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Growth Effects of Progressive Taxes*

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*The views expressed in this paper are solely those of the authors and do not necessarily represent those of the Federal Reserve Bank of Philadelphia, the Federal Reserve Bank of Richmond, or the Federal Reserve System.

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Abstract

We study the effects of progressive taxes in conventional endogenous growth models augmented to include heterogeneous households. In contrast to representative agent models with flat-rate taxes, this framework allows us to distinguish between marginal tax rates and the empirical proxies that are typically used for these rates such as the share of tax revenue, or government expenditures, in GDP. The analysis then illustrates how the endogenous nature of these proxy variables causes them to be weakly correlated, or even increase, with economic growth. Our study, therefore, helps explain why cross-country regressions have mostly failed to uncover the distortional growth effects of taxes. In fact, while past U.S. tax reforms appear to have contributed only small increases in per capita GDP growth, our analysis nevertheless suggests that differences in tax codes across countries explain a two and a half percent variation in cross-sectional growth rates. Finally, we show that progressivity also introduces significant lags in the effects of tax changes on output growth.

JEL Classification: E13, O23

Keywords: Economic Growth, Progressive Taxation, Heterogeneous Households

1 Introduction

In contrast to the older neoclassical literature, endogenous growth models imply that government policy helps determine the rate of economic growth. Calibration of basic linear growth setups to U.S. data initially showed that the growth effects of flat-rate taxes range from negligible (Lucas [1990]) to very large (Jones, Manuelli, and Rossi [1993]). Stokey and Rebelo (1995) showed that much of this variation depends on critical parameters, including factor shares, depreciation rates, and the intertemporal elasticity of substitution. More important, along with Jones (1995), they argued that U.S. time series data is at odds with the notion that tax changes induce significant effects on economic growth. Specifically, the dramatic increase in income taxation in the early 1940s would have been expected to decrease contemporaneously the U.S. per capita growth rate. But this did not appear to be the case. At the same time, cross-country studies, including Levine and Renelt (1992) and Levine and Zervos (1993), have generally been unable to confirm any negative link between government policy and output growth. Thus, both cross-country and time-series work has suggested that long-run growth is mostly independent of fiscal policy.

In this paper, we illustrate how the endogeneity problem associated with standard proxies for marginal tax rates can result in an apparent lack of correlation between growth and policy in cross-sectional regressions. In addition, while our analysis indicates that the growth effects of tax changes have likely been small in the U.S., we find that cross-country differences in tax codes can explain more than a two and a half percent variation in growth rates.

We study the effects of progressive taxation in conventional growth models augmented to include heterogeneous households. In such frameworks, the tax code helps to determine simultaneously the pre-tax income distribution and the rate of technical progress. Because the pre-tax income distribution is endogenous, so too are income taxes collected and, consequently, the share of government spending in output. Therefore, in contrast to a large class of representative household frameworks with flat-rate taxes, our models no longer imply a necessarily decreasing relationship between the share of government expenditures and economic growth across countries.

Of course, because cross-country marginal tax rates are not easily observable, one is typically forced to use some share of government expenditures (or tax revenue) in GDP as a proxy.[1] To see why this can be particularly misleading given the models we study, consider the consequences for an economy whose tax system becomes more progressive.

First, with marginal tax rates increasing for the rich relative to the poor, high-income households have less incentive to accumulate both human and physical capital and, ulti-

[1] Regressing various measures of tax revenue on their tax base is also common (Koester and Koermendi [1989], and Easterly and Rebelo [1993]).

mately, may have lower pre-tax earnings in equilibrium.[2] Hence, as the degree of tax progressivity increases, it is not clear that the share of tax revenue in GDP should rise; in fact, it may even decline. Simultaneously, because more progressive tax systems are generally more distortional (see Sarte [1997], and Castañeda, Diaz-Gimenez, Rios-Rull [1999]), they are likely to be associated with lower economic growth *ceteris paribus*. Together, these two endogenous outcomes imply that variations in progressivity across economies cause output growth and the share of public expenditures in GDP to have either little or positive correlation. This result summarizes precisely the empirical findings of Levine and Renelt (1992), Levine and Zervos (1993), and Easterly and Rebelo (1993), among others. Furthermore, it holds irrespective of whether government services play a productive role in production.

Over the past two decades, the marked reductions in top U.S. statutory tax rates have paradoxically coincided with higher-income households' bearing a greater share of the tax burden. The models we present help explain these observations because lower *statutory* progressivity leads to increased pre-tax income inequality that potentially offsets the lower statutory rates for richer households. In other words, with high-income households earning more in relative terms, *effective* progressivity – as captured by the actual degree of tax concentration – can increase. The fact that U.S. income inequality has indeed consistently risen over the past 20 years is now widely documented. Furthermore, when we calibrate differences in tax codes to yield the observed degree of income inequality across countries, we find that variations in fiscal policy can explain more than a two and a half percent difference in economic growth.

The explicit modeling of non-linear taxes also has important dynamic implications. Consider, for instance, a closed economy where all factors of production are reproducible and the technology is linear. This is in effect the Ak framework. Because the marginal tax rate increases in income in our environments, the after-tax rate of interest is now a function of the composite capital good. Consequently, contrary to the original framework, a change in tax policy will induce some transitional dynamics as the economy moves from one balanced growth path to another (see Yamarik [2001]).

In models calibrated to U.S. data, we find that the wave of tax reforms that began in the early 1980s had small but protracted effects on per capita GDP growth. Thus, the long transition dynamics between balanced growth paths can only increase the difficulty of identifying growth effects of tax changes in time series data. Furthermore, the initial impact of tax reforms depends importantly on whether government services contribute to private production. Remarkably, when government expenditures finance productive services, gradually *decreasing* tax rates may be associated with *decreasing* growth rates in the short

[2] Moreoever, in developing economies, these agents often spend resources in order to escape taxation altogether.

run. This finding, in addition to the fact that transitions between balanced growth paths may now be quite protracted, contrasts sharply with the implications of early endogenous growth models. Unlike Stokey and Rebelo (1995), our analysis suggests that testing for contemporaneous breaks in average growth cannot be used to identify the effects of discrete changes in tax policy.

This paper is organized as follows. In section 2, we briefly review previous cross-country evidence on fiscal policy and economic growth. Section 3 introduces our modeling of progressive taxes, which stays constant across the different frameworks we consider. Section 4 revisits Rebelo's (1991) original endogenous growth model with progressive taxes and heterogeneous households. In section 5, we allow government expenditures to play a productive role along the lines of Barro (1990). Section 6 offers concluding remarks.

2 Fiscal Policy and Economic Growth in the Cross-Section

Under the assumptions of proportional taxes and a representative agent, endogenous growth models typically predict a negative correlation between growth, γ, and the ratio of public spending to GDP, G/Y. This negative correlation reflects the distortional effects of taxation in that, with proportional taxes, $G/Y = \tau$. While this prediction is a hallmark of the endogenous growth literature, empirical cross-country growth studies have generally been unable to confirm this negative correlation.

Figures (1a) and (1b) illustrate this notion. Figure 1, panel (a) plots average per capita growth rates versus taxes on income, profits, and capital gains as a fraction of GDP across 107 countries over the period 1976-1997. Figure 1, panel (b) illustrates the link between per-capita growth rates and the ratio of government expenditures to GDP for the same set of countries. The measure of government spending in this case excludes expenditures on public infrastructure (i.e., fixed capital assets and land, as well as non-military and non-financial assets), which we do not model in this paper.[3] The data are obtained from the World Development Indicators published by the World Bank in 2000. If anything, the link between per-capita growth rates and the relative size of public expenditures is *increasing*. Figure 1, panels (c) and (d) illustrate the same relationships as in Figures (1a) and (1b) for OECD countries only. In both cases the data fail to establish a negative link between the relative size of government and per-capita output growth.[4] Because neither the figures with

[3] As a fraction of GDP, public spending on infrastructure is typically small. Among OECD countries, for instance, this ratio is at most 5 percent (Luxembourg).

[4] Levine and Renelt (1992) argue that this result continues to hold even when a wide range of conditioning variables are taken into account, including initial income.

tax revenue nor those with government expenditures imply a decreasing relationship with output growth, we abstract from debt considerations below.

On a less equivocal note, Tanzi and Zee (2000) argue that the relative size of government is actually higher for richer countries. They find "that for the period 1985-1987, the average total tax level in developing countries was about 17.5 percent of GDP. ... In contrast, the average total tax level in OECD countries in the same period was more than twice as high (36.6 percent of GDP), although there was significant variance across the OECD subcountry groups. Essentially all of the foregoing comparative observations are equally applicable to the tax revenue data for the period 1995-1997."

To account for these cross-sectional relations, the next sections explore the growth effects of progressive taxes in two prototypical endogenous growth models augmented to include a non-degenerate distribution of income. These models, one first formulated by Barro (1990) and the other by Rebelo (1991), account for two polar assumptions regarding the use of public expenditures. At one extreme, in Rebelo's (1991) two-sector framework, government spending does not play a productive role. At the other extreme, in the environment envisioned by Barro (1990), all tax revenue serves to finance public services that enter as an input into private production. In both cases, we show that long-run growth can increase with the ratio of tax revenue to GDP as in the cross-section. In essence, the fact that taxes are progressive now drives a wedge between the average marginal tax rate and the ratio of tax revenue to GDP; the distortional effects of higher marginal tax rates remain but cannot be captured empirically with the latter ratio. Contrary to the original models, we also show that changes in tax policy now induce protracted effects on economic growth.

3 Progressive Taxation

We begin by describing the modeling of tax policy, which is common across the frameworks we consider. The government balances its budget at each point in time and chooses a tax code summarized by the tax rate, $\tau(y/Y)$, where y denotes household income and Y is aggregate income. Thus, the tax rate that applies to a given household depends only on its standing in the economy. This modeling assumption ensures that not all households eventually face the highest marginal tax rate simply as a result of economic growth. In other words, for the purpose of this paper, we abstract from tax drift considerations.[5] In the analysis below, we

[5] This phenomenon is also known as "bracket creep." As part of the Cato Institute's policy recommendations to the 106th U.S. Congress, Moore (1999) suggests that "real income bracket creep should be ended by indexing tax brackets for inflation plus real income growth. ... In 1998, for example, worker incomes rose by a respectable 6 percent, but tax receipts were up 10 percent. The primary culprit is real bracket creep."

further assume that the government sets $\tau(y/Y)$ according to the following tax schedule:

$$\tau(\frac{y}{Y}) = \zeta \left(\frac{y}{Y}\right)^{\phi}, \text{ with } 0 \leq \zeta < 1, \ \phi > 0, \tag{1}$$

where, similarly to Lansing and Guo (1998), the parameters ζ and ϕ determine the level and the slope of the tax schedule, respectively. When $\phi > 0$, households with higher taxable income are subject to higher tax rates, and the more common case of proportional taxes corresponds to $\phi = 0$, $\tau(y/Y) = \zeta$. In making decisions about how much to consume and invest, households will take into account the particular way in which the tax schedule affects their earnings.

Given the tax rate in (1), $\tau(y/Y)y$ represents the total amount of taxes paid by a household with income y. Because we wish to show the implications of progressivity for economic growth, it is helpful to distinguish between average and marginal tax rates. In this case, as taxable income varies, the change in total taxes paid is given by:

$$\frac{\partial\left[\tau(y/Y)y\right]}{\partial y} = \tau_m(\frac{y}{Y}) = (1+\phi)\zeta\left(\frac{y}{Y}\right)^{\phi}, \tag{2}$$

where $\tau_m(y/Y)$ is the tax rate applied to the last dollar earned. The average tax rate, $\tau_a(y/Y)$, is simply $\tau(y/Y)$.

While there exists no single appropriate way to define the degree of progressivity of a tax schedule, one of the more widely used definitions is expressed in terms of the ratio of the marginal to the average tax rate. Specifically, a statutory tax schedule is said to be progressive whenever the marginal rate exceeds the average rate at all levels of income.[6] In our set-up, equations (1) and (2) imply that:

$$\frac{\tau_m(y/Y)}{\tau_a(y/Y)} = 1 + \phi, \tag{3}$$

so that the parameter ϕ captures the degree of progressivity in the tax code. In the limit, where $\phi = 0$, the tax schedule is "flat" and $\tau_m(y/Y) = \tau_a(y/Y)$. Other methods of measuring progressivity involve the use of indices and attempt in part to capture the degree of tax burden borne by households at different income levels.[7] A crucial problem here is that the distribution of pre-tax income is endogenous and, therefore, expected to vary in response to changes in statutory tax rates. To the extent that one is concerned with effective progressivity, Creedy (1999) writes that "the tax structure alone is insufficient to judge progressivity because the overall effect of a tax structure on the distribution of tax payments and the inequality of net income cannot be assessed independently of the form of the distribution of

[6] See Musgrave and Musgrave (1989). Another way to define progressivity is to require that the average tax rate be increasing over all income ranges, which is also satisfied in our framework.

[7] See, for instance, Kakwani (1977) and Suits (1977).

pre-tax income." In the models below, we shall illustrate how ϕ directly influences both the distribution of pre-tax income and economic growth.

While we summarize the tax code by equation (1) for simplicity, it can be difficult in practice to gauge the degree of statutory progressivity of a given tax schedule. Even absent tax drift, such calculations involve sifting through the tax code and accounting for various deductions to be netted out of gross income, determining the income tax rate that applies to net income, and computing the credits deductible from the resultant tax liability. Sicat and Virmani (1988) manage to work out marginal statutory tax rates at discrete income levels for a number of low-income and middle-income countries. Their results show that marginal tax rates on the highest bracket vary anywhere from 30 percent (Burkina Faso) to 95 percent (Tanzania) among the low-income countries alone. In contrast, the marginal tax rate on the lowest bracket computed for the same set of countries varies only from 2 percent to 20 percent. Although the authors do not publish estimated average tax schedules, their findings are nevertheless suggestive of significant differences in statutory progressivity across economies.

In the U.S., the statutory income tax has undergone dramatic changes over the past two decades following several important pieces of legislation. Most notable among these changes in tax laws are the Economic Recovery Tax Act of 1981 (ERTA) and the Tax Reform Act of 1986 (TRA-86). Important features of these two laws regarding individual income taxes are as follows:

- According to the Congressional Budget Office (CBO), ERTA "cut individual income tax rates by a cumulative 25 percent over three years, dropping the top rate from 70 percent to 50 percent. ERTA also indexed tax brackets for inflation, reducing bracket "creep" that subjected taxpayers to ever higher rates of inflation" (CBO [2001], p. 4).

- TRA-86 continued this trend, especially for high-income households. "Prior statutory rates that had ranged as high as 50 percent were cut to just 15 and 28 percent. TRA-86 also increased the levels of the personal exemption and the standard deduction. The act further changed the taxation of capital gains ... making the maximum rate on long-term gains for top income earners 28 percent" (CBO [2001], p. 4).

Other changes in tax laws in the 1980s and early 1990s include the Social Security Amendments of 1983, as well as the Omnibus Budget Reconciliation Acts of 1990 and 1993. The latter two acts somewhat raised marginal tax rates, but these changes generally did very little to offset the statutory effects of the 1981 and 1986 acts (see Burman, Gale and Weiner [1998]).

Interestingly, the U.S. tax reforms that generated sharp declines in maximum marginal tax rates in the 1980s occurred in Sweden and the United Kingdom at about the same time.

The top marginal rates were reduced from 75 to 50 percent in Sweden between 1982 and 1985, and from 80 to 40 percent in the United Kingdom between 1979 and 1988. In addition, Bishop, Formby, and Zheng (1998) observe that as in the U.S., these changes in tax laws were followed by rising pre-tax income inequality in both Sweden and the U.K.. For the purpose of this paper, we shall interpret the wave of U.S. tax reforms as a gradual decrease in *statutory* progressivity over five years (i.e., ERTA in 1981 and TRA-86). Consistent with U.S. data, we shall show that, because a decrease in statutory progressivity gives rise to more income inequality, it can also paradoxically lead to an increase in the effective tax share borne by high-income households.

4 Long-Run Policy and Long-Run Growth Revisited

This section modifies Rebelo's (1991) original linear endogenous growth model to account for progressive taxes. For progressivity to play a redistributive role, we introduce a non-degenerate distribution of income and wealth into the environment by assuming that households differ in their rates of impatience. We adopt this method of inducing income heterogeneity mainly for tractability. There exists, however, substantial empirical work that links differences in earnings and wealth to diverse rates of time preference.[8] Ultimately, the results in this paper hinge on the fact that relatively wealthier agents may have an incentive to increase their pre-tax earnings relative to aggregate income as the tax schedule becomes less progressive. In principle, this channel would remain operative in models where heterogeneity arises from other considerations, such as borrowing constraints as in Hugget (1993), Ayagari (1994), and Rios-Rull (1995) among others, or permanent differences in productivity as in Caucutt, Imrohoroglu, and Kumar (2001).

Consider a closed economy populated by a large number of households uniformly distributed on $[0, 1]$. There are N types of households, and each household type is indexed by a discount factor β_j, where $0 < \beta_1 \leq \beta_2 ... \leq \beta_N < 1$. Thus, the most patient households have discount factor β_N. Within each group, the measure of households is given by $1/N$. Each household receives income from previous savings and a non-reproducible factor. The quantity of the non-reproducible factor is denoted by T and is available in fixed supply in each time period (e.g., land). Income is either saved or used to purchase consumption goods. Households are allowed to borrow and finance their debt out of wage income. Because households face a progressive tax schedule, the most patient group will not end up owning all available wealth in equilibrium.[9]

[8] See Hausman (1979), Lawrance (1991) for work using the Panel Study of Income Dynamics, Samwick (1998) for an analysis using the Survey of Consumer Finances, as well as Warner and Pleeter (2001) for an article based on the military drawdown program of the early 1990s.

[9] Below, we discuss the derivation of a non-degenerate equilibrium with constant long-run growth. The

On the supply side, the economy remains exactly as in Rebelo (1991) and consists of two production sectors. The first sector produces investment goods, I_t, using a fraction $1-\eta_t$ of the available capital stock, Z_t, according to the linear technology $I_t = A(1-\eta_t)Z_t$. Here, Z_t is to be interpreted as a reproducible composite capital good that includes both human and physical capital and that can be accumulated over time. Specifically, $Z_{t+1} = I_t + (1-\delta)Z_t$, where $0 < \delta < 1$ is the capital depreciation rate. The second sector combines the remaining capital stock, $\eta_t Z_t$, with non-reproducible factors to produce consumption goods, C_t. Consumption goods are produced according to the Cobb-Douglas technology, $C_t = B(\eta_t Z_t)^{\alpha} T^{1-\alpha}$.

Each household of type j chooses paths for consumption, $\{c_{jt}\}_{t=0}^{\infty}$, and capital, $\{z_{jt}\}_{t=0}^{\infty}$, to solve:

$$\max_{c_{jt},\, z_{jt+1}} \sum_{t=0}^{\infty} \beta_j^t \frac{c_{jt}^{1-\sigma}-1}{1-\sigma},\ \sigma > 0,\ j = 1, ..., N, \tag{P1}$$

$$\text{subject to } q_t c_{jt} + z_{jt+1} = y_{jt}\left[1-\zeta\left(\frac{y_{jt}}{Y_t}\right)^{\phi}\right] + z_{jt}, \tag{4}$$

$$\text{where } y_{jt} = r_t z_{jt} + u_t T,\ Y_t = \sum_{j=1}^{N} y_{jt}\frac{1}{N}, \tag{5}$$

$$\text{and } c_{jt},\ z_{jt} \geq 0 \text{ for all } j \text{ and } t,\ z_{j0} > 0 \text{ given for all } j.$$

We denote the price of consumption in terms of the composite capital good by q_t. The variables r_t and u_t denote the rates of return to capital and non-reproducible factors, respectively. In solving their optimal consumption-investment allocation problem, households take the sequence of prices $\{r_t\}_{t=0}^{\infty}$ and $\{u_t\}_{t=0}^{\infty}$ as given. Thus, the following Euler equation is obtained for each household of type j:

$$\frac{q_{t+1}}{q_t}\left(\frac{c_{jt+1}}{c_{jt}}\right)^{\sigma} = \beta_j\left\{\left[1-(1+\phi)\,\zeta\left(\frac{y_{jt+1}}{Y_{t+1}}\right)^{\phi}\right] r_{t+1} + 1\right\},\ j = 1, ..., N. \tag{6}$$

In addition, a transversality condition must hold for each household type, $\lim_{t\to\infty} \beta_j^t \left(c_{tj}^{-\sigma}/q_t\right) z_{jt} = 0$.

Firms make their production decisions to maximize profits and solve $\max_{\eta,\, Z,\, T} A(1-\eta_t)Z_t + q_t B(\eta_t Z_t)^{\alpha} T^{1-\alpha} - r_t Z_t - \delta Z_t - u_t T$, where $Z_t = \sum_{j=1}^{N} z_{jt}(1/N)$. Optimal firm behavior implies that:

$$r_t + \delta = A(1-\eta_t) + q_t \alpha B \eta_t^{\alpha} Z_t^{\alpha-1} T^{1-\alpha}, \tag{7}$$

$$u_t = q_t(1-\alpha)B(\eta_t Z_t)^{\alpha} T^{-\alpha}, \tag{8}$$

appendix then shows that existence and uniqueness of such an equilibrium requires that there be enough progressivity in the tax schedule, ϕ, relative to the spread in discount factors, $\beta_1/\beta_N < 1$.

and

$$q_t \alpha B(\eta_t Z_t)^{\alpha-1} T^{1-\alpha} = A. \tag{9}$$

Total tax revenues are simply used to finance government expenditures on goods and services. The government budget constraint is then given by

$$G_t = \sum_{j=1}^{N} \zeta \left(\frac{y_{jt}}{Y_t} \right)^{\phi} y_{jt} \frac{1}{N}. \tag{10}$$

It can be easily shown that the above set-up implicitly defines an economy-wide resource constraint.

4.1 Equilibrium

An equilibrium for this economy is a set of prices $\{r_t, u_t, q_t\}$, $t = 0, ..., \infty$, *household allocations* $\{c_{jt}, z_{jt}\}$, $t = 0, ..., \infty$, $j = 1, ..., N$, *and firms' decision rules* $\{\eta_t, Z_t, T\}$, $t = 0, ..., \infty$, *such that given prices and the tax schedule* $\tau(.)$, *i) households' allocation decisions maximize their lifetime utility, ii) firms' decision rules maximize profits, and iii) all markets clear.*

We now turn to the description of a balanced growth equilibrium in which all individual and aggregate variables, expressed in units of the composite capital good, eventually grow at the same constant rate.[10] In what follows, we denote the growth rate of variable X by $\gamma_X = X_{t+1}/X_t$.

Along a balanced growth path, η_t is constant and the relative price of consumption increases at rate $\gamma_q = \gamma_Z^{1-\alpha}$ by equation (9). Given the production technology in the consumption sector, we have that $\gamma_C = \gamma_Z^{\alpha}$. Hence, when measured in units of the composite capital good, aggregate consumption, $q_t C_t$, grows at rate $\gamma_{qC} = \gamma_Z$.

From (5), we have that $Y_t = \sum_{j=1}^{N} y_{jt}(1/N) = r_t \sum_{j=1}^{N} z_{jt}(1/N) + u_t T = r_t Z_t + u_t T$. Since $r_t Z_t + u_t T = A(1 - \eta_t) Z_t + q_t B(\eta_t Z_t)^{\alpha} T^{1-\alpha} - \delta Z_t$ by equations (7) and (8), substituting for q_t in this last expression yields $Y_t = A(1 - \eta) Z_t + (A/\alpha)\eta Z_t - \delta Z_t$. It follows that $\gamma_Y = \gamma_Z$ in the steady state.

Observe also that $r_t = A - \delta$ using equations (7) and (9). The law of motion for capital further implies that $\gamma_I = \gamma_Z$. To summarize, we have that $\gamma_{qC} = \gamma_Y = \gamma_I = \gamma_Z$; and it remains only for us to describe how the growth rate of the composite capital good, γ_Z, is determined in equilibrium.

Because individual and aggregate variables grow at the same rate in the long run, y_j/Y in equation (6) is constant in the steady state. The left-hand side of this equation can

[10]Note that if individual variables grow at some constant rate, and their aggregate also grows at a constant rate, then these rates must all be equal.

be written as $\gamma_q \gamma_{c_j}^{\sigma} = \gamma_Z^{1-\alpha} \gamma_{cj}^{\sigma}$ and, since γ_{c_j} is the same for all j, individual consumption increases at rate $\gamma_C = \gamma_Z^{\alpha}$ in the long run. In this model, therefore, the balanced growth rate, γ_Z, and the relative distribution of income, as summarized by y_j/Y for each j, are jointly determined as a set of $N+1$ equations in $N+1$ unknowns:

$$\gamma_Z^{1-\alpha(1-\sigma)} = \beta_j \left\{ \left[1 - \underbrace{(1+\phi)\,\zeta \left(\frac{y_j}{Y} \right)^{\phi}}_{\text{marginal tax rate}} \right] (A-\delta) + 1 \right\}, \; j = 1, ..., N, \tag{11}$$

and

$$\sum_{j=1}^{N} \left(\frac{y_j}{Y} \right) \frac{1}{N} = 1. \tag{12}$$

The following proposition provides sufficient conditions for the existence of a unique solution to this set of $N+1$ equations.

Proposition: *If* $(1+\phi)\zeta < 1$ *and* $[A+1-\delta-(A-\delta)(1+\phi)\zeta] \leq \left(\frac{\beta_1}{\beta_N}\right)[A+1-\delta]$*, then an equilibrium with balanced growth,* γ_Z*, and non-degenerate relative distribution of income,* $\frac{y_j}{Y} \geq 0$*,* $j = 1, ..., N$*, exists and is unique.*

Proof: see Appendix.

The first condition places an upper bound on the scale of the marginal tax schedule, $\tau_m(y/Y) = (1+\phi)\zeta(y/Y)^{\phi}$, and ensures that households have sufficient incentive to invest to sustain a balanced growth path. The second condition, while seemingly less intuitive, holds when the degree of progressivity in the tax schedule, ϕ, is large enough relative to the spread in discount factors $\beta_1/\beta_N < 1$. Hence, this second condition puts in enough curvature in marginal tax rates to ensure that all households have non-negative relative income.[11]

A crucial difference between this model and Rebelo's (1991) original framework is that tax reforms affect both economic growth, γ_Z, and the distribution of relative pre-tax income, y_j/Y, simultaneously. Furthermore, it follows that effective marginal tax rates, $(1+\phi)\,\zeta\left(\frac{y_j}{Y}\right)^{\phi}$, are ultimately endogenous. In the original single agent set-up with proportional taxes, the formula for long-run growth:

$$\gamma_Z^{1-\alpha(1-\sigma)} = \beta\left\{(1-\tau)(A-\delta)+1\right\}, \tag{13}$$

with τ being the constant marginal tax rate, could not possibly capture any feedback effects from economic growth to effective tax rates. In interpreting their results, Easterly and Rebelo (1993) explicitly recognized that this feature represented a serious caveat to their analysis.[12]

[11] As in Sarte (1997), a progressive tax schedule helps avoid the kind of degenerate equilibrium first studied by Becker (1980).

[12] The idea that changes in marginal tax rates has non-trivial effects on the distribution of income in U.S. data is developed extensively in Altig and Carlstrom (1999).

Because households' relative income responds to changes in progressivity in the environment, we consider the direction in which the share of tax revenue in output adjusts is not immediately clear. Therefore, whatever the growth response, it may have been misleading to look for evidence of a robust negative relationship between the size of government, as measured by the ratio of government expenditures to GDP, and economic growth. In contrast, more conventional endogenous growth models with flat rate taxes, where $G = \tau Y$, necessarily predict a rise in G/Y as τ increases, and this rise is unambiguously accompanied by a fall in the rate of growth by equation (13).

4.2 Intuition for the Steady State Effects of Changes in Progressivity

To understand the importance of progressivity for the cross-sectional relationship linking growth and taxes, consider the effects of a decrease in ϕ. For simplicity, let us focus on the case where there are only two household groups: impatient households indexed by β_1 and patient households with discount rate $\beta_2 > \beta_1$.

Figure 2, panel (a) illustrates a typical equilibrium where y_1/Y and y_2/Y solve equation (11), reproduced below as:

$$\underbrace{(1+\phi)\zeta\left(\frac{y_j}{Y}\right)^{\phi}}_{\tau_m\left(\frac{y_j}{Y}\right)} = 1 - \frac{1}{A-\delta}\left[\frac{\gamma_Z^{1-\alpha(1-\sigma)}}{\beta_j} - 1\right], \tag{14}$$

for impatient and patient households, respectively. As expected, impatient households are relatively poorer in the long run. At the initial equilibrium growth rate, γ_Z, equation (12) must also hold so that $(1/2)\sum_{j=1}^{2}(y_j/Y) = 1$.

Suppose that ϕ falls to ϕ' in Figure 2, panel (b), so that the marginal tax rate decreases at all levels of income. Because taxes are progressive, this downward shift entails a lighter tax burden for the patient households at the initial solutions for y_1/Y and y_2/Y. Furthermore, faced with lower marginal tax rates, all households have an incentive to increase their relative pre-tax earnings to y_1'/Y and y_2'/Y, and this change is particularly pronounced for the more patient households. However, at the initial growth rate, γ_Z, y_1'/Y and y_2'/Y no longer represent an equilibrium distribution of relative income, since $(1/2)\sum_{j=1}^{2}(y_j'/Y) > 1$. Hence, in order to reach the new steady state, the growth rate must rise to γ_Z' in Figure 2, panel (b), which induces the new distribution y_1''/Y and y_2''/Y. We conclude that a decrease in ϕ leads to an increase in economic growth, slightly lower pre-tax relative income for impatient households, and higher pre-tax income for patient households so that $(1/2)\sum_{j=1}^{2}(y_j''/Y) = 1$. Consistent with U.S. experience over the past two decades, the decrease in statutory rates coincides with an increase in pre-tax income inequality (i.e., $[y_1/Y, y_2/Y] \subseteq [y_1''/Y, y_2''/Y]$) and, therefore, a larger share of the tax burden potentially falling on high-income households.

The effects of the adjustment mechanism we have just described are less straightforward for the steady-state share of government expenditures, or tax revenue, in GDP. In our example, G/Y is initially given by $(1/2)\sum_{j=1}^{2}\zeta(y_j/Y)^{1+\phi}$. In response to the change in tax policy, and given Figure (2b), the relative size of government expenditures becomes $(1/2)\sum_{j=1}^{2}\zeta(y_j''/Y)^{1+\phi'}$ where $\phi' < \phi$, $y_1''/Y < y_1/Y$, and $y_2''/Y > y_2/Y$. The end result of a decrease in progressivity, therefore, is ambiguous as patient and impatient households' relative earnings move in different directions. It follows that, while γ_Z unambiguously rises in Figure 2b), the relationship between γ_Z and G/Y may be much flatter than originally suggested by the early growth literature. In fact, if G/Y also rises as the tax schedule becomes less progressive, then differences in progressivity across economies would lead to an *increasing* relationship between economic growth and the relative size of government.

4.3 Calibrated Examples and The Recent U.S. Experience

As indicated earlier, U.S. statutory marginal tax rates have fallen significantly during the past two decades, especially for high-income households. Over the same period, however, the burden of individual income taxes has consistently shifted toward the highest income households (see Figure 3). According to the CBO (2001), the top income quintile of households paid 78 percent of total individual income taxes in 1997, up from 66 percent in 1979. By contrast, the next richest quintile bore only 15 percent of total income tax liabilities in 1997 versus 20 percent 18 years earlier. Overall, the shifts in tax burden depicted in Figure 3 are consistent with a Tax Concentration Index (TCI) rising from 0.59 in 1979 to 0.68 in 1997.[13] In effective terms, therefore, progressivity has increased since the early 1980s.

The shifts in tax liabilities shown in Figure 3 are not entirely surprising, given the widely documented increase in income inequality over the past 20 years. From 1979 to 1997, the Census Bureau documents an increase of 0.06 in the Gini coefficient of pre-tax income to 0.46. The Current Population Survey similarly estimates an increase of approximately 0.05 over the same period. Further, according to the CBO (2001), the rapid rise in the income of richer taxpayers "has generated more than a proportional increase in federal tax revenues. In turn, that increase has driven up the total effective tax rate faster than income growth."

There exist several possible explanations for the apparent increase in inequality, including higher demand for skilled workers stemming from new technologies (Snower [1998]), and changes in demographics (Bishop, Formby, and Smith [1997]). As Figure 2 suggests, we also

[13] Analogously to the Gini coefficient, the Tax Concentration Index is a measure of the relative tax burden borne by households at different income levels and, in our framework, is defined as $TCI = 1 - (2/N^2)\sum_{j=1}^{N}\sum_{i=1}^{j}\{[\tau(y_i/Y)y_i]/TR\}$, where TR is total tax revenue, $(1/N)\sum_{i=1}^{N}\tau(y_i/Y)y_i$.

expect that changes in tax laws affected the distribution of pre-tax income in significant ways. Evidence of this channel from ERTA is presented in Lindsey (1987). Further evidence from TRA-86 can be found in Feenberg and Poterba (1993), as well as Feldstein (1995). Feldstein, in particular, estimates that for high-income groups, the elasticity of taxable income with respect to the net-of-tax rate may be high enough to generate a Laffer-type inverse revenue response.[14] Admittedly, Slemrod (1998) points to several potential methodological problems associated with the measurement and interpretation of taxable income. Furthermore, in practice, increases in income inequality have likely been the result of a combination of factors. However, to the extent that these factors include the fiscal reforms of the 1980s, our framework allows us to quantify an upper bound for the growth effects of progressive taxes. With this in mind, we now turn to a numerical simulation of the recent U.S. experience.

4.3.1 Calibration to U.S. Benchmarks

The U.S. economy has grown at an average 1.8 percent in real terms since 1979 (i.e. $\gamma = 1.018$), and the following discussion assumes that we attempt to match this value in the steady state. Households have log utility under our benchmark case, $\sigma = 1$. From the capital accumulation equation, we have that $\gamma = I/Z + (1-\delta)$ along a balanced growth path. Given that $\gamma = 1.018$, we follow Cooley and Prescott (1995) and choose $\delta = 0.058$ to match a value of 0.076 for I/Z. Using this value for δ, we calibrate A so that $r = 6.40$ percent (Lucas [1990]). Since the real rate is simply $A - \delta$, this immediately implies that $A = 0.122$.

Once δ and A are calibrated, the technology for producing investment goods along with the accumulation equation imply that $1 - \eta = \frac{\gamma-(1-\delta)}{A}$, or $\eta = 0.68$. As in Rebelo (1991), $Y = qC + I - \delta Z$ so that, after substituting for q, $Y/Z = A[1 - \eta + \eta/\alpha] - \delta$. Therefore, given values of δ, A, and η, we choose α to match a capital output ratio of 3.32 (Cooley and Prescott [1995]). This implies $\alpha = 0.16$.

Finally, it remains to choose the scaling parameter in the tax schedule, ζ, the degree of progressivity, $1 + \phi = \tau_m/\tau_a$, and the discount factors, β_j, $j = 1, ..., N$. We set these parameters so as to match the share of government spending in output, approximately 20 percent, the per capita GDP growth rate, 1.8 percent (assumed in the above discussion), and the quintile distribution of income in 1997.[15] While labor is not modeled specifically in Rebelo (1991), we choose to target total income rather than non-wage income because, in that framework, endogenous growth emerges with a definition of capital that is broad enough to include some human component. Therefore, the notion of income inequality here partly

[14] See Slemrod and Bakija (2000) for a survey of this literature.

[15] For consistency, all distributional measures below are taken from the same source, namely the CBO (2001) study on effective tax rates that covers 1979 to 1997.

reflects differences in skill acquisition. The parameter values that achieve our calibration targets are summarized in Table 1A. Specifically, $\zeta = 0.17$, $1 + \phi = 1.68$, and β ranges from 0.963 to 0.991. Surprisingly, relatively small differences in discount rates are needed to reproduce the U.S. income quintile distribution.[16]

We report the main properties of our benchmark model economy and their data counterparts in the second column of Table 2A. As shown in the table, the model, although stylized, does well in reproducing the statistics our calibration set out to match. In addition, our framework is also able to match tax-related statistics we had not explicitly targeted. Table 2B shows that both the shares of individual tax liabilities and the after-tax income distribution conform relatively well to the data. Since we abstract from income transfers not implicitly reflected in the degree of progressivity, the share of total taxes paid by the top income quintile in the model is slightly lower than its data counterpart. In particular, observe that the lowest income quintile in the data bears a small negative tax burden.

4.3.2 Growth Effects of Tax Reforms in the Steady State

According to the Census Bureau, the U.S. Gini coefficient of income rose by 0.06 between 1979 and 1997. To match a more equal distribution of income in 1979, with a Gini of 0.39, our model requires that $\tau_m/\tau_a = 1.75$ instead of 1.68 in the benchmark case. Recall from Figure 2 that higher degrees of progressivity generate a more equal distribution of pre-tax income. Therefore, to be consistent with lower income inequality in 1979, our model must indeed feature the higher statutory marginal tax rates in effect before the tax reforms of the 1980s.

With $\tau_m/\tau_a = 1.75$, the model predicts a rate of output growth of 1.76 percent in 1979. As expected, this rate is lower than the benchmark growth rate. Specifically, in this model, the long-run effects of policy changes in the 1980s amount to a difference of 0.13 percent. This change, although not negligible as in Lucas (1990), is small enough that standard statistical tests for breaks in time series would likely not detect it. Note that for the period spanning 1979 to 1997, the standard deviation of per capita GDP growth in the U.S. is roughly 1.93 percent. Hence, in terms of the U.S. experience, this finding is closer to those of Stokey and Rebelo(1995) than to the large estimates provided by Jones, Manuelli, and Rossi (1993).

Because a higher value for τ_m/τ_a in 1979 also implies less income inequality, the question of shifts in individual tax liabilities immediately arises. On the one hand, a higher degree of progressivity in 1979 suggests that the top income quintile might have paid a greater share of total taxes at that time. On the other hand, lower income inequality in 1979 suggests exactly the reverse. In fact, as in Figure 3, our framework predicts a *lower* share of tax liabilities

[16] Estimates of discount rates from the empirical literature imply values for β that range from 0.71 (Hausman [1979]) to 1 (Warner and Pleeter [2001]).

for the top income quintile prior to the decrease in statutory rates. Thus, the fifth income quintile pays only 68.8 percent of total tax liabilities when $\tau_m/\tau_a = 1.75$, which is 5.2 percent lower than in the benchmark case. Furthermore, as in U.S. data, our model also predicts a *higher* tax burden for the remaining four income quintiles prior to the tax reforms. The fourth quintile contributes 16.5 percent of total taxes in our simulated 1979 economy versus 14.9 percent in 1997. Similarly, the third and second income quintiles bear, respectively, 1.6 and 1.3 percent more taxes when $\tau_m/\tau_a = 0.75$[17]. These results underscore the point made by Creedy (1999) in that more progressive statutory rates do not always translate into more progressive effective rates. Put another way, one cannot judge the progressivity effects of a statutory reform independently of the induced changes in the distribution of pre-tax income.

With the share of total taxes rising for the top income quintile as statutory rates fall, the model-generated ratio of public expenditures to output is higher in our benchmark case, 20.2 percent, than prior to the decline in statutory rates, 19.3 percent when $\tau_m/\tau_a = 1.75$. Because the tax reforms also produce a small increase in economic growth, our framework then points to an increasing relationship between the relative size of government and output growth.

To illustrate the implication of this last finding for cross-country studies, we calibrate τ_m/τ_a to reproduce the spread of pre-tax income Gini coefficients across countries. In a study of income inequality covering 80 countries, Deininger and Squire (1997) provide Gini coefficients ranging from 0.21 in the Slovak Republic to 0.62 in South Africa. Matching this range while varying τ_m/τ_a produces panels (a) and (b) of Figure 4. Thus, changes in τ_m/τ_a create up to a 1 percent cross-country variation in growth rates. Furthermore, Figure 4, panel (b), which depicts a weakly increasing relationship between G/Y and γ, stands as the model analog to Figure 1, panels (a) through (d). Evidently, Figure (4b) also shows that if accurate cross-country data on effective marginal tax rates were obtained, one would indeed expect a negative correlation between per capita output growth and average marginal tax rates.[18] Finally, Figure (4c) shows that changes in the scaling parameter, ζ, calibrated to match the range of cross-country Ginis predict a 2.5 percent divergence in economic growth. This range represents approximately 20 percent of the full sample variation in growth rates shown in Figure 1. The potential growth effects of tax policy, therefore, are non-trivial in the cross section. As illustrated in Figure (4d), the relationship between the share of

[17]For comparison, Figure 3 reveals that households in the top income quintile contributed 12 percent less to total taxes in 1979. The remaining four quintiles paid between 1 and 4 percent more of aggregate taxes in that year. Consequently, following the change in ϕ, our model predicts smaller shifts in tax liabilities for the top two quintiles relative to the data. Not suprisingly, this suggests that over the last 20 years, income inequality has increased at a rate faster than that implied by fiscal considerations alone (i.e. given a fixed ϕ, rising inequality would naturally lead to a greater share of tax liabilities for high-income households).

[18]In our model, the average marginal tax rate is given by $(1/N)\sum_{j=1}^{N}(1+\phi)\zeta(y_j/Y)^{\phi}$.

government spending in GDP and output growth is now decreasing but, nevertheless, much less pronounced than that between average marginal tax rates and output growth.

Thus far, an increase in progressivity that mimics the U.S. tax code prior to the reforms of the 1980s is associated with both lower growth, γ, and a lower public spending share in output, G/Y. The latter effect results from the perverse shift in tax liabilities. As a normative experiment, observe that a rise in ζ meant to restore G/Y to its benchmark value necessarily increases the distortions associated with the tax schedule and, therefore, further lowers economic growth. When $\tau_m/\tau_a = 1.75$, a value of $\zeta = 0.183$ is needed instead of 0.17 to keep the share of government spending in GDP at 20 percent. A 1.61 rate of output growth emerges under this alternative calibration, which represents a difference of 0.28 percent with the benchmark case. This result amounts to roughly twice the difference in the growth effect induced by a change in τ_m/τ_a alone.

4.3.3 Tax Policy and the Dynamics of Economic Growth

The original environment described in Rebelo (1991) did not allow for transitional dynamics. Recall from equation (13) that any change in the marginal tax rate would have been instantaneously reflected in a new steady-state growth rate. Once progressive taxes are introduced into the environment, however, equation (4) shows explicitly that after-tax output exhibits diminishing returns with respect to the composite capital good. Hence, because changes in tax rates may now induce a long transitional period between balanced growth paths, testing for breaks in average growth rates to identify the effects of tax policy, as suggested in Stokey and Rebelo (1995), may prove inappropriate.

To study the dynamics induced by a change in tax policy, we must first transform our economy's variables so as to make them constant in the steady state. This is achieved by normalizing each variable by the composite capital good, Z_t, except for consumption variables, which we divide by Z_t^{α}, and their relative price, which we normalize by $Z_t^{1-\alpha}$. This transformation defines a new set of state-like variables, z_{jt}/Z_t, $j = 1, ..., N$. Given the size of our state space, we then linearize the dynamics of our transformed system around its stationary equilibrium. The resulting set of linearized equations possesses a continuum of solutions, but only one of these is consistent with the transversality condition for each household type.

Figure 5 illustrates the growth effects of a fall in τ_m/τ_a from 1.75 down to 1.68 evenly divided over five years. The implied decrease in the tax schedule then captures the gradual statutory changes introduced by ERTA and TRA-86 in the first half of the 1980s. In Rebelo's (1991) framework, we already saw that the long-run effect of these reforms was to increase economic growth 0.13 percent. Figure 5 panel (b), shows that the introduction of progressive taxation also implies some transitional dynamics. However, the striking aspect of the transition from the old to the new balanced growth path is that most of the adjustment occurs contemporaneously. At the time of the shock, the balanced growth rate increases roughly 0.12 percent. The growth rate continues to increase slightly as the tax schedule gradually shifts down and then converges to a permanently higher steady state. Observe that once the short-run growth effects have taken place, the model implies substantial lags in the adjustment process. Ultimately, however, there appears to be little difference between the original representative agent formulation with flat rate taxes and our model with heterogeneous households and progressive taxes. This is not the case in the next model we study, a re-formulation of Barro's (1990) environment where government services play a productive role.

5 Government Spending in a Simple Model of Endogenous Growth: New Implications

In the previous section, all tax proceeds were spent in a way that affected neither the marginal utility of private consumption nor the production possibilities of the private sector. We now explore an alternative formulation, first suggested by Barro (1990), in which tax revenue is used to finance public services that contribute to private production.[19] We modify this case to incorporate progressive taxes and heterogeneous households for two reasons.

First, we show that the cross-sectional relationships in Figure 1 emerge even in this set-up with growth-augmenting government services. In Barro's initial representative agent environment, the relation between growth and taxes tended to be that of an inverted U, reflecting higher productive expenditures financed by higher taxes on the one hand and the distortional effects of higher taxes on the other. In our framework, however, the relative size of government expenditures, G/Y, *falls* in the long run as progressivity increases; since γ also falls with τ_m/τ_a, this explains why G/Y increases with γ in Figure 4, panel (b). Therefore, as the marginal tax rate rises relative to the average rate in this new setting, growth unambiguously falls not only because of the distortional effects of taxes but also because government contributions to private output are lower. Consequently, accounting for non-linear taxation and heterogeneous households removes the familiar inverted U-shaped relation between the share of government expenditures and output growth. In the end, the cross-sectional implications of this environment, where the proceeds from taxation affect private-sector production, revert back to those of Section 4.

Second, while less progressive taxes raise output growth, the fact that taxes also finance productive public services suggests that the favorable effects of lower tax rates may be small

[19] See also Glomm and Ravikumar (1994), (1997).

initially or even reversed. With non-linear taxes, a decrease in marginal rates motivated by lower progressivity creates an endogenous adjustment in pre-tax income. In the long run, this mechanism increases public expenditures by raising effective tax revenue from high-income households. In the short run, however, the income distribution adjustment is limited, and a decrease in marginal rates simply reduces the level of productive public spending. It follows that the growth effects of a fall in progressivity may be quite muted initially.[20] To illustrate these ideas, we now turn to a more detailed description of the economic environment.

The production technology is given by:

$$Y_t = AK_t^{\alpha}G_t^{1-\alpha}, \text{ with } 0 < \alpha < 1, \tag{15}$$

where K_t denotes aggregate capital. As much as possible, we have attempted to keep the notation in this and the previous section as in the original papers. We continue to think of K_t as a composite capital good that includes both human and physical components. Total government purchases at date t are represented by G_t. For the purpose of this analysis, we shall think of G_t as nonrival and nonexcludable and, therefore, abstract from congestion considerations.[21]

As in the section above, we assume that there exists a large number of profit-maximizing firms that solve:

$$\max_{K_t} \Pi_t = AK_t^{\alpha}G_t^{1-\alpha} - r_tK_t - \delta K_t, \tag{16}$$

where r_t denotes the rental rate on aggregate capital. Profit maximization yields

$$r_t = \alpha A \left(\frac{G_t}{K_t}\right)^{1-\alpha} - \delta. \tag{17}$$

The household side of the economy remains essentially as in section 4. We describe the problem of a type j household as:

$$\max_{c_{jt},\, k_{jt+1}} \sum_{t=0}^{\infty} \beta_j^t \frac{c_{jt}^{1-\sigma} - 1}{1-\sigma}, \; \sigma > 0, \; j = 1, ..., N, \tag{P2}$$

$$\text{subject to } c_{jt} + k_{jt+1} = y_{jt}\left[1 - \zeta\left(\frac{y_{jt}}{Y_t}\right)^{\phi}\right] + k_{jt}, \tag{18}$$

$$\text{where } y_{jt} = r_tk_{jt} + \Pi_t, , \tag{19}$$

$$\text{and } c_{jt},\ k_{jt} \geq 0 \text{ for all } j \text{ and } t,\ k_{j0} > 0 \text{ given for all } j.$$

[20]Because Barro's (1990) original framework models government services rather than public infrastructure, the analysis cannot give rise to transitional dynamics without progressive taxation.

[21]See Barro and Sala-i-Martin (1992) for a discussion of how congestion in public services can eliminate scale effects in economic growth.

All households take the sequence of prices, $\{r_t\}_{t=0}^{\infty}$, and profits, $\{\Pi_t\}_{t=0}^{\infty}$, as given, and the following Euler equation obtains:

$$\left(\frac{c_{jt+1}}{c_{jt}}\right)^{\sigma} = \beta_j \left\{ \left[1 - (1+\phi)\,\zeta \left(\frac{y_{jt+1}}{Y_{t+1}}\right)^{\phi}\right] r_{t+1} + 1 \right\},\ j = 1, ..., N. \tag{20}$$

In addition, the usual transversality condition must also hold for each j, $\lim_{t\to\infty} \beta_j^t c_{tj}^{-\sigma} k_{jt} = 0$. Government purchases are financed by tax revenue as in equation (10), which we reproduce below:

$$G_t = \sum_{j=1}^{N} \zeta \left(\frac{y_{jt}}{Y_t}\right)^{\phi} y_{jt} \frac{1}{N}. \tag{21}$$

The definition of equilibrium is analogous to that in section 4. Thus, we now describe a balanced growth equilibrium in which all individual and aggregate variables grow at the same constant rate, γ.

Along the balanced growth path, y_j/Y is constant for each j. Equation (21) implies that the relative size of government expenditures is given by $G/Y = (1/N) \sum_{j=1}^{N} \zeta \left(y_j/Y\right)^{1+\phi}$ in the steady state. Furthermore, by equation (17), r is constant and equal to $\alpha A \left(G/K\right)^{1-\alpha} - \delta$. Since the technology in (15) implies that $(G/K)^{\alpha} = A\,(G/Y)$, we immediately have that:

$$r = \alpha A^{\frac{1}{\alpha}} \left(\frac{G}{Y}\right)^{\frac{1-\alpha}{\alpha}} - \delta. \tag{22}$$

In this model, therefore, an increase in public services relative to GDP unambiguously raises the marginal product of capital.

In the end, we can think of long-run growth, γ, the long-run distribution of relative pre-tax earnings, y_j/Y, and the size of government in the steady state, G/Y, as being simultaneously determined as a set of $N+2$ equations in $N+2$ unknowns:

$$\gamma^{\sigma} = \beta_j \left\{ \left[1 - (1+\phi)\,\zeta \left(\frac{y_j}{Y}\right)^{\phi}\right] \left(\alpha A^{\frac{1}{\alpha}} \left(\frac{G}{Y}\right)^{\frac{1-\alpha}{\alpha}} - \delta\right) + 1 \right\},\ j = 1, ..., N, \tag{23}$$

$$\frac{G}{Y} = \sum_{j=1}^{N} \zeta \left(\frac{y_j}{Y}\right)^{1+\phi} \frac{1}{N}, \tag{24}$$

and

$$\sum_{j=1}^{N} \left(\frac{y_j}{Y}\right) \frac{1}{N} = 1. \tag{25}$$

With public expenditures contributing to private production, the long-run effects of changes in progressivity can no longer be worked out in terms of a simple diagram as in

Figure 2. The endogenous adjustment in the distribution of pre-tax earnings now affects economic growth not only directly, through the income tax rate, but also indirectly through its impact on the relative size of public infrastructures. Furthermore, unlike the case with flat rate taxes originally explored by Barro (1990) and Glomm and Ravikumar (1994, 1997), these two channels must not necessarily offset each other.

5.1 Long-Run Growth Effects of Progressive Taxes

To explore the long-run effects induced by changes in progressivity in this new environment, we introduce once more an example calibrated to the U.S. We shall also use this example in computing the transition between different balanced growth paths.

5.1.1 Calibration

As in the previous section, households are assumed to have log utility in the benchmark case. Given 1.8 percent growth in the steady state, we continue to set $\delta = 0.058$ to match a ratio of investment to capital of 0.076 (recall that $\gamma = I/K + 1 - \delta$). Empirical estimates of $1 - \alpha$, the elasticity of output with respect to government expenditures, vary significantly across studies. Glomm and Ravikumar (1997) cite values ranging from as low as 0.03 (Eberts [1986]) to as high as 0.39 (Aschauer [1989]). We set $1 - \alpha = 0.25$ to approximate a consensus view. Conditional on matching the U.S. quintile distribution of income, we know from the previous section that setting $1 + \phi = \tau_m/\tau_a = 1.68$ reproduces successfully the relative shares of tax liabilities in 1997.

It remains to set the technological factor, A, the scaling parameter in the tax schedule, ζ, and the discount factors β_j, $j = 1, ..., N$. However, because we use an independent estimate for α and have already set $1 + \phi$, we now have more targets than free parameters relative to our previous numerical example. In particular, we would like to continue matching the remaining four statistics as well as the distribution of income in Table 2A. We choose $A = 0.41$, $\zeta = 0.22$, and set the discount factors between 0.954 and 0.997. These values, shown in Table 1B, allow us to closely match per capita output growth, the share of public spending in output, and the 1997 quintile distribution of pre-tax income. The capital-output ratio that now emerges is somewhat higher than our target, but since the models above assume a broad concept of capital, this may well be appropriate.

5.1.2 Steady-State Effects with Productive Government Services

Similarly to section 4, an increase in τ_m/τ_a from 1.68 (our benchmark) to 1.75 is needed to reproduce a Gini coefficient of pre-tax income of 0.39 in 1979. This produces once more a shift in tax liabilities where high-income households pay a smaller share of total taxes prior to the tax reforms of the 1980s. Specifically, the top income quintile contributes 70 percent of aggregate taxes when $\tau_m/\tau_a = 1.75$ versus 75 percent in the benchmark case.[22]

While changes in progressivity produce shifts in individual taxes that are similar to those discussed in section 4, the implication of these shifts for growth are different than in our previous example. With $\tau_m/\tau_a = 1.75$ in 1979, the model predicts an output growth rate of 1.46 percent, 0.29 percent lower than when $\tau_m/\tau_a = 1.68$. In Figure 5, panel (b), the same change in τ_m/τ_a in Rebelo's (1991) model generated less than half that difference in the long run, 0.13 percent. The growth effects of tax policy are more pronounced in this case precisely because high-income households pay a smaller share of total taxes under the more progressive rates in effect before ERTA and TRA-86. The implied difference in tax burden means a public spending share of only 20 percent in the 1979 economy compared to 21 percent when $\tau_m/\tau_a = 1.68$. By equation (22), this lower ratio of public services to output lowers the return to investment independently of the conventional distortional effects of higher marginal tax rates.

On the whole, changes stemming from U.S. tax reforms in the 1980s continue to be relatively modest. Furthermore, recall that they constitute only an upper bound in the sense that the difference in τ_m/τ_a is calibrated to explain the entire change in Gini coefficients over the past two decades. Nevertheless, because differences in progressivity now affect the return to investment both directly (through more distortional marginal rates), and indirectly (through changes in G/Y), we expect the model to predict a larger cross-sectional variation in economic growth relative to those shown in Figure 4.

Figure 6, panels (a) and (b), illustrate the effects of changes in τ_m/τ_a calibrated to match the Deininger and Squire (1997) cross-country range of Gini coefficients of income. Note first in panel (a) that differences in progressivity now create more than a 2.5 percent divergence in cross-sectional output growth. This difference represents more than 20 percent of the range in growth rates shown in Figure 1. Furthermore, because G/Y also falls as marginal tax rates increase relative to average rates, panel (b) continues to depict a slightly rising relationship between GDP growth and the share of public spending in output. In this context, therefore, the endogenous adjustments in pre-tax income and corresponding tax liabilities undo the familiar inverted U-relationship that typically links γ and G/Y in this class of models. Interestingly, Figure 6, panels (c) and (d), indicate that, within the range of Gini coefficients observed across countries, this inverted U-relation is no longer present even when we vary the tax scaling parameter, ζ.

We conclude that if there exist differences in tax progressivity across economies, whether

[22] At the same time, the lower four income quintiles bear between 0.5 and 1.6 percent more of total tax liabilities before the changes in tax laws. Once again, therefore, more progressive statutory rates, as exemplified by $\tau_m/\tau_a = 1.75$, imply less progressive effective rates.

or not government expenditures contribute to private production is immaterial for the cross-sectional correlation between economic growth and the ratio of public expenditures to output. In either case, the upward shift in higher marginal tax rates implied by higher values of ϕ lowers output growth and G/Y simultaneously. Should government services play a productive role, the downward adjustment in G/Y simply decreases economic growth further. These results thus provide a theoretical foundation for the empirical findings of Levine and Renelt (1992), Levine and Zervos (1993), and Easterly and Rebelo (1991).

5.2 Dynamic Implications for Economic Growth

We saw in section 4 that the dynamics implied by progressive taxation did little to modify the standard endogenous growth effects of higher marginal tax rates. In particular, Figure 5 showed that most of the adjustment to the new balanced growth path in Rebelo's framework took place on impact. This is not the case when government spending plays a productive role.

Figure 5 panel (b) shows that in Barro's (1990) environment, a gradual decrease in τ_m/τ_a from 1.75 to 1.68 over five years leads to a small increase in growth contemporaneously relative to the long run. The intuition underlying this result derives from the fact that the distribution of relative pre-tax income, y_j/Y, adjusts gradually to a change in progressivity. Therefore, on impact, the immediate effect of a decrease in the tax schedule is to finance a lower ratio of public services to GDP, G/Y. Given the model's assumptions, this decrease in the relative size of government expenditures initially lowers the marginal product of capital and, as a result, reduces the favorable growth effects of lower marginal tax rates. Moreover, Figure 5, panel (b), shows that this effect noticeably mutes the growth response to a continuing fall in the ratio of marginal to average tax rates. Strikingly, the period of tax reforms spanning years 2 through 5 associates declining statutory tax rates with essentially flat, or even decreasing, growth rates. Of course, in the long run, the more prosperous (i.e., patient) households have higher pre-tax income in relative terms. This eventual adjustment implies more tax revenue relative to output and, consequently, more public services and higher long-run growth.

The key point here is that the growth effects of tax reform may not be monotonic over time. Contrary to standard linear growth frameworks with flat rate taxes, a permanent decrease in marginal tax rates does not imply a corresponding and permanent rise in economic growth contemporaneously. Observe in Figure 5 (b) that the transition to a higher balanced growth path suggests significant lags in the effects of tax changes on output growth.

To identify the growth effects of tax policy in the U.S., Stokey and Rebelo (1995) suggest testing for breaks in the average value of per capita output growth. The transitional dynamics of Barro's model, however, imply that this strategy may be inappropriate for two reasons.

First, the magnitudes involved in Figure 5, panel (b) are small relative to average variations in the time series of U.S. output growth. Second, even in a situation where a country adopted tax reforms drastic enough to cause a significant shift in balanced growth paths, Barro's framework shows very little change on impact and a slow convergence to the steady state. In the end, our analysis indicates that the history of U.S. growth and tax changes over the last 20 years is not necessarily at odds with standard endogenous growth frameworks. Evidently, as in Figure 6, this does not prohibit variations in tax policies across countries from leading to notable differences in growth rates.

6 Summary and Conclusions

With the advent of the endogenous growth framework, it became theoretically possible to address some of the cross-country dispersion in average growth rates in terms of differences in public policy. Unfortunately, early endogenous growth models, of the type posited by Jones and Manuelli (1990), or Rebelo (1991), were later shown to be at odds with the data. Above all, these models implied that economic growth should fall with the size of government spending and tax revenue relative to GDP.

In this paper, we have attempted to show that allowing for progressive taxes and household heterogeneity in standard growth models considerably changes their predictions both in the cross-section and the time series. In the economies presented above, a decrease in tax progressivity did lead to higher growth. However, the endogenous adjustment in the distribution of pre-tax income prevented this policy change from yielding lower tax revenues as a fraction of GDP. When plotted against each other, both of these results seemed to match well with available cross-country evidence. Our calibrated examples suggested that differences in tax code across countries could explain up to a two and half percent variation in economic growth.

We also showed that the explicit modeling of non-linear taxes implied important lags in the effects of tax policy on per capita output growth. In the case where public spending served as an input into private production, we found that the favorable growth effects of lower marginal tax rates could be significantly muted in the short run. Remarkably, our calibrated example indicated that a decreasing tax schedule could be associated with flat, or even decreasing, growth rates in the short run. Finally, our analysis suggested that considerable changes in U.S. tax laws between 1981 and 1986 contributed at most 0.29 percent to per capita GDP growth. This finding sheds doubt on the ability to use tax policy to significantly alter prospects for long-run U.S. economic growth.

Appendix

If (i) $(1+\phi)\zeta < 1$, and (ii) $[A+1-\delta-(A-\delta)(1+\phi)\zeta] < \left(\frac{\beta_1}{\beta_N}\right)[A+1-\delta]$, then a solution to the set of equations (11) and (12) exists and is unique.

Proof:

Re-write equation (11) as

$$\frac{y_j}{Y} = \left\{\frac{1}{(1+\phi)\zeta(A-\delta)}\left[A+1-\delta-\frac{\gamma_Z^{1-\alpha(1-\sigma)}}{\beta_j}\right]\right\}^{\frac{1}{\phi}},\ j=1,...,N. \tag{A1}$$

From equation (12), it follows that a solution for $\gamma_Z \geq 0$ must solve

$$\underbrace{\sum_{j=1}^{N}\left\{\frac{1}{(1+\phi)\zeta(A-\delta)}\left[A+1-\delta-\frac{\gamma_Z^{1-\alpha(1-\sigma)}}{\beta_j}\right]\right\}^{\frac{1}{\phi}}\left(\frac{1}{N}\right)}_{F(\gamma_Z)} = 1. \tag{A2}$$

Now define the left-hand side of (A2) as $F(\gamma_Z)$. There are two cases to consider, namely, $1-\alpha(1-\sigma) \geq 0$ and $1-\alpha(1-\sigma) < 0$.

Suppose first that $1-\alpha(1-\sigma) \geq 0$. Since we allow for $\phi > 1$, the expression inside the square brackets of equation (A1) cannot be negative. Define $\overline{\gamma}_Z = \{\beta_1[A+1-\delta]\}^{\frac{1}{1-\alpha(1-\sigma)}}$. Then, $\forall\gamma_Z \leq \overline{\gamma}_Z$, $A+1-\delta-\frac{\gamma_Z^{1-\alpha(1-\sigma)}}{\beta_1} \geq 0$ and, since β_1 is the smallest discount rate, $A+1-\delta-\frac{\gamma_Z^{1-\alpha(1-\sigma)}}{\beta_j} > 0$ for $j=2,...,N$. Hence, $F(\gamma_Z)$ is always well defined for $\gamma_Z \leq \overline{\gamma}_Z$. In other words, $\overline{\gamma}_Z$, sets an upper bound for the range of feasible growth rates, and this range guarantees $y_j/Y \geq 0$ for $j=1,...,N$.

Now, when $1-\alpha(1-\sigma) \geq 0$, $F(0) = \sum_{j=1}^{N}\left\{\frac{1}{(1+\phi)\zeta}\left[\frac{A+1-\delta}{A-\delta}\right]\right\}^{\frac{1}{\phi}}\left(\frac{1}{N}\right)$. Therefore, if $(1+\phi)\zeta < 1$ (i.e. condition (i) above), then $\frac{1}{(1+\phi)\zeta} > 1$ and $F(0) > 1$ for any $A \geq 0$.

Define $\widetilde{\gamma}_Z = (\beta_N\{[A-\delta][1-(1+\phi)\zeta]+1\})^{\frac{1}{1-\alpha(1-\sigma)}}$. Then, $\frac{1}{(1+\phi)\zeta(A-\delta)}\left[A+1-\delta-\frac{\widetilde{\gamma}_Z^{1-\alpha(1-\sigma)}}{\beta_N}\right] = 1$. Furthermore, because $\beta_j < \beta_N$, $j=1,...,N-1$, (i.e. β_N is the discount rate of the most patient households), $\frac{1}{(1+\phi)\zeta(A-\delta)}\left[A+1-\delta-\frac{\widetilde{\gamma}_Z^{1-\alpha(1-\sigma)}}{\beta_j}\right] < 1$ for $j=1,...,N-1$. It follows that $F(\widetilde{\gamma}_Z) < 1$.

Since $F(\gamma_Z)$ is continuous, by the Intermediate Value Theorem, there exists $0 < \gamma_Z < \widetilde{\gamma}_Z$ such that $F(\gamma_Z) = 1$. In addition, because $F(\gamma_Z)$ falls monotonically with γ_Z, this solution is unique (see Figure 7).

It remains to check that $\widetilde{\gamma}_Z$ falls within the domain of feasible growth rates, $\widetilde{\gamma}_Z \leq \overline{\gamma}_Z$. The condition $[A+1-\delta-(A-\delta)(1+\phi)\zeta] < \left(\frac{\beta_1}{\beta_N}\right)[A+1-\delta]$ (i.e. condition (ii) above) ensures that this will indeed be the case. Given the solution for γ_Z, one can then solve for the distribution of relative income, y_j/Y for each j, by simply using (A1). The case where $1-\alpha(1-\sigma) < 1$ can be worked out in a similar fashion. ¤

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Table 1. Calibrated Benchmark Parameters

A. *Parameters in Rebelo (1991)*		Value
Preferences		
σ	Intertemporal Elasticity of Substitution	1
β_j	Time Discount Rates	$\left[\ 0.963,\ \ 0.968,\ \ 0.970,\ \ 0.975,\ \ 0.991\ \right]$
Technology		
δ	Capital Depreciation Rate	0.058
A	Technological Scalar	0.12
α	Elasticity of Consumption Sector Output with respect to Capital	0.16
Tax Policy		
ζ	Scalar in Tax Schedule	0.17
$1+\phi$	Ratio of Marginal to Average Tax Rate	1.68

Table 1. Calibrated Benchmark Parameters

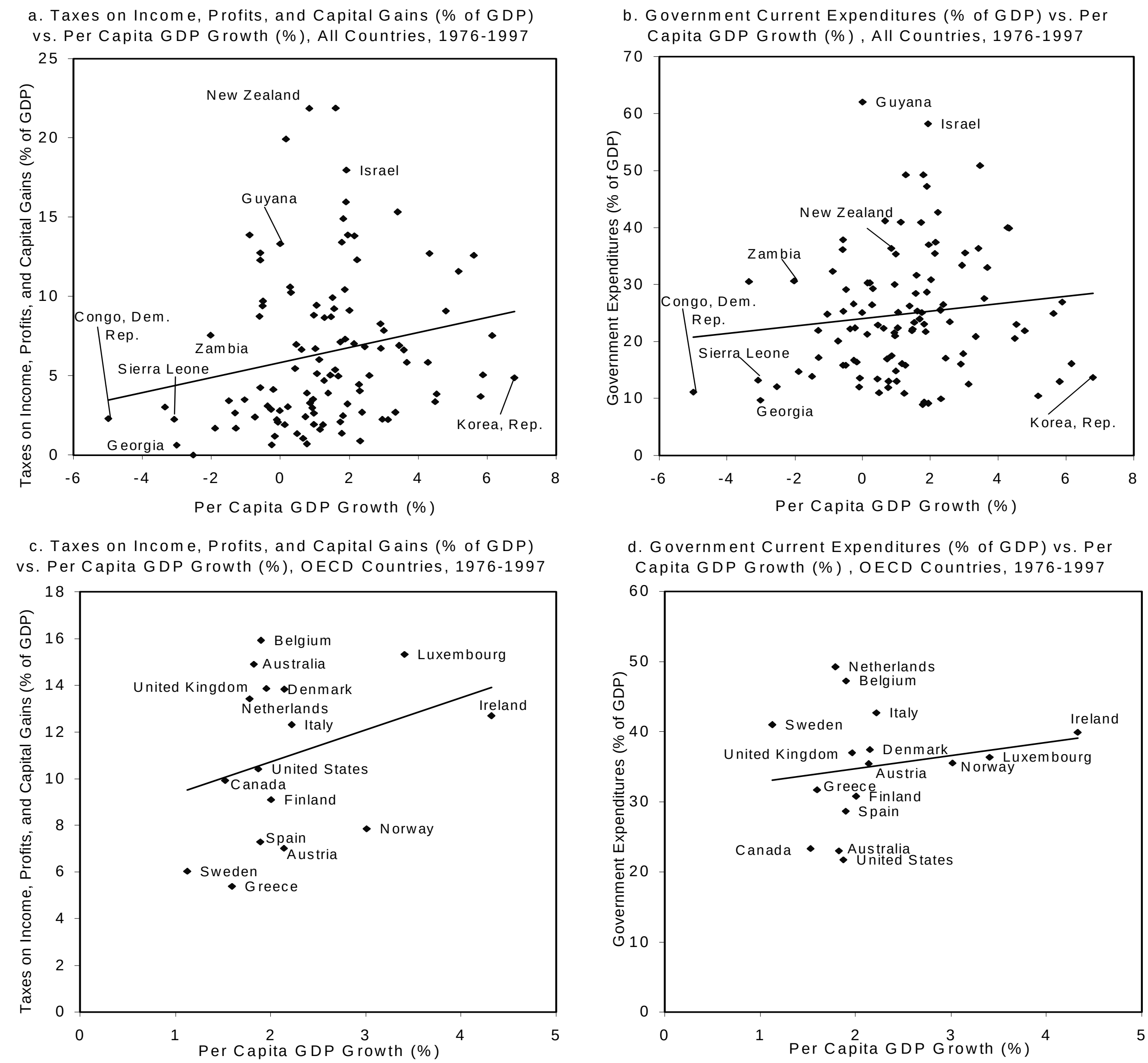
B. *Parameters in Barro (1990)*		Value
Preferences		
σ	Intertemporal Elasticity of Substitution	1
β_j	Time Discount Rates	$\begin{bmatrix} 0.954, & 0.960, & 0.964, & 0.971, & 0.997 \end{bmatrix}$
Technology		
δ	Capital Depreciation Rate	0.058
A	Technological Scalar	0.41
$1-\alpha$	Elasticity of Output with respect to Government Services	0.25
Tax Policy		
ζ	Scalar in Tax Schedule	0.22
$1+\phi$	Ratio of Marginal to Average Tax Rate	1.68

Table 2. Benchmark Model Economies

A. *Targeted Statistics*	U.S. Data	Rebelo (1991)	Barro (1990)
Growth Rate (%)	1.80	1.89	1.75
Real Rate (%)	6.40	6.40	7.50
Investment/Capital	0.076	0.077	0.075
Capital/Output	3.32	3.41	5.60
Government Expenditures/Output (%)	20	20.17	21.19
Quintile Distribution of Income (%)			
Highest Quintile	53.2	53.8	54.3
Fourth Quintile	20.2	20.7	20.0
Third Quintile	13.9	13.0	12.9
Second Quintile	9.0	8.8	8.9
First Quintile	4.0	3.6	3.8
B. *Other Statistics*			
Gini Coefficient of Pre-Tax Income	0.46	0.45	0.45
Share of Individual Tax Liabilities (% by Income Quintile)			
Highest Quintile	77.9	73.8	74.7
Fourth Quintile	14.8	14.9	141.1
Third Quintile	7.1	6.9	6.8
Second Quintile	2.0	3.5	3.6
First Quintile	-1.8	0.8	0.9
After-Tax Income Distribution (%)			
Highest Quintile	49.8	47.4	45.0
Fourth Quintile	20.8	22.6	22.8
Third Quintile	14.8	15.0	15.8
Second Quintile	10.1	10.4	11.4
First Quintile	4.9	4.5	5.1

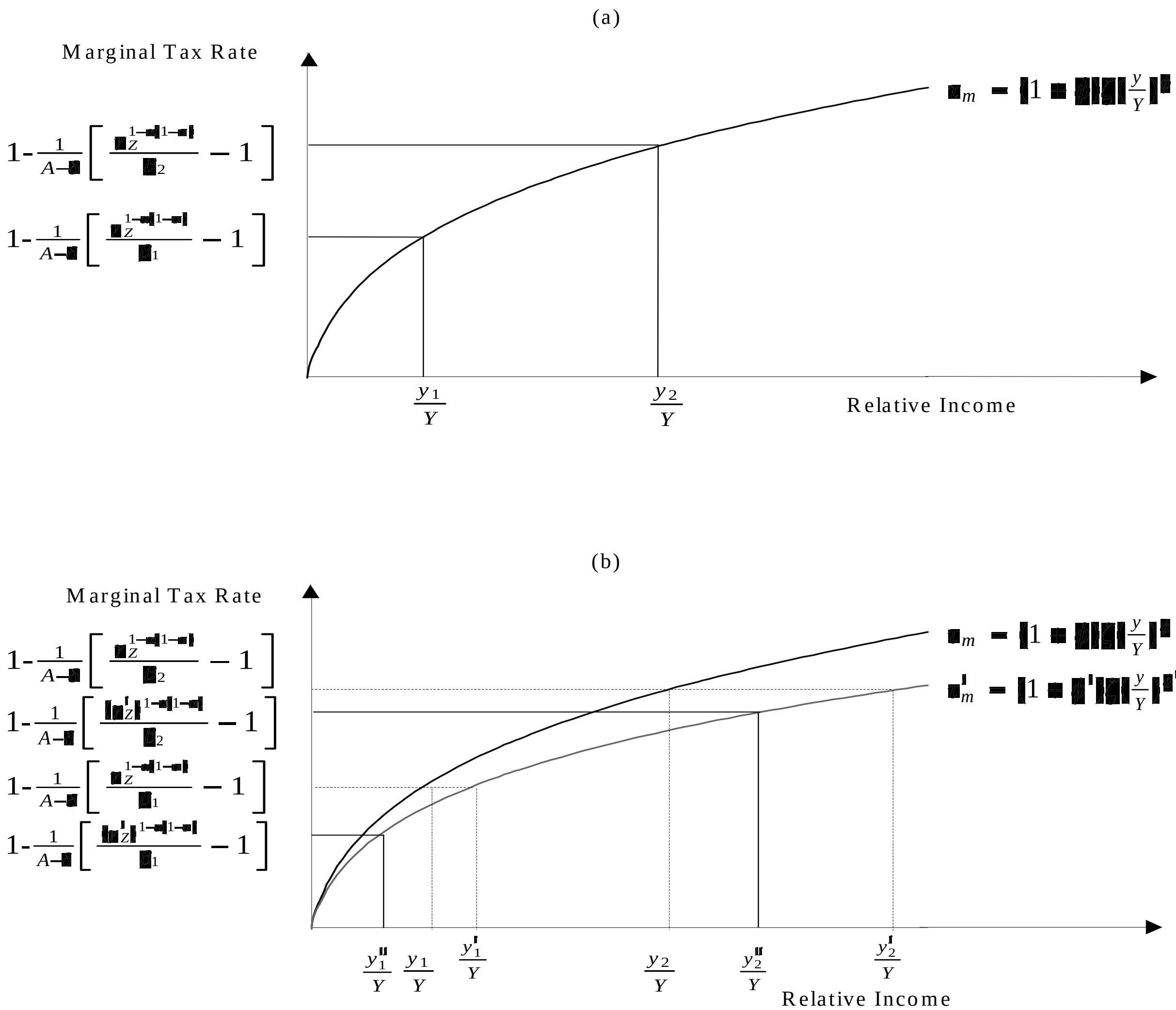
Note: The U.S. quintile distributions of pre-tax and after-tax income are obtained from Table G-1c in CBO (2001). The shares of individual income tax liabilities are obtained from Table G-1b.

Figure 1



Note: GDP at market prices, constant local currency units

Figure 2



(a)
Marginal Tax Rate
Relative Income
(b)
Marginal Tax Rate
Relative Income

Figure 3

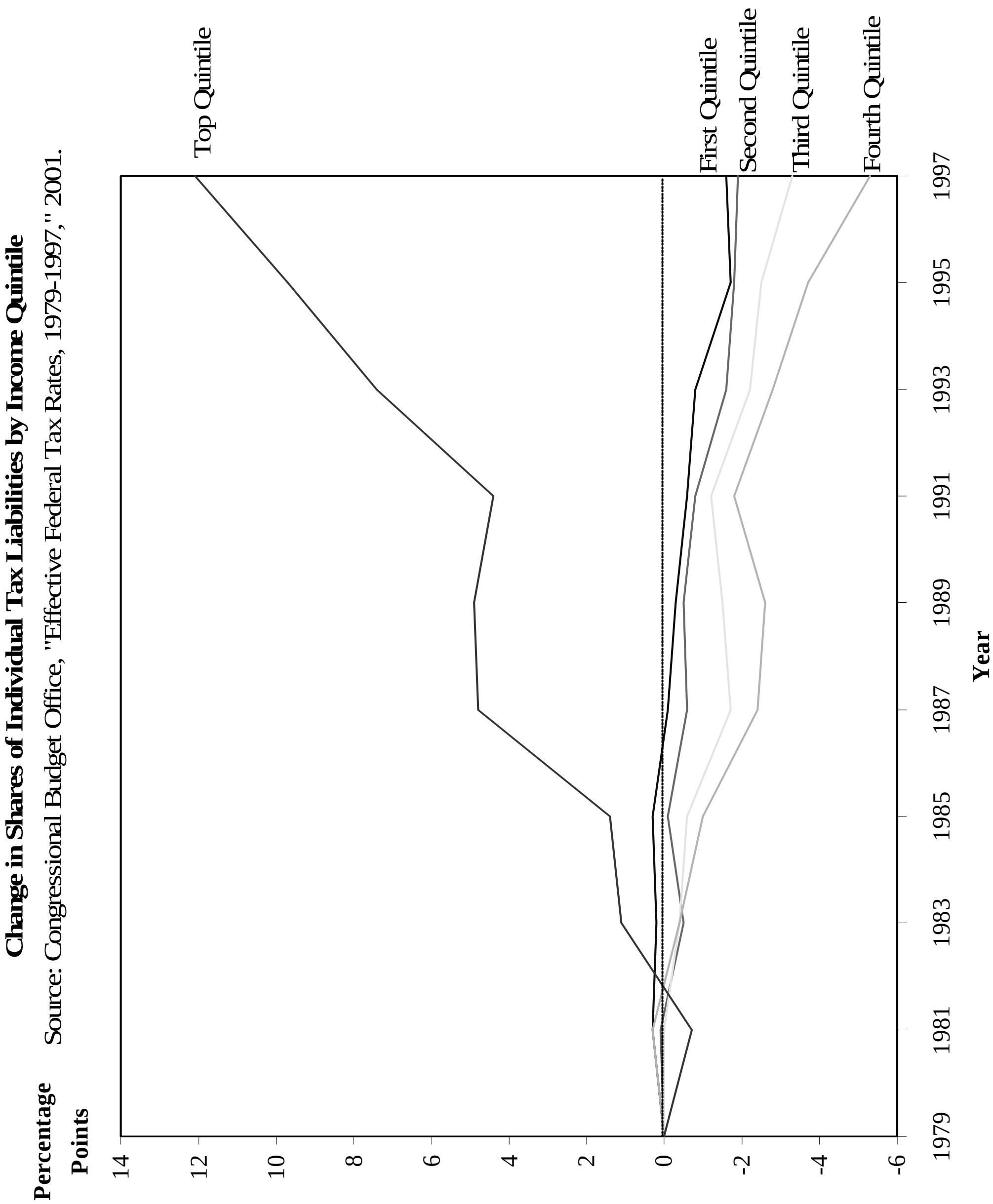

Change in Shares of Individual Tax Liabilities by Income Quintile
Source: Congressional Budget Office, "Effective Federal Tax Rates, 1979-1997," 2001.
Percentage Points
14
12
10
8
6
4
2
0
-2
-4
-6
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
Year
Top Quintile
First Quintile
Second Quintile
Third Quintile
Fourth Quintile

Figure 4

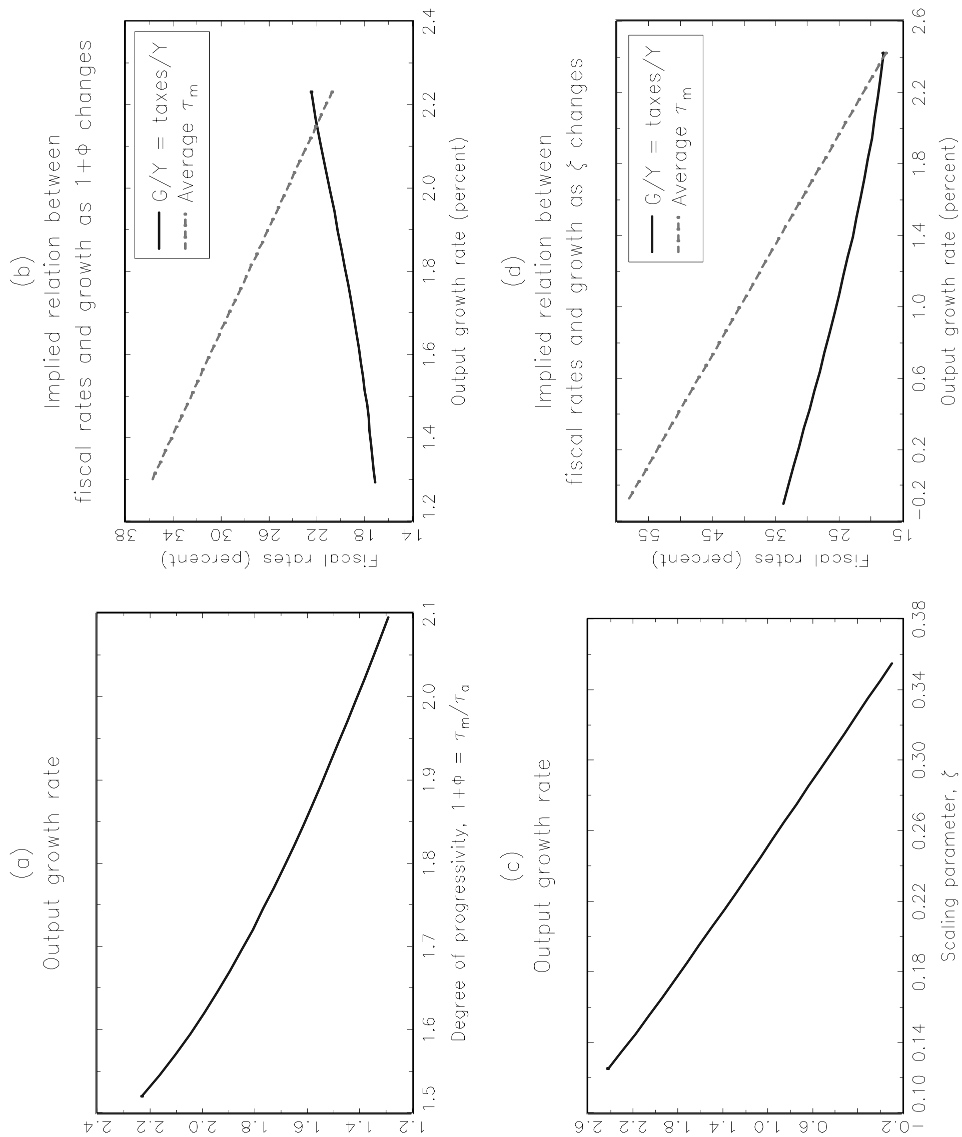
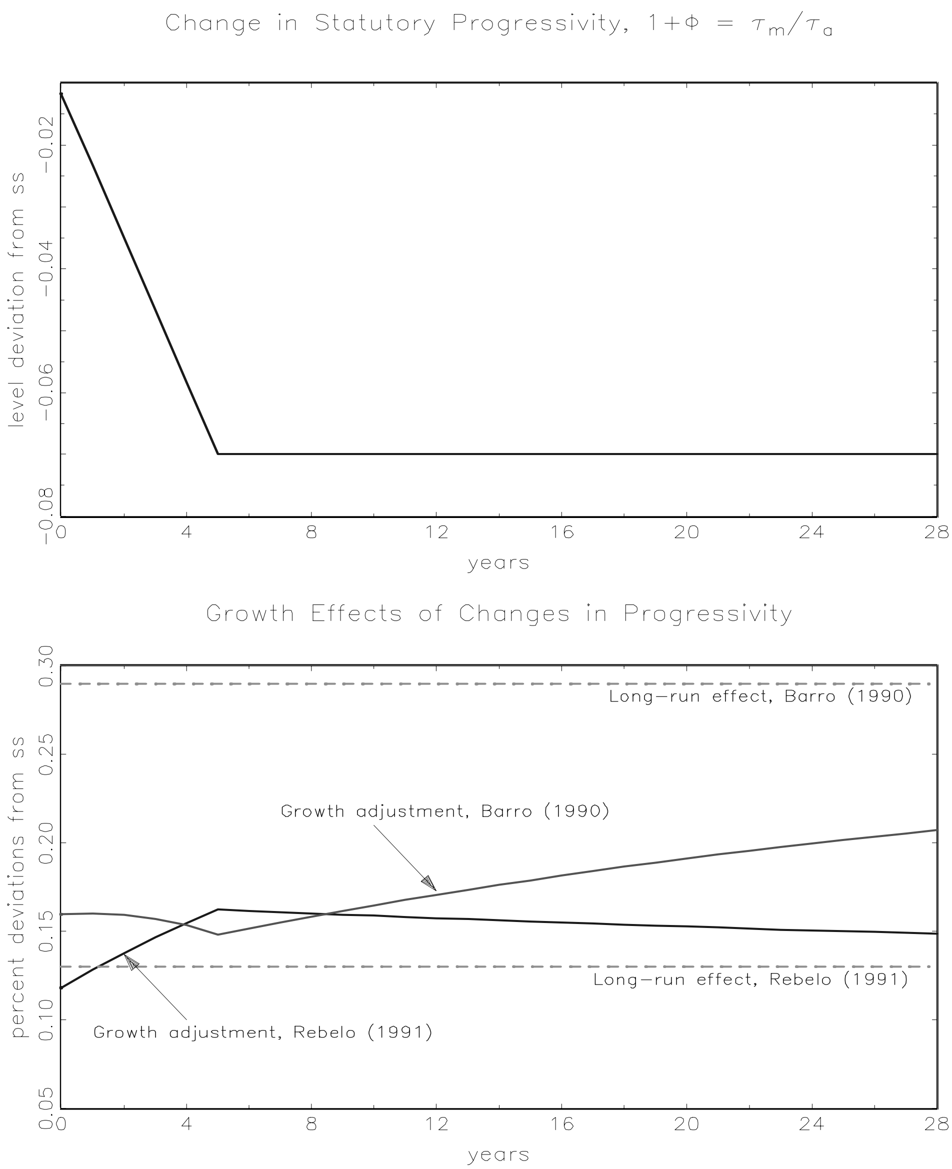

(a)
Output growth rate
percent
Degree of progressivity, 1+Φ = τm/τa
(b)
Implied relation between
fiscal rates and growth as 1+Φ changes
G/Y = taxes/Y
Average τm
Fiscal rates (percent)
Output growth rate (percent)
(c)
Output growth rate
percent
Scaling parameter, ζ
(d)
Implied relation between
fiscal rates and growth as ζ changes
G/Y = taxes/Y
Average τm
Fiscal rates (percent)
Output growth rate (percent)

Figure 5



Change in Statutory Progressivity, $1+\Phi = \tau_m/\tau_a$
level deviation from ss
-0.02
-0.04
-0.06
-0.08
0
4
8
12
16
20
24
28
years
Growth Effects of Changes in Progressivity
percent deviations from ss
0.30
0.25
0.20
0.15
0.10
0.05
0.0
Long-run effect, Barro (1990)
Growth adjustment, Barro (1990)
Long-run effect, Rebelo (1991)
Growth adjustment, Rebelo (1991)

Figure 6

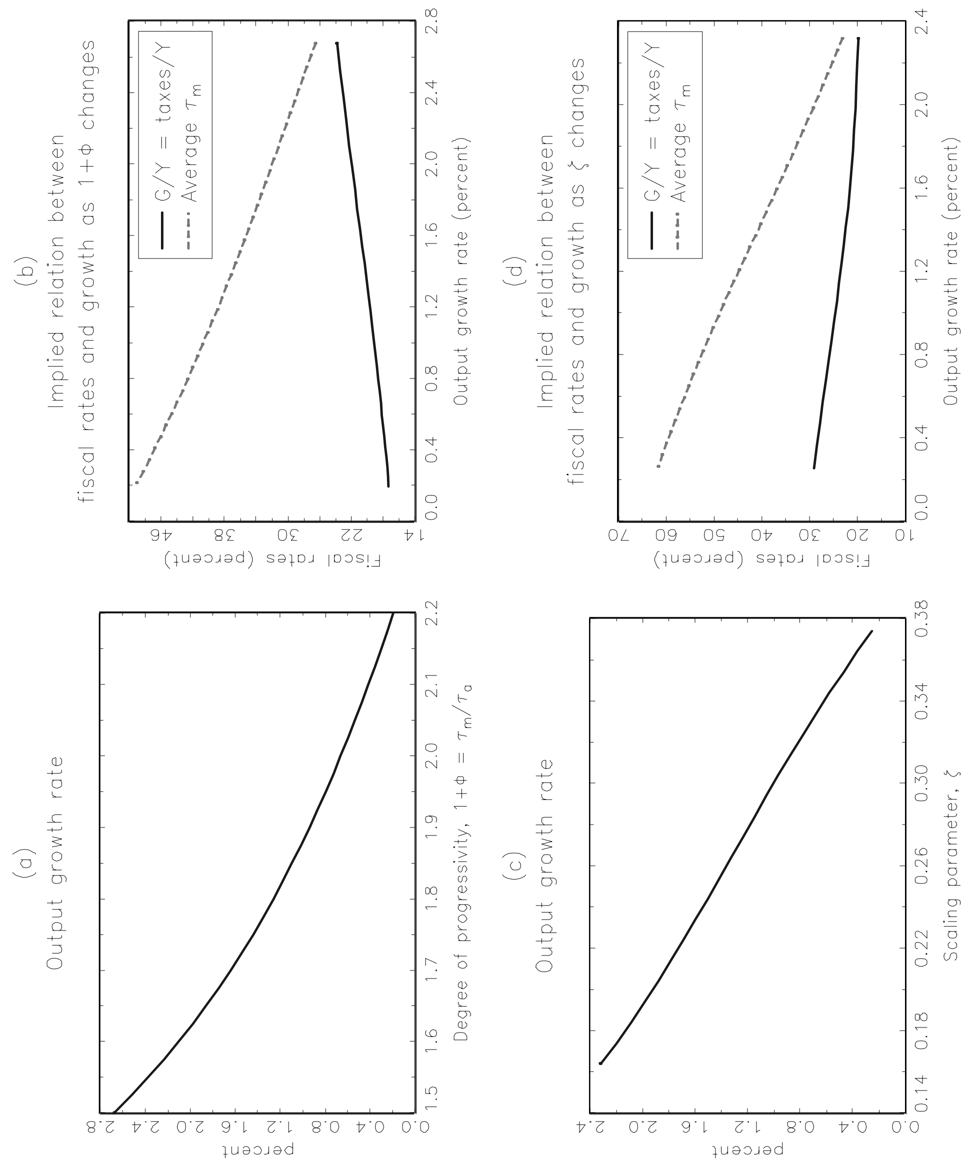

(a)
Output growth rate
percent
Degree of progressivity, 1+ϕ = τm/τa
(b)
Implied relation between
fiscal rates and growth as 1+ϕ changes
G/Y = taxes/Y
Average τm
Fiscal rates (percent)
Output growth rate (percent)
(c)
Output growth rate
percent
Scaling parameter, ζ
(d)
Implied relation between
fiscal rates and growth as ζ changes
G/Y = taxes/Y
Average τm
Fiscal rates (percent)
Output growth rate (percent)

Figure 7