FRBSF Working Paper 98-09

Tax Reform with Useful Public Expenditures*

Steven P. Cassou†
Kansas State University

Kevin J. Lansing‡
Federal Reserve Bank of San Francisco

December 28, 2004

Abstract

This paper examines the economic effects of tax reform in an endogenous growth model that allows for two types of useful public expenditures; one type contributes to human capital formation while the other provides direct utility to households. We show that the optimal fiscal policy calls for full expensing of private investment which shifts the tax base to private consumption. The efficient levels of public investment and public consumption relative to output are uniquely pinned down by parameters that govern both technology and preferences. In general, implementing the optimal fiscal policy requires a change in the size of government. If a tax reform holds the size of government fixed to satisfy a revenue-neutrality constraint, then the reform will be suboptimal; theory alone cannot tell us if welfare will be improved. For some calibrations of the model, we find that commonly-proposed versions of revenue-neutral tax reforms can result in large welfare gains. For other quite plausible calibrations, the exact same reform can result in tiny or even negative welfare gains as the revenue-neutrality constraint becomes more severely binding. Comparing across calibrations, we find that the welfare rankings of various reforms can change, depending on parameter values. Overall, our results highlight the uncertainty surrounding the potential welfare benefits of fundamental U.S. tax reform.

Keywords: Tax Reform, Public Expenditures, Human Capital, Growth.

JEL Classification: C68, E62, H52, O41

* Forthcoming, *Journal of Public Economic Theory*. For helpful comments and suggestions, we thank Kenneth Judd, Ignacio Palacios-Huerta, Richard Rogerson, seminar participants at many places, the editor of this journal, and two anonymous referees. This project was started while Lansing was a national fellow at the Hoover Institution, whose hospitality is gratefully acknowledged.

† Department of Economics, 327 Waters Hall, Kansas State University, Manhattan, KS, 66506, (785) 532-6342, Fax: (785) 532-6919, email: scassou@ksu.edu, homepage: www.ksu.edu/economics/scassou.

‡ Corresponding author. Research Department, FRB San Francisco, P.O. Box 7702, San Francisco, CA 94120, (415) 974-2393, email: kevin.j.lansing@sf.frb.org, homepage: www.frbsf.org/economics/economists/klansing.html

1 Introduction

In recent years, many policymakers and economists have advocated a consumption-based tax system for the U.S. economy. The efficiency arguments for a consumption tax are drawn from optimal tax theory. Under commonly-used assumptions, the theory supports the principle of uniform commodity taxation. When applied to a dynamic economy, this principle calls for the elimination of saving distortions so that present and future consumption goods are taxed at the same rate.[1] All of the major consumption tax proposals are designed to be revenue-neutral. The intent is to improve economic efficiency through changes in the tax code while leaving aside arguments about the appropriate size of government.[2]

In this paper, we examine the potential welfare benefits of some commonly-proposed tax reforms in a model where public-sector expenditures can have a direct impact on private-sector production or household utility. Once we allow for useful public expenditures, it follows that there is some optimal level of public expenditures relative to output in the post-reform economy. Taking this logic one step further, we are forced to confront the fact that switching to a revenue-neutral consumption tax is inherently suboptimal because the reform optimizes over tax variables but not public expenditure variables. In such an economy, adopting a revenue-neutral consumption tax would replace one suboptimal fiscal policy with another; theory alone cannot tell us if welfare will be improved. We demonstrate that this result is not just an abstract theoretical point—it has important quantitative implications for U.S. tax reform.

There are many studies in the literature that examine the potential benefits of adopting a revenue-neutral consumption tax or some close variant thereof.[3] These studies typically model public expenditures as wholly exogenous variables that do not contribute to either production or utility. As in the original Ramsey (1927) model, public expenditures are typically viewed as being entirely wasteful; their only role is to determine how much revenue must be collected by the tax system. Within this basic competitive framework, switching to a consumption tax while holding revenue constant is guaranteed to improve welfare; the only question is the size of the resulting welfare gain.

In this paper, we examine the economic effects of tax reform in a model that departs from the standard assumption of wasteful public expenditures. The framework for our analysis is a tractable endogenous growth model with physical and human capital. The model allows for two types of useful public expenditures; one type contributes to human capital formation while the other provides direct utility to households. The inputs to the human capital technology are household time (which gives rise to untaxed foregone earnings), private goods investment by households (such as college tuition), and a government-provided input which we interpret as public expenditures on education, job training, and research and development (R&D). A variety of empirical evidence suggests that these types of public expenditures are productive.[4]

[1] The optimality of uniform commodity taxation can be overturned by deviating from assumptions of separable utility in leisure, perfect competition, or complete markets. For a discussion, see Stern (1992).

[2] See, for example, Hall and Rabushka (1995, p. 34).

[3] See , for example, the two conference volumes: *Frontiers of Tax Reform* (Boskin 1996) and *Economic Effects of Fundamental Tax Reform* (Aaron and Gale 1996), and the two U.S. government publications: Joint Committee on Taxation (1997) and U.S. Congressional Budget Office (1997).

[4] For evidence from U.S. states, see Evans and Karras (1994). For cross-country evidence, see Barro and Salai-i-Martin (1995, p. 433). For a survey of empirical studies, see Gerson (1998).

To establish a benchmark for comparing some commonly-proposed tax reforms, we compute the optimal fiscal policy by endogenizing public expenditures and the government's choice of the tax base and tax rates. With regard to the tax base, the government can choose between a pure consumption tax, a pure income tax, or some hybrid of the two systems.[5] We show that the optimal fiscal policy calls for full expensing of private investment which shifts the tax base to private consumption. The efficient levels of public investment and public consumption relative to output are uniquely pinned down by parameters that govern both technology and preferences. In general, implementing the optimal fiscal policy requires a change in the size of government. If a reform holds the size of government fixed to satisfy a revenue-neutrality constraint, then the reform will be suboptimal.

We undertake a quantitative assessment of these issues using a calibrated version of the model. The calibration reflects the existing hybrid income-consumption tax system in the U.S. economy. We begin by considering a series of consumption tax reforms that differ according to their implications for the post-reform size of government. The fully-optimal reform implements the optimal fiscal policy which is determined by joint optimization of tax and spending variables. This experiment establishes a useful upper-bound on the potential benefits of tax reform in the model. The other three experiments impose constraints on the post-reform size of government. The purpose of these experiments is to explore how the benefits of a consumption tax are affected by the imposition of a revenue-neutrality constraint.

We also examine two additional revenue-neutral reforms that are motivated by some elements of real-world tax proposals. These are a "flat tax" and an income tax. The flat tax experiment captures the point made by Judd (1998) that many consumption-based tax proposals would allow full expensing of new investment in physical capital but not human capital. The income tax experiment captures some features of historical tax legislation that has attempted to broaden the tax base and reduce the dispersion of tax rates across alternative income-producing activities.

For our initial calibration, the fully-optimal reform calls for the government to devote more resources to public investment and less resources to public consumption relative to the U.S. baseline. The overall size of government is reduced as total public expenditures fall to 19.6% of output versus 21% in the baseline economy. In contrast, a revenue-neutral consumption tax reform maintains public expenditures at 21% of output. We find that the appropriate size and composition of government expenditures is quite important for efficiency. The fully-optimal reform produces a net welfare gain of 6.6% (measured in units of per-period private consumption) versus a gain of only 1.4% for a revenue-neutral consumption tax. Intermediate welfare gains are obtained for consumption tax reforms that adjust one type of public expenditures to achieve efficiency but not the other.

In addition to investigating the normative aspects of tax reform, we provide a complete description of the positive effects, including computation of the transition paths for key macroeconomic variables such as output growth, capital ratios, work effort, schooling time, factor prices, and Tobin's q. By allowing full expensing of private investment, a consumption tax reform shrinks the tax base relative to the baseline tax code which only allows for partial expensing. The smaller tax base may necessitate a higher post-reform tax rate even if the reform reduces the size of government. A higher post-reform tax rate initially discourages work effort and schooling time thus leading to a

[5] Previous studies of optimal fiscal policy in human-capital based models allow the government to choose the tax rates but not the tax base. See, for example, Lucas (1990), Jones, Manuelli, and Rossi (1993), Corsetti and Roubini (1996), Judd (1999), and Jones and Manuelli (1999).

temporary reduction in output growth along the transition path. As the transition proceeds, work effort, schooling time, and output growth all rebound to higher levels as households accumulate more capital in response to the reform's investment incentives.

All of the reforms we consider exhibit relatively small growth effects due to the form of the human capital technology where untaxed foregone earnings represent the largest input to the production of human capital. With the exception of the income tax, all of the reforms shift household resources to investment and achieve long-run growth gains. The resulting transition dynamics can differ dramatically, however, leading to a wide range of welfare outcomes.

We explore the sensitivity of our results to a variety of calibrations for which the optimal size of government can be either smaller or larger than the U.S. baseline. For some calibrations, adopting a revenue-neutral consumption tax can result in tiny or even negative welfare gains. Under these calibrations, the optimal size of government lies further below the U.S. baseline, thus causing the revenue-neutrality constraint to become more severely binding. Comparing across calibrations, we find that the welfare rankings of various reforms can change, depending on parameter values. The uncertainty that exists about the optimal size of government strengthens the main message of our study; if policymakers do not know the efficient level of public expenditures in the post-reform economy, then they cannot know the degree to which the revenue-neutrality constraint will bind when implementing a revenue-neutral tax reform. Overall, our results highlight the uncertainty surrounding the potential welfare benefits of fundamental U.S. tax reform.

The remainder of the paper is organized as follows. Section 2 describes the model. The optimal fiscal policy is derived in section 3. Section 4 describes our calibration procedure. Section 5 presents our quantitative results. Section 6 presents our sensitivity analysis. Section 7 concludes.[6]

2 The Model

The model economy consists of households, firms, and the government. We allow for variable leisure, investment adjustment costs, differential tax treatment of physical and human capital, and useful public expenditures. Our choice of functional forms, inspired by the work of Hercowitz and Sampson (1991), permits a closed-form solution of the model. The solution allows us to explicitly characterize the economy's transition path following a tax reform and to decompose the net welfare change into three parts: a long-run level effect, a long-run growth effect, and a transition effect. The model also captures an important feature of consumer behavior observed during real-world tax reforms, namely, a lack of an anticipation response. We will elaborate further on this point in our discussion of the equilibrium decision rules.

2.1 The Household's Problem

A large but fixed number of identical infinitely-lived households each maximize

$$\sum_{t=0}^{\infty} \beta^t \left\{ \log \left[c_t - V\left(h_t, l_t\right) \right] + D \log \left(g_t \right) \right\}, \qquad \beta \in (0,1), \quad D \geq 0, \tag{1}$$

[6] A technical appendix accompanies the web version of the article. The appendix provides details of the model solution and our procedure for computing welfare changes.

where β is the discount factor, c_t is private consumption, l_t is time devoted to non-leisure activities (work or education), and h_t is the household's stock of human capital or knowledge. The disutilty of non-leisure time is governed by the functional form

$$V(h_t, l_t) = Bh_t l_t^{\gamma} \qquad B > 0, \quad \gamma > 0, \tag{2}$$

which implies that foregone leisure is adjusted for "quality," as measured by h_t, reminiscent of the models of Becker (1965) and Heckman (1976). Alternatively, we may interpret $V(h_t, l_t)$ as the reduced form of a more-elaborate specification that incorporates home production.[7] As $\gamma \to \infty$, the model reduces to one with fixed time allocations. The intertemporal elasticity of substitution in labor supply is given by $1/(\gamma - 1)$.

We allow for the possibility that per capita public consumption goods g_t provide direct utility to households. Empirical studies by Karras (1994) and Amano and Wirjanto (1998) indicate that one cannot reject the hypothesis of additive separability in private and public consumption. By incorporating g_t into the utility function, we ensure that public consumption will grow at the same (endogenous) rate as output when fiscal policy is chosen by the government to maximize household welfare. As a result, public consumption will continue to represent a significant fraction of resources as $t \to \infty$. An alternative modeling strategy would be to set $D = 0$ and specify g_t as some fixed fraction of output or of the capital stock. A problem with this strategy is that it creates a negative externality; tax reforms that stimulate output growth will automatically increase g_t and thereby contribute to a drain on productive resources.[8] Later, we show that this specification can lead to a substantial downward adjustment in the computed welfare gain from a growth-enhancing tax reform, even when the growth effect is small.

The household faces the following within-period budget constraint:

$$c_t + i_{kt} + i_{ht} = r_t k_t + w_t h_t(l_t - e_t) - \tau_t \left[r_t k_t + w_t h_t(l_t - e_t) - \phi_{kt} i_{kt} - \phi_{ht} i_{ht} \right], \tag{3}$$

where i_{kt} and i_{ht} represent investment in physical capital k_t and human capital h_t, respectively. We interpret i_{ht} as private-sector expenditures on education, training, and R&D, that all contribute to a broadly-defined stock of knowledge. Given a total time endowment normalized to one, households allocate their time across three activities: they supply labor effort to firms in the amount $l_t - e_t$, devote time to human capital formation (learning) in the amount e_t, and spend the remainder of their time $1 - l_t$ in leisure.

Households obtain income by supplying capital and labor services to firms. They receive a rental rate r_t for each unit of physical capital used in production and earn a wage w_t for each unit of effective labor $h_t(l_t - e_t)$ employed by the firm. Taxable income in equation (3) is given by the expression in square brackets.

Our analysis focuses on tax reforms that may involve different trajectories for public-sector expenditures, depending on whether the reform abides by a revenue-neutrality constraint. To aid intuition, we have adopted a very transparent dynamic tax model that abstracts from many of the details of the U.S. tax code. We assume that a single proportional tax rate τ_t is applied to

[7] The linearity of (2) in h_t ensures that household time allocations are stationary along the model's balanced growth path. See Greenwood, Rogerson, and Wright (1995, p. 161).

[8] An externality of this sort is present in the endogenous growth models of Lucas (1990), Laitner (1995), and Grüner and Heer (2000). These authors specify fixed ratios of g_t/h_t or g_t/y_t, but then assume that g_t is thrown away.

all taxable income, but allow for differential tax treatment of physical and human capital via the policy variables ϕ_{kt} and ϕ_{ht}. These represent the fractions of each type of investment that can be "expensed," or immediately deducted from taxable income.

For comparison with the U.S. tax system, ϕ_{kt} and ϕ_{ht} can be interpreted as index numbers that summarize the various elements of the tax code that encourage saving or investment. Features that influence ϕ_{kt} include: the depreciation allowance for physical capital; the tax-deferred status of saving done through pensions, 401(k)s, Keoughs, and IRAs; the favorable tax treatment of long-term capital gains; and the relatively tax-free status of service flows from owner-occupied housing. Regarding ϕ_{ht}, firms may expense the costs of formal worker training, the wages of workers engaged in on-the-job training, job-related employee tuition, and expenditures for R&D. There is also a 20 percent tax credit for qualifying increases in R&D expenditures.[9] The 1998 U.S. Federal budget law introduced a variety of tax incentives designed to help individuals pay for higher education. These include tax credits, penalty-free IRA withdrawals, and the deductibility of student loan interest.[10] Earnings foregone while in school $w_t h_t e_t$ are implicitly expensed under the current tax code (see Boskin, 1977) and would receive the same treatment under all proposed reforms.

The following equations describe the laws of motion for the two capital stocks:

$$k_{t+1} = A_1 \, k_t^{1-\delta_k} \, i_{kt}^{\delta_k}, \qquad k_0 \text{ given,} \tag{4}$$

$$h_{t+1} = A_2 \, h_t^{1-\delta_h-\delta_g} \, i_{ht}^{\delta_h} \, i_{gt}^{\delta_g} \, e_t^{\nu}, \qquad h_0 \text{ given,} \tag{5}$$

where $A_1, A_2 > 0$, $\delta_i \in (0, 1]$ for $i = k, h, g$, and $\nu \geq 0$. The above specifications can be interpreted as reflecting investment adjustment costs as in Lucas and Prescott (1971). Equation (4) implies that households can add to their stock of physical capital in only one way: through goods investment i_{kt}.[11] Equation (5) implies that human capital can be increased by private goods investment i_{ht}, by the allocation of household time e_t, or by government goods investment i_{gt}. Including i_{ht} as an input to the production of human capital has an effect that is similar to including physical capital k_t because private goods must be produced using physical capital.[12]

We interpret i_{gt} as public-sector expenditures on education, job training, and R&D and assume that i_{gt}, i_{ht}, and e_t are complements in the production of human capital. The relevant public-sector input in equation (5) is the per capita flow of goods that the government makes available to households. Specifying i_{gt} as a per capita quantity ensures that there are no scale effects associated with the number of households.

2.2 The Tax Base

The tax base under the current U.S. system is best described as a hybrid between income and consumption such that $\phi_{kt}, \phi_{ht} \in (0, 1)$. By choosing appropriate values for ϕ_{kt} and ϕ_{ht}, we can

[9] For further details on the tax treatment of human capital, see Quigley and Smolensky (1990) and Steuerle (1996).

[10] See Hoxby (1998) for a detailed description and analysis of tax incentives for higher education.

[11] Kim (2003) shows that equation (4) can be viewed as a special case of a more general specification where $k_{t+1} = A_1 \left[(1-\delta_k) \, k_t^{1-\sigma} + \delta_k \, (i_{kt}/\delta_k)^{1-\sigma} \right]^{1/(1-\sigma)}$. Our setup implies $\sigma = 1$, whereas a linear law of motion with no adjustment costs would imply $\sigma = 0$. Aside from reflecting adjustment costs, our setup can be viewed as capturing the behavior of an aggregate capital stock that is measured by adding up different types of capital (structures, equipment, consumer durables, residential) which each display different depreciation characteristics.

[12] Our setup assumes a clear distinction between private human-capital investment and private consumption. Davies, Zeng, and Zhang (2000) consider a model where this distinction is not fully observable. They show that the degree of observability can affect the level of the optimal consumption tax.

shift the tax base in our model to reflect various fundamental reforms. When $\phi_{kt} = \phi_{ht} = 1$ the tax structure is equivalent to a pure consumption tax at the rate $\tau_{ct} = \tau_t / (1 - \tau_t)$.[13] When $\phi_{kt} = \phi_{ht} = 0$, we have a pure income tax at the rate τ_t. An income tax favors human capital over physical capital because foregone earnings while in school will continue to be fully expensed. Finally, we can endogenize the tax base by allowing the government to choose ϕ_{kt} and ϕ_{ht}, together with the other fiscal policy variables, to maximize household welfare.

2.3 The Firm's Problem

Output y_t is produced by identical private firms that rent capital from households and hire effective labor $h_t(l_t - e_t)$ in order to maximize profits. The firm's decision problem can be summarized as:

$$\max_{k_t,\ h_t(l_t - e_t)} \left[y_t - r_t k_t - w_t h_t \left(l_t - e_t \right) \right] \tag{6}$$

$$\text{subject to:} \qquad y_t = A_0 k_t^{\theta} \left[h_t (l_t - e_t) \right]^{1-\theta}, \qquad A_0 > 0, \quad \theta \in (0,1), \tag{7}$$

where (7) describes the goods-producing technology. Profit maximization implies

$$r_t = \frac{\theta\, y_t}{k_t}, \tag{8a}$$

$$w_t = \frac{(1-\theta)\, y_t}{h_t \left(l_t - e_t \right)}. \tag{8b}$$

2.4 Household Decision Rules

Standard techniques yield the following expressions for the household's optimal decision rules:

$$i_{kt} = a_0 (1 - \tau_{kt}) y_t, \qquad \tau_{kt} \equiv \frac{(1 - \phi_{kt})\, \tau_t}{1 - \phi_{kt} \tau_t}, \tag{9a}$$

$$i_{ht} = b_0 (1 - \tau_{ht}) y_t, \qquad \tau_{ht} \equiv \frac{(1 - \phi_{ht})\, \tau_t}{1 - \phi_{ht} \tau_t}, \tag{9b}$$

$$c_t = (1 - a_0 - b_0)(1 - \tau_t) y_t, \tag{9c}$$

$$l_t - e_t = A_3 \left[(1 - \tau_t) \left(\frac{h_t}{k_t} \right)^{-\theta} \right]^{\frac{1}{\theta + \gamma - 1}}, \tag{9d}$$

$$e_t = A_3 A_4 \left[(1 - \tau_t) \left(\frac{h_t}{k_t} \right)^{-\theta} \right]^{\frac{1}{\theta + \gamma - 1}}, \tag{9e}$$

where a_0, b_0, A_3, and A_4 represent combinations of deep parameters and y_t is equilibrium per capita output.[14] By substituting equation (9d) into equation (7), we obtain the following expression for equilibrium per capita output:

$$y_t = A_0 A_3^{1-\theta} k_t^{\frac{\theta\gamma}{\theta+\gamma-1}} h_t^{\frac{(1-\theta)(\gamma-1)}{\theta+\gamma-1}} (1 - \tau_t)^{\frac{1-\theta}{\theta+\gamma-1}}. \tag{10}$$

Household investment decisions depend on the effective marginal tax rates τ_{kt} and τ_{ht} which combine the "statutory" tax rate τ_t with the investment expensing variables ϕ_{kt} and ϕ_{ht}. A consumption tax implies $\phi_{kt} = \phi_{ht} = 1$ such that $\tau_{kt} = \tau_{ht} = 0$. A labor supply distortion will continue

[13] In this case, the household budget constraint (3) becomes: $(1 + \tau_{ct})\, c_t + i_{kt} + i_{ht} = r_t k_t + w_t h_t (l_t - e_t)$.

[14] Details are contained in the technical appendix that accompanies the web version of this article.

to exist under a consumption tax, however, so long as $\gamma < \infty$. As $\gamma \to \infty$, labor supply becomes fixed thus making a consumption tax equivalent to a lump-sum tax. All else equal, equation (10) implies that per capita output (or income) is a decreasing function of the ratio h_t/k_t, a result that stems from the labor decision rule (9d). The labor decision rule says that time devoted to market work declines as the household acquires more human capital relative to physical capital. The education decision rule (9e) says that time devoted to schooling or training also declines as the household acquires more human capital relative to physical capital. Intuitively, these results obtain because higher levels of human capital raise the opportunity cost of time that is not used for leisure.

Our choice of functional forms allows us to solve for the household decision rules without having to specify how tax rates will evolve in the future. The combination of log utility and Cobb-Douglas production technologies causes the income and substitution effects of future after-tax interest rate movements to exactly cancel so that households only need to observe the current state of the economy in order to decide how much to consume and invest. Empirical studies provide some support for this idea. For example, Poterba (1988) and Watanabe, Watababe, and Watanabe (2001) find evidence that large fractions of U.S. and Japanese consumers do not adjust their consumption in anticipation of tax changes but instead wait until tax changes are implemented.

Most studies of tax reform assume that households are surprised by the change in tax policy. This is not an innocent assumption. First, it represents somewhat of a contradiction to the notion of rational expectations because household decision rules in the baseline economy are computed for an environment where the current tax system is expected to remain in place forever. Second and more importantly, it can strongly influence quantitative results. Auerbach and Kotlikoff (1987, pp. 82-87) show that preannouncing structural tax reforms can "greatly reduce if not reverse the efficiency gains from such reforms." In their model, preannouncement discourages saving as agents take steps to avoid the one-time tax on existing wealth that occurs when shifting to a consumption tax. These issues do not arise in our model because household decisions at time t do not depend on future policy variables. Hence, preannouncing the reform would not change any of our results.

2.5 Transition Dynamics and Balanced Growth

Given the model's tractable nature, we are able to explicitly characterize the economy's dynamic transition path for any set of initial conditions k_0 and h_0. By substituting the decision rules and the expression for equilibrium output (10) into the laws of motion (4) and (5) we obtain

$$k_{t+1} = A_1 \left[a_0 A_0 A_3^{1-\theta} (1-\tau_{kt})(1-\tau_t)^{\frac{1-\theta}{\theta+\gamma-1}} \left(\frac{h_t}{k_t}\right)^{\frac{(1-\theta)(\gamma-1)}{\theta+\gamma-1}} \right]^{\delta_k} k_t, \tag{11}$$

$$\begin{aligned} h_{t+1} = {} & A_2 (A_3 A_4)^{\nu} \left[b_0 (1-\tau_{ht})\right]^{\delta_h} \times \\ & \left[A_0 A_3^{1-\theta} (1-\tau_t)^{\frac{1-\theta+\nu/(\delta_h+\delta_g)}{\theta+\gamma-1}} \left(\frac{h_t}{k_t}\right)^{\frac{-\theta\gamma-\theta\nu/(\delta_h+\delta_g)}{\theta+\gamma-1}} \right]^{\delta_h+\delta_g} \left(\frac{i_{gt}}{y_t}\right)^{\delta_g} h_t, \end{aligned} \tag{12}$$

for all $t \geq 0$, where y_t is given by equation (10). The fiscal policy variables τ_{kt}, τ_{ht}, τ_t, and i_{gt} can all influence the transition path.

Our specification of a goods-producing technology (7) that exhibits constant returns to scale in the two reproducible factors k_t and h_t, together with the functional forms (1), (4), and (5), imply that the model possesses a unique balanced growth path.

Definition. (Balanced Growth). *Balanced growth is when k_t, h_t, y_t, c_t, i_{kt}, i_{ht}, i_{gt}, and g_t all grow at the same constant rate.*

The above definition implies that the ratios h_t/k_t, i_{gt}/y_t, and g_t/y_t are constant along the balanced growth path. From equations (11) and (12), we see that balanced growth can only occur when τ_{kt}, τ_{ht}, and τ_t are constant over time. To derive an expression for the per capita balanced growth rate μ, we consider an environment where $\tau_{kt} = \tau_k$, $\tau_{ht} = \tau_h$, $\tau_t = \tau$, $i_{gt}/y_t = \psi_{ig} > 0$, $g_t/y_t = \psi_g > 0$, and $h_t/k_t = R > 0$. Variables without time subscripts represent constants for all t. By taking logarithms of equations (11) and (12), we obtain two equivalent expressions for μ:

$$\mu = \log \tfrac{k_{t+1}}{k_t} = \log \tfrac{h_{t+1}}{h_t} = \log \tfrac{y_{t+1}}{y_t} = \log \tfrac{c_{t+1}}{c_t}$$

$$= \log \left[A_1 \left(a_0 A_0 A_3^{1-\theta} \right)^{\delta_k} \right] + \delta_k \log (1 - \tau_k) + \frac{(1-\theta)\,\delta_k}{\theta + \gamma - 1} \log \left[(1-\tau)\, R^{\gamma - 1} \right], \tag{13}$$

$$= \log \left[A_2 \left(A_3 A_4 \right)^{\nu} b_0^{\delta_h} \left(A_0 A_3^{1-\theta} \right)^{\delta_h + \delta_g} \right] + \delta_h \log (1 - \tau_h)$$

$$+ \frac{1}{\theta + \gamma - 1} \log \left[(1-\tau)^{(1-\theta)(\delta_h + \delta_g) + \nu} R^{-\theta\gamma(\delta_h + \delta_g + \nu/\gamma)} \right] + \delta_g \log \psi_{ig}, \tag{14}$$

where the endogenous balanced-growth ratio $R = h_t/k_t$ depends on a combination of deep parameters and the fiscal policy parameters τ, τ_k, τ_h, and ψ_{ig}.[15]

Our specification of the human capital technology (5) helps to provide some insight into the robustness of results reported in the literature regarding the effects of distortionary taxes on long-run growth. Models that omit goods investment in human-capital (either by households or the government), or alternatively, assume fixed time allocations, will shutdown some channels through which fiscal policy can affect growth. For example, Lucas (1990) finds that distortionary taxes have very small growth effects in a model where the only inputs to the production of human capital are h_t and household time. This case corresponds to our model with $\delta_h = \delta_g = 0$. In the models of King and Rebelo (1990) and Kim (1998), the human-capital inputs are h_t and i_{ht}. This case corresponds to our model with $\nu = \delta_g = 0$. A commonly-used specification is one where the human capital inputs are h_t, k_t (or i_{ht}), and household time. This case corresponds to our model with $\delta_g = 0$. Glomm and Ravikumar (1998) allow public goods to contribute to human capital formation, but not private goods. This case corresponds to our model with $\delta_h = 0$.[16] Our setup most closely resembles the models of Corsetti and Roubini (1996) and Jones and Manuelli (1999) where the human capital inputs are h_t, k_t (or i_{ht}), i_{gt}, and household time.

[15] The expression for R is derived in the technical appendix that accompanies the web version of this article.

[16] Glomm and Ravikumar (1998) further assume that leisure is fixed, but allow households to allocate their non-leisure time between market work and school.

3 Optimal Fiscal Policy

To establish a benchmark for comparing various reforms, we compute the optimal fiscal policy by endogenizing public expenditures and the government's choice of the tax base and tax rates. The constraints on the government's problem include the household decision rules, the laws of motion for the two capital stocks, and the government budget constraint given by

$$i_{gt} + g_t = \tau_t \left(y_t - \phi_{kt} i_{kt} - \phi_h i_{ht} \right). \tag{15}$$

Our specification imposes a period-by-period balanced budget. Without such a restriction, models of dynamic optimal fiscal policy typically imply that the government uses an initial capital levy to acquire a stock of assets. The interest earned on these assets provides a nondistortionary source of revenue to help finance future expenditures.[17] It is doubtful, however, that such a policy would be politically feasible as part of any real-world tax reform. In our view, a balanced-budget environment represents a closer approximation to actual constraints than one which allows the government to borrow or lend large amounts.[18] Finally, our simple representative agent framework abstracts from any redistributive transfers paid by the government.

The absence of household anticipation effects implies that the optimal fiscal policy is time consistent. Since household decisions at time t do not rely on any promises about future policy actions, the government perceives no gain from reneging on a pre-announced plan. The solutions to the government's problem under commitment and discretion are the same.[19]

To compute the optimal fiscal policy, we use the equilibrium conditions to eliminate c_t, l_t, e_t, ϕ_{kt}, ϕ_{ht}, and y_t from the government's problem so that the policymaker chooses $\{\tau_t, i_{gt}, g_t, k_{t+1}, h_{t+1},\}_{t=0}^{\infty}$. Once known, these sequences can be used to recover the other variables.

The government's problem can be written as

$$\max_{\substack{\tau_t, i_{gt}, g_t, \\ k_{t+1}, h_{t+1}}} \sum_{t=0}^{\infty} \beta^t \left\{ \log \left[d_0 \left(1 - \tau_t \right) y_t \right] + D \log \left(g_t \right) \right\}, \tag{C_1}$$

subject to

$$y_t \left[a_0 + b_0 + \tau_t \left(1 - a_0 - b_0 \right) \right] - i_{gt} - g_t - A_1^{\frac{-1}{\delta_k}} k_{t+1}^{\frac{1}{\delta_k}} k_t^{\frac{\delta_k - 1}{\delta_k}} -$$

$$A_2^{\frac{-1}{\delta_h}} \left(A_3 A_4 \right)^{\frac{-\nu}{\delta_h}} h_{t+1}^{\frac{1}{\delta_h}} h_t^{\frac{\delta_h + \delta_g - 1}{\delta_h}} \left(\frac{h_t}{k_t} \right)^{\frac{\theta \nu}{\delta_h (\theta + \gamma - 1)}} \left(1 - \tau_t \right)^{\frac{-\nu}{\delta_h (\theta + \gamma - 1)}} i_{gt}^{\frac{-\delta_g}{\delta_h}} = 0,$$

$$y_t = A_0 A_3^{1-\theta} k_t^{\frac{\theta \gamma}{\theta + \gamma - 1}} h_t^{\frac{(1-\theta)(\gamma - 1)}{\theta + \gamma - 1}} \left(1 - \tau_t \right)^{\frac{1-\theta}{\theta + \gamma - 1}},$$

[17] See, for example, Jones, Manuelli, and Rossi (1993).

[18] Period-by-period balanced budgets are used in the quantitative studies of Trostel (1993), Pecorino (1993, 1994), Glomm and Ravikumar (1998), and Kim (1998). Other studies, such as King and Rebelo (1990), Devereux and Love (1994), Stokey and Rebelo (1995), and Ortigueira (1998) assume that tax revenues are rebated to households in a lump-sum manner. Finally, Lucas (1990), Laitner (1995), and Grüner and Heer (2000) impose constant ratios of government debt to either human capital or output.

[19] Kydland and Prescott (1977, p. 476) note that optimal policies will be time consistent when agents' current decisions do not depend on future policy actions. For other examples where this occurs, see Xie (1997) and Lansing (1999).

with k_0 and h_0 given. The constant d_0 represents a combination of deep parameters. We assign the label C_1 to this problem because the optimal policy turns out to be a consumption tax. The closed-form solution to C_1 is summarized by the following proposition.

Proposition 1. (Optimal Fiscal Policy). *The unique, time-invariant policy rules that maximize household welfare are given by*

$$\tau_{kt} = 0, \text{ or equivalently, } \phi_{kt} = 1,$$

$$\tau_{ht} = 0, \text{ or equivalently, } \phi_{ht} = 1,$$

$$i_{gt} = \left(\frac{\delta_g}{\delta_h}\right) b_0 y_t, \text{ or equivalently, } i_{gt} = \left(\frac{\delta_g}{\delta_h}\right) i_{ht},$$

$$g_t = \frac{D}{1+D}\left[1 - a_0 - b_0\left(1 + \frac{\delta_g}{\delta_h} + \frac{\nu}{\delta_h \gamma}\right) - \frac{(1-\theta)}{\gamma}\right] y_t,$$

$$\tau_t = \frac{i_{gt}/y_t + g_t/y_t}{1 - a_0 - b_0} = \frac{D}{1+D}\left[\frac{1 - a_0 - b_0\left(1 - \frac{\delta_g}{D\delta_h} + \frac{\nu}{\delta_h \gamma}\right) - \frac{(1-\theta)}{\gamma}}{1 - a_0 - b_0}\right],$$

for all $t \geq 0$*, where* y_t *is given by equation* (10).[20]

The optimal policy calls for full expensing of private investment which, as noted earlier, is equivalent to a pure consumption tax. This result is consistent with a large public finance literature that argues in favor of consumption taxes over income taxes. The efficient levels of public expenditures relative to output are uniquely pinned down by parameters that govern both technology and preferences. The efficient ratio of public to private investment in human capital is given by the simple relationship $i_{gt}/i_{ht} = \delta_g/\delta_h$ where δ_g and δ_h are the production elasticities for each type of investment in the human capital technology (5).

Since the efficient levels of public expenditures will generally differ from those that prevail in the baseline economy (except by chance), implementing the optimal fiscal policy will require a change in the size of government. If a proposed reform holds the size of government fixed to satisfy a revenue-neutrality constraint, then the reform will be suboptimal. Proposition 1 establishes this point in a transparent way for an economy that allows for a realistic but limited disaggregation of public expenditures. A more complete disaggregation would include such categories as health care or infrastructure spending. That said, all we need for our main theoretical result to go through is that there exists some efficient level of public expenditures in the post-reform economy that is determined by joint optimization of tax and spending variables. Given this basic premise, a revenue-neutral tax reform will be rendered suboptimal.

4 Calibration

Parameter values and tax rates are chosen such that the model's balanced growth path matches various "facts" identified from empirical data. A time period in the model is taken to be one year. We calibrate the pre-reform tax system to resemble the hybrid income-consumption tax system in

[20] Details of the proof are contained in the technical appendix that accompanies the web version of this article.

the U.S. economy. As many authors have noted, the existing tax code already allows a significant portion of U.S. saving to escape distortionary taxation.

Our calibration strategy assumes that neither tax or spending variables are optimally chosen initially—a reasonable assumption for the U.S. economy in our view. Hence we do not impose the parameter restrictions implied by Proposition 1 when choosing values for δ_g and D. Instead, we choose δ_g to match empirical estimates of the growth effects of public-sector investment in education and we choose D to match an empirical estimate of the marginal rate of substitution between public and private consumption goods. Since other calibration strategies for δ_g and D could be used, we examine the sensitivity of our results to alternative values of these parameters.

A cross-country study by Barro and Sala-i-Martin (1995, table 12.3) regresses per capita output growth on a large number of economic and demographic variables, including measures of GDP and human capital. The estimated coefficient on *G-educ/Y* (the 10-year average ratio of government spending on education to GDP) is reported as 0.062 (standard error = 0.085) using a seemingly unrelated regression technique and 0.229 (standard error = 0.109) using an instrumental variables technique. For calibration purposes, we adopt a mid-range coefficient of 0.1. In the model, the effect of an increase in i_{gt}/y_t on per capita growth can be seen by dividing both sides of equation (5) by h_t, rearranging, and then taking logarithms to obtain

$$\mu = \log \frac{h_{t+1}}{h_t} = \log \left[A_2 \left(\frac{y_t}{h_t}\right)^{\delta_h + \delta_g} \left(\frac{i_{ht}}{y_t}\right)^{\delta_h} \left(\frac{i_{gt}}{y_t}\right)^{\delta_g} e_t^{\nu} \right]. \tag{16}$$

For the postwar U.S. economy, government spending on education, training, and R&D has averaged about 6 percent of GDP.[21] Taking $i_{gt}/y_t = \psi_{ig} = 0.06$, we choose $\delta_g = 0.006$ such that the baseline model exhibits the property $\partial\mu/\partial\left(i_{gt}/y_t\right) = \delta_g/\psi_{ig} = 0.1$.

Aschauer (1985) estimates the degree of substitutability between public and private consumption for a model where agents derive utility from a composite consumption good given by $c_t + \alpha g_t$. This specification implies that the marginal rate of substitution between public and private consumption is constant and equal to α. Aschauer's estimates for α are in the range of 0.23 to 0.42. In contrast, the utility function in our model is additively separable in the two types of consumption—a specification supported by the empirical studies of Karras (1994) and Amano and Wirjanto (1998).[22] The within-period utility function in our model can be written as

$$U\left(c_t, g_t\right) = \log \left[\left(\tfrac{d_0}{1-a_0-b_0} \right) c_t \right] + D \log\left(g_t\right), \tag{17}$$

where we have made use of the equilibrium relationships $c_t - B h_t l_t^{\gamma} = d_0\left(1-\tau_t\right) y_t$ and $c_t = \left(1 - a_0 - b_0\right)\left(1-\tau_t\right) y_t$. Equation (17) implies that the equilibrium marginal rate of substitution between public and private consumption is given by $D \times \left(c_t/g_t\right)$. Our calibration procedure yields $c_t/g_t = 3.63$ to match the corresponding average ratio in the U.S. economy. Using U.S. data from 1953 to 1994, Amano and Wirjanto (1998) estimate a utility specification where the marginal rate of substitution between public and private consumption is given by $0.49 \times \left(c_t/g_t\right)^{0.64}$. Substituting

[21] Data sources are as follows: Education expenditure data are from the Citibase series GAGEED & GAGEL (public-sector) and GAESE (private-sector). R&D expenditure data are from National Science Foundation (1995, table B-15 and p. 10). Physical capital and investment data are from U.S. Bureau of Economic Analysis (1998). Total government expenditure data are from the Citibase series GGEQ.

[22] Karras (1994, fn 8) restimates Aschauer's specification but controls for autocorrelation of the error term. The resulting point estimate for α is not statistically different from zero. Amano and Wirjanto (1998) estimate a more-general utility specification and reach similar conclusions.

$c_t/g_t = 3.63$ into their expression yields a marginal rate of substitution of 1.12. Equating this figure with the marginal rate of substitution implied by (17) yields $D = 0.310$ for our initial calibration. Our sensitivity analysis examines alternative calibrations with larger and smaller values of D.

Empirical research indicates that the response of prime-age male labor supply to changes in the after-tax wage is near zero. Females exhibit a larger labor supply response, particularly if one considers adjustments along both intensive and extensive margins (see Eissa, 1996). Based on the evidence, we choose $\gamma = 6$ which implies an intertemporal elasticity of substitution in labor supply of $(1-\gamma)^{-1} = 0.2$. Later, we examine the sensitivity of our results to a more-elastic labor supply.

We choose $\theta = 0.36$ to match the average share of capital income in U.S. GDP, as estimated by Poterba (1997). The constants A_0, A_1, and A_2 are chosen to achieve the calibration targets of $\mu = 1.80\%$, $k_t/y_t = 2.6$ and $h_t/k_t = 13$. Our measure of the U.S. physical capital stock includes structures, equipment, consumer durables, and residential components. Our target for h_t/k_t is based on the Jorgenson and Fraumeni (1989, table 5.33) capital stock estimates which take into account the imputed value of human capital in nonmarket activities such as school, leisure, or home production.[23]

The elasticity parameters δ_k and δ_h are chosen so that the model matches the U.S. average ratios of $i_{kt}/y_t = 0.22$ and $i_{ht}/y_t = 0.025$. Consistent with our measure of physical capital, i_{kt} includes structures, equipment, consumers durables, and residential components.[24] Our measure of i_{ht} includes private-sector expenditures on education, training, and R&D.

We choose the discount factor β to achieve an after-tax interest rate of 4% based on the estimates of Poterba (1997, table 1).[25] The elasticity parameter ν in the human capital technology and the household preference parameter B are chosen to achieve the balanced-growth time allocations of $e_t = 0.12$ and $l_t - e_t = 0.17$. These are the values estimated by Jones, Manuelli, and Rossi (1993, fn 2) for the U.S. economy.

We adopt Auerbach's (1996, p. 51) estimate of $\tau_k = 0.16$ to calibrate the baseline value of ϕ_k because his estimate takes into account the effective tax rates for both residential and nonresidential capital. A difficult parameter to pin down is ϕ_h, which represents the fraction of private goods investment in human capital that is tax deductible. Recall that our measure of i_{ht} includes private-sector expenditures on education, training, and R&D. Privately-funded R&D investment (which is tax deductible) has averaged slightly more than 1% of GDP since 1954. Private expenditures for education and training (which are mostly not tax deductible) are roughly the same magnitude. We combine these observations to come up with an estimate of $\phi_h = 0.5$. Later, we demonstrate that our quantitative results are not very sensitive to changes in ϕ_h.

Finally, given the parameter values and calibration targets noted above, we solve for the tax rate τ in the baseline economy such that the government budget constraint (15) is satisfied with $i_{gt}/y_t = \psi_{ig} = 0.06$ and $g_t/y_t = \psi_g = 0.15$. These are the average ratios of public expenditures to GDP in the U.S. economy. Table 1 summarizes the results of our calibration exercise.

---

[23] Studies that restrict their attention to market activities obtain estimates of $h_t/k_t \approx 3$. See Davies and Whalley (1991, Appendix) for a review of various studies that estimate the aggregate value of human capital.

[24] A standard linear law of motion for physical capital implies $k_{t+1}/k_t = 1 - \widehat{\delta}_k + i_{kt}/k_t$, where $\widehat{\delta}_k$ is the geometric depreciation rate. Equating this expression to k_{t+1}/k_t from (4) and solving for $\widehat{\delta}_k$ yields an effective depreciation rate of $\widehat{\delta}_k = 0.066$ along the model's balanced-growth path.

[25] The after-tax interest rate $\hat{r}$ is defined by introducing privately-issued real bonds (which exist in zero net supply) into the household budget constaint. The balanced-growth version of the first-order condition for bonds implies $\hat{r} = \exp(\mu - \ln\beta) - 1$.

Table 1: Initial Calibration.

Parameter	Value	Empirical Fact to Match
γ	6.000	Labor supply elasticity $(\gamma - 1)^{-1} = 0.2$
θ	0.360	Average share of physical capital in output $= 0.36$
A_0	0.232	Average per capita output growth $\mu = 1.80\%$
A_1	1.173	Average $k_t/y_t = 2.6$
A_2	1.139	Average $h_t/k_t = 13$
δ_k	0.057	Average $i_{kt}/y_t = 0.22$
δ_h	0.002	Average $i_{ht}/y_t = 0.025$
δ_g	0.006	Growth effect of public expenditures $\partial\mu/\partial\left(i_{gt}/y_t\right) = 0.1$
β	0.979	After-tax interest rate $= 4\%$
ν	0.029	Fraction of time in school or training $e_t = 0.12$
B	6.954	Fraction of time in market work $l_t - e_t = 0.17$
D	0.310	Marginal rate of substitution between c_t and $g_t = 1.12$
ϕ_k	0.368	Effective marginal tax rate $\tau_k = 0.16$
ϕ_h	0.500	Fraction of tax deductible investment in human capital
ψ_{ig}	0.060	Average $i_{gt}/y_t = 0.06$
ψ_g	0.150	Average $g_t/y_t = 0.15$
τ	0.232	Average $\left(i_{gt} + g_t\right)/y_t = 0.21$

As a check on parameter values, we can compare some properties of the model to the findings of empirical studies. From equation (4), Tobin's q in the model is given by

$$q_t = \frac{\partial k_{t+1}/\partial k_t}{\partial k_{t+1}/\partial i_{kt}} = \frac{\left(1-\delta_k\right)}{\delta_k}\frac{i_{kt}}{k_t} = 1.39. \tag{18}$$

Eberly (1997, Table 1) estimates Tobin's q using U.S. firm level data over the period 1981 to 1994. She obtains a mean estimate of 1.56 and a median estimate of 1.18. Comparing these figures to equation (18) suggests that our model provides a reasonable portrayal of U.S. investment fundamentals.

With $\phi_k = 0.368$ and $\phi_h = 0.500$, the baseline tax structure is slightly more favorable to human capital when it comes to private goods investment. Our calibration implies that untaxed foregone earnings represent 84% of the total costs (private and public) of producing human capital.[26] Of the privately-borne costs, only about 3% are not tax deductible.[27] As a comparison, Clotfelter (1991, p. 72) estimates that foregone earnings represent 49-79% of college education costs (tuition, room, board, and foregone earnings) for males and 41-71% for females over various two-year periods from 1969 to 1988.[28] Dupor, et al. (1996) estimate an upper bound of 8% for the share of privately-borne costs which are not tax deductible.

5 Quantitative Effects of Tax Reform

This section describes the positive and normative effects of various tax reforms. We begin with a comparison of four consumption tax reforms (labeled C_1 through C_4) that differ according to

[26] Foregone earnings are given by $w_t h_t e_t$. The total costs of producing human capital are given by $w_t h_t e_t + i_{ht} + i_{gt}$. For our calibration, $w_t h_t e_t / \left(w_t h_t e_t + i_{ht} + i_{gt}\right) = 0.842$.

[27] The privately-borne costs of producing human capital are given by $w_t h_t e_t + i_{ht}$. The non tax deductible portion of these costs are given by $\left(1-\phi_h\right) i_{ht}$. For our calibration, $\left(1-\phi_h\right) i_{h_t} / \left(w_t h_t e_t + i_{ht}\right) = 0.026$.

[28] Since government-provided financial aid may help pay for college tuition, we interpret these figures as measuring the ratio of foregone earnings to total (private and public) costs of producing human capital.

their implications for the size of government. We then examine two additional revenue-neutral reforms. Since tax policy can affect the trend growth rate of all variables in our model, the concept of revenue neutrality used here is a relative one. A revenue-neutral reform holds tax revenues (and hence public-sector expenditures) fixed relative to output.[29]

Tables 2 and 3 summarize the balanced-growth properties and the transition paths of the reforms. Table 4 summarizes the welfare and growth effects of the reforms.

5.1 Consumption Tax Reforms

The benchmark consumption tax reform, labeled C_1, implements the optimal fiscal policy given by Proposition 1. This experiment establishes an upper bound on the attainable welfare gains from tax reform in the model. As noted earlier, the fully optimal reform calls for a change in the size of government in order to achieve the efficient ratios for i_{gt}/y_t and g_t/y_t. We examine the implications of deviating from the efficient ratios by considering three suboptimal consumption tax reforms, labeled C_2, C_3, and C_4. The C_2 reform implements the efficient ratio for i_{gt}/y_t, but maintains the baseline ratio $g_t/y_t = \psi_g$. The C_3 reform maintains the baseline ratio $i_{gt}/y_t = \psi_{ig}$ but implements the efficient ratio for g_t/y_t. The C_4 reform satisfies our definition of revenue neutrality by maintaining *both* baseline ratios $i_{gt}/y_t = \psi_{ig}$ and $g_t/y_t = \psi_g$. Given the public expenditure ratios implied by each suboptimal reform, we solve for the post-reform tax rate τ that satisfies the government's budget constraint (15) with $\phi_k = \phi_h = 1$.

5.1.1 Consumption Tax with Efficient Public Expenditures

For the initial calibration, the efficient public expenditure ratios from Proposition 1 are $i_{gt}/y_t = 0.094$ and $g_t/y_t = 0.102$. The corresponding ratios in the baseline economy are $i_{gt}/y_t = 0.060$ and $g_t/y_t = 0.150$ (Table 2). The fully optimal reform calls for the government to devote more resources to public investment and less resources to public consumption. This outcome is consistent with the pro-growth nature of the reform. Overall, the C_1 reform calls for a smaller size of government; total public expenditures $i_{gt} + g_t$ fall to 19.6% of output from 21% in the baseline economy.

By allowing full-expensing of private investment ($\phi_k = \phi_h = 1$), the C_1 reform shrinks the tax base relative to the baseline tax code which only allows for partial expensing. Thus, despite the smaller size of government, the tax rate must be increased from $\tau = 0.232$ in the baseline economy to a post-reform value of $\tau = 0.277$. Full expensing yields $\tau_k = \tau_h = 0$ which encourages private investment. The balanced-growth ratio i_{kt}/y_t increases from 0.220 in the baseline economy to a post-reform value of 0.262. The balanced-growth ratio i_{ht}/y_t increases from 0.025 to 0.029.

With more resources devoted to investment (both public and private) the economy's balanced growth rate μ increases by 0.35 percentage points to 2.15%. All of the reforms we consider exhibit relatively small growth effects due to the form of the human capital technology where untaxed foregone earnings represent the largest input to human capital production. The computed growth effects would have been even smaller if we had adopted a utility function with more curvature than logarithmic (implying higher risk aversion). Small growth effects from tax reform are consistent

[29] Altig et al. (2001) employ a similar definition of revenue neutrality by holding tax revenues fixed when measured in effective units of labor. In our model, effective labor is given by $h_t\,(l_t - e_t)$, which grows at the same rate as output along the economy's balanced growth path.

with the findings of many authors including Lucas (1990), Devereux and Love (1994), and Stokey and Rebelo (1995).

The transition paths for selected variables are shown in the top panel of Table 3. In the very short-run (corresponding to year 1), the higher post-reform tax rate τ discourages work effort $l_t - e_t$ and schooling time e_t which both fall by about 1%. The investment stimulus from the C_1 reform leads to an 18% first-year increase in Tobin's q. It takes time for the increased investment to raise the capital stocks due to the form of equations (4) and (5) which imply investment adjustment costs. In the short-run, the capital stocks cannot increase fast enough to compensate for the drop in work effort. This accounts for the temporary reduction in output growth to 1.08% in year 1.

By year 5, the capital stocks have had time to respond to the investment stimulus and we observe output growth rebounding to 2.32%. Along the transition path, physical capital grows faster than human capital which causes the ratio h_t/k_t to decline. The balanced-growth value of h_t/k_t is influenced by the policy variables τ, τ_k, τ_h, and i_{gt}/y_t. All four of these policy variables change during the C_1 reform. For this calibration, the effect of a lower τ_k dominates the effects of the other three variables and we observe a decline in h_t/k_t as the economy moves to a new balanced growth path. The decline in h_t/k_t translates directly into a rise in the before-tax wage via equation (8b). As the transition proceeds, the rising wage leads to a rebound in work effort and schooling time. The more-rapid growth of k_t relative to h_t causes the ratio k_t/y_t to increase along the transition path. This translates directly into a decline in the before-tax rental rate r_t via equation (8a). As r_t declines, households have less incentive to invest in physical capital and we observe Tobin's q falling as the transition proceeds beyond year 1. Ultimately, however, Tobin's q ends up 6% above its pre-reform value.

The welfare effects of the C_1 reform are shown in Table 4. Welfare effects are measured by the constant percentage change in per-period private consumption in the baseline economy that makes the representative household indifferent to the reform. We decompose the net welfare change into three separate components: (1) a long-run level effect linked directly to changes in the balanced-growth values of h_t/k_t, τ, and g_t/y_t, (2) a long-run growth effect linked directly to changes in the balanced growth rate μ, and (3) a transition effect defined as the residual component of lifetime utility computed by numerically simulating the transition path for 1500 periods.[30]

Given equation (17), lifetime utility can be written as

$$V = \sum_{t=0}^{\infty} \beta^t \left\{ \log \left[\left(\tfrac{d_0}{1-a_0-b_0} \right) c_t \right] + D \log (g_t) \right\}, \tag{19}$$

which shows that the welfare effects of any reform depend entirely on the resulting trajectories for c_t and g_t. The trajectories are plotted in Figures 1 through 4 as deviations from the pre-reform trend. To provide some intuition for the welfare results, Table 4 also reports the 100-year average growth rates for c_t and g_t. The first 100 years of the transition account for most of the contribution to lifetime utility. The welfare rankings of the various reforms need not correspond one-for-one with the magnitude of the average growth rates, however. This is because the average growth rates depend only on the net changes in c_t and g_t over 100 years, whereas the welfare computation takes into account the precise temporal patterns in c_t and g_t over the entire transition path.

[30] The details of the decomposition procedure are contained in the technical appendix that accompanies the web version of this article.

Table 4 shows that the C_1 reform yields a net welfare gain of $\Delta W_{\text{net}} = 6.59\%$, measured in units of per-period private consumption. There is a large positive contribution from the long-run growth effect (22.1%) that outweighs smaller negative contributions from the long-run level effect and the transition effect (-9.52% and -5.94%, respectively). The intuition for these results is straightforward. By increasing the fraction of output devoted to public and private investment, the C_1 reform raises the economy's balanced growth rate to 2.15%—the highest growth rate of any reform we consider. This result accounts for the large contribution to welfare from the long-run growth effect. It is well known that even small changes in growth can have very large welfare consequences because growth rates are compounded over many years. Regarding the long-run level effect, the C_1 reform brings about a decline in the h_t/k_t ratio, an increase in the tax rate τ, and a decline in the g_t/y_t ratio. All else equal, equation (10) implies that a lower h_t/k_t ratio raises the long-run level of per capita output (or income) while a higher tax rate τ has the opposite effect. A higher tax rate also reduces *disposable* income which impacts private consumption directly via the decision rule (9c). All else equal, a decline in the g_t/y_t ratio reduces long-run welfare whenever $D > 0$. The combination of these various elements yields a negative contribution from the long-run level effect. The transition effect yields a negative contribution because households must initially sacrifice consumption to accumulate the capital needed to support higher consumption in the future.

Both c_t and g_t undergo sharp drops in year 1 relative to their pre-reform trends as the C_1 reform shifts resources away from consumption towards investment (Figures 1 and 2). The 100-year average growth rates for c_t and g_t are 2.12 % and 1.80%, respectively (Table 4). The average growth rate for c_t exceeds the baseline growth rate of 1.80% whereas the average growth rate for g_t is just equal to the baseline growth rate. Thus, despite the sharp drops in year 1, both types of consumption recover by year 100 to meet or exceed the levels that would have prevailed without the reform.

5.1.2 Consumption Tax with Inefficient Public Expenditures

The C_2 reform implements the efficient ratio $i_{gt}/y_t = 0.094$ but maintains the baseline ratio $g_t/y_t = 0.150$. The reform calls for a larger size of government as total public expenditures rise to 24.4% of output versus 21% in the baseline economy. The combination of a larger government and a smaller tax base (from allowing full-expensing of investment) pushes up the post-reform tax rate to $\tau = 0.344$. The higher tax rate discourages work effort and schooling time, leading to a smaller long-run growth gain in comparison to the C_1 reform. The C_2 reform increases the economy's balanced growth rate by 0.28 percentage points to 2.08% versus a 0.35 percentage point gain under the C_1 reform. The transition path (Table 3) is qualitatively similar to that of the C_1 reform but output growth in year 1 drops more severely—to the point of actually turning negative. Again, this is due to the higher post-reform tax rate which causes a larger short-run decline in work effort and schooling when the reform is implemented in year 1. The C_2 reform produces a net welfare gain of $\Delta W_{\text{net}} = 3.24\%$ versus a 6.59% gain for the C_1 reform (Table 4). By maintaining the inefficient baseline ratio of $g_t/y_t = 0.150$, the C_2 reform forgoes more than one-half of the available welfare gain from shifting to a consumption tax. The intuition for this result can be seen in Figure 1. The higher post-reform tax rate needed to maintain the baseline g_t/y_t ratio brings about a large drop in c_t relative to trend. This drop weighs heavily on lifetime utility because it occurs at the beginning of the transition path. The 100-year average growth rates for c_t and g_t are 1.95% and 2.11%, respectively. The C_2 reform is characterized by a higher average growth rate for g_t because public consumption does not undergo a sharp drop relative to trend when the reform is implemented.

The C_3 reform maintains the baseline ratio $i_{gt}/y_t = 0.060$ but implements the efficient ratio $g_t/y_t = 0.102$. The reform calls for a smaller size of government as total public expenditures fall to 16.2% of output. Unlike the C_1 reform, the effect of a smaller government outweighs the effect of a smaller tax base thereby resulting in a lower post-reform tax rate of $\tau = 0.229$. The slightly lower tax rate imparts a mild stimulus to work effort and schooling time in both the short-run and long-run. Along the transition path, we now observe a small uptick in output growth to 1.84% in year 1. In the long-run, the C_3 reform increases growth by 0.15 percentage points to 1.95%. The long-run growth gain is smaller in comparison to the two earlier reforms because the C_3 reform does not raise the fraction of output devoted to public investment in human capital—an important contributor to growth. Despite the smaller growth change, the C_3 reform produces a net welfare gain of $\Delta W_{\text{net}} = 3.73\%$, the second highest gain among all of the reforms. The welfare decomposition reveals a positive contribution from the long-run level effect (1.70%). This is due to the combined effects of a lower h_t/k_t ratio and a lower τ relative to the baseline economy. All else equal, both elements serve to increase the long-run level of disposable income. In contrast, the two earlier reforms are characterized by a lower h_t/k_t ratio and a *higher* τ relative to the baseline economy, which have offsetting effects on the long-run level of disposable income. The 100-year average growth rates for c_t and g_t are 2.02% and 1.64%, respectively.

Real-world tax proposals are often designed to be revenue-neutral. This reflects a tendency on the part of policymakers to separate decisions about tax policy from decisions about public expenditures (or public borrowing). The revenue-neutral C_4 reform maintains both baseline ratios $i_{gt}/y_t = 0.060$ and $g_t/y_t = 0.150$. The full-expensing provision shrinks the tax base, requiring the tax rate to be increased to $\tau = 0.296$. The higher post-reform tax rate pushes down work effort and schooling time in the short-run and we observe a temporary slowdown in output growth to 0.76% in year 1 (Table 3). In later years, work effort and schooling time both recover in response to the rising wage. The C_4 reform increases the economy's balanced growth rate by only 0.1 percentage points to 1.90%, the smallest growth gain among the four consumption tax reforms. The growth gain is smaller for two reasons: (1) because of the higher post-reform tax rate τ and (2) because the reform does not raise the fraction of output devoted to public investment in human capital. The C_4 reform produces a net welfare gain of $\Delta W_{\text{net}} = 1.43\%$, only about one-fifth as large as the 6.59% gain produced by the fully-optimal C_1 reform. Figure 1 again provides some intuition. The higher post-reform tax rate under the C_4 reform leads to an initial drop in c_t relative to trend. Although the initial drop is less severe than say, the C_2 reform, the subsequent recovery of c_t is less rapid because the long-run growth gain from the C_4 reform is very small—only 0.1 percentage points. The 100-year average growth rate for c_t is 1.85%, the lowest figure among the four consumption tax reforms.

Taken together, the above experiments show that not all consumption tax reforms are created equal; the benefits of a shifting to a consumption tax are strongly influenced by assumptions about the post-reform size of government. For our initial calibration, a reform that only implements the efficient g_t/y_t ratio yields a slightly larger net welfare gain ($\Delta W_{\text{net}} = 3.73\%$ for the C_3 reform) than a reform that only implements the efficient i_{gt}/y_t ratio ($\Delta W_{\text{net}} = 3.24\%$ for the C_2 reform). Later, we show that this ordering can be reversed for alternative calibrations.

5.2 Other Revenue-Neutral Reforms

5.2.1 Flat Tax

Judd (1998) notes that many consumption tax proposals are actually biased in favor of physical capital. In particular, the "flat tax" proposal of Hall and Rabushka (1995), calls for the immediate expensing of new investment in physical capital, but contains no provisions to ensure equivalent treatment of human capital. Expenditures by individuals on education would not be deductible from taxable income under the Hall-Rabushka plan. In contrast, the Nunn-Dominici USA (unlimited saving allowance) tax proposal includes a limited deduction for family expenditures on college tuition, vocational training, or remedial education.[31] Judd (1998) also points out that the Hall-Rabushka proposal would actually eliminate some features of the tax code that appear to encourage human-capital investment. These include the deductibility of charitable contributions to educational institutions and the deductibility (for taxpayers who itemize) of state and local taxes—a fraction of which is spent on public education. To capture these ideas, we consider a reform that allows full-expensing for investment in physical capital but reduces the tax incentives for investment in human capital. Specifically, our version of a flat tax imposes $\phi_k = 1$ and $\phi_h = 0.25$. Given these values, revenue neutrality is achieved by adjusting the post-reform tax rate τ to satisfy the government's budget constraint (15) after substituting in $i_{gt} = 0.06\, y_t$ and $g_t = 0.15\, y_t$.

Table 2 shows that the flat tax is characterized by $\tau = 0.287$, $\tau_k = 0$, and $\tau_h = 0.232$. Since the flat tax only allows for partial expensing of human-capital investment, the tax rate τ needed to maintain revenue neutrality is lower than under the C_4 reform. Despite the lower value of τ, the flat tax yields a smaller long-run growth gain of 0.06 percentage points versus 0.1 percentage points for the C_4 reform. This is due to the lower value of ϕ_h under the flat tax which implies a smaller tax incentive for private investment in human capital —a contributor to growth. The lower value of ϕ_h relative to the baseline economy causes the ratio i_{ht}/y_t to decrease from 0.025 in the baseline economy to a post-reform value of 0.022. In contrast, this ratio *increases* from 0.025 to 0.029 under the C_4 reform. The impact of this difference on long-run growth is mild because non-deductible private goods investment in human capital $(1 - \phi_h)\, i_{ht}$ accounts for only a small fraction of the total costs of producing human capital in our model. The largest input to the production of human capital is foregone earnings which is already implicitly expensed. Not surprisingly, therefore, the transition path for the flat tax is very similar to that of the C_4 reform (Table 3, Figures 1 and 2).

The net welfare gain from implementing the flat tax is $\Delta W_{\text{net}} = 1.20\%$, only slightly less than the gain of 1.43% produced by the C_4 reform (Table 4). Overall, this experiment shows that the expensing policy for private goods investment in human capital has only minor welfare and growth consequences.

5.2.2 Income Tax

An income tax can be interpreted as capturing some elements of the Tax Reform Act of 1986 (TRA86) which was designed to achieve a simpler and more efficient federal tax system. TRA86 broadened the tax base by eliminating many tax breaks and substantially reduced the dispersion of tax rates across alternative income-producing activities. Among other things, the act eliminated

[31] For details on the Nunn-Dominici plan, see Weidenbaum (1996).

the investment tax credit (which had applied to equipment but not structures) and eliminated the capital gains preference by taxing gains as ordinary income.[32]

In our model, an income tax is obtained by setting $\phi_k = \phi_h = 0$ which eliminates the tax deductibility of private goods investment for both types of capital. Substituting these values into the government's budget constraint (15) together with the revenue-neutrality conditions $i_{gt} = 0.06\, y_t$ and $g_t = 0.15\, y_t$ yields $\tau = 0.21$.

The broader tax base under an income tax allows for a lower post-reform tax rate; τ goes from a baseline value of 0.232 to a post-reform value of 0.210. The lower value of τ induces an initial jump in work effort and schooling time and we observe a temporary increase in output growth to 2.13% in year 1. Despite the lower value of τ, the non-deductibility of private goods investment results in higher values for the effective tax rates τ_k and τ_h. This feature of the reform accounts for the decline in the ratios i_{kt}/y_t and i_{ht}/y_t (Table 2). The dropoff in private investment causes Tobin's q to decline by 6% in year 1. Since foregone earnings while in school continue to be fully expensed, the income tax favors human capital as evidenced by the rising h_t/k_t ratio (Table 3).

Because it discourages private investment, the income tax lowers the economy's balanced growth rate by 0.04 percentage points to 1.76%. The welfare decomposition reveals negative contributions from the long-run level effect and the long-run growth effect. The transition effect yields a positive contribution, however, because the reform stimulates consumption in the short-run at the expense of investment. Overall, the net welfare change from the reform is $\Delta W_{\text{net}} = -1.34\%$ (Table 4) We note, however, that our analysis abstracts from some potential benefits of a simplified tax system, such as improved taxpayer compliance or reduced administrative costs.

6 Sensitivity Analysis

Since our model, like many others, includes some parameters whose values are not precisely pinned down by empirical studies, we wish to examine the sensitivity of the results to plausible changes in these parameters. Specifically, we consider alternative values for the labor supply elasticity $(\gamma - 1)^{-1}$, the human-capital production elasticity for public investment δ_g, and the utility parameter for public consumption D. The results of the sensitivity analysis are presented in Table 5. For comparison, the upper left panel of the table reproduces the results for the initial calibration.

6.1 Labor Supply Elasticity

It is well-known that assumptions about the labor supply elasticity can influence the behavior of dynamic tax models. To explore this issue, we consider an alternative calibration with $(\gamma - 1)^{-1} = 0.5$. This elasticity is more than twice that of the baseline calibration but still within the range of empirical estimates reported by some studies.[33] To provide some intuition, Figure 3 plots the efficient public expenditure ratios over a range of elasticities.[34] Both expenditure ratios decline as labor supply becomes more elastic. This is because larger elasticities raise the distortionary costs of collecting the tax revenue needed to finance the expenditures. The efficient g_t/y_t ratio declines

[32] For additional description and analysis of TRA86, see the two symposia in *Journal of Economic Perspectives*, Summer 1987 and Winter 1992.

[33] See, for example, Mulligan (1999).

[34] For each elasticity value plotted in Figure 3, we recalibrate the remaining parameters of the model to match the empirical facts summarized in Table 1. A similar procedure is followed in constructing Figures 4 and 5.

more gradually than the efficient i_{gt}/y_t ratio because the former directly contributes to household utility.

When $(\gamma - 1)^{-1} = 0.5$, the efficient public expenditure ratios are $i_{gt}/y_t = 0.054$ and $g_t/y_t = 0.069$. Relative to the baseline economy, the fully-optimal C_1 reform now calls for a reduction in both public expenditure ratios. The optimal size of government falls to 12.3% of output versus an optimal size of 19.6% under the initial calibration. The reduction in the optimal size of government leads to a lower post-reform tax rate ($\tau = 0.173$) and a larger net welfare gain ($\Delta W_{\text{net}} = 15.8\%$) in comparison to the initial calibration. Since the optimal size of government is now further below the U.S. baseline, imposing revenue-neutrality can have significant adverse welfare consequences. The revenue-neutral C_4 reform, which maintains the size of government at 21% of output, now produces a net welfare *loss* of $\Delta W_{\text{net}} = -0.71\%$. The C_2 reform, which reduces the size of government slightly to 20.4% of output, now produces a net welfare loss of $\Delta W_{\text{net}} = -0.14\%$. Of the three suboptimal consumption tax reforms, the C_3 reform produces the largest net welfare gain ($\Delta W_{\text{net}} = 15.7\%$) because this reform reduces the size of government to 12.9% of output—very close to the optimal size of 12.3%.

As before, the results for the flat tax are close to the C_4 reform, but the welfare rankings are now reversed. Under this calibration, the flat tax yields a slightly better outcome than the C_4 reform ($\Delta W_{\text{net}} = -0.56\%$ versus -0.71%), but both reforms still end up reducing welfare. The welfare reversal is due to the lower post-reform tax rate τ afforded by the flat tax which takes on added importance as labor supply become more elastic.

The welfare performance of the income tax actually improves with a more-elastic labor supply, although the reform still produces a net loss of $\Delta W_{\text{net}} = -1.10\%$. The improvement occurs because the post-reform tax rate of $\tau = 0.210$ now induces an larger initial jump in work effort and hence a larger early stimulus to consumption in comparison to the initial calibration.

6.2 Production Elasticity for Public Investment

Under the initial calibration, the efficient public investment ratio $i_{gt}/y_t = 0.094$ exceeds the U.S. average ratio $i_{gt}/y_t = 0.06$. We now consider the opposite case where the efficient ratio lies below the U.S. ratio. To achieve this outcome, we choose a smaller production elasticity for public investment, $\delta_g = 0.0014$, such that the efficient public investment ratio is $i_{gt}/y_t = 0.026$. In this way, we maintain the same absolute distance between the efficient ratio and the U.S. ratio as under the initial calibration. The baseline economy now exhibits the property $\partial\mu/\partial\,(i_{gt}/y_t) = 0.023$, which falls within the 95% confidence interval implied by the empirical estimates of Barro and Sala-i-Martin (1995, table 12.3).

Figure 4 shows that smaller values of δ_g lower the efficient i_{gt}/y_t ratio but *raise* the efficient g_t/y_t ratio. The effect of a lower i_{gt}/y_t ratio dominates, however, such that the optimal size of government falls to 14.4% of output versus an optimal size of 19.6% under the initial calibration (which imposes $\delta_g = 0.006$). Thus, as in the case of a more-elastic labor supply, the optimal size of government is now further below the U.S. baseline in comparison to the initial calibration. Once again, this causes the revenue neutrality constraint to become more severely binding.

The results are presented in the lower left panel of Table 5. Once again, we see that imposing revenue-neutrality can exert a dramatic influence on the welfare effects of shifting to a consumption tax. The fully-optimal C_1 reform produces a net welfare gain of $\Delta W_{\text{net}} = 5.27\%$, whereas the revenue-neutral C_4 reform yields only a tiny net gain of $\Delta W_{\text{net}} = 0.07\%$. A reform that only implements the efficient i_{gt}/y_t ratio yields a larger welfare gain ($\Delta W_{\text{net}} = 4.07\%$ for the C_2 reform) than a reform that only implements the efficient g_t/y_t ratio ($\Delta W_{\text{net}} = 1.78\%$ for the C_3 reform). Recall that this ordering was reversed under the initial calibration.

Table 5 shows that all of the reforms exhibit smaller long-run growth changes relative to the initial calibration. For example, the revenue-neutral C_4 reform increases the economy's balanced growth rate by only 0.05 percentage points (to $\mu = 1.85\%$) versus a 0.10 percentage point growth gain under the initial calibration. The explanation for this result can be seen in equation (14) where smaller values of δ_g restrict some channels through which fiscal policy can affect long-run growth.

6.3 Utility Parameter for Public Consumption

All of the previous calibrations share the feature that the optimal size of government is below the U.S. baseline. We now examine the opposite case by imposing a larger value of D, the utility parameter for public consumption. Specifically, we set $D = 0.837$ such that the efficient public consumption ratio is $g_t/y_t = 0.198$. This value maintains the same absolute distance between the efficient ratio and the U.S. ratio as under the initial calibration.[35] Figure 5 shows that larger values of D raise the efficient g_t/y_t ratio but have no effect on the efficient i_{gt}/y_t ratio. When $D = 0.837$, the optimal size of government is 29.2% of output versus an optimal size of 19.6% under the initial calibration (which imposes $D = 0.310$).

The fully-optimal C_1 reform now produces a welfare gain of $\Delta W_{\text{net}} = 15.7\%$. This figure is considerably larger than the 6.59% gain obtained under the initial calibration. The enhanced welfare gain is driven by a larger contribution from the long-run level effect which in turn derives from the higher g_t/y_t ratio and the larger value of D. As with the previous calibrations, imposing revenue neutrality results in significant foregone welfare gains. The revenue-neutral C_4 reform now produces a welfare gain of $\Delta W_{\text{net}} = 5.59\%$, only about one-third the size of the gain produced by the fully-optimal C_1 reform.

With the exception of the income tax, all of the reforms exhibit improved welfare performance relative to their counterparts under the initial calibration. The welfare performance of the income tax deteriorates relative to the initial calibration: $\Delta W_{\text{net}} = -2.94\%$ versus -1.34% under the initial calibration. The distinguishing feature of the income tax that accounts for this result is the reform's effect on the long-run growth rate μ. The income tax *reduces* μ whereas the other reforms increase μ. For any given g_t/y_t ratio, reforms that stimulate output growth will automatically increase g_t which is more highly valued when $D = 0.837$ versus when $D = 0.310$.

Although not reported in Table 5, we also examined a calibration with $D = 0$ which implies that public consumption is entirely wasteful. In this case, revenue-neutral reforms that stimulate growth in y_t will automatically increase g_t and thereby contribute to a drain on productive resources. The welfare-reducing consequences of this negative externality will be more pronounced for reforms that yield higher growth in y_t and hence g_t. When $D = 0$, the revenue-neutral C_4 reform produces a welfare *loss* of $\Delta W_{\text{net}} = -0.94\%$. This figure compares to a gain of $\Delta W_{\text{net}} = 1.43\%$ when $D = 0.310$ and a gain of $\Delta W_{\text{net}} = 5.59\%$ when $D = 0.837$. In contrast, the welfare performance

[35] When $D = 0.529$, the efficient public consumption ratio coincides exactly with the U.S. baseline ratio of $g_t/y_t = 0.150$. When $D \to \infty$, the efficient public consumption ratio from Proposition 1 is $g_t/y_t = 0.434$.

of the income tax improves when $D = 0$ because this reform *reduces* the growth rate of y_t and hence g_t. When $D = 0$, the income tax produces a loss of $\Delta W_{\text{net}} = -0.38\%$. This figure compares to a loss of $\Delta W_{\text{net}} = -1.34\%$ when $D = 0.310$ and a loss of $\Delta W_{\text{net}} = -2.94\%$ when $D = 0.837$. These experiments demonstrate that the practice of modeling g_t as entirely wasteful while holding these expenditures fixed relative to the size of the economy can result in a substantial downward adjustment to the computed welfare gain from a reform that increases the economy's long-run growth rate. We note that the studies of Lucas (1990), Laitner (1995), and Grüner and Heer (2000) model g_t as entirely wasteful while holding the ratios g_t/h_t or g_t/y_t fixed. Hence, their welfare computations for growth-enhancing capital tax reforms would appear to be biased downwards.

6.4 Discussion

The sensitivity analysis described above provides something akin to a confidence interval for the potential benefits of tax reform in the model. By comparing across calibrations in Table 5, we see that the potential benefits of commonly-proposed reforms can vary over a wide range—and may even turn negative. For example, the net welfare gain produced by a revenue-neutral consumption tax reform (C_4) ranges from a high of $\Delta W_{\text{net}} = 5.59\%$ to a low of $\Delta W_{\text{net}} = -0.71\%$. The net welfare gain produced by a revenue-neutral flat tax reform ranges from a high of $\Delta W_{\text{net}} = 4.70\%$ to a low of $\Delta W_{\text{net}} = -0.56\%$. The net welfare gain produced by a revenue-neutral income tax reform ranges from a high of $\Delta W_{\text{net}} = -0.79\%$ to a low of $\Delta W_{\text{net}} = -2.94\%$. All of these results are derived using a simple and transparent model.

The introduction of additional model features or parameters would likely contribute to an even wider range of welfare results. Possibilities include a model version where long-run growth is exogenous or one that allows for more curvature in the within-period utility function. Based on the quantitative results of Ortigueira (1998, Figure 2), both features would be expected to exert a strong impact on the welfare costs of existing distortionary taxes in the baseline economy. Allowing for variation of these model features in the sensitivity analysis would be expected to widen the range of welfare effects from a reform that alters the level and composition of distortionary taxes.

Table 2: Balanced-Growth Properties of Tax Reforms

	i_{gt}/y_t	g_t/y_t	$(i_{gt}+g_t)/y_t$	τ	τ_k	τ_h	ϕ_k	ϕ_h	c_t/y_t	i_{kt}/y_t	i_{ht}/y_t	μ %
U.S. Baseline	0.060	0.150	0.210	0.232	0.160	0.131	0.368	0.500	0.545	0.220	0.025	1.80
Cons. Tax (C_1)	0.094	0.102	0.196	0.277	0	0	1	1	0.513	0.262	0.029	2.15
Cons. Tax (C_2)	0.094	0.150	0.244	0.344	0	0	1	1	0.465	0.262	0.029	2.08
Cons. Tax (C_3)	0.060	0.102	0.162	0.229	0	0	1	1	0.547	0.262	0.029	1.95
Cons. Tax (C_4)	0.060	0.150	0.210	0.296	0	0	1	1	0.499	0.262	0.029	1.90
Flat Tax (F)	0.060	0.150	0.210	0.287	0	0.232	1	0.250	0.506	0.262	0.022	1.86
Income Tax (I)	0.060	0.150	0.210	0.210	0.210	0.210	0	0	0.560	0.207	0.023	1.76

Notes: C_1 = fully optimal reform. i_{gt}/y_t = ratio of public human-capital investment to output, g_t/y_t = ratio of public consumption to output, τ = income tax rate, = τ_k = effective tax re ate for physical-capital investment, τ_h = effective tax rate for human-capital investment, ϕ_k = fraction of tax deductible physical-capital investment, ϕ_h = fraction of tax deductible human-capital investment, c_t/y_t = ratio of private consumption to output, i_{kt}/y_t = ratio of private physical-capital investment to output, i_{ht}/y_t = ratio of private human-capital investment to output, μ = per capita output growth.

Table 3: Transition Paths for Tax Reforms

	Year	$\ln(y_t/y_{t-1})$	k_t/y_t	h_t/k_t	$l_t - e_t$	e_t	w_t/w_0	r_t/r_0	Tobin's q_t/q_0
U.S. Baseline	0	1.80%	2.60	13.0	0.170	0.120	1.00	1.00	1.00
Cons. Tax (C_1)	1	1.08%	2.62	13.0	0.168	0.119	1.00	0.993	1.18
	5	2.32%	2.66	12.7	0.168	0.119	1.01	0.977	1.16
	10	2.29%	2.70	12.3	0.169	0.119	1.02	0.961	1.14
	50	2.17%	2.87	11.2	0.170	0.120	1.06	0.908	1.08
	∞	2.15%	2.91	10.9	0.170	0.120	1.07	0.892	1.06
Cons. Tax (C_2)	1	−0.08%	2.65	13.0	0.165	0.117	1.01	0.981	1.17
	5	2.25%	2.69	12.7	0.165	0.117	1.02	0.966	1.15
	10	2.22%	2.74	12.3	0.166	0.117	1.03	0.950	1.13
	50	2.11%	2.90	11.2	0.167	0.118	1.06	0.896	1.07
	∞	2.08%	2.95	10.9	0.167	0.118	1.07	0.883	1.05
Cons. Tax (C_3)	1	1.84%	2.60	13.0	0.170	0.120	1.00	1.00	1.19
	5	2.19%	2.66	12.5	0.171	0.120	1.01	0.979	1.17
	10	2.15%	2.72	12.1	0.171	0.121	1.03	0.957	1.14
	50	1.99%	2.95	10.5	0.173	0.122	1.07	0.881	1.05
	∞	1.95%	3.01	10.1	0.173	0.122	1.09	0.863	1.03
Cons. Tax (C_4)	1	0.76%	2.63	13.0	0.167	0.118	1.01	0.990	1.18
	5	2.13%	2.69	12.5	0.168	0.118	1.02	0.968	1.15
	10	2.09%	2.75	12.1	0.168	0.119	1.03	0.946	1.13
	50	1.93%	2.98	10.5	0.170	0.120	1.08	0.872	1.04
	∞	1.89%	3.04	10.2	0.170	0.120	1.09	0.854	1.02
Flat Tax (F)	1	0.91%	2.62	13.0	0.168	0.118	1.01	0.991	1.18
	5	2.11%	2.68	12.5	0.168	0.119	1.02	0.969	1.15
	10	2.06%	2.75	12.0	0.169	0.119	1.03	0.946	1.13
	50	1.90%	3.00	10.4	0.170	0.120	1.08	0.868	1.03
	∞	1.86%	3.06	10.0	0.171	0.120	1.10	0.849	1.01
Income Tax (I)	1	2.13%	2.59	13.0	0.171	0.121	0.998	1.00	0.94
	5	1.68%	2.57	13.2	0.171	0.121	0.994	1.01	0.95
	10	1.69%	2.55	13.3	0.171	0.120	0.990	1.02	0.96
	50	1.74%	2.48	14.0	0.170	0.120	0.974	1.05	0.98
	∞	1.76%	2.46	14.1	0.170	0.120	0.970	1.06	0.99

Notes: C_1 = fully optimal reform, $\ln(y_t/y_{t-1})$ = per capita output growth in year t, k_t/y_t = ratio of physical capital stock to output, h_t/k_t = ratio of human to physical capital stocks, $l_t - e_t$ = fraction of time spent working, e_t = fraction of time spent in school/training, w_t/w_0 = before-tax real wage relative to baseline, r_t/r_0 = before-tax rental rate relative to baseline, q_t computed using equation (19).

Table 4: Welfare and Growth Effects of Tax Reforms

	Components of Welfare Change				100-yr. Ave. Growth Rate %	
	Long-Run Level Effect %	Long-Run Growth Effect %	Transition Effect %	ΔW_{net} %	c_t	g_t
Cons. Tax (C_1)	−9.52	22.1	−5.94	6.59	2.12	1.80
Cons. Tax (C_2)	−9.00	17.9	−5.64	3.24	1.95	2.11
Cons. Tax (C_3)	1.70	10.0	−7.98	3.73	2.02	1.64
Cons. Tax (C_4)	2.98	6.16	−7.72	1.43	1.86	1.95
Flat Tax (F)	5.32	3.97	−8.10	1.20	1.85	1.92
Income Tax (I)	−1.23	−2.58	2.47	−1.34	1.77	1.74

Notes: C_1 = fully optimal reform. All simulations start from the balanced growth path of the baseline economy with $k_0 = 1$ and $h_0 = 13$ and run for 1500 periods. The tax reform is implemented at $t = 1$ and maintained until the end of the simulation. ΔW_{net} = net welfare change measured by the constant percentage change in per-period private consumption in the baseline economy that makes the household indifferent to the tax reform. The decomposition of ΔW_{net} is described in the appendix. 100-yr. ave. growth rate = $\log(c_{100}/c_0)/100$ or $\log(g_{100}/g_0)/100$.

Table 5: Sensitivity Analysis

	Initial Calibration						More-Elastic Labor Supply					
	τ	i_{gt}/y_t	g_t/y_t	c_t/y_t	μ %	ΔW_{net} %	τ	i_{gt}/y_t	g_t/y_t	c_t/y_t	μ %	ΔW_{net} %
U.S. Baseline	0.232	0.060	0.150	0.545	1.80	—	0.232	0.060	0.150	0.545	1.80	—
Cons. Tax (C_1)	0.277	0.094	0.102	0.513	2.15	6.59	0.173	0.054	0.069	0.586	2.22	15.8
Cons. Tax (C_2)	0.344	0.094	0.150	0.465	2.08	3.24	0.287	0.054	0.150	0.505	1.90	−0.14
Cons. Tax (C_3)	0.229	0.060	0.102	0.547	1.95	3.73	0.182	0.060	0.069	0.580	2.24	15.7
Cons. Tax (C_4)	0.296	0.060	0.150	0.499	1.90	1.43	0.296	0.060	0.150	0.499	1.92	−0.71
Flat Tax (F)	0.287	0.060	0.150	0.506	1.86	1.20	0.289	0.060	0.150	0.504	1.90	−0.56
Income Tax (I)	0.210	0.060	0.150	0.560	1.76	−1.34	0.210	0.060	0.150	0.560	1.74	−1.10
	Less-Productive Public Investment						**More Utility From Public Consumption**					
	τ	i_{gt}/y_t	g_t/y_t	c_t/y_t	μ %	ΔW_{net} %	τ	i_{gt}/y_t	g_t/y_t	c_t/y_t	μ %	ΔW_{net} %
U.S. Baseline	0.232	0.060	0.150	0.545	1.80	—	0.232	0.060	0.150	0.545	1.80	—
Cons. Tax (C_1)	0.204	0.026	0.118	0.565	1.81	5.27	0.411	0.094	0.198	0.418	2.02	15.7
Cons. Tax (C_2)	0.248	0.026	0.150	0.533	1.78	4.07	0.344	0.094	0.150	0.465	2.08	11.3
Cons. Tax (C_3)	0.252	0.060	0.118	0.531	1.88	1.78	0.363	0.060	0.198	0.452	1.83	11.2
Cons. Tax (C_4)	0.296	0.060	0.150	0.499	1.85	0.07	0.296	0.060	0.150	0.499	1.90	5.59
Flat Tax (F)	0.287	0.060	0.150	0.506	1.82	0.05	0.287	0.060	0.150	0.506	1.86	4.70
Income Tax (I)	0.210	0.060	0.150	0.560	1.77	−0.79	0.210	0.060	0.150	0.560	1.76	−2.94

Notes: C_1 = fully optimal reform. More-elastic labor-supply: $(\gamma - 1)^{-1} = 0.5$. Less-productive public investment: $\delta_g = 0.0014$. More utility from public consumption: $D = 0.837$. All other parameters are recalibrated to match the empirical facts shown in Table 1. τ = income tax rate, i_{gt}/y_t = ratio of public human-capital investment to output, g_t/y_t = ratio of public consumption to output, c_t/y_t = ratio of private consumption to output, μ = per capita output, ΔW_{net} = net welfare change measured by the constant percentage change in per-period private consumption in the baseline economy that makes the household indifferent to the tax reform.

7 Conclusion

Most studies of tax reform do not consider how tax policy might interact with public expenditures to influence welfare and growth. This is because public expenditures are typically assumed to be exogenous variables that are entirely wasteful. In addition to being at odds with a variety of empirical evidence, the idea that public expenditures have no economic value is hard to reconcile with the sheer magnitude of public-sector activity in the U.S. economy.

The objective of this paper was to assess the economic effects of fundamental tax reform using a model that departs from the standard assumption of wasteful public expenditures. We showed that if public expenditures are productive or provide direct utility to households, then a revenue-neutral tax reform will replace one suboptimal policy with another; theory alone cannot tell us if welfare will be improved.

In our model, a fully-optimal reform requires the government to tax private consumption and adjust its spending to achieve the efficient levels of public investment and public consumption relative to output. The reform may call for the size of government to either shrink or expand, depending on parameter values and the existing level of expenditures in the baseline economy. Consumption tax reforms that deviate from the optimal size of government can result in significant foregone welfare gains. Under some calibrations, maintaining the pre-reform size of government can even produce a net welfare loss. More generally, our results demonstrate that the benefits of shifting to a consumption tax are sensitive to assumptions about the post-reform trajectory of public expenditures and the values of some key parameters that influence the optimal size of government. In our view, this represents an important caveat to previous studies that have ignored the useful nature of public expenditures.

The economic consequences of real-world tax reform will of course depend on additional factors that our present model is not equipped to handle. These include the movement away from a graduated-rate tax system (Cassou and Lansing 2004 and Caucutt et al. 2003), the role played by the tax code in providing insurance against income uncertainty (Eaton and Rosen 1980, and Hamilton 1987), and finally, distributional consequences (Altig et al. 2001 and Ventura 1999). That said, our results illustrate the importance of taking into account both sides of the government's budget constraint when assessing the potential welfare benefits of fundamental tax reform.

References

[1] Aaron, H.J. and W.G. Gale (eds.) (1996) *Economic Effects of Fundamental Tax Reform.* (1996). Washington, DC: Brookings Institution Press.

[2] Altig, D., A.J. Auerbach, L.J. Kotlikoff, K.A. Smetters, and J. Walliser. (2001). "Simulating Fundamental Tax Reform in the United States," *American Economic Review*, 91, 574-595.

[3] Amano, R.A. and T.S. Wirjanto. (1998). Government Expenditures and the Permanent-Income Model," *Review of Economic Dynamics,* 1, 719-730

[4] Aschauer, D.A. (1985). "Fiscal Policy and Aggregate Demand," *American Economic Review*, 75, 117-127.

[5] Auerbach, A.J. (1996). "Tax Reform, Capital Accumulation, Efficiency, and Growth," in H.J Aaron and W. G. Gale, eds., *Economic Effects of Fundamental Tax Reform.* Washington D.C.: Brookings Institution Press, pp. 29-73.

[6] Auerbach, A.J. and Laurence J. Kotlikoff. (1987). *Dynamic Fiscal Policy.* Cambridge UK: Cambridge University Press.

[7] Barro, R.J. and X. Sala-i-Martin. (1995). *Economic Growth.* New York: McGraw Hill.

[8] Becker, G.S. (1965). "A Theory of the Allocation of Time," *Economic Journal*, 75, 493-517.

[9] Boskin, M.J. (1977). "Notes on the Tax Treatment of Human Capital," in *Conference on Tax Research 1975.* Washington DC: Office of Tax Analysis, Department of the Treasury, pp. 185-195.

[10] Boskin, M.J. (ed.) (1996) *Frontiers of Tax Reform.* Stanford CA: Hoover Institution Press.

[11] Caucutt, E.M., S. İmrohoroğlu and K.B. Kumar (2003). "Growth and Welfare Analysis of Tax Progressivity in a Heterogenous Agent Model," *Review of Economic Dynamics*, 6, 546-577.

[12] Cassou, S.P. and K.J. Lansing (2004). "Growth Effects of Shifting From a Graduated-Rate Tax System to a Flat Tax," *Economic Inquiry*, 42, 194-213.

[13] Clotfelter, C.T. (1991). "Demand for Undergraduate Education," in C.T. Clotfelter, R.G. Ehrenberg, M. Getz, and J.J. Siegfried, eds., *Economic Challenges in Higher Education.* Chicago: University of Chicago Press, pp. 17-139.

[14] Corsetti, G. and N. Roubini. (1996). "Optimal Government Spending and Taxation in Endogenous Growth Models," National Bureau of Economic Research, Working Paper 5851.

[15] Davies, J.B. and J. Whalley. (1991). "Taxes and Capital Formation: How Important is Human Capital?" in B.D. Bernheim and J.B. Shoven, eds., *National Saving and Economic Performance.* Chicago: University of Chicago Press, pp. 163-197.

[16] Davies, J.B., J. Zeng, and J. Zhang. (2000). "Consumption vs. Income Taxes when Private Human Capital Investments are Imperfectly Observable," *Journal of Public Economics*, 77, 1-28.

[17] Devereux, M.B. and D.R.F. Love. (1994). "The Effects of Factor Taxation in a Two-Sector Model of Endogenous Growth," *Canadian Journal of Economics*, 27, 509-536.

[18] Dupor, B., L. Lochner, C. Taber, and M.B. Wittekind. (1996). "Some Effects of Taxes on Schooling and Training," *American Economics Association Papers and Proceedings*, 86, 340-346.

[19] Eaton, J. and H.S. Rosen. (1980). "Taxation, Human Capital, and Uncertainty," *American Economic Review*, 70, 705-715.

[20] Eberly, J.C. (1997). "International Evidence on Investment Fundamentals," *European Economic Review*, 41, 1055-1078.

[21] Eissa, N. (1996). "Tax Reforms and Labor Supply," in J.M. Poterba. ed., *Tax Policy and the Economy 10.* Cambridge MA: MIT Press, 119-151.

[22] Evans, P. and G. Karras. (1994). "Are Government Activities Productive? Evidence From a Panel of U.S. States," *Review of Economics and Statistics*, 76, 1-11.

[23] Gerson, P. (1998). "The Impact of Fiscal Policy Variables on Output Growth," International Monetary Fund, Working Paper 98/1.

[24] Glomm, G. and B. Ravikumar. (1998). "Flat-Rate Taxes, Government Spending on Education, and Growth," *Review of Economic Dynamics*, 1, 306-325.

[25] Greenwood, J., R. Rogerson, and R. Wright. (1995). "Household Production in Real Business Cycle Theory," in T. F. Cooley, ed., *Frontiers of Business Cycle Research,* Princeton, NJ: Princeton University Press, pp. 157-174.

[26] Grüner, H.P. and B. Heer. (2000). "Optimal Flat-Rate Taxes on Capital: A Reexamination of Lucas' Supply Side Models," *Oxford Economic Papers*, 52, 289-305.

[27] Hall, R.E. and A. Rabushka. (1995). *The Flat Tax, Second Edition.* Stanford, CA: Hoover Institution Press.

[28] Hamilton, J.H. (1987). "Optimal Wage and Income Taxation with Wage Uncertainty," *International Economic Review*, 28, 373-388.

[29] Heckman, J.J. (1976). "A Life-Cycle Model of Earnings, Learning, and Consumption," *Journal of Political Economy,* 84, S11-S44.

[30] Hercowitz, Z. and M. Sampson. (1991). "Output Growth, the Real Wage, and Employment Fluctuations," *American Economic Review,* 81, 1215-1237.

[31] Hoxby, C.M. (1998). "Tax Incentives for Higher Education," in J.M. Poterba. ed., *Tax Policy and the Economy 12.* Cambridge, MA: MIT Press, pp. 49-81.

[32] Joint Committee on Taxation. (1997). *Joint Committee on Taxation Tax Modeling Project and 1997 Tax Symposium Papers*, Series JCS-21-97. Washington DC: Government Printing Office.

[33] Jones, L.E., R. Manuelli, and P.E. Rossi. (1993). "Optimal Taxation in Models of Endogenous Growth," *Journal of Political Economy,* 101, 485-517.

[34] Jones, L.E. and R. Manuelli. (1999). "On the Taxation of Human Capital," Northwestern University and University of Wisconsin, unpublished manuscript.

[35] Jorgenson, D.W. and B.M. Fraumeni. (1989). "The Accumulation of Human and Nonhuman Capital, 1948-84," in R.E. Lipsey and H.S. Tice, eds., *The Measurement of Saving, Investment, and Wealth.* Chicago: University of Chicago Press, pp. 227-282.

[36] Judd, K.L. (1998). "Taxes, Uncertainty, and Human Capital," *American Economics Association Papers and Proceedings*, 88, 289-292.

[37] Judd, K.L. (1999). "Optimal Taxation and Spending in General Competitive Growth Models," *Journal of Public Economics*, 71, 1-26.

[38] Karras, G. (1994). "Government Spending and Private Consumption: Some International Evidence," *Journal of Money, Credit, and Banking*, 26, 9-22.

[39] Kim, J. (2003). "Functional Equivalence Between Intertemporal and Multisectoral Adjustment Costs," *Journal of Economic Dynamics and Control*, 27, 533-549.

[40] Kim, S.-J. (1998). "Growth Effect of Taxes in an Endogenous Growth Model: To What Extent Do Taxes Affect Economic Growth?" *Journal of Economic Dynamics and Control,* 23, 125-158.

[41] King, R.G. and S.T. Rebelo. (1990). "Public Policy and Economic Growth: Developing Neoclassical Implications," *Journal of Political Economy,* 98, S126-S150.

[42] Kydland, F.E. and E.C. Prescott. (1977). "Rules Rather than Discretion: The Inconsistency of Optimal Plans," *Journal of Political Economy*, 85, 473-491.

[43] Laitner, J. (1995). "Quantitative Evaluations of Efficient Tax Policies For Lucas' Supply Side Models," *Oxford Economic Papers*, 47, 471-492.

[44] Lansing, K.J. (1999). "Optimal Redistributive Capital Taxation in a Neoclassical Growth Model," *Journal of Public Economics,* 73, 423-453.

[45] Lucas, R.E., Jr. and Edward C. Prescott. (1971). "Investment Under Uncertainty," *Econometrica,* 39, 659-681.

[46] Lucas, R.E., Jr. (1990). "Supply-Side Economics: An Analytical Review," *Oxford Economic Papers*, 42, 293-316

[47] Mulligan, C.B. (1999). "Substitution Over Time: Another Look at Labor Supply over the Life Cycle," in B.S. Bernanke and J. Rotemberg, eds., *NBER Macroeconomics Annual 1998.* Cambridge MA: MIT Press, pp. 75-134.

[48] National Science Foundation. (1995). *National Patterns of R&D Resources: 1994.* National Science Foundation.

[49] Ortigueira, S. (1998). "Fiscal Policy in an Endogenous Growth Model with Human Capital Accumulation," *Journal of Monetary Economics*, 42, 323-355.

[50] Pecorino, P. (1993). "Tax Structure and Growth in a Model with Human Capital," *Journal of Public Economics*, 52, 251-271.

[51] Pecorino, P. (1994). "The Growth Effects of Tax Reform," *Oxford Economic Papers*, 46, 492-501.

[52] Poterba, J.M. (1988). "Are Consumers Forward Looking? Evidence from Fiscal Experiments," *American Economics Association Papers and Proceedings*, 78, 413-418.

[53] Poterba, J.M. (1997). "The Rate of Return to Corporate Capital and Factor Shares: New Estimates Using Revised National Income Accounts and Capital Stock Data," National Bureau of Economic Research, Working Paper 6263.

[54] Quigley, J.M. and E. Smolensky. (1990). "Improving Efficiency in the Tax Treatment of Training and Educational Expenditures," *Research in Labor Economics*, 11, 77-95.

[55] Ramsey, F.P. (1927). "A Contribution to the Theory of Taxation," *Economic Journal*, 37, 47-61.

[56] Stern, N. (1992). "From the Static to the Dynamic: Some Problems in the Theory of Taxation," *Journal of Public Economics*, 47, 273-297.

[57] Steuerle, C.E. (1996). "How Should Government Allocate Subsidies for Human Capital?" *American Economics Association Papers and Proceedings*, 86, 353-357.

[58] Stokey, N.L. and S. Rebelo. (1995). "Growth Effects of Flat-Rate Taxes," *Journal of Political Economy*, 103, 519-551.

[59] Trostel, P.A. (1993). "The Effect of Taxation on Human Capital," *Journal of Political Economy*, 101, 327-350.

[60] U.S. Bureau of Economic Analysis. (1998). "Fixed Reproducible Tangible Wealth in the United States: Revised Estimates for 1925-1997," *Survey of Current Business*, 78 (September), 36-36.

[61] U.S. Congressional Budget Office. (1997). *The Economic Effects of Comprehensive Tax Reform.* Washington DC: Government Printing Office.

[62] Ventura, G. (1999). "Flat Tax Reform: A Quantitative Exploration," *Journal of Economic Dynamics and Control*, 23, 1425-1458.

[63] Watanabe, K., T. Watababe, and T. Watanabe. (2001). "Tax Policy and Consumer Spending: Evidence from Japanese Fiscal Experiments," *Journal of International Economics*, 53, 261-281.

[64] Weidenbaum, M. (1996). "The Nunn-Domenici USA Tax: Analysis and Comparisons," in M. Boskin ed., *Frontiers of Tax Reform.* Stanford CA: Hoover Institution Press, pp. 54-69.

[65] Xie, D. (1997). "On Time Inconsistency: A Technical Issue in Stackelberg Dynamic Games," *Journal of Economic Theory*, 76, 412-430.

Fig 1: Response of Private Consumption to Tax Reforms

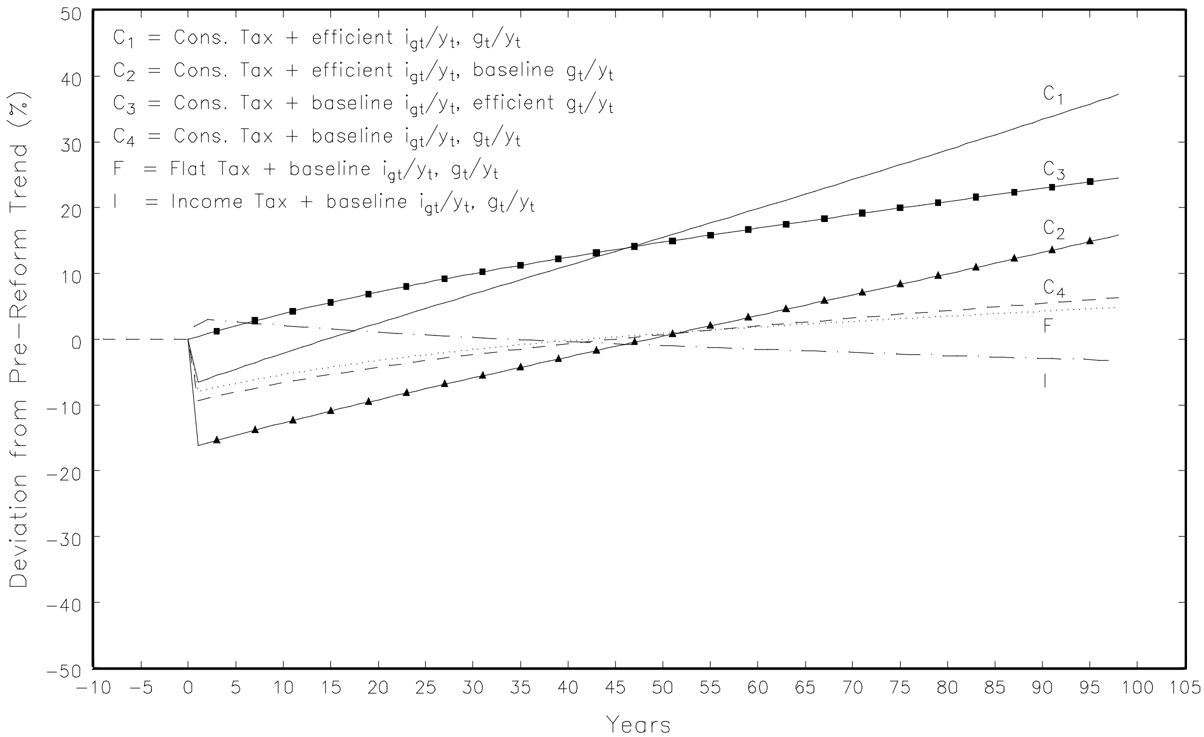


Fig 2: Response of Public Consumption to Tax Reforms

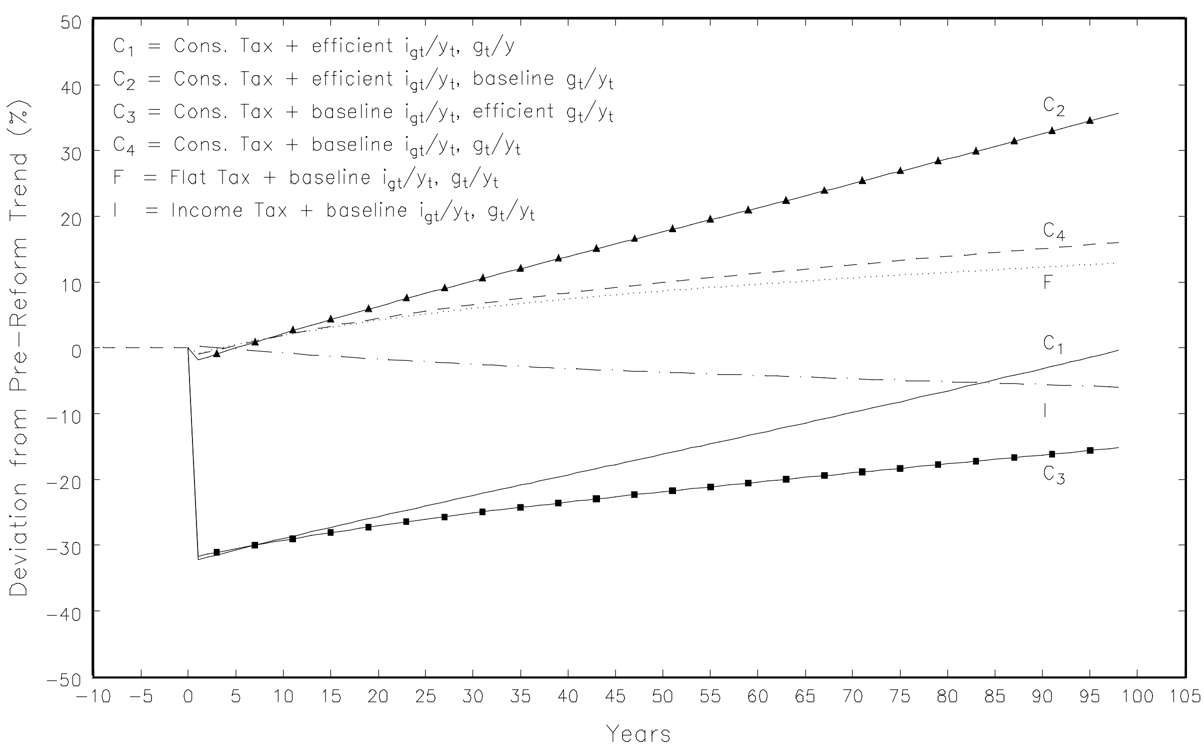


Fig 3: Optimal Size of Government vs Labor Supply Elasticity

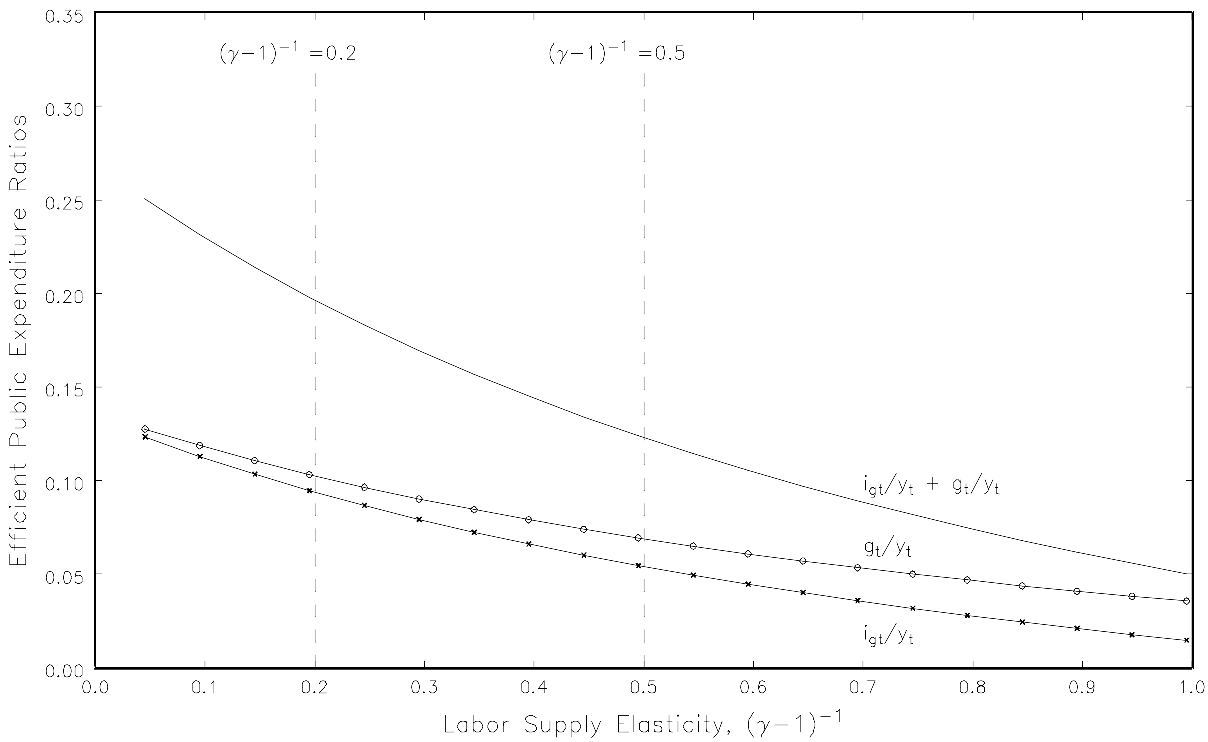


Fig 4: Optimal Size of Government vs Production Elasticity for Public Investment

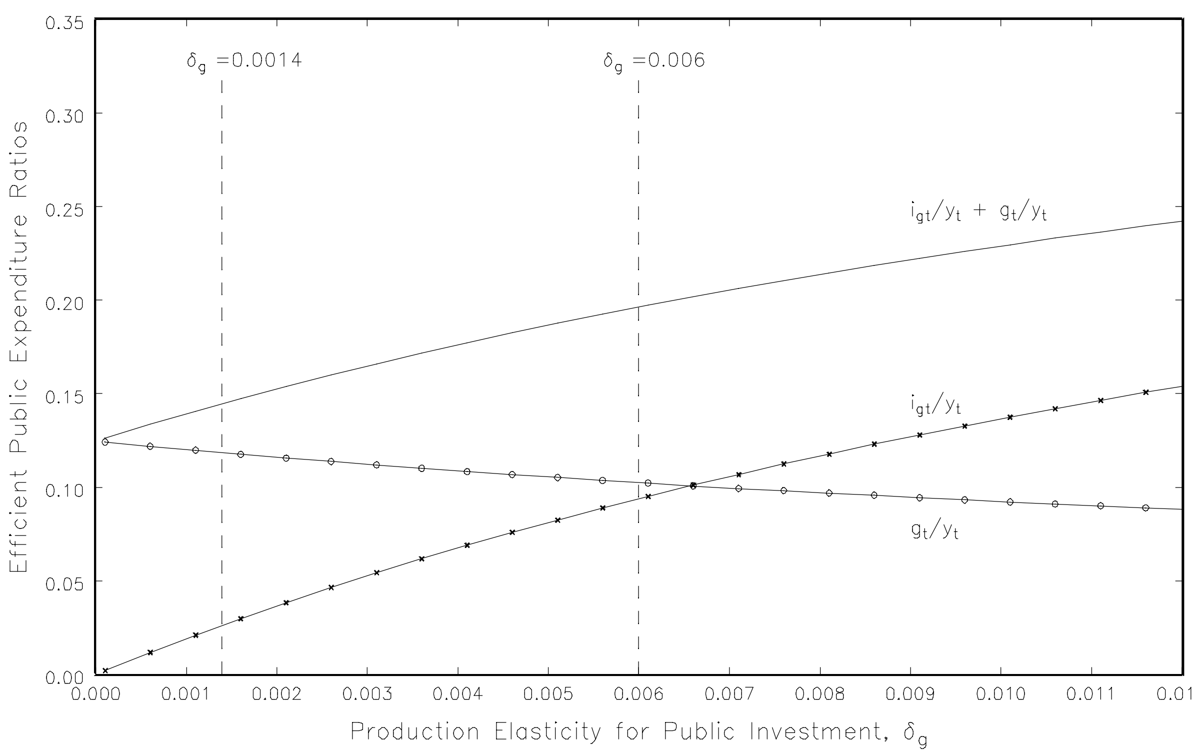
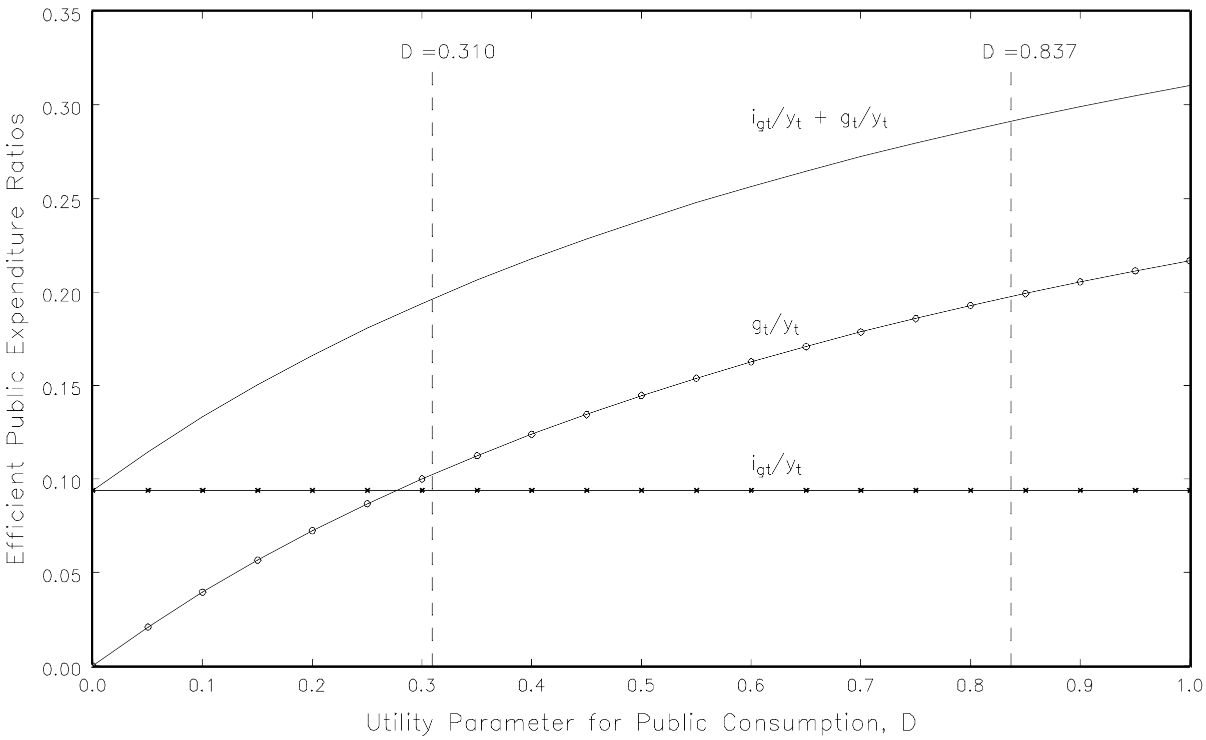


Fig 5: Optimal Size of Government vs Utility Parameter for Public Consumption



A Technical Appendix

This appendix provides details of the model solution and welfare computations presented in "Tax Reform with Useful Public Expenditures," *Journal of Public Economic Theory*, forthcoming, by Stephen P. Cassou and Kevin J. Lansing.

A.1 Household Decision Rules

The section derives the equilibrium decision rules for the representative household. The household takes factor prices and fiscal policy variables as given. By solving equations (4) and (5) for i_{kt} and i_{ht} and substituting these expressions into equation (3), we obtain the following household first-order conditions with respect to the indicated variables:

$$k_{t+1} \; : \; \lambda_t \frac{(1-\phi_{kt}\tau_t)i_{kt}}{\delta_k k_{t+1}} = \beta\lambda_{t+1}\left[(1-\tau_{t+1})\,r_{t+1} + \frac{(1-\phi_{kt+1}\tau_{t+1})(1-\delta_k)i_{kt+1}}{\delta_k k_{t+1}}\right], \quad \text{(A.1a)}$$

$$h_{t+1} \; : \; \lambda_t \frac{(1-\phi_{ht}\tau_t)i_{ht}}{\delta_h h_{t+1}} = \frac{-\beta B l_{t+1}^{\gamma}}{c_{t+1} - B h_{t+1} l_{t+1}^{\gamma}} +$$

$$\beta\lambda_{t+1}\left[(1-\tau_{t+1})\,w_{t+1}(l_{t+1}-e_{t+1}) + \frac{(1-\phi_{ht+1}\tau_{t+1})(1-\delta_h-\delta_g)i_{ht+1}}{\delta_h h_{t+1}}\right], \quad \text{(A.1b)}$$

$$c_t \; : \; \lambda_t = \frac{1}{c_t - B h_t l_t^{\gamma}}, \quad \text{(A.1c)}$$

$$l_t \; : \; \lambda_t\,(1-\tau_t)\,w_t h_t = \frac{B\gamma h_t l_t^{\gamma-1}}{c_t - B h_t l_t^{\gamma}}, \quad \text{(A.1d)}$$

$$e_t \; : \; (1-\tau_t)\,w_t h_t = (1-\phi_{ht}\tau_t)\frac{\nu}{\delta_h}\frac{i_{ht}}{e_t}, \quad \text{(A.1e)}$$

where λ_t is the Lagrange multiplier associated with the budget constraint (3). The transversality conditions are $\lim_{t\to\infty} \beta^t \lambda_t k_{t+1} = 0$ and $\lim_{t\to\infty} \beta^t \lambda_t h_{t+1} = 0$. The first term on the right side of equation (A.1b) shows that households take into account the influence of human capital on the amount of "quality adjusted" leisure. In particular, higher levels of human capital will raise the opportunity cost of time which is not devoted to leisure.

The household decision rules are obtained using the method of undetermined coefficients. First, we make the conjecture that decision rules take the form:

$$i_{kt} = a_0\left(\frac{1-\tau_t}{1-\phi_{kt}\tau_t}\right)y_t, \quad \text{(A.2)}$$

$$i_{ht} = b_0\left(\frac{1-\tau_t}{1-\phi_{ht}\tau_t}\right)y_t, \quad \text{(A.3)}$$

$$\lambda_t^{-1} = d_0\,(1-\tau_t)\,y_t, \quad \text{(A.4)}$$

$$(l_t - e_t) = f_0 l_t \quad \text{(A.5)}$$

where a_0, b_0, d_0, and f_0 are constants to be determined and y_t is equilibrium per capita output. By substituting the conjectured decision rules and the profit maximization conditions (8a) and (8b) into the first-order conditions for k_{t+1} and h_{t+1}, and also making use of equations (A.1c) and (A.1d), we obtain

$$a_0 = \frac{\theta\delta_k}{\rho+\delta_k}, \tag{A.6}$$

$$b_0 = \frac{(1-\theta)\delta_h}{\rho+\delta_h+\delta_g}\left(1-\frac{1}{\gamma f_0}\right), \tag{A.7}$$

where $\rho \equiv 1/\beta - 1$ is the household's rate of time preference. The coefficients a_0 and b_0 can be interpreted as marginal propensities to save out of after-tax income.

Substituting the expression for w_t from equation (8b) into the first order condition (A.1e), and then making use of equations (A.3), (A.5), and (A.7) yields

$$f_0 = \frac{\rho+\delta_h+\delta_g+\nu/\gamma}{\rho+\delta_h+\delta_g+\nu}. \tag{A.8}$$

Substituting equation (A.8) back into equation (A.7) and solving for b_0 yields

$$b_0 = \frac{(1-\theta)\delta_h}{\rho+\delta_h+\delta_g+\nu/\gamma}\left(\frac{\gamma-1}{\gamma}\right). \tag{A.9}$$

A convenient property of the utility function (1) is that l_t can be solved for independently of the marginal utility of income λ_t. Substituting the expression for w_t from equation (8b) into the first order condition for l_t and then making use of equations (A.1c), (A.5), and (A.8) yields

$$l_t = \left\{\frac{A_0(1-\theta)}{B\gamma}\left[1+\frac{\nu}{\rho+\delta_h+\delta_g+\nu/\gamma}\left(\frac{\gamma-1}{\gamma}\right)\right]^{\theta}(1-\tau_t)\left(\frac{h_t}{k_t}\right)^{-\theta}\right\}^{\frac{1}{\theta+\gamma-1}}. \tag{A.10}$$

Equation (A.10) can now be used to solve for $(l_t - e_t)$ and e_t using the conjectured relationships $(l_t - e_t) = f_0 l_t$ and $e_t = \left(f_0^{-1}-1\right)(l_t - e_t)$. The results are

$$(l_t - e_t) = A_3\left[(1-\tau_t)\left(\frac{h_t}{k_t}\right)^{-\theta}\right]^{\frac{1}{\theta+\gamma-1}}, \; A_3 \equiv \left\{\frac{A_0(1-\theta)}{B\gamma}\left[1+\frac{\nu}{\rho+\delta_h+\delta_g+\nu/\gamma}\left(\frac{\gamma-1}{\gamma}\right)\right]^{1-\gamma}\right\}^{\frac{1}{\theta+\gamma-1}} \tag{A.11}$$

$$e_t = A_3A_4\left[(1-\tau_t)\left(\frac{h_t}{k_t}\right)^{-\theta}\right]^{\frac{1}{\theta+\gamma-1}}, \; A_4 \equiv \frac{\nu}{\rho+\delta_h+\delta_g+\nu/\gamma}\left(\frac{\gamma-1}{\gamma}\right). \tag{A.12}$$

The next step is to verify that the conjectured forms of equations (A.2)-(A.5) are correct by showing that d_0 is in fact constant. We use the first order condition for c_t to obtain

$$\begin{aligned} c_t &= \underbrace{d_0(1-\tau_t)\,y_t}_{\lambda_t^{-1}} + Bh_t l_t^{\gamma}, \\ &= d_0(1-\tau_t)\,y_t + \frac{1-\theta}{\gamma f_0}(1-\tau_t)\,y_t, \end{aligned} \tag{A.13}$$

where the second equality replaces $Bh_t l_t^{\gamma}$ by an equivalent expression that is obtained by combining equations (A.1c) and (A.1d). Substituting equation (A.13), together with the conjectured decision rules (A.2) and (A.3) into the household budget constraint (3) yields

$$d_0 \;=\; 1 - a_0 - b_0 - \frac{1-\theta}{\gamma f_0}, \tag{A.14}$$

which is a constant and thus verifies our conjecture. Finally, substituting the above expression for d_0 back into equation (A.13) yields

$$c_t \;=\; (1 - a_0 - b_0)\,(1 - \tau_t)\, y_t, \tag{A.15}$$

where $(1 - a_0 - b_0)$ can be interpreted as the household's marginal propensity to consume out of after-tax income.

To derive an expression for the balanced growth ratio $R = h_t/k_t$, we consider an environment where $\tau_{kt} = \tau_k$, $\tau_{ht} = \tau_h$, $\tau_t = \tau$, $i_{gt}/y_t = \psi_{ig} > 0$, and $g_t/y_t = \psi_g > 0$. Variables without time subscripts represent constants for all t. Dividing equation (12) by equation (11) and imposing $R = h_{t+1}/k_{t+1} = h_t/k_t$ yields

$$R = \frac{h_t}{k_t} = \left\{ \frac{A_2\,(A_3 A_4)^{\nu}\,[b_0\,(1-\tau_h)]^{\delta_h} \left[A_0 A_3^{1-\theta}\,(1-\tau)^{\frac{1-\theta+\nu/(\delta_h+\delta_g)}{\theta+\gamma-1}}\right]^{\delta_h+\delta_g} \psi_{ig}^{\delta_g}}{A_1 \left[a_0 A_0 A_3^{1-\theta}\,(1-\tau_k)\,(1-\tau)^{\frac{1-\theta}{\theta+\gamma-1}}\right]^{\delta_k}} \right\}^{\frac{\theta+\gamma-1}{(1-\theta)(\gamma-1)\delta_k+\theta\gamma(\delta_h+\delta_g+\nu/\gamma)}} \tag{A.16}$$

A.2 Proof of Proposition 1 (Optimal Fiscal Policy)

The objective function in (C_1) is obtained by substituting $c_t - Bh_t l_t^{\gamma} = d_0\,(1-\tau_t)\,y_t$ from equation (A.13) into the household utility function (1) to eliminate c_t and l_t. The government budget constraint in (C_1) is obtained as follows. First, we use the investment decision rules (9a) and (9b) to eliminate ϕ_{kt} and ϕ_{ht} from equation (15) yielding:

$$i_{gt} + g_t = y_t\,[a_0 + b_0 + \tau_t\,(1 - a_0 - b_0)] - i_{kt} - i_{ht}. \tag{A.17}$$

Next, we eliminate i_{kt} and i_{ht} from equation (A.17) using the laws of motion (4) and (5) and then eliminate e_t from the resulting expression using the decision rule (9e). To solve (C_1), we first eliminate y_t by substituting equation (10) into the objective function and the government budget constraint. The government's first-order conditions with respect to the indicated variables are given by:

$$\tau_t \;:\; \frac{-\gamma}{(\theta+\gamma-1)\,(1-\tau_t)} + \lambda_{gt}\left\{(1-a_0-b_0)\,y_t - [a_0+b_0+\tau_t\,(1-a_0-b_0)]\,\frac{(1-\theta)\,y_t}{(\theta+\gamma-1)\,(1-\tau_t)} - \frac{-\nu\, i_{ht}}{\delta_h\,(\theta+\gamma-1)\,(1-\tau_t)}\right\} \;=\; 0, \tag{A.18a}$$

$$i_{gt} \;:\; -1 + \frac{\delta_g}{\delta_h}\frac{i_{ht}}{i_{gt}} \;=\; 0, \tag{A.18b}$$

$$g_t \quad : \quad \frac{D}{g_t} - \lambda_{gt} \;=\; 0, \tag{A.18c}$$

$$\begin{aligned} k_{t+1} \quad : \quad & \frac{\beta\theta\gamma}{(\theta+\gamma-1)\,k_{t+1}} - \lambda_{gt}\left(\frac{i_{kt}}{\delta_k k_{t+1}}\right) + \beta\lambda_{gt+1}\left\{[a_0+b_0+\tau_{t+1}(1-a_0-b_0)]\,\frac{\theta\gamma\, y_{t+1}}{(\theta+\gamma-1)\,k_{t+1}}\right. \\ & \left. + \frac{(1-\delta_k)\,i_{kt+1}}{\delta_k k_{t+1}} + \frac{\theta\nu\, i_{ht+1}}{\delta_h(\theta+\gamma-1)\,k_{t+1}}\right\} \;=\; 0, \end{aligned} \tag{A.18d}$$

$$\begin{aligned} h_{t+1} \quad : \quad & \frac{\beta(1-\theta)(\gamma-1)}{(\theta+\gamma-1)\,h_{t+1}} - \lambda_{gt}\left(\frac{i_{ht}}{\delta_h h_{t+1}}\right) + \beta\lambda_{gt+1}\left\{[a_0+b_0+\tau_{t+1}(1-a_0-b_0)]\,\frac{(1-\theta)(\gamma-1)\; y_{t+1}}{(\theta+\gamma-1)\,h_{t+1}}\right. \\ & \left. + \frac{(1-\delta_h-\delta_g)\,i_{ht+1}}{\delta_h h_{t+1}} - \frac{\theta\nu\, i_{ht+1}}{\delta_h(\theta+\gamma-1)\,h_{t+1}}\right\} \;=\; 0, \end{aligned} \tag{A.18e}$$

for all $t \geq 0$, where λ_{gt} is the Lagrange multiplier associated with the government budget constraint.

The optimal policy rules are obtained by the method of undetermined coefficients. First, we note that (A.18b) implies $i_{gt} = (\delta_h/\delta_g)\,i_{ht}$ for all $t \geq 0$. Next, we conjecture that the remaining policy rules take the form

$$i_{kt} \;=\; a_1 y_t, \tag{A.19}$$

$$i_{ht} \;=\; b_1 y_t, \tag{A.20}$$

$$\lambda_{gt}^{-1} \;=\; d_1 y_t, \tag{A.21}$$

$$g_t \;=\; f_1 y_t, \tag{A.22}$$

$$\tau_t \;=\; \tau, \tag{A.23}$$

for all $t \geq 0$, where a_1, b_1, d_1, f_1, and τ are constants to be determined and y_t is per capita output. Substituting the conjectured policy rules into equations (A.18a), (A.18c), (A.18d), (A.18e), and (A.17) and then rearranging yields the following system of five linear equations in the five unknown constants:

$$\frac{(1-\theta)}{\gamma} \;-\; (1-a_0-b_0) \;=\; -\frac{\nu}{\gamma\delta_h}b_1 \;-\; d_1 \;-\; \tau\,(1-a_0-b_0)\,, \tag{A.24a}$$

$$\frac{D}{f_1} \;=\; \frac{1}{d_1}, \tag{A.24b}$$

$$a_0+b_0 \;=\; \frac{(\theta+\gamma-1)\,(\rho+\delta_k)}{\theta\gamma\delta_k}\,a_1 \;-\; \frac{\nu}{\gamma\delta_h}b_1 \;-\; d_1 \;-\; \tau\,(1-a_0-b_0)\,, \tag{A.24c}$$

$$a_0+b_0 \;=\; \frac{[(\theta+\gamma-1)\,(\rho+\delta_h+\delta_g)+\theta\nu]}{(1-\theta)\,(\gamma-1)\,\delta_h}\,b_1 - \; d_1 - \; \tau\,(1-a_0-b_0)\,, \tag{A.24d}$$

$$\frac{\delta_g}{\delta_h}b_1 \;+\; f_1 \;=\; a_0+b_0 \;+\; \tau\,(1-a_0-b_0) - a_1 \;-\; b_1. \tag{A.24e}$$

The linearity of the above system guarantees a unique solution to the government's first-order necessary conditions. Straightforward algebra yields

$$a_1 = a_0, \tag{A.25}$$

$$b_1 = b_0, \tag{A.26}$$

$$d_1 = \frac{1}{1+D}\left[1 - a_0 - b_0\left(1 + \frac{\delta_g}{\delta_h} + \frac{\nu}{\delta_h \gamma}\right) - \frac{(1-\theta)}{\gamma}\right], \tag{A.27}$$

$$f_1 = D d_1, \tag{A.28}$$

$$\tau = \frac{(\delta_g/\delta_h)\, b_0 + f_1}{1 - a_0 - b_0}, \tag{A.29}$$

Since $i_{kt} = a_1 y_t = a_0 (1 - \tau_{kt})\, y_t$, equation (A.25) implies $\tau_{kt} = 0$ or equivalently, $\phi_{kt} = 1$. Similarly, equation (A.26) implies $\tau_{ht} = 0$ or equivalently, $\phi_{ht} = 1$.

A.3 Welfare Computations

This section describes our procedure for computing the welfare results shown in Table 4. By making use of equations (A.13) and (A.15), lifetime utility in the baseline economy can be written as

$$V_{\text{baseline}} = \sum_{t=0}^{\infty} \beta^t \left\{ \log\left[\left(\tfrac{d_0}{1-a_0-b_0}\right) c_t\right] + D \log(g_t) \right\}. \tag{A.30}$$

We wish to determine the constant percentage amount by which c_t must be increased in the baseline economy, with $\{g_t\}_{t=0}^{\infty}$ unchanged, in order to bring lifetime utility up to V_{reform}. Hence, we solve for x such that

$$\begin{aligned} V_{\text{reform}} &= \sum_{t=0}^{\infty} \beta^t \left\{ \log\left[\left(\tfrac{d_0}{1-a_0-b_0}\right) c_t\,(1+x)\right] + D \log(g_t) \right\}. \\ &= V_{\text{baseline}} + \frac{\log(1+x)}{1-\beta}, \end{aligned} \tag{A.31}$$

which implies $x = \exp\left[(V_{\text{reform}} - V_{\text{baseline}})(1-\beta)\right] - 1$ and $\Delta W_{\text{net}} = 100x$. For the simulations, we use 1500 periods to approximate the infinite horizon.

To facilitate a decomposition of ΔW_{net} into its constituent parts, we use equations (A.13) and (10) to obtain the following alternative expression for lifetime utility:

$$\begin{aligned} V &= \sum_{t=0}^{\infty} \beta^t \left\{ \log\left[d_0 (1-\tau_t)\, y_t\right] + D \log(g_t) \right\}, \\ &= \sum_{t=0}^{\infty} \beta^t \left\{ \log\left[d_0 (1-\tau_t)\, y_t\right] + D \log(y_t) + D \log(g_t/y_t) \right\}, \\ &= \sum_{t=0}^{\infty} \beta^t \left\{ \log\left[d_0 \left(A_0 A_3^{1-\theta}\right)^{1+D}\right] + \log\left[(h_t/k_t)^{\frac{-\theta\gamma(1+D)}{\theta+\gamma-1}} (1-\tau_t)^{\frac{\gamma+D(1-\theta)}{\theta+\gamma-1}} (g_t/y_t)^D\right] + \log\left[h_t^{1+D}\right] \right\}, \end{aligned} \tag{A.32}$$

If the economy initially starts off on its balanced growth path, then h_t/k_t, τ_t, and g_t/y_t must be constant (see Definition 1) and we can write $h_t = h_0 e^{\mu t}$, where μ is the balanced growth rate given by equation (13) or (14). With these restrictions, equation (A.32) can be used to obtain the following expression for "steady-state" lifetime utility:

$$\bar{V} = \frac{\log\left[d_0\left(A_0 A_3^{1-\theta} h_0\right)^{1+D}\right]}{1-\beta} + \underbrace{\frac{\log\left[(h/k)^{\frac{-\theta\gamma(1+D)}{\theta+\gamma-1}}(1-\tau)^{\frac{\gamma+D(1-\theta)}{\theta+\gamma-1}}(g/y)^{D}\right]}{(1-\beta)}}_{\text{Long-Run Level Effect}} + \underbrace{\frac{\mu(1+D)\beta}{(1-\beta)^2}}_{\text{Long-Run Growth Effect}} \tag{A.33}$$

where we drop the time subscripts from h/k and g/y because these ratios are constant in the long-run. Equation (A.33) shows that the long-run level effect is linked directly to the values of h/k, τ, and g/y, whereas the long-run growth effect is linked directly to the balanced growth rate μ.

To compute the steady-state welfare change (which ignores transition dynamics), we imagine an instantaneous jump from the baseline values of h/k, τ, g/y, and μ to those implied by the reform, holding h_0 constant. Implicitly, we are treating k_t as a jump variable for this computation. The change in steady-state welfare is defined as

$$\Delta W_{\text{ss}} = 100\left\{\exp\left[\left(\bar{V}_{\text{reform}} - \bar{V}_{\text{baseline}}\right)(1-\beta)\right] - 1\right\}, \tag{A.34}$$

where $\bar{V}_{\text{reform}}$ and $\bar{V}_{\text{baseline}}$ are computed using equation (A.33). We can further decompose ΔW_{ss} into two parts attributable to each of the two terms in equation (A.33) that we label as the long-run level effect and the long-run growth effect. Specifically, we solve for x_1 and x_2 such that

$$\begin{aligned} 1 + x_1 + x_2 &= 1 + \Delta W_{\text{ss}}/100, \\ &= \exp\left[\Delta\bar{V}_{\text{ss}}(1-\beta)\right], \\ &= \exp\left[\Delta\bar{V}_1(1-\beta)\right] \times \exp\left[\Delta\bar{V}_2(1-\beta)\right], \\ &= (1+a)\times(1+b), \\ &= 1 + a + b + ab, \end{aligned} \tag{A.35}$$

where $\Delta\bar{V}_{\text{ss}} = \bar{V}_{\text{reform}} - \bar{V}_{\text{baseline}} = \Delta\bar{V}_1 + \Delta\bar{V}_2$ and we define $a \equiv \exp\left[\Delta\bar{V}_1(1-\beta)\right] - 1$ and $b \equiv \exp\left[\Delta\bar{V}_2(1-\beta)\right] - 1$. A reasonable (although not unique) solution to this decomposition problem is $x_1 = a + ab\left\{|a|/(|a|+|b|)\right\}$ and $x_2 = b + ab\left\{|b|/(|a|+|b|)\right\}$. Given ΔW_{net} (computed from the numerical simulation) and ΔW_{ss} (computed above), we define the transition effect as the residual: $\Delta W_{\text{transition}} = \Delta W_{\text{net}} - \Delta W_{\text{ss}}$.