia	United Kingdom
Iran	United States
Ireland	Uruguay
Israel	Venezuela
Italy	Zambia
Jamaica	Zimbabwe
Japan	

Note: Countries in bold are ones that we added to the 70 countries that Lee and Gordon identified as being included in their study.

Data on population growth, inflation (GDP deflator measure), and primary school enrollment came from the World Bank's World Development Indicators (WDI). LG did not specify which measure of inflation they used; data on the GDP deflator measure is more complete than data on the consumer price index, and so we only used that measure in the regressions. We backwards extrapolated the primary school enrollment variable across the entire time series of each country. This was done in order to augment the number of observations for that variable because, even after interpolation, it was missing many observations. Thus, if data was missing for a country from 1980 through 1984, the value for 1985 was used in those years. For the updated regressions we introduced a measure of education which was more complete and of higher quality. Barro and Lee (2011)'s educational measure, average years of schooling, better captures the level of educational attainment within a country since it reflects the actual amount of education gained by the populace, whereas primary school enrollment rates only reflect the educational attainment of the populace's younger cohorts. Barro and Lee's data was available at the same five-year intervals that LG used.

The WDI data also provided information on GDP per capita in constant 2000 US$. However, complete GDP per capita data on Haiti, which was one member of the original 70 country sample, is not available through WDI before 1991. LG did not discuss this problem or their solution. For the sake of completeness, we replaced the GDP per capita data on Haiti from WDI with GDP per capita data from the Penn World Table (henceforth, PWT) for both the replications and updates. We also used PWT data for Kuwait and Qatar instead of WDI data because the former was more complete.

The ICRG Index has complete data on corruption and bureaucratic quality for 1985-2010 for the 79 country sample, with six countries missing data in 1984. For the years 1980-1983, which were missing data for all countries, we simply extrapolated the 1984 data to fill in the missing years. Thus the average ICRG value for the 1980-1984 period for each country is simply the 1984 value. Note that we combined the data for West Germany and Germany into one country ("Germany") in line with the OTPR and WDI datasets (there was no overlap between the two original countries).

In order to investigate the effect of tax structure on long run growth, we need to hold constant the size of government (the rationale is discussed in detail below). Unfortunately, data for this variable with good coverage for the 79 country sample for the period of interest, 1980-2010, is difficult to find. The best measure of government size is a measure of total (sub-national and central) tax revenues as a share of GDP from the OECD's tax database; unfortunately this is also the fiscal variable with the fewest observations: it only covers 27 countries for the period. Mauro *et al* (2013) published data on government revenues and expenditures for around 45 countries in the sample for the entire period, but these variables are not as robust measures of government size as the OECD variable. Focusing on their revenue data, we found that some of their observations come from the general government level and some observations come from only the central level.[14] In order to achieve a fiscal variable with the most completeness, we created a composite government revenue variable using the OECD and Mauro *et al* data. For each country, we used only one measure of revenue, either OECD revenue, Mauro *et al*'s general government revenue, or Mauro *et al*'s central government revenue; if multiple measures of revenue were available for one country, we used only one measure of revenue but gave priority in the order just given (see Table A5 for details). This composite revenue variable has data for 51 countries. The other government size variable is general government consumption expenditure

[14] Central government refers to the national level of government for a country, while general government refers to all the government levels of a nation, from national to local.

from the WDI. This comprises a very limited definition of government expenditure given that a large part of government spending goes into non-consumption activities such as investment or transfers. Despite its drawbacks, it has very complete coverage and we therefore included it as a control in my panel extensions. Thus, we have two measures of government size that we use as a control both in the extension of Lee and Gordon and the subsequent panel cointegration tests.

For openness, we used two different variables. The first, the Sachs and Warner (henceforth, SW) Index used by LG only covers the period from 1980-1992. Wacziarg and Welch (henceforth, WW) (2008) updated the Index through 2001, and we used the SW data augmented by the WW update for the replication. However, there are no updates for the SW index available after 2001. Thus we turned to an alternate index, the KOF Absence of Trade Restrictions Index.[15] This reports trade openness within a country as a measure of that country's trade policies; thus, like the Sachs and Warner Trade Index, it is fairly exogenous to growth. On this index, a score of 100 indicates very few restrictions to trade, while a score of 0 indicates a large number of trade restrictions. The KOF Index is missing all of the data for three countries in our sample and partially missing data for another.

[15] Note that this is distinct from the KOF Index of Economic Globalization or Overall Globalization.

Table A5: Sources of the Government Tax Revenue as a Percentage of GDP Variable

OECD – General Government Tax Revenue	Mauro *et al* – General Government Tax Revenue	Mauro *et al* – Central Government Tax Revenue
Argentina	Bolivia	Chile
Australia	Honduras	China
Austria	India	Costa Rica
Brazil	Indonesia	Ghana
Belgium	Iran	Hong Kong
Canada	Panama	Pakistan
Colombia	Philippines	Peru
Denmark	Venezuela	South Africa
Dominican Republic		Thailand
Ecuador		Uruguay
El Salvador		
Finland		
France		
Germany		
Greece		
Guatemala		
Ireland		
Israel		
Italy		
Japan		
Korea, Rep.		
Luxembourg		
Mexico		
Netherlands		
New Zealand		
Norway		
Paraguay		
Portugal		
Spain		
Sweden		
Switzerland		
Turkey		
United Kingdom		
United States		

3. Additional Estimates Referred to in the Text

Table A6: Lee and Gordon Panel Regressions Update, 1980-2010

VARIABLES	(1) Baseline	(2) Remove ICRG index	(3) Remove Barro-Lee education	(4) No ICRG or Barro and Lee
Corporate Top Tax rate^{+}	-0.0543**	-0.0512**	-0.0551***	-0.0520**
	(0.0206)	(0.0210)	(0.0205)	(0.0209)
Personal Top Tax rate^{+}	-0.00940	-0.0110	-0.00904	-0.0106
	(0.0129)	(0.0131)	(0.0127)	(0.0129)
Log of GDP per capita	-5.625***	-5.635***	-5.645***	-5.657***
	(1.143)	(1.112)	(1.141)	(1.109)
Primary school enrollment (WDI)$^{+}$				
Years of Primary Schooling (BL)	-0.103	-0.117		
	(0.202)	(0.205)		
KOF Trade Openness Index	0.0776***	0.0828***	0.0784***	0.0839***
	(0.0188)	(0.0199)	(0.0187)	(0.0200)
Average ICRG Index	0.342		0.347	
	(0.260)		(0.261)	
Average population growth	-0.245	-0.236	-0.248	-0.238
	(0.282)	(0.291)	(0.283)	(0.293)
Average inflation (GDP deflator)	-0.00210***	-0.00208***	-0.00210***	-0.00207***
	(0.000210)	(0.000213)	(0.000212)	(0.000216)
Constant	44.49***	45.30***	45.31***	44.83***
	(9.836)	(9.645)	(10.06)	(9.498)
Fixed Effects?	Yes	Yes	Yes	Yes
Year Effects?	Yes	Yes	Yes	Yes
Observations	443	443	443	443
R-squared	0.347	0.344	0.347	0.344
Number of countries	76	76	76	76

$^{+}$ Data for this variable was interpolated (by country, by five-year period)
Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table A7: Lee and Gordon Panel Regressions Update, 1980-2010:
Restricted Sample

VARIABLES	(1) Baseline	(2) Add Government Consumption
Corporate Top Tax rate+	-0.0343*	-0.0339*
	(0.0190)	(0.0197)
Personal Top Tax rate+	-0.00667	-0.00513
	(0.0130)	(0.0133)
Log of GDP per capita	-6.426***	-6.075***
	(1.281)	(1.257)
KOF Trade Openness Index	0.0911***	0.0870***
	(0.0212)	(0.0210)
Average population growth	-0.312	-0.337
	(0.301)	(0.299)
Average inflation (GDP deflator)	-0.00169	-0.000732
	(0.00201)	(0.00124)
Government Consumption		-0.0680
(% of GDP)		(0.0435)
Constant	52.04***	48.80***
	(11.70)	(10.98)
Fixed Effects?	Yes	Yes
Year Effects?	Yes	Yes
Observations	408	400
R-squared	0.356	0.341
Number of countries	69	68

Robust clustered standard errors are in parentheses.

Table A8a: Results of Tests for Whether Each Variable is Non-Stationary

Variable	Time dummies?	Trends?	IPS ADF-Statistic	Number of countries
Corporate Tax Rate	No	No	3.63	70
	Yes	No	-0.80	70
	No	Yes	2.81	70
	Yes	Yes	2.25	70
Personal Tax Rate	No	No	2.83	78
	Yes	No	-1.12	78
	No	Yes	6.29	78
	Yes	Yes	1.82	78
Log of real GDP per capita	No	No	6.12	79
	Yes	No	2.50	79
	No	Yes	3.23	79
	Yes	Yes	4.24	79
First-difference of log real GDP per capita, 1980-1997	No	No	0.19	77
	Yes	No	0.99	77
	No	Yes	3.89	77
	Yes	Yes	3.89	77
First-difference of log real GDP per capita, 1980-2010	No	No	-6.13*	79
	Yes	No	-4.55*	79
	No	Yes	-4.11*	79
	Yes	Yes	-2.93*	79

*Indicates rejection of the null hypothesis of non-stationarity. Otherwise, results indicate we cannot reject non-stationarity.
All variables are tested using the data from 1980 to 2010 unless otherwise noted

Table A8b: Results of Tests for Whether Each Variable is Non-Stationary, Continued

Variable	Time dummies?	Trends?	IPS ADF-Statistic	Number of countries
Gov't Tax Revenue	No	No	0.86	51
(as a % of GDP)	Yes	No	0.85	51
	No	Yes	1.36	51
	Yes	Yes	2.69	51
Gov't Consumption	No	No	-1.10	69
Expenditure (as a % of	Yes	No	-0.62	69
GDP)	No	Yes	1.10	69
	Yes	Yes	0.83	69
KOF Trade Openness	No	No	2.12	75
Index	Yes	No	2.69	75
	No	Yes	0.91	75
	Yes	Yes	1.54	75
Population	No	No	15.73	79
	Yes	No	4.47	79
	No	Yes	8.38	79
	Yes	Yes	3.49	79

*Indicates rejection of the null hypothesis of non-stationarity. Otherwise, results indicate we cannot reject non-stationarity.
All variables are tested using the data from 1980 to 2010 unless otherwise noted.

Table A9: Three-Way Joint Panel Cointegration Test Results: Government Size, Tax Rates, and GDP per capita

Right-Hand Side Variables	**Time fixed effects?**	**Country specific time trends?**	**Group Mean ADF Statistic**	**Number of countries**
Corporate Tax Rate and…				
Gov't revenue as a percentage of GDP (Mauro)	No	No	4.27	41
	Yes	No	5.41	41
	No	Yes	6.26	41
	Yes	Yes	6.63	41
Gov't expenditure as a percentage of GDP (Mauro)	No	No	3.46	41
	Yes	No	5.31	41
	No	Yes	5.68	41
	Yes	Yes	5.96	41
Personal Tax Rate and...				
Gov't revenue as a percentage of GDP (Mauro)	No	No	3.68	25
	Yes	No	5.03	25
	No	Yes	3.22	25
	Yes	Yes	2.54	25
Gov't expenditure as a percentage of GDP (Mauro)	No	No	5.92	25
	Yes	No	5.68	25
	No	Yes	4.85	25
	Yes	Yes	2.89	25
All tests use log of GDP per capita as the left-hand side variable. All tests control for country fixed effects.				

Table A10: Joint Panel Cointegration Test Results with Controls: KOF Trade Openness Index, GDP deflator measure of inflation, and population

Right-Hand Side Variables*	**Time fixed effects?**	**Country-specific trends?**	**Group Mean ADF Statistic**	**Number of countries**
Corporate Tax Rate	No	No	6.32	69
	Yes	No	6.33	69
	No	Yes	5.40	69
	Yes	Yes	8.12	69
Personal Tax Rate	No	No	6.72	74
	Yes	No	8.00	74
	No	Yes	5.73	74
	Yes	Yes	8.73	74
Both Tax Rates	No	No	8.91	69
	Yes	No	9.95	69
	No	Yes	8.07	69
	Yes	Yes	9.94	69
Both Tax Rates and Revenue (Mauro)	No	No	9.64	50
	Yes	No	11.20	50
	No	Yes	10.68	50
	Yes	Yes	11.23	50
Both Tax Rates and Expenditure (Mauro)	No	No	11.19	68
	Yes	No	12.72	68
	No	Yes	12.52	68
	Yes	Yes	13.16	68
All tests use log of GDP per capita as the left-hand side variable and KOF Trade Openness Index, GDP deflator measure of inflation, and population as RHS variables. All tests control for country fixed effects.				