The growth effects of tax rates in the OECD†

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Abstract

This paper explores the merits of macro- and micro-based tax rate measures within an open economy 'fiscal policy and growth' model. Using annual data for 15 OECD countries we find statistically small, non-robust long-run growth effects of macro-based average tax rates on capital income and consumption, but some evidence for average labor income tax effects. Changes in 'micro' marginal income tax rates at both the personal and corporate levels yield statistically robust GDP responses of modest size. Both domestic *and* foreign corporate taxes appear relevant. In general, tax effects on GDP operate largely via factor productivity rather than factor accumulation.

Keywords: marginal tax rates, average tax rates, personal tax, corporate tax, GDP growth

JEL classification: 1124; 1130;

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1. Introduction

The empirical literature testing for the effects of taxes on long-run growth have generally been motivated by two foundational endogenous growth models. The first, Barro (1990) established a so-called 'inverted-U' relationship between steady-state growth and income tax rates in a model in which a 'distortionary' proportional tax on (capital and labor) income and a 'non-distortionary' consumption tax financed a mixture of utility-enhancing and private production-enhancing public expenditures.

Secondly, focusing more on the tax side of the government budget, a suite of related models by Devereux and Love (1994, 1995), Roubini and Milesi-Ferretti (1994a, b), Mendoza, Milesi-Ferretti and Asea (1997), and Milesi-Ferretti and Roubini (1998) established steady-state growth effects of labor and capital income and consumption taxes in endogenous growth models with physical and human capital. These papers demonstrated that whether – and how much – each of those taxes affect long-run growth depends on how 'leisure' is specified in individuals' utility functions, and the 'technology' of human capital production.[1] The key public finance characteristics of these models are that growth effects depend on the *form* of taxation, the *type* of public expenditure that is tax-financed and the 'technology' of goods and human capital production.

These models have subsequently proved popular as a basis for empirical testing. In the case of the Barro model this partly reflects the convenience of the 'distortionary/non-distortionary' tax and 'productive/non-productive' expenditure distinctions for identifying empirical proxies; see, for example, Kneller et al. (1999), Bleaney et al. (2001), Adam and Bevan (2005), Arnold (2008) and Gemmell et al. (2011). In addition, Mendoza, Milesi-Ferretti and Asea (1997) –

hereafter MMA (1997) – suggested a convenient method for estimating tax rates on capital and labor income and consumption, suitable for testing their models on macro data. Following Mendoza, Razin and Tezar (MRT, 1994), they proposed a method of calculating macro-level effective tax rates based on estimates of tax revenues and tax bases. Subsequently known as 'MRT tax rates', a variety of methodological modifications have been suggested[2] and have been used to examine tax-growth effects by, for example, Angelopoulos, *et al*. (2007), and Romero-Ávila and Strauch (2008).[3]

As well as providing a testable theoretical model MMA (1997) provided evidence in support of 'Harberger's superneutrality conjecture' that "although theory predicts that changes in tax rates affect investment and growth in the long-run, in practice tax policy is an ineffective instrument to influence growth" (MMA, p.99). Using their constructed MTR tax rates for an OECD country panel of 5-yearly averaged data, they found modest effects of capital and labor income taxes on investment (a 10 percentage point reduction in tax rates generating a 12% increase in investment). However, they found negligible effects on GDP growth a statistically insignificant 0.1-0.2% increase in GDP growth rates from the same tax reductions.[4]

Subsequent research on the tax-growth relationship in OECD countries, such as the studies cited above, has tended to find more evidence of adverse effects of various taxes on growth.[5] These subsequent studies have used a variety of tax rates, calculated using different methods, usually applied to annual or period-averaged data and, in some cases, yielding non-robust results for tax-growth effects.

It therefore remains unclear how far this evidence overturns, or confirms, the original MMA (1997) conclusion that tax policy is largely incidental for long-run GDP growth rates. In particular, criticisms leveled at the current evidence include:

1. The potential endogeneity of tax rates calculated from tax revenues – both MRT tax rates and the 'implicit' average tax rates obtained from revenue/GDP ratios.
2. Both these are *average* tax rates. While traditional models of labor supply, and more recent models of foreign direct investment (FDI), suggest roles for both average and marginal tax rates, most theoretical macro tax-growth models focus on *marginal effects*, though generally from models with proportional taxes, where average and marginal rates are equal (Li and Sarte, 2005, is an exception).
3. The empirical literatures on FDI and innovation have focused on the impacts of *corporate* or *personal* tax rates (with potential effects on GDP) rather than the capital/labor distinction of much of the macro tax-growth literature.
4. Recent tax-growth models such as Peretto (2003, 2007), and empirical studies by Lee and Gordon (2005), and Arnold et al. (2011), have proposed or examined tax effect on GDP transmitted via innovation and entrepreneurship effects on multi-factor productivity instead of, or as well as, via investment.

This paper addresses each of those aspects. We explore GDP responses to both aggregate average and micro-level marginal tax rates using both capital/labor and personal/corporate distinctions, and we examine how far estimated tax-growth effects are transmitted via investment or productivity. In addition, we examine the implications of theoretical open-economy growth models, such as Roubini and Milesi-Ferretti (RMF, 1994b), for tests of GDP responses to capital tax rates; in particular focusing on the role of international tax competition and capital/technology flows.

The remainder of the paper is organized as follows. Section 2 summarizes the relevant tax-growth theory including open-economy growth aspects. Section 3 discusses the choice of suitable tax rates and other issues that arise when 'taking theory to the data'. Section 4 first presents some evidence on the various tax rates for our sample of OECD countries, then discusses our regression results. Section 5 concludes.

2. Taxes and Growth in Closed and Open Economies: Theory

This section summarizes the main elements of the closed economy MMA (1997) endogenous growth model, as extended to incorporate foreign investment, following RMF (1994b). Since the former model at least is well-known, we only sketch its main components here.

MMA (1997) set out a model in which a composite good, *Y*, and human capital, *H*, are each produced from inputs of human and physical capital, *K*, using CRS technology. Thus:

$$Y = A(vK)^{\alpha}(uH)^{1-\alpha} \tag{1}$$

and $$\dot{H} = B[(1-v)K]^{\beta}(zH)^{1-\beta} - SH \tag{2}$$

where $1\text{-}v$ (z) is the share of physical (human) capital devoted to human capital accumulation, and u is the share of human capital used in goods production. Both types of capital depreciate at rate , and physical capital accumulates according to:

$$\dot{K} = Y - SK - C - G \tag{3}$$

where C is consumption and G is government expenditure (= tax revenues net of any transfers).[6] Each individual's time endowment is normalized to unity, with $(1-z-u)$ the fraction of leisure time. Individuals maximize their lifetime utility based on a CES instantaneous utility function having consumption, *C*, and leisure, *l*, as arguments.

MMA (1997) solve the first order conditions for this problem to obtain the balanced growth equilibrium. This uses the familiar 'fundamental growth equation':

$$\gamma = \theta(r - \rho) = \theta((1 - \tau K)RK - \delta - \rho) \quad (4)$$

in which the equilibrium growth rate of consumption, γ, is the difference between the rate of time preference, ρ, and the net after-tax rate of return on capital, *r*, adjusted by the inverse of the inter-temporal elasticity of substitution in consumption, B. Also, in (4) τK is the rate of capital income tax, and R^K is the pretax rate of return. It is useful to note three further conditions (in (5) to (7) below) used to derive the semi-reduced form expression for the growth rate in (8): These are:[7]

$$r = (1 - \tau K)\alpha A (vK)^{\alpha - 1} - \delta \quad (5)$$

$$r = (1 - \beta)B\left(\frac{(1-v)K}{zH}\right)^{\beta}(u + z) - \delta \quad (6)$$

$$\frac{u}{v} = \frac{\alpha}{1-\alpha}\,\frac{1-\beta}{\beta}\,\frac{(1-\tau K)}{(1-}\,\frac{1-v}{} \quad (7)$$

Hence: $\gamma = \theta$

$$\{[D(1 - \tau K)^{\alpha\beta}(1 - \tau H)^{(1-\alpha)\beta}(u + z)^{1-\alpha}]^{\frac{1}{1-\alpha+\beta}} - \rho - \delta\} \quad (8)$$

where *D* is a function of the production function parameters *A*, *B*, *a* and *fl*. Together (5) – (8) demonstrate both the direct effect of both T^K and T^H on growth (as shown in (8)) and the indirect effects - through (*u* + *z*) in (8), and operating through the factor ratios, *vK/uH* and *(1-v)K/zH* (as seen in (5), (6) and (7)). Though the consumption tax rate, τ^C, does not appear explicitly in (5) – (8), MMA show that

z^C affects the value of $(u + z)$ to the extent that there are labor supply effects. However, as RMF (1994a) demonstrate, if leisure is 'quality time' or it represents 'home production' (both of which embody human capital), or if labor supply is inelastic ($\epsilon = 0$), the term in $(u + z)$ drops out of (6) and (8) and there are no indirect growth effects from changes in z^C.

RMF (1994b) extend this model to capture small open economy aspects by allowing (a) perfect international mobility of capital, but immobile human capital; and (b) the government to fund its expenditures from bond issues and taxation of foreign assets (based on the residence principle) at rate, z''. The economy takes the world interest rate, r^*, as given, and domestic bonds and foreign assets are perfect substitutes. Thus net of tax rates of return are equated, introducing an additional expression for r in equilibrium growth:

$$r = r^*(1 - \tau F) \ . \tag{9}$$

It follows from the definitions of r in (4) and (9), that in equilibrium the interest rate on bonds, r, must equal the net-of-tax return on capital and the net-of-tax return on foreign assets. Further, from (9), it is not possible to set z'', z^K, and z^H independently in equilibrium since:

$$\tau F = 1 - r^* r \tag{10}$$

where, from (4) and (8), r is equal to:

$$r = [D(1 - \tau^K)\alpha\beta(1 - \tau H)(1-\alpha)\beta\ (u + z)^{1-}\ \overline{1-\alpha+\beta} - \delta \tag{11}$$

Therefore, tax rates $\alpha]$ on foreign and domestic assets, and human capital, are positively correlated. Other things equal, a rise in z^K, for example, will reduce the net-of-tax return on domestic investment and require an increase in z'' to avoid arbitrage opportunities leading to an outflow of capital.[8] As Rebelo (1992) notes, this residence-based (or 'worldwide') tax system in it's pure form implies capital tax rates determined by $max(z^K, z^F)$, where credits are given for any foreign taxes up to the value of domestic tax liabilities.[9] In such a system, the growth effects of domestic taxes continue to apply.[10] However, in the RMF (1994b) model, the introduction of a territorial tax system (as operates in some EU countries, Australia, New Zealand), in which foreign income is exempt from domestic taxation, implies that all capital locates abroad in equilibrium when $z^K > z^F$, and vice versa for $z^K < z^F$. Hence steady state growth is unaffected by changes in tax rates in this case (and there are no transitional dynamics).

In practice, most countries' tax systems for foreign capital income are neither pure 'residential' nor 'territorial' systems, and often differentiate between capital income earned under personal and corporate tax codes. As a result, in most countries z^F is determined by a combination of tax rates set domestically and set abroad, depending for example on treatment of non-domestic assets, the use of withholding taxes, availability of foreign tax credits, whether tax is levied on accrual or on repatriation, etc. Hence setting of z^F in conjunction with domestic tax rates as described above may not be straightforward, even where the objective is to set those rates to maximize growth in equilibrium.

A limitation of each of the models described above is that government expenditure affects neither utility nor goods productions. The Barro model does this. It omits a human capital production process, and labor supply is exogenous, but adds 'productive' government spending, *G*, to the production function (effectively replacing *uH* in (1)), with an income tax at rate z^Y funding total public spending: hence $z^Y = G/Y$.[11] There are constant returns to total 'public plus private capital' (though public expenditure is a flow rather than a capital 'stock'), and firms take government productive spending as given in making their decisions. Hence the fundamental growth equation (4) above becomes:

$$\gamma = \frac{1}{\theta}\{\alpha A(1-\tau^{Y})g^{(1-\alpha)} - \delta - \rho\} = \frac{1}{\theta}\{\alpha A(1-\tau^{Y})(\tau^{Y})^{1-\alpha} - \delta - \rho\} \qquad (12)$$

where $g = G/Y$, and $\{\alpha A(1-\tau^{Y})g^{(1-\alpha)} - \delta\}$ in (12) is the net-of-depreciation, after-tax return on capital. Here income taxes can be seen to have non-linear effects on growth, due to the combined effect of reductions in investment, via $(1 - \tau Y)$, and increased investment via the positive externality effect of government spending: $(\tau^{Y})^{1-\alpha}$. An important aspect of (12) for empirical testing is that, where government productive expenditure is controlled for, tax effects on long-run growth are expected to be negative, whereas if government expenditure is not controlled for, a non-linear, inverted-U relationship is expected.

The relationship between steady-state growth and the various tax rates can readily be illustrated for a set of parameter values in the above equations. Rather than simulate a particular economy, parameter values have been chosen to yield sensible values for real long-run growth rates (around 2-3%) at income tax rates around 0.2 to 0.4.[12] Using fairly standard values for key parameters, such as elasticities for production functions, rates of substitution, time preference etc (see Appendix 1), Figure 1A simulates the relationship between growth and tax rates $_{K\,H}$, and $_{Y}$, using equation (8) or (12). The Figure shows that, as capital and labor tax rates are raised in the MMA model, growth rates decline. Unsurprisingly, the rate of decline is greatest when both capital and labor rates increase, and is least when only labor income tax rates increase. This latter effect depends, of course, on the respective magnitudes of the assumed responses of capital and labor to tax rate changes. The profile shown for the Barro model reveals the inverted-U pattern with the adverse growth effects of income taxes dominating in this case at rates in excess of around 0.25.

Using (10) and (11) above, Figure 1B shows the relationship between domestic and foreign tax rates in the open economy extension to the MMA model. Many combinations of the three tax rates are of course possible and compatible with equilibrium, but illustrative simulations set $T_K = T_H$. The broken line represents the 45^o line where $T_F = T_K = T_H$, with the unbroken line showing the equilibrium values of T_F for each T_K (= T_H). This particular set of parameter values implies $T_F > T_K$ for T_K less than around 0.15, but $T_F < T_K$ at higher domestic tax rates. That is, raising the tax rate on domestic (capital and labor) income increasingly requires a lower tax rate on foreign capital income if investment is not to be attracted abroad by higher real returns. (The three tax rates approach equality again as domestic rates are raised further towards 1.0).[13] Conversely, if foreign capital tax rates are falling exogenously (e.g. because foreign corporate rates are declining and domestic firms' foreign investment income is not fully taxed at a higher domestic rate) then domestic tax rates will also have to fall to maintain equilibrium growth.

3. Taking Theory to the Data

The models described in section 2 identify circumstances in which empirical investigations could be expected to identify a negative correlation between long-run growth rates and a combination of domestic taxes on capital and labor income, foreign income and, possibly consumption. However, they are silent on a number of other empirically important aspects.

3.1 Average versus marginal effects

All those models treat tax systems as proportional so that marginal and average tax rates are equal. Clearly this is not the case in practice. Furthermore various theoretical arguments would lead us to expect different responses to marginal versus average rates. Labor supply responses at extensive and intensive margins are an obvious example, with implications for long-run output levels or growth rates. In addition, following Devereux and Griffith (1998, 2003), it is recognized that firms' investment location decisions will be more influenced by the effective *average* rate of corporate tax on investment. The effective marginal rate is, however, likely more relevant to subsequent investment choices, conditional on location, while choices over the location of profit across tax jurisdictions are more influenced by the statutory corporate rate (see de Mooij and Ederveen, 2008; Huizinga and Laeven, 2008).

These considerations suggest that *which* tax rates are relevant to an analysis of the impact of taxation on GDP growth will depend on the particular decision margins such as labor supply and investment, which may differ across countries, time and circumstances. Hence empirical testing should potentially examine both rates in an effort to disentangle the role of each or at least allow for either to have an impact.

3.2 Macro versus micro tax rates and endogeneity

A major advantage of the MRT (1994) tax rates for macro-level growth studies is that these tax rates capture average tax rates at that macro level whilst also being based on a clear conceptual measure of tax wedges – pre-tax and post-tax prices. Hence changes in those rates might be expected to capture the overall effect of changes in observed average tax burdens on economic activity. However like the 'implicit average tax rates' (IATRs) which are based on a measure of tax revenue relative to GDP, the MRT rates rely on tax revenues for their construction. Both potentially suffer from endogeneity to the extent that observed tax revenues are derived from the *ex post* tax base which, in turn, includes responses to any changes in statutory or effective tax rates at the micro level. Nevertheless the MRT rates are conceptually superior to the IATRs by avoiding the compounding effects of endogenous GDP responses relative to tax base responses.

Micro-based tax rate measures, on the other hand, such as the statutory or effective rates faced by individual suppliers of labor, investors or firms, are probably a better conceptual measure of the tax rate that induces a behavioral response by the individuals in question. But it remains unclear which micro-based rates are likely to be most relevant and how pervasive their effects are likely to be at the macro level. For example, if the top marginal tax rate is increased by 10 percentage points but the average revenue-based MRT labor tax rate changes very little, it is unclear what lies behind these differences. It may reflect large and widespread negative behavioral responses to the increased top rate which largely cancel out the direct increase in revenues, or there may be negligible responses to the marginal rate increase, or the relevant taxpayers affected may simply be small in overall revenue terms, when viewed at the macro level.

There is therefore a trade-off between using micro-based tax rates that are relatively less contaminated by endogeneity concerns than macro-based tax rates, but which are capturing tax changes of unknown salience at the macro level. Ideally nested regression models that allow for output responses to both types of tax rate may provide some insight into their relative merits. We pursue this in section 4.

Finally, recent research on the macroeconomic effects of taxes has increasingly focused on foreign direct investment (FDI).[14] To the extent that these responses predominate among broader capital income responses, *corporate* rates become more relevant – either statutory or effective. Further, the recent evidence of Devereux *et al.* (2008) provides strong support for the view that, since the early 1980s, OECD countries have increasingly competed over corporate tax rates (statutory and effective) to attract mobile capital. If this has spillover effects onto aggregate economic growth, any reduced-form relationship between *domestic* tax rates and GDP growth rates may miss out on a key determinant, namely the interaction between domestic, and competing foreign, tax rates.

The Devereux *et al.* evidence is also consistent with the prediction of the open-economy endogenous growth models discussed above; namely, that in equilibrium, tax rates on foreign-sourced and domestically-sourced capital will be jointly endogenously determined. These theoretical models generally have no transitional dynamics: introducing taxes induces an immediate shift to a new equilibrium. But testing for international tax aspects empirically, especially with annual data, needs to recognize that over shorter periods international capital tax rates may diverge from equilibrium settings and induce temporary investment flows with potential impacts on GDP. Furthermore, in a 'many country' context, and with international competition over tax rates, it is less clear how tax rates on domestic and foreign investment can be set in conjunction in equilibrium. The foreign rates consistent with growth maximization are likely to vary, depending for example, on the main sources and destinations of FDI and other capital flows.

Devereux *et al.* (2008) argue that OECD data supports evidence of increasing openness over time for many countries but that some remain more insulated from international flows. For this latter category, domestic tax rates would be expected to assume a greater importance, relative to other countries' settings. Overall, this literature suggests that trying to identify empirically the respective roles of foreign and domestic tax rates on FDI or GDP is likely to be complicated by the heterogeneity of circumstances that apply across countries and time.

3.3 Growth effects via investment or productivity

As noted in the Introduction, the channel by which taxes affect GDP in the theoretical models described in section 2 is generally investment in physical and human capital. However, a number of more recent theoretical models, or *a priori* arguments, have stressed productivity-related channels though which taxes may affect GDP. For example, Peretto (2003, 2007), and Lee and Gordon (2005) argue for tax-growth effects via impacts on innovation or entrepreneurship. Arnold et al. (2011) provide some empirical support for tax effects on productivity at the firm level.

While this does not undermine evidence obtained from observing the reduced-form relationship between taxes and GDP growth, it does suggest that evidence on the direct relationship between taxes and investment is not the only, nor necessarily most important, means by which taxes can affect GDP growth. In section 4 we therefore look for tax effects on GDP growth using three alternative approaches. (i) Examining reduced-form regressions in which tax rates enter regressions either with, or without, investment variables; (ii) the direct impact of tax rates on investment; and (iii) allowing capital and other inputs to impact on GDP in a 'first stage' then test for tax effects directly on this 'residual' growth variable (a form of multi-factor productivity growth).

3.4 The government budget constrain (GBC)

As the Barro (1990) model emphasizes, and most recent tests now recognize, it is important to accommodate the GBC when testing empirically for an aggregate impact of taxes on growth. That is, since the government budget is a 'closed system', any change in one element must be accompanied by equivalent changes in at least one other element. As a result, any government budget items not included in the estimating equation are implicitly the funding elements associated with the included budget categories. Recent empirical tests of the impact of fiscal variables on growth have, following Barro (1990), typically summarized these as 'distortionary'/'non-distortionary' taxes, 'productive'/'unproductive' expenditures and budget deficits; see Gemmell *et al* (2011), Adam and Bevan (2005).

Previous use of implicit' tax rates (IATRs), measured by revenues/expenditures/deficits as ratios of GDP, allow the GBC to be specified 'exactly' in growth regressions with one or more categories omitted (the implicit financing) to avoid perfect collinearity.[15] However, when statutory or effective marginal or average tax rates are used in regressions the 'omitted financing element' is less clear, making appropriate interpretation of parameters less obvious. To reduce this problem, we always include budget deficits and 'productive' public spending as 'fiscal controls' in regressions reported below.

3.5 Control variables

Controlling for non-fiscal determinants of growth is not straightforward. Most previous exercises have attempted to control for standard growth model determinants: labor, capital (more usually, investment rates) and human capital, with or without various other macro variables (inflation, trade openness, convergence effects, etc). However, since taxes are hypothesized to impact on output partly via physical and/or human capital investment, arguably these controls will capture some of the fiscal effects of interest, leaving only productivity-transmitted effects to be picked up by tax rate variables. This problem is compounded when poor proxies are relied on to measure fiscal impacts.

We therefore begin by comparing regressions respectively with/without fiscal or control variables. We use four control variables: labor force growth, human capital growth (measured as years of schooling embodied in the labor force)[16], the ratio of private non-residential investment to GDP, and (the log of) lagged per capita GDP to capture convergence effects. Finally, the limited availability of some fiscal data limits our sample coverage to 15 OECD countries, data for most countries spanning the late-1970s to the mid-2000s.[17] To facilitate comparisons across specifications we generally use a common set of countries in all regressions. Using effective tax rate data limits the sample to 12 countries from 1980.

3.6 Econometric methods

Our analysis uses two methodologies applied to annual panel data. Firstly, we use the pooled mean group (PMG) methodology proposed by Pesaran *et al* (1999). This allows a dynamic specification in which short- and long-run effects differ, and heterogeneous constants and marginal short-run effects across countries can be accommodated, while maintaining homogeneity of the long-run responses. The major advantage of this approach is that it makes full use of the available time-series information and provides estimates of long-run parameters without the need for long lag structures. For similar regressions - but based on IATRs - Gemmell e*t al.* (2011) and Arnold *et al.* (2011) report that the PMG estimator performs better than alternative dynamic fixed-effects or mean group (MG) estimators in this context.

Concern over endogeneity is perhaps the major source of unease over the reliability of previous tests of tax rates on growth, despite various attempts to control for this. Pesaran (1997) contends that the PMG approach continues to be applicable even if the independent variables are endogenous, so that valid asymptotic inferences can be made on the short-run and long-run parameters from this method.[18] Nevertheless, given limitations in the PMG's ability to deal with endogeneity via contemporaneous feedbacks between g_{it} and F_{it} in (3), in small samples, where relevant we further test the robustness to our results to possible endogeneity.[19]

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The resulting regression equation which we estimate by PMG or IV methods is of the following 'error correcting' form:

$$\Delta g_{it} = \phi_i(g_{i,t-1} - \beta F_{i,t-1}) + \sum_{m=1}^{M-1} \lambda_{i,m}\Delta g_{i,t-m} + \sum_{k=0}^{K-1} \gamma_{i,k}\Delta F_{i,t-k} + \varepsilon_{i,t} \quad (13)$$

where i denotes the country, t is time, g is the rate of growth of GDP, F is a matrix of fiscal and control variables and $\varepsilon_{i,t}$ is a classical error term. The parameter ϕ vectors and β respectively capture the error correction and (homogeneous) long-run growth effects, while $\lambda_{i,m}$ and $\gamma_{i,k}$ capture the heterogeneous short-run responses to g and F respectively (with lag lengths $M, K = 1$). We focus on results for the long-run parameter vector, β, which identifies whether fiscal and other effects on *g* persist into the long-run. That is, a value of $_J\boldsymbol{\theta} \neq 0$, implies that any observed short-run effects observed in the annual data do not decay towards zero over the 'long-run'. Rather, non-zero effects persist within the time period of around 30 years in our dataset. With the number of sample countries, *i*, approximately half the number of time-series observations per country, *t*, and the PMG method allowing for both long-run and short-run (annual) income dynamics, it might be expected that results from regression in the form of (13) will primarily be driven by the time-series properties of the panel rather its cross-sectional dimension.

3.7 Tax rate data

The OECD sample coverage – of countries and years - is largely determined by overlaps in available datasets for tax, other fiscal, and 'control' variables. Average tax rates for capital, labor and consumption are the MRT-type rates calculated by McDaniel (2007), and used in McDaniel (2011), for a sub-sample of OECD countries, based on the original MRT (1994) approach and the later amendments from Carey and Rabesona (2002).

Marginal tax rate measures are more difficult because suitable macro-based estimates are generally only available for cross-section or long-run period-averaged data.[20] Using micro-based rates requires choices over which, of several possible, tax rates. These marginal rates are generally available for 'personal' and 'corporate' tax categories rather than capital/labor/ consumption distinctions.

For personal income taxes, because of their wide availability, we use the top statutory personal income tax rates from the Office of Tax Policy Research (ITPR) at the University of Michigan, and the OECD Tax Database. We regard these as primarily measures of marginal tax rates on labor income though equivalent rates on personal capital income are often similar.[21] When used in regressions in conjunction with an average tax rate (such as the MRT rate on labor income) these marginal rates might be expected to capture a combination of the effects of labor income tax progressivity and/or tax base broadening/narrowing.

For corporate-level capital income tax rates we use (i) the statutory corporate rate at central and (where available) sub-central level from the OECD Tax Database; and (ii) the 'forward-looking' effective average and marginal tax rates (EATRs, EMTRs) calculated by Devereux *et al* (2002) and updated by the Institute for Fiscal Studies (IFS, 2005). These effective rates are estimated for hypothetical firm-level investments in different countries and years based on information, for example, on statutory rates, effective depreciation allowances, type of financing, inflation and interest rates, etc.

By using these rates we hope to capture effects on GDP indirectly through investment, FDI, productivity or profit-shifting. Any effect on corporate profit-shifting would generally have little direct effect on *real* economic activity - to the extent that they represent pure accounting effects via transfer pricing. However, as Grubert and Slemrod (1998) argue, real resource transfers by multinationals are often complimentary to profit-shifting strategies. In addition, countries' *measured* GDP will be affected, even if real activity is unchanged, to the extent that shifted profits are captured in National Accounting profit measures and other output/input price effects.

3.8 Foreign tax rates

We have argued that foreign corporate tax rates are potentially relevant to domestic investment decisions, and should therefore be included in an empirical growth model. For each country in the sample we construct a weighted average of statutory tax rates, EATRs and EMTRs, in other countries. In their analysis of corporate tax competition, Devereux *et al.* (2008) use countries' GDP and recent

FDI flows as weights.[22] We use as weights: (a) the inverse of distance; (b) GDP; and (c) unweighted; i.e. equal weight. [23] Since the ‘economic distance’ that influences corporate responses to international tax differences may be reflected in a variety of factors, we explore all three of these weighting schemes.

In fact, we find that (a) and (c) behave similarly and mainly report results for the distance-weighted case. GDP-weighting generates unreliable estimates, probably because GDP-weighting leads to an emphasis on just a few countries. Of the 15 countries included in most of our regressions, the US accounts for around 50% of total GDP, with 75% accounted for by just four countries: the US, Germany, UK, France. If, as Devereux *et al* (2008) argue, tax competition causes country *i's* tax rates to react to country *j*'s tax-setting choices and *vice versa*, then individual country corporate tax rates are endogenous. Their empirical solution is to instrument directly for each country's tax rate using the determinants of *other* sample counties' tax rates. We follow a similar approach, discussed further in section 4.

Finally, if foreign tax rates are important, this may include countries outside our OECD sample. Obvious examples would be developing country tax havens though, for those countries, profit-shifting is often alleged to be the primary tax response – with a more tenuous connection to GDP growth rates. Unfortunately, to include foreign tax rates for a wider group of countries requires annual data on all the relevant tax rate variables used in our analysis and these are generally unavailable on a consistent annual basis.[24] We therefore do not include additional non-OECD country tax rates, but recognize that our included foreign tax rate variables may be proxying for a wider group of relevant countries. Since international trade and investment data suggest that intra-OECD flows (and FDI stocks) dominate total world flows/stocks, we expect any effects of omitting other foreign country tax rate variables to be small.

4. Empirical Results

4.1 *Trends in tax rate data*

Figure 2 shows average MRT tax rates for consumption, capital and labor income (left-hand panels) from McDaniel (2007), and the statutory/effective corporate, and top statutory personal income tax rates (right-hand panels). The figure shows unweighted averages for our sample countries and one sample standard deviation bands.[25]

The figure indicates a clear tendency for average consumption and labor tax rates to rise since the mid-1970s but no similar trend for capital tax rates. Sample statutory corporate tax rates can be seen to begin a downward trend from the late 1980s, initially fairly rapidly, then more steadily and this appears to be continuing. This pattern is also reflected in the IFS (2005) data on EMTRs, with a substantial decline (on average) during the 1980s but a relatively flatter profile in the 1990s. A similar picture emerges for the top personal tax rate with a rapid decline phase throughout the 1980s and modest declines thereafter.

More generally these data suggest quite different patterns over time in the average rates of labor, capital and consumption tax compared to marginal rates applicable to corporate and top personal incomes. The data on corporate/capital tax rates are consistent with observations from Devereux (2007) that corporate tax base broadening in association with declining statutory marginal rates over time has ensured stable or increasing average 'revenue-to-base' tax rates.

Correlations across tax rate measures

	Statutory top personal	Statutory corporate	Average capital	Average labor
Statutory corporate	0.490*			
Average capital	-0.064	0.011		
Average labor	-0.190*	0.249*	0.351*	
Average consumption	0.008	-0.130*	0.201*	0.445*

* Significantly different from zero at 1% or less.

Correlations across the tax rate measures are given below Figure 2 (EMTRs are excluded because of the shorter time-series). It can be seen than none of the tax rates is highly correlated with each other; the highest correlation (0.49) being between the top personal and corporate rates. Among the average MRT rates, the correlation between consumption and labor tax rates is highest at 0.45, with the capital-labor tax rate correlation at 0.35, and consumption-capital at 0.20. These average rates are not highly correlated with the marginal rates, no doubt partly reflecting the different tax bases relevant to the marginal rates, compared to the average rates shown. Hence, including any or all of those tax rates in a growth regression is unlikely to suffer from high collinearity among the different rates.

4.2 *Regression results: testing control and alternative tax rate variables*

In this sub-section we apply the various tax rate measures to test empirical analogues of the models described earlier, based on Pooled Mean Group regressions of the form in equation (13). In particular we re-test the Mendoza et al. (1997) hypothesis that growth responds to taxes on capital, labor and consumption, but allowing for the insights from empirical tests of the Barro model. In particular, we follow the methodology proposed by Kneller et al (1999) and Bleaney et al. (2001) to allow for productive and non-productive public spending and focus on marginal tax rates for taxes hypothesized to distort investment decisions. Reported regression parameters relate to the long-run parameter vector , in equation (13). These parameter estimates should be interpreted as persistent 'equilibrium' effects within the time-dimension of our data – around three decades – after accounting for short-run dynamics and error-correction processes.

We begin in Table 1 by considering how well a model that excludes all fiscal variables explains OECD countries' GDP growth.[26] Regression [1] can be interpreted as a form of growth-accounting regression (including per capita income convergence), but with an investment/GDP ratio rather than a capital growth rate on the RIFTS. As a result, parameters on inputs are not necessarily expected to sum to unity. This simple relationship performs fairly well, supporting positive growth effects associated with larger investment, labor force and human capital growth (though human capital is not statistically significant). Strong convergence effects are evident – countries and years in which per capita income is high tend to be associated with lower subsequent GDP growth.[27]

Regressions [2] and [3] in Table 1 introduce fiscal variables.[28] First the 'fiscal control' variables – productive spending levels and budget surpluses (as % of GDP) – aim to take account of the government budget constraint within fiscal-growth regressions as discussed above. It can be seen that both variables take positive signs as expected: more productive spending and larger surpluses are growth-enhancing but are statistically significant only in [3]. Regressions [2] and [3] (where [2] adds the MRT tax rates and [3] instead adds the top personal and corporate marginal rates), allow comparisons of the two sets of tax variables before nesting their effects in regression [5].

Regression [2] yields negative and statistically significant effects on growth associated with higher average capital and labor income tax rates but positive or zero effects associated with the average consumption tax rate. This is similar to the result obtained by MMA (1997) though their parameters were generally smaller and statistically insignificant, and the capital tax rate parameter was sometimes positive (MMA, 1997, Table 5). MMA (1997, p.122) did report, however, that 'some limited evidence of statistically significant effects of taxes on per-capita GDP growth was found using a panel of annual data'. They interpret this as likely capturing short-run transitional relationships. Here, the short-run dynamic adjustments explicitly allowed for in the PMG approach together with evidence of statistically significant long-run parameters, suggest that our observed tax effects are persistent, at least within the time-series dimension of our data.[29]

Results for regression [2] also suggest that the 'fiscal control' variable parameters are small and statistically weak in this specification, while the statistically strong parameter on the average labor tax rate, at -0.34, is perhaps implausibly large in absolute value. Regression [3] shows that, when only our top personal (P_i-top) and statutory corporate tax (C_i-stat) are added to the regression specification, these perform as predicted with statistically significant negative signs but modest absolute values. These values, of -0.02 or -0.06, imply that a 10 percentage point fall in the top personal or corporate rate (equivalent to around a one standard deviation change in Figure 2) is predicted to increase annual GDP growth by 0.2 or 0.6 of a percentage point (e.g. from 2.0% to 2.2% or 2.6%). In addition, parameters on fiscal control variables in [3] become (absolutely) larger and statistically significant, and 'other controls' all perform with the expected signs. This type of sensitivity has long been known for these fiscal control variables (Kneller et al, 1999).

Regression [4] adds the mean value of 'other countries' corporate tax rates – that is, the average of the *j=n–1* 'foreign' countries in the sample, where this value therefore differs for each 'domestic' country *i*. This 'foreign' aspect is explored in more detail below, but here it would appear that the addition of an 'average' foreign corporate tax rate contributes no useful additional information, and other parameters remain largely unaffected. This absence of direct foreign tax effects also suggests that foreign tax rates may be suitable instruments for domestic capital/corporate tax rates, explored further below.

When both the average MRT, and marginal personal/corporate, tax rate variables are nested within a single model in regression [5], the parameters on the statutory/marginal tax rate variables, P_i-top and C_i-stat, remain largely unchanged and well defined. Parameters on the MRT tax rates $_{i,K}$ and $_{i,C}$ however both become positively signed and statistically so (or nearly), while the parameter on

$_{i,L}$ becomes absolutely smaller at a more plausible, but non-trivial, -0.06 (t = -2.72). That is, holding the top marginal rate constant, a 10 percentage point fall in the economy-wide average labor tax rate (e.g. from 0.30 to 0.20) is associated with increased growth by 0.6 of a percentage point (e.g. 2.0% to 2.6%).

The appropriate interpretation of the fiscal parameters in [1] to [5] is complicated by the fact that the implied 'omitted elements' of the government budget constraint are less clear in these regressions compared to when implicit average tax rates are used. The omitted GBC elements in Table 1 regressions (that may change in association with changes in the included fiscal variables) include government 'unproductive' (consumption) expenditures and tax revenues not captured by the included average tax rate variables. Since the three included MRT tax rates represent the lion’s share of total tax revenues, the included tax rates should perhaps be interpreted as the effect of changing tax rates to finance a change in government consumption expenditures. If, in addition, the Barro (1990) model prediction is correct in practice – that these have no growth effects – then the fiscal parameters can be interpreted approximately as the ‘net’ effect of changes in the included tax variables on long-run GDP growth.

One way to interpret the fiscal parameters in Table 1 is that, inclusion of the three average MRT tax rates helps control for any endogenous revenue effects associated with changes in marginal personal and corporate rates. Hence the parameters on P_i-top and C_i-stat can be more reliably interpreted as the GDP growth response to exogenous changes in these marginal rates (or, at least, changes independent of revenue-related feedback effects. Discretionary changes to marginal rates could still represent an endogenous political response to observed GDP growth). However, since tax bases and hence revenues, generally respond positively to faster economic growth, the parameters on the MRT tax rates may be contaminated by endogeneity. This might underlie the estimated positive capital tax rate parameter if it reflects the effect of higher rates of GDP growth on capital tax revenues (the latter growing faster than the capital tax base via fiscal drag).

Another interpretation is that the parameters on P_i-top and C_i-stat, with average tax rates held constant, could reflect the impact of increased progressivity. Alternatively, with marginal tax rates held constant, an increase in the average MRT rates could represent the effects of base-broadening. If so, these average tax rates may primarily capture income effects, and the positive parameters on ${}_{i,K}$ are less surprising than at first sight. Under this interpretation, capital/corporate tax changes which simultaneously increasing average and marginal capital tax rates have an ambiguous net effect on growth. For labor taxes, the evidence more clearly supports net negative effects from average and marginal rate increases. In this case a constant or declining average labor tax rate could occur with a rising top personal rate if lower rates of personal tax are reduced or thresholds increased.

Whatever the appropriate interpretation, it is clear from Table 1 that inclusion of the MRT tax rates in [5] has negligible effect on the size of the parameters on the two marginal tax rates (if anything, they become more negative), but improves their precision slightly. We postpone further discussion of these aspects until after further robustness testing of our tax rate, and other, variables.

4.3 *Including foreign tax rates*

The open economy growth models discussed in section 2 left open the question of where the final tax rates applicable to income from foreign assets (the $_{i,}{}^{F}$s) are set – by the domestic or foreign tax authorities. Devereux and Hubbard (2003) and Devereux *et al.* (2008) show that for investment location decisions both are relevant with their precise relationship depending on the nature of the investment tax regime, such as the treatment by domestic tax authorities of any foreign tax paid (credit versus exemption regimes; the degree of deferral allowed etc.). Importantly, Devereux and Hubbard (2003) develop a model in which profit-maximizing firms choose between exporting to, or investing in, foreign countries. They show that, whether foreign tax rates are higher or lower than in the domestic economy is important in determining whether, and where, firms invest abroad.

On-line Appendix 2 provides an illustration based on the Devereux and Hubbard model. This demonstrates that, at least under the more common 'foreign tax credit' system (with or without deferral), whereby taxes paid abroad are partially credited against domestic tax liabilities, investing in foreign assets in *lower* tax countries is strongly favored over investing in *higher* tax countries. Importantly, this shows that if both ‘high tax’ and ‘low tax’ foreign countries reduce their tax rates, but country tax rate rankings do not change, investment is incentivized to move to the ‘low tax’ country but not (or less so) to the ‘high tax’ country despite both having reduced their tax rates. This process underlies the hypothesized ‘race to the bottom’ in corporate tax competition. It may be expected to affect GDP growth directly through the inflows of foreign investment and enhanced technology (productivity), and the indirect spillover effects on domestic firms.

These asymmetric effects of foreign inflows suggest the possibility that, in assessing effects on investment or productivity (and hence growth), the foreign country tax rates relevant to any individual country, i, may differ depending on that countries position in the international ranking of capital tax rates. In particular, among the $j=n-1$ ‘foreign’ countries, changes in capital tax rates in country j, when $t_{j,K} > t_{i,K}$, may have less impact on investment and technology flows between i and j than when $t_{j,K} < t_{i,K}$.

To explore this possibility, we construct foreign country averages of corporate tax rates, as described in section 3, but distinguishing between those countries (and years) where $t_{j,K} > t_{i,K}$, and those where $t_{j,K} < t_{i,K}$, using the statutory (or effective) corporate tax rate to measure t_K. In our regression analysis we refer to these tax rates as C_j-stat-L and C_j-stat-H respectively for ‘low’ and ‘high’ tax countries. Note that, if an individual country’s corporate tax rate falls or rises over time such that its position in the cross-country ranking changes, the composition of countries in its C_j-stat-L and C_j-stat-H averages will also change.

We use these tax rates in three ways. Firstly, if foreign corporate tax rates exert an independent influence on GDP growth, they may be added to our previous regressions. Secondly, if international corporate rates are set inter-dependently (as seems likely at least for more open OECD economies) we need to allow for this inter-dependence of corporate rates. Thirdly, a plausible alternative hypothesis (and one that is consistent with the theoretical modeling earlier) is that foreign tax rates have no direct impact on GDP, but only via their effects on the setting of domestic corporate rates. This can be tested by instrumenting for C_s-stat using the foreign average rates, rather than including those foreign rates directly in the growth regression.

Table 1 shows the results of testing foreign corporate tax rates. We begin by omitting the MRT variables from the PMG regression in [6] and replacing C_i-stat from regression [3] with both C_i-stat-H and C_i-stat-L. Regression [7] expands [6] by adding the MRT tax rates for labor and capital. These regressions continue to support the previous negative association between growth and the top personal, and domestic corporate, tax rates. MRT tax rates on capital and labor continue to take positive and negative signs respectively but are not statistically significant (at 10%). The parameters on C_i-stat-H and C_i-stat-L suggest, as predicted, a positive association between the tax rate in 'low tax' foreign countries and domestic growth rates with effectively no association with C_i-stat-H. However, neither parameter is statistically strong.

When we omit the domestic corporate rate, C_s-stat in [8] – effectively assuming only foreign tax rates directly determine domestic GDP growth – the results for C_i-stat-L are unchanged, but C_i-stat-H is now statistically significant. This strongly suggests that the effects of C_i-stat-H, the foreign corporate tax rate, on growth operate at least in part through C_i-stat, its domestic counterpart. If domestic rates are determined by foreign tax rates, such that the latter affect GDP growth only indirectly, we can instrument for C_i-stat using the foreign corporate tax rate averages. We do this in the instrumental variable regressions, [9] and [10] (see Table 2) using C_j-stat-L (both distance-weighted and GDP-weighted): the parameter on C_i-stat continues to be robustly negative and similar in magnitude to previous regression estimates. Parameters for the MRT tax rates also become more robustly estimated though larger (in absolute value) and signs remain negative (positive) for the labor (capital) average tax rate.[30]

Finally regressions [11] and [12] omit our control for private non-residential investment. If most of the impact of taxes on GDP growth is through investment responses, then omitting investment should increase the observed association between the fiscal variables and GDP growth − compared with the equivalent regressions [9] and [10]. In fact, parameters on our marginal tax rates remain largely unaffected while those on the MRT average tax rates become absolutely smaller. This would seem to suggest that, to the extent that fiscal variables are associated with GDP growth, the primary mechanism is not via investment.[31]

The regressions in Tables 1and 2 therefore provide broad support for the conclusion that lower GDP growth tends to be associated with higher personal, and domestic corporate, marginal tax rates. There is also a positive association between GDP growth and corporate tax rates in foreign countries initially below the country of interest. However, these latter effects may best be thought of as occurring through their effect on domestic corporate rates. For example, for a given country *i*, as foreign corporate rates fall over time, they simultaneously drive down country *i*'s corporate rate. For labor tax rates, results generally support the view that higher average and marginal tax rates (the latter captured by the top personal rate) are each associated with lower GDP growth. In all cases these results relate to long-run parameters suggesting that observed annual changes tend to persists over several years.[32]

4.4 *Results using effective corporate tax rates*

In Table 3 we report on the impact of capital tax rates on growth using the forward-looking effective average and marginal corporate tax rates from IFS (2005). These effective rates are hypothetical rates applicable to specified investment types undertaken under alternative assumptions regarding, for example, the relevant rate of interest, inflation rate, method of financing (debt, equity) etc. IFS (2005) calculate ETRs using a number of alternative assumptions for each year for 12 of the countries in our sample.[33]

These measures of taxation have the advantage over actual tax rates (revenue-based or otherwise), that they do not include the response to current or past changes in policy. For that reason they might reasonably be regarded as genuinely exogenous though, of course, they are not 'macro' tax rates and may therefore not provide a suitable proxy for 'aggregate' capital tax rates changes. They are also available for a more limited sample of countries and years. Nevertheless, in view of their exogeneity properties we consider them as measures of average and marginal capital tax rates – at the corporate level. In view of the arguments that, for many investment location decisions, it is the average, rather than marginal, tax rate that is relevant, we consider both effective rates. However, there are two important limitations on the use of these effective rates.

Firstly, the average and marginal rate measures tend to be highly correlated within countries. [34] To minimize this effect in our regressions we include the

EMTR, and the *difference between* the EMTR and EATR. When an EMTR is included in regressions, parameters on the *difference* variable should therefore be interpreted as the impact of changes in the effective average tax rate, for a given effective marginal rate. The effect of EMTR changes will be captured by *both* parameters. Since corporate taxes tend not to display progressive structures, in these data an increase in the EATR, for a given EMTR, primarily reflects base broadening via limitations to corporate tax deductions such as depreciation allowances.

Secondly, these country- and year-specific effective tax rate measures tend to move together over time, in part because their construction involves some common components, such as annual inflation and interest rates. As a result testing for separate responses to ‘foreign’ and ‘domestic’ effective tax rates is likely to be less reliable. To help combat this we generally enter our $EMTR_i$, $EMTR_j$-H, $EMTR_i$-L variables only one (or at most two) at a time in regressions.

Table 3 reports regressions similar to those in Table 1 but using these *effective* average or marginal corporate tax rates. We focus first on results for labor tax rates. Results for the top marginal income tax rate, P_i-top, can be seen to be consistently negative and significant in Table 3 regressions, with parameter estimates, around – 0.02 to –0.04, that are similar to, or (absolutely) slightly smaller than, those in Tables 1 and 2. Unlike the top personal rate, the parameters on the average MRT tax rate for labor, $_{i,L}$ appears to be non-robustly estimated in Table 3, with estimates varying between –0.02 and +0.25.

For corporate effective tax rates however, consistent with the results from Table 2, regression (1) in Table 3 confirms a negative association between a county’s $EMTR_i$ and GDP growth, but a positive association with $EMTR_j$s in foreign ‘low tax' countries ($EMTR_j$-L). When the domestic $EMTR_i$ is omitted and $EMTR_j$-H is introduced in regression (2), this appears to have little effect on the estimated parameter on $EMTR_j$-L, while the parameter on $EMTR_j$-H confirms no additional effect on growth from those 'high tax' countries.

Regressions (3) and (4) introduce the $EATR_i$ difference variable ($EMTR_i$ – $EATR_i$), with and without $EMTR_i$. Firstly, these regressions confirm a positive, statistically significant parameter associated with low tax foreign countries, $EMTR_j$-L, at around –0.05. Secondly when both $EMTR_i$ and ($EMTR_i$ – $EATR_i$) are included in (4) it is clear the primary association between effective tax rates and growth is via the *difference* between the $EMTR_i$ and $EATR_i$. This is confirmed by comparing regressions (1) and (3): in regression (3) where $EMTR_i$ is excluded the parameter estimate on ($EMTR_i$ – $EATR_i$) is –0.075, and exceeds that on $EMTR_i$ of –0.35 in (1) where ($EMTR_i$ – $EATR_i$) is excluded.[35]

Despite the limitations noted above on these EMTR/EATR variables and sample, these results offer surprisingly robust confirmation of those in Tables 1 and 2; namely that the top marginal labor tax rate is robustly negatively associated with GDP growth, while results for the average labor tax rate are less clear. Similarly, domestic and foreign corporate tax rates are respectively negatively and positively associated with GDP growth, as found earlier. These *corporate-level* capital tax rates would appear to be more consistently associated with GDP growth with the expected signs.

4.5 *Further specification testing*

In this, and the next, sub-sections we investigate the sensitivity of our results to the inclusion/exclusion of various macroeconomic control variables. We previously demonstrated that our tax results appear not to be sensitive to excluding private non-residential investment from our regressions. Here we investigate the impact of (a) omitting the lagged GDP per capita ‘convergence’ term; (b) adding other macro controls – inflation and trade openness; and (c) omitting all foreign tax effects. Sub-section 4.6 examines the effects of allowing all macro input variables (investment, labor force and human capital) to impact on growth first and then test for tax effects on the resulting ‘residual’ measure of multi-factor productivity growth. As a benchmark we use PMG regression [7] in Table 1 - which includes all foreign and domestic tax rates (except the average consumption tax rate).

Results are shown in the right-hand columns of Table 2, which repeats regression [7] for comparison. In regression [13], omitting the per capita income convergence term, $ln(\text{GDP p.c.})_{t-1}$, has no impact on the signs, and little impact on the statistical significance, of the personal marginal tax rate or the various corporate tax rates – though C_i-stat-L now becomes highly statistically significant. However, both the labor and capital average MTR tax rates appear to be sensitive to this change in specification – with changes in parameter signs and standard errors. It would seem therefore that these ‘macro’ tax rates are sensitive to the inclusion/exclusion of other macro controls but our ‘micro’ tax rates are not.

A number of recent studies, such as Lee and Gordon (2005) and Angelopoulos *et al* (2007) have added further macroeconomic control variables to their fiscal-growth regression – mainly inflation rates and trade openness variables (but have ignored the ‘openness’ aspect to corporate tax impacts). When we add those variables to Table 1 regressions (not shown in Table 2), using [5] and [7] which respectively exclude and include foreign taxes, we find little effect on the sign or statistical significance of the parameters on our tax rate variables, while the

inflation and openness variables enter with the expected signs (negative and positive respectively) or are close to zero.

We noted earlier that adding a combined 'foreign corporate tax rate' in regression [4] was largely redundant, while including 'low' and 'high' tax regimes supported the inclusion of the former. In regression [14] all foreign corporate tax rates are omitted and it can be seen that the parameter on the domestic corporate rate is little affected – but with a slightly smaller point estimate and smaller variance compared to [7]. Since this parameter estimate is also similar to that obtained using IV methods (based on foreign tax instruments) in regressions [9] and [10], this would suggest that results for the corporate tax rate are highly robust to alternative approaches to capturing their effect on long-run domestic GDP growth rates. As suggested by Devereux *et al.* (2008), a high degree of co-determination of these foreign/domestic rates seems plausible.

4.6 *'Residual growth' regressions*

As noted above, tax rate effects on growth may operate primarily through factors such as innovation and entrepreneurship that affect factor *productivity*, and our earlier evidence seems to suggest that the identified tax effects did not operate via physical capital investment. Of course, omission of investment from growth regressions may induce omitted variable bias whenever these control variables are a function of non-tax, as well as tax, variables.[36] An alternative is to disallow *any* impacts of tax via our control variables and compare the resulting estimates with those obtained above. To the extent that these parameters are similar, it would suggest that tax impacts on GDP growth operate primarily through productivity rather than factor inputs.

To test this we use residuals from a regression similar to regression [1] in Table 1 but excluding the lagged per capita income term. These residuals represent a form of total factor productivity (TFP) growth measure, being the growth rate of GDP net of any associated changes in investment, labor and human capital growth. We refer to this as 'residual growth', g_R, and examine how far our fiscal variables can explain this residual.

Regressions [15] and [16] in Table 2 report PMG regressions for g_R specifications that respectively exclude and include foreign corporate tax rate variables. These regressions may be compared with the GDP regressions [14] and [7] respectively. We would not suggest that these regressions represent appropriately specified explanations of total factor productivity growth. Even a cursory reading of the literature on the determinants of productivity growth identifies several non-fiscal right-hand-side variables likely to affect TFP in addition to lagged GDP per capita (R&D expenditure, innovation, distance from 'frontier' technology, business regulation, financial market constraints, etc.). Rather, our objective here is to establish whether the tax rate variables continue to have any explanatory power when our previous control variables are first allowed maximum effect.

Considering first the case where foreign tax rates are included: compare regressions [16] and [7]. Parameters on the personal and corporate marginal tax rate variables are largely unaffected. These are generally close to those obtained for GDP growth – though there is stronger evidence of a statistically significant direct effect of C_j-stat-L on productivity growth in [16] than on GDP growth in [7]. Thus, even after attributing maximum effect to 'input' variables, both personal and corporate tax rates continue to display statistically strong association with growth via productivity impacts. These results suggest that the previously estimated GDP impacts of personal and corporate tax rates operate primarily through productivity effects rather than via investment etc. Though statistically non-zero, their estimated long-run magnitudes continue to be modest in size − a 1 percentage point (ppt) change in these tax rates generating around a 0.01 to 0.03 ppt change in long-run residual (TFP) growth rates (e.g. from 2.0% to 2.01% or 2.03%).

For the labor and capital MTR average tax rates, regressions [15] and [16] suggest that these remain small and statistically non-robust, especially for the average capital tax rate. That is, they do not reliably identify effects of changes in average tax rates on productivity growth. Similarly, Table 2 shows that our other fiscal control variables, productive public expenditures and budget surpluses, generally have no statistically robust impact on long-run TFP growth (unlike their estimated impact on GDP). This is also a plausible outcome, suggesting that to the extent that increases in, for example, public infrastructure, health and education expenditures affect output growth, this is primarily observed in association with increases in investment and human capital inputs rather than TFP. Finally a comparison of regressions [15] and [16] suggests that, erroneously omitting the (significant) effects of foreign corporate tax rates leads to an under-estimate of the productivity response to domestic corporate rates, C_i-stat − the latter appearing close to zero in [15] when C_j-stat-L is omitted from the specification.

5. Conclusions

This paper has sought to deal with two perceived weaknesses in recent aggregate tests of the impact of taxes on long-run growth rates in OECD countries. First, existing evidence is largely based on macro measures of average tax rates which are constructed from tax revenue data. Theoretical aggregate-level growth models generally assume proportional taxes and hence cannot distinguish between marginal and average tax rates in determining long-run growth. More specific models (for example, microeconomic models of labor supply or FDI) recognize separate output effects from average and marginal tax rates. The choice of appropriate tax rates to test these growth models, and how best to deal with endogeneity associated with tax revenue-based measures, remain debated issues.

Second, despite increased awareness and testing of corporate tax effects on aggregate growth, the models previously tested are essentially 'closed economy' in nature. Based on an open economy extension of the Mendoza *et al.* (1997) model, we have proposed an approach to test how far both domestic and foreign corporate tax settings affect individual countries' aggregate long-run growth rates. Identifying these 'foreign' tax effects on GDP growth is not straightforward empirically, but we suggest that such effects may be asymmetric between countries with corporate tax rates (statutory and/or effective) below, or above, the domestic equivalent rate.

Based on annual panel data for a sample of 15 OECD countries, we have tested for aggregate tax-growth effects associated with changes in both macro 'Mendoza-Razin-Tezar' measures of *average* capital and labor tax rates and the more micro-based marginal rates associated with personal and corporate tax regimes. To the extent possible we have explored both statutory and effective marginal rates. We find:

(i) Robust evidence that increases in the marginal rate of personal income tax as measured by the top rate, and (less robustly) the average labor tax rate are associated with adverse long-run growth outcomes;

(ii) The ‘macro’ MRT average tax rates – on consumption, labor and, especially, capital – generally appear to be less robustly associated with GDP or productivity growth than the ‘micro-based’ marginal tax rates on personal and corporate income.

(iii) Despite methodological difficulties separately identifying both domestic and foreign corporate tax rate effects on GDP, these appear to have affected OECD growth rates as predicted by open-economy growth models. Particularly strong corporate tax effects appear to be associated with tax reductions in ‘lower-tax’ foreign countries, while reductions in ‘higher-tax’ foreign countries appear of limited relevance for domestic growth rates. There is some evidence that corporate tax rates are jointly endogenously determined across countries.

(iv) Like Mendoza et al (1997), we also find no evidence of harmful long-run growth effects from increases in (average) consumption tax rates.

Our estimates suggest growth effects of a 1 percentage point change in personal or corporate marginal tax rates that would be observed at the second, not the first, decimal point: e.g. annual GDP growth rising from 2% to 2.03% not 2.3%. Alternatively, it would need a tax cut such as from 40% to 30% in the top personal or corporate rate to raise growth from 2.0% to 2.3% over the long-run, assuming other countries do not follow suit. These results seem plausible to us as estimates of aggregate tax effects; they imply small but non-trivial effects on GDP levels over several decades.

Finally, given the difficulties diagnosing the channels by which our micro-based marginal tax rates might impact on aggregate output measures such as GDP growth, we are *not* suggesting that the particular rates we have tested are *the* key ones associated with GDP growth outcomes. Rather, we view them as proxies for the various personal and corporate marginal tax rates that potentially affect output across OECD countries. Future research might usefully construct and test macro-based marginal tax rates for OECD country panels, such as those developed by Barro and Sahasakul (1986) and Romer and Romer (2010) for the US. Unfortunately, the detailed country-specific information requirements to construct such measures make their application to multi-country samples resource-intensive and difficult to implement consistently.

Appendix 1: Parameters used in Figure 1 simulations

Parameters used in simulating the Barro (1990) and MMA (1997) models in Figures 1A & 1B are given in the table below. Together with tax rates, these parameter values enter into equations (8), (10) and (12).

Parameters		Barro (1990)	MMA (1997)	Parameters		Barro (1990)	MMA (1997)
Production functions *	A	0.16	0.75	Time preference rate	p	0.03	0.03
	$\boldsymbol{B}$	-	0.75	Depreciation rate	5	0	0
	a	0.70	0.70	Labor time allocation	u	-	0.70
	p	-	0.25	World interest rate	z	-	0.07
		Inter-temporal elasticity of substitution			9	1	1

* A value of D = 0.225 in (8) is obtained for given values of other production function parameters.

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FIGURE 1 Simulating alternative models

1A 1B

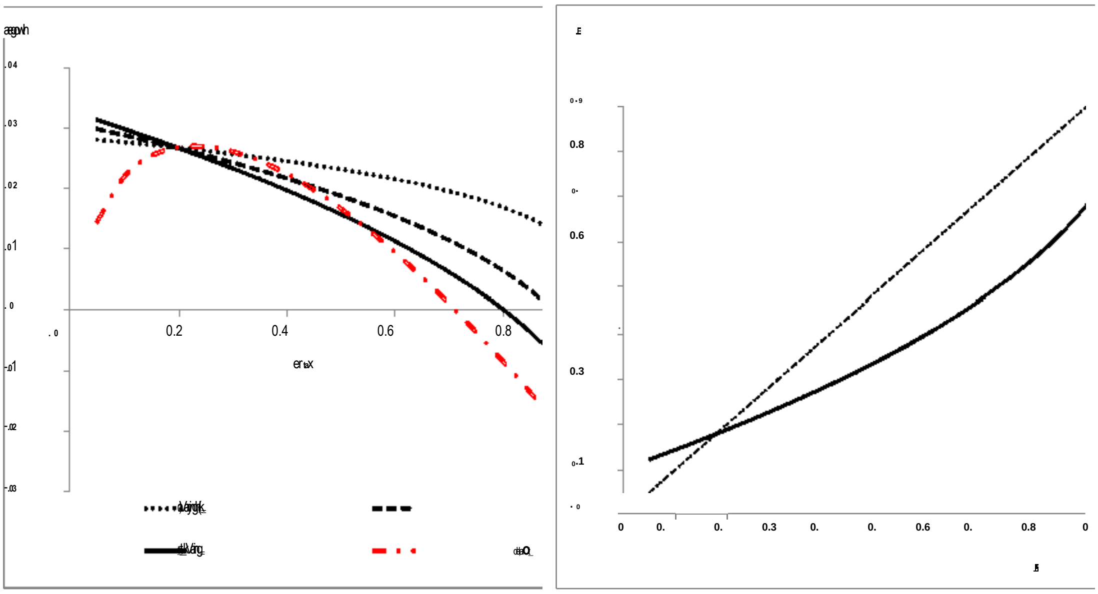
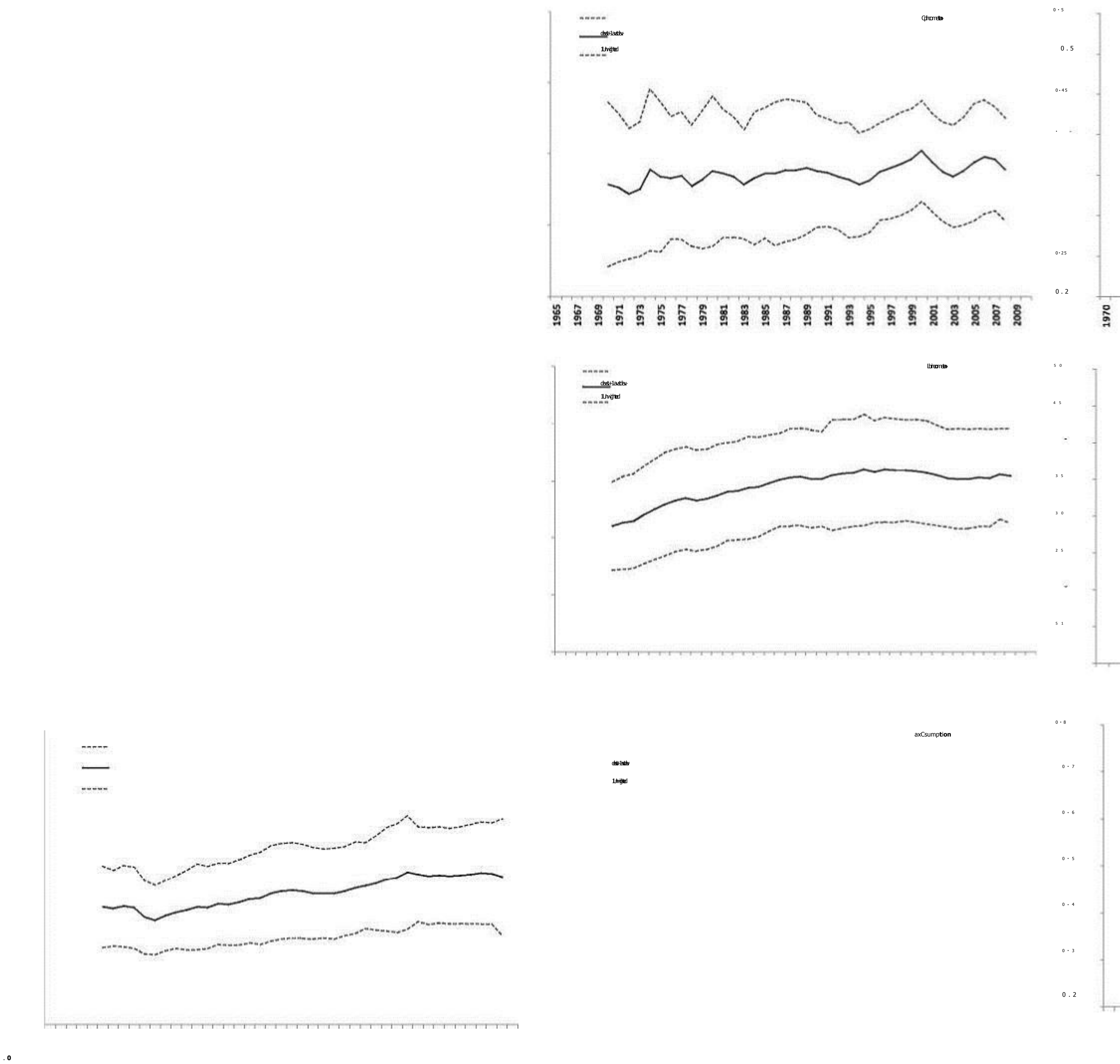


FIGURE 2 Tax rates

Average MTR tax rates

Marginal corporate & personal tax rates



Sources: MRT tax rates: McDaniel (2007); Corporate and personal tax rates: Tax Policy Research Centre, Univesity of Michigan, Institute for Fiscal Studies (2005) and OECD (2012).

TABLE 1 Testing average and marginal tax rates

Regression No:	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**
Method:	PMG	PMG	PMG	PMG	PMG	PMG	PMG	PMG
Tax Rates:								
$_{i,K}$		-0.086			0.076		0.051	0.032
		(2.78)** -			(3.44)** -		(1.79) -	(1.62)
$_{i,L}$		0.342			0.061		0.028	0.001
		(4.54)**			(2.72)**		(0.93)	(0.04)
$_{i,C}$		0.047			0.027			
		(1.11)			(1.89)			
P_i-top			-0.055	-0.053	-0.059	-0.053	-0.082	-0.058
			(6.76)**	(7.08)**	(7.57)**	(6.70)**	(5.66)**	(5.82)**
C_i-stat			-0.020	-0.019	-0.021	-0.033	-0.027	
			(2.72)**	(2.41)*	(3.21)**	(3.32)**	(1.90)	
C_j-stat				0.000				
				(0.00)				
C_j-stat-L						0.016	0.013	0.012
						(1.67)	(0.77)	(0.89)
C_j-stat-H						0.001	-0.012	-0.015
						(0.18)	(1.26)	(2.21)*
Fiscal Controls:								
Productive expenditure		0.055	0.109	0.110	0.122	0.094	0.132	0.105
		(1.03)	(4.81)**	(4.84)**	(5.65)**	(4.04)**	(3.91)**	(3.06)**
Budget surplus		0.003	0.151	0.147	0.115	0.132	0.103	0.024
		(0.07)	(6.44)**	(6.00)**	(4.97)**	(5.55)**	(3.10)**	(0.72)
Other Controls:								
Investment ratio	0.164	0.293	0.084	0.100	0.051	0.089	0.144	0.233
	(4.16)**	(3.17)**	(1.84)	(2.21)*	(1.57)	(2.09)*	(2.37)**	(3.56)*
Labour force growth	0.195	0.368	0.301	0.316	0.341	0.311	0.427	0.379
	(4.70)**	(3.79)**	(7.91)**	(7.94)**	(8.22)**	(7.36)**	(6.30)**	(6.35)**
Human capital growth	0.304	-0.380	0.785	0.671	0.963	0.573	1.189	0.111
	(0.62)	(0.69)	(3.10)**	(2.77)**	(4.15)**	(2.19)*	(3.24)**	(0.31)
$ln(\text{GDP p.c.})_{t-1}$	-0.781	-0.521	-4.19	-4.39	-4.40	-4.15	-6.823	-5.808
	(1.86)	(0.82)	(6.00)**	(6.09)**	(7.92)**	(6.38)**	(5.65)**	(5.71)**
Observations/ countries	472/15	447/15	420/15	420/15	416/15	420/15	416/15	422/15
Log likelihood	-709.7	-620.8	-544.9	-536.1	-456.3	-522.8	-457.6	-499.4

TABLE 2 Instrumental variable regressions and robustness testing

Regression No:	[9]	[10]	[11]	[12]	[7]	[13]	[14]	[15]	[16]
Method:	IV	IV	IV	IV	PMG	PMG	PMG	PMG	PMG
Tax Rates:								Depend. variable = ‘Residual growth’	
i,K		0.124		0.076	0.051	-0.060	0.040	-0.007	0.007
		(3.71)**		(3.09)**	(1.79)	(2.53)**	(1.63)	(0.49)	(0.47)
i,L		-0.121		-0.071	-0.028	0.029	-0.038	-0.031	-0.017
		(3.41)**		(2.30)*	(0.93)	(1.24)**	(1.51)	(-2.00)*	(1.13)
P_i-top	-0.056	-0.086	-0.051	-0.062	-0.082	-0.037	-0.069	-0.017	-0.010
	(6.01)*	(6.47)**	(5.34)**	(6.08)**	(5.66)**	(4.15)**	(6.76)**	(3.57)**	(1.95)
C_i-stat §	-0.024	-0.037	-0.024	-0.029	-0.027	-0.035	-0.022	-0.003	-0.028
	(2.82)*	(3.63)**	(2.78)*	(3.14)**	(1.90)	(1.85)	(2.94)**	(0.42)	(2.62)**
C_j-stat-L					0.013	0.090			0.030
					(0.77)	(5.00)**			(3.08)**
C_j-stat-H					-0.012	-0.001			-0.002
					(1.26)	(0.13)			(0.39)
Fiscal Controls:									
Productive expenditure	0.125 (4.33)**	0.142 (4.38)**	0.124 (4.45)**	0.118 (4.29)**	0.132 (3.91)**	0.074 (2.98)**	0.118 (4.48)**	0.025 (0.85)	-0.016 (0.56)
Budget surplus	0.146 (5.12)**	0.107 (3.17)**	0.185 (7.38)**	0.148 (5.64)**	0.103 (3.10)**	0.141 (4.60)**	0.124 (4.62)**	0.030 (1.43)	0.012 (0.59)
Excluded:	-	-	Investment	Investment	-	Lagged GDP p.c.	Foreign taxes	All input vars.	All input vars.
Other Controls?	YES	YES	YES	YES	YES	YES	YES	No	No
Observations/ countries	431/15	422/15	431/15	422/15	416/15	416/15	416/15	415/15	415/15
Log likelihood	-587.9	-498.4	-626.0	-552.1	-457.6	-517.2	-481.3	-556.0	-531.9

§ Instrumenting for C_i-stat by C_j-stat-L, using both distance and GDP as weights.

Parameters shown are long-run estimates. Absolute value of *z* statistics in parentheses; * = significant at 5%; ** = significant at 1%. P_i-top = top statutory rate of personal income tax; C_i-stat = statutory corporate rate; C_j-stat = average statutory corporate tax rates in other countries; C_j-stat-L/H = average statutory tax rates in other countries when below/above those in country *i*.

Diagnosis tests

Regression No.:	**[0]**	**[10]**	**[11]**	**[12]**
Method:	IV	IV	IV	IV
Sargan test	$x^2(1) = 0.060$ p-value 0.81	$x^2(1) = 1.921$ p-value 0.17	$x^2(1) = 0.754$ p-value 0.39	$x^2(2) = 3.627$ p-value 0.16
Anderson under-identification test	$x^2(2) = 313.0$ p-value 0.00	$x^2(2) = 307.9$ p-value 0.00	$x^2(2) = 310.3$ p-value 0.00	$x^2(3) = 314.8$ p-value 0.00
Weak identification test:	647.4	616.4	426.3	667.1
Cragg-Donald statistic	CV : 19.93	CV : 19.93	CV : 19.93	CV : 22.30

Instruments for C_i stat are C_j-stat- L, both distance -weighted and GDP-weighted.

TABLE 3 Testing effective tax rates

Regression No: *Method:*	(1) PMG	(2) PMG	(3) PMG	(4) PMG
Tax Rates:				
$_{i,L}$	0.094	-0.019	0.183	0.247
	(3.01)**	(1.32)**	(6.71)**	(8.03)**
P_i-top	-0.023	-0.018	-0.022	-0.039
	(2.34)**	(3.45)**	(2.73)**	(3.51)**
Corporate tax:				
$EMTR_i$-$EATR_i$			-0.075	-0.126
			(3.67)**	(4.38)**
$EMTR_i$	-0.035			0.003
	(1.59)			(0.13)
$EMTR_j$-L	0.078	0.054	0.046	0.043
	(2.85)**	(2.98)**	(4.09)**	(2.03)*
$EMTR_j$-H		0.001		
		(0.04)		
Fiscal Controls:				
Productive expenditure	0.230	0.084	0.123	0.157
	(3.78)**	(2.75)**	(4.21)**	(4.49)**
Budget surplus	0.363	-0.056	0.119	0.182
	(5.92)**	(3.64)**	(4.23)**	(4.19)**
Other Controls?	YES	YES	YES	YES
Observations/ countries	278/12	278/12	278/12	278/12
Log likelihood	-250.20	-245.9	-252.2	-236.3

Parameters shown are long-run estimates. Absolute value of *z* statistics in parentheses.

* = significant at 5%; ** = significant at 1%.

$_{i,L}$ = average MRT labor tax rate. P_i-top = top statutory personal income tax rate.

$EMTR_i$ ($EATR_i$) = Effective marginal (average) corporate tax rate in country *i*;

$EMTR_j$-H(-L) = Effective marginal corporate tax rate in country *j* where *j*'s EMTR is above (H), or below (L), country *i*'s (distance-weighted).

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[1] For example, whether both physical *and* human capital are required to produce human capital. Subsequent endogenous growth models with taxation include Kaas (2003), Kalyvitis (2003), Zagler and Durnecker (2003), Park and Philippopoulos (2003), Ho and Wang (2005), and Peretto (2003, 2007). Barro, *et al* (1995) and Turnovsky (2004) examine the transitional dynamics of tax-growth effects. Futagami et al. (1993) adapt the Barro (1990) model to allow for externalities from public *capital stocks*, rather than public *expenditure flows*.

[2] See, for example, Martinez-Mongay (2000), Carey and Tchilinguirian (2000), Carey and Rabesona (2002), Immervol (2004), de Haan *et al.* (2004), and McDaniel (2007).

[3] McDaniel (2011) also applies MRT tax rates to aggregate-level tests of labor supply responses. Earlier Barro and Sahasakul (1983, 1986) proposed using an income-weighted 'average marginal tax rate' (AMTR) as a suitable macro-level equivalent of the marginal tax rates normally used to capture individuals' labor supply responses to changes in tax rates. Using this measure, Barro and Redlick (2011) find evidence of lower growth in the US in association with higher marginal tax rates. The method however is data intensive, requiring annual income distribution data for example, and therefore is not readily applied to large panel datasets.

[4] MMA (1997) acknowledge however that, using *annual* data, they did find some (unreported) evidence of statistically significant effects of taxes on GDP growth. They interpret this as evidence of transitional growth effects.

[5] In addition, if the 0.2% increase in growth estimated by MMA (1997), albeit with a large margin of error, was realized over the long-run – say, from 2.0% p.a. to 2.2% p.a. - GDP would be around 4% higher after 20 years, and 6% higher after 30 years. Though not large, these are also not trivial improvements over the counterfactual. Gemmell et al. (2011) also caution against considering the

growth effects of tax changes without also considering the growth effects of other simultaneous changes in expenditures, deficits or other taxes, mandated by the government budget constraint.

[6] Note that G does not enter either firms' productions functions, nor the household's utility function.

[7] See MMA (1997) for further discussion of the derivation of these conditions.

[8] Note that, since $r^*(1 - T_F) = R^K(1 - T_K) - 8$, the tax rates on domestic and foreign assets need not be equal in equilibrium. However, where fiscal depreciation allowances are set such that $r = (R_K - 8)(1 - T_K)$, then perfect capital mobility ensures that $r^* = R_K - 8$ and $T_F = T_K$ (assuming the same consumer preferences and technology across countries).

[9] This system is 'worldwide' since all of a resident's income is taxed domestically regardless of where it is earned. It is used in the US and UK, for example.

[10] This is because if ($z^K > z''$), then z^K will apply and there is no *foreign tax-induced* incentive to invest, while if $z^K < z''$, then z'' applies, and no investment abroad would occur.

[11] Barro suggests treating *K* as 'broad capital', potentially including human capital. As a result his income tax rate is implicitly a uniform rate on both labor and capital income. In an extension to the basic model, Barro (1990, p.S117-118) also adds utility-enhancing government spending and a consumption tax.

[12] In particular, having established suitable parameter values for the MMA simulations, the technology parameter, A, in the Barro production function was selected such that the Barro model yields the same growth rate as the MMA model when labor and capital income tax rates equal 20%.

[13] This reflects the model's properties that as domestic tax rates rise and domestic growth rates becomes very low or negative, domestic investment is also very low such that the tax-disincentive to investing abroad becomes less relevant. As domestic tax rates approach unity, tax rates on foreign income also need to approach unity for equilibrium.

[14] See Blonigen (2005) and de Mooij and Ederveen (2008) for reviews.

[15] Kneller *et al* (1999) recommend omitting unproductive spending and/or non-distortionary taxes from such regressions – since theory suggests these should have little or no growth effect, making interpretation of parameters on included fiscal variables easier.

[16] The human capital data is based on Arnold *et al* (2007). We are grateful to Jens Arnold, Andrea Bassanini and Stefano Scarpetta at the OECD for supplying the data.

[17] The full country sample is: Australia*, Austria*, Canada*, Denmark, Finland*, France*, Germany*, Netherlands*, New Zealand, Norway*, Spain*, Sweden*, Turkey, UK*, USA*. Most regressions use 15 countries; an asterisk indicates the country is included in the reduced 12 country sample when *effective* corporate tax rates are used. For most countries data on tax rate variables are generally available till 2009 or 2010 (see Figure 2 and on-line Appendix 3). However effective tax rates data (EMTR, EATR) are only available to 2004; regressions therefore generally include data up to 2004. This avoids the period of severe macroeconomic disequilibrium and recession from 2008 and allows regressions using different tax rate measures to be compared directly.

[18] Indeed Pesaran and Smith (1995) argue that the assumption of homogeneity of the short-run parameter estimates across countries is a more serious problem in the DFE estimator than the bias generated by the inclusion of lagged dependent variables and can lead to inconsistent and misleading results even for large T and large N.

[19] See Pesaran (1997, pp.182-184) for further discussion.

[20] Studies such as Padovano and Galli (2002) for example, estimate 'aggregate' marginal tax rates by regressing tax revenues on an income measure over a number of years. The resulting parameter is then used as a marginal tax rate proxy in cross section/panel growth regressions.

[21] Some data for statutory marginal personal capital income tax rates (e.g. on interest and dividend income) are available for OECD countries but coverage is generally limited both across countries and annually. OECD (2012) data on top rates of personal tax on dividend income are highly correlated (across counties) with top personal rates on earned income. For 2007, for example, personal MTRs on dividend and wage income are correlated across our 17 country sample at r = 0.75. Data from Tables I.4 & II.4 at www.oecd.org/ctp/taxdatabase.

[22] With 15 countries and around 30 annual observations, we do not have sufficient degrees of freedom in our panel regressions to include each 'foreign' country's tax rate separately.

[23] We do not use FDI data due to limited availability for early years of our sample. Physical distance is measured by the inverse of distance between the capital cities of all sample countries. This means, for example, that for a country such as New Zealand, Australia takes a 95% weight compared to a 5% weight for other countries – reflecting the likelihood for New Zealand's case that flows to/from Australia dominate the potential gains/losses from international inflows or outflows. Data on New Zealand's investment in/out-flows suggest this is the case.

24 As with our included foreign tax rate variables, each additional foreign tax rate variable would need to be constructed such that values differs across each in-sample country, otherwise it becomes a form of country fixed effect. In addition the use of the PMG regression method, which estimates separate short-run responses for each variable and country, means that each additional variable included in regressions substantially reduces degrees of freedom.

25 Averages are for 13 or 14 of the sample countries. No data are available for Iceland and Luxembourg and the time-series for Turkey is too short. On-line Appendix 3 shows individual country tax rates and GDP growth rates. See McDaniel (2007) for derivation of her MRT rates, country-specific results and comparisons with the original MRT (1994) measures.

26 For all regression results we report the homogeneous long-run parameters and omit country-specific, short-run parameters to save space. For 'foreign' corporate tax rates, distance-weighted statutory rates are reported.

27 Note that the parameter on ln(GDP p.c.)$_{t-1}$ cannot be interpreted as a 'rate of convergence' as is common in long-run growth regressions, since the dependent variable is the change in aggregate GDP, and all regressions also include an 'error correction' term capturing the short-run annual adjustment of GDP to equilibrium. This short-run effect might be expected to pick up mainly demand-induced deviations from equilibrium, whereas long-run convergence is more associated with longer-term supply-side adjustments.

28 The models described in section 2 assume that fiscal effects on GDP are transmitted through private investment or human capital accumulation such that, arguably, these variables should not be included as 'controls' in our regressions if the full fiscal impact is to be identified. We investigate this aspect further in sub-section 4.5.

29 See Gemmell et al (2011) for further discussion of, and evidence on, this timing/persistence aspect.

30 IV diagnostics shown below Table 2 support the instruments chosen. We also examine IV regressions in which we instrument additionally for the MRT tax rates (using 'low tax' countries weighted MTR rates as instruments), other fiscal variables and investment. Since the only additional instruments available for other fiscal variables and investment are the 3rd/4th lagged (predetermined) values, we do not place a great deal of weight on these results. Nevertheless, the parameters and statistical significance of our various tax rate measures remain similar to those given in Tables 1 & 2.

[31] This is confirmed when we replace GDP growth with the investment rate as our dependent variable. In this case, unlike MMA (1997), we find no significant effects of our tax rates on investment – though we would caution that such regressions are somewhat *ad hoc* in specification and are not derived from a fully-specified model of the determinants of investment.

[32] This evidence is consistent with Romer and Romer (2010) who found, using VAR methods, that strong negative impacts of income tax rates on US GDP estimated for up to 5 years, appeared to persist beyond this period.

[33] Table 3 reports regressions for the case of assumed uniform inflation rates across countries. Other assumptions are: investment is in plant and machinery, financed by equity or retained earnings, taxation at shareholder level is not included, rate of economic rent = 10% (i.e. financial return = 20%), real discount rate = 10%, inflation rate = 3.5%, depreciation rate = 12.25%; see Devereux and Griffith (2003) for details. We also obtained results using ETRs calculated using each country's own inflation rate; results are similar.

[34] In this sample the EATRs and EMTRs are highly correlated overall: r = 0.90 to 0.98 (for the 3 weighting cases) across the 12 OECD countries.

[35] The parameter estimates on ($EMTR_i$ – $EATR_i$) in (3) and (4) imply that raising the EATR, whilst holding the EMTR constant, has a positive association with GDP growth. We interpret this as an income effect from the implicit inframarginal increase in depreciation deductions associated with the EATR rise.

[36] Ideally, a structural model that sought to model both tax and non-tax determinants of our controls variables could be used. While such components of such a model are increasingly being pursued at the micro level – e.g. estimating tax impacts within investment equations – it is because of difficulties fully specifying and estimating such structural models at the aggregate level that the reduced forms used here have been commonplace in recent literature.