CHAPTER 11

Dynamic Overlapping Generations Computable General Equilibrium Models and the Analysis of Tax Policy: The Diamond–Zodrow Model

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Abstract

We examine the use of dynamic overlapping generations (OLG) computable general equilibrium (CGE) models to analyze the economic effects of tax reforms, using as a paradigm our Diamond–Zodrow (DZ) model. Such models are especially well-suited to analyzing both the short-run transitional and the long-run dynamic macroeconomic effects of tax reforms, including the time paths of reform-induced changes in labor supply, saving, and investment, as well as the redistributional effects of reforms across and within generations. We begin with a brief overview of the use of OLG-CGE models in the analysis of tax reform, focusing on the seminal contribution of Auerbach and Kotlikoff (1987). We then consider a variety of extensions of this work, including the multiple-good, multiple-individual model constructed by Fullerton and Rogers (1993), as well as the addition of open economy factors, human capital accumulation and uncertainty. Many of the applications of these models have focused on changes in capital income taxation or, more generally, the replacement of an income tax system that fully taxes capital income with a consumption-based tax system that exempts normal returns to capital, and we focus on such reforms. We describe in considerable detail the DZ model, which is characterized by 55 cohorts, 12 income groups within each cohort, four production sectors and explicit calculation of reform-induced changes in asset values. We conclude by describing numerous applications of the DZ model, ranging from incremental reforms of the income tax system including deficit-financed tax cuts to 'fundamental tax reforms' that involve replacing the income tax with a consumption-based tax system, to the implementation of a value-added tax imposed in addition to the income tax as a means of reducing current deficits and the national debt in the US.

Keywords

Computable general equilibrium, overlapping generations, dynamic modeling, tax reform simulation, incidence analysis, redistributive effects of tax reform, macroeconomic modeling

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11.1 INTRODUCTION

The use of computable general equilibrium (CGE) models to analyze the effects of changes in economic policy has become widespread, as vividly demonstrated by the wide range of applications discussed in this Handbook. In this chapter, we focus on the use of dynamic overlapping generations (OLG) life-cycle CGE models to analyze the economic effects of tax reforms. Such models are characterized by a large number of adult cohorts and sometimes also have multiple types of individuals with varying lifetime incomes within each cohort. These models are especially well-suited to analyzing both the short-run transitional and the long-run dynamic macroeconomic effects of tax reforms, especially the time paths of reform-induced changes in labor supply, saving and investment, as well as the redistributional effects of reforms, including the changes in the prices of existing assets, across and within generations. The analysis of the effects of such behavioral responses and all of their complex interactions in a completely specified general equilibrium framework distinguishes the OLG-CGE approach from the alternative 'static' or 'microsimulation' approach that distributes the effects of tax reforms without taking into account such responses.[1] We examine both the structure of OLG-CGE models and their applications to analyzing tax reforms in this chapter, using as a paradigm a model that we have constructed, the Diamond–Zodrow (DZ) model.

The chapter is organized as follows. In the next section, we provide a brief overview of the use of OLG-CGE models in the analysis of tax reform, focusing on the seminal contribution of Auerbach and Kotlikoff (1987) who, following the path breaking work of Summers (1981), constructed a dynamic OLG-CGE model that has spawned a vast literature. We also consider a variety of subsequent extensions of this work, including the multiple-good, multiple-individual model constructed by Fullerton and Rogers (1993), and many other extensions including the addition of open economy factors, human capital accumulation, uncertainty, and age-dependent taxes.[2] Many of the applications of these models have focused on the effects of changes in capital income taxation or, more generally, the replacement of an income tax system that fully taxes capital income with a consumption-based tax system that exempts normal returns to capital and we focus on such reforms in our review of this literature. In Section 11.3, we describe the DZ model, which is characterized by 55 cohorts, 12 income groups within each cohort and four production sectors (a corporate and a non-corporate composite non-housing consumption good, and owner-occupied and rental residential housing), and explicit

1 On the other hand, the microsimulation approach is able to model the tax system in much more detail than the stylized approach used in OLG-CGE models. For further elaboration, see the discussions of 'dynamic scoring' of tax reforms by Auerbach (2005) and Altshuler *et al*. (2005).

2 We focus on the historical development of OLG-CGE models, especially models that significantly extended the model of Auerbach and Kotlikoff; for a complementary literature review, see Fehr *et al*. in Chapter 27 of this Handbook, which focuses on recent extensions that emphasize demographic changes in an international context, endogenous retirement decisions, and uncertainty.

calculation of reform-induced changes in all asset values. We then describe several applications of the DZ model in Section 11.4.[3] Finally, Section 11.5 offers some conclusions.

11.2 BRIEF HISTORY OF OLG-CGE MODELING OF TAX REFORM

11.2.1 Early (non-OLG) models

Most discussions of general equilibrium tax incidence models begin with the celebrated contribution of Harberger (1962) — although some antecedents are in Musgrave (1953, 1959). Harberger constructed a two-sector model to analyze the incidence of the corporate income tax, but assumed a static framework in which aggregate supplies of labor and capital were fixed, although both factors were mobile across the production sectors. Within this context, he showed that the corporate income tax tended to be borne entirely by all owners of the taxed factor, as capital migrated from the taxed corporate sector to the untaxed non-corporate sector, depressing the overall return to capital. Although this result was based on a differential analysis and thus strictly applicable to only small tax increases, Shoven and Whalley (1972) constructed the first CGE analog to the Harberger model and confirmed his result for large tax changes.

The Harberger model is an excellent tool to study issues related to tax-induced reallocations of fixed total supplies of capital and labor, but it ignores the central question of the effects of tax-induced reductions on the rate of return to capital on saving and investment behavior and thus on capital accumulation. Early studies of this issue simply added taxes to the neoclassical growth model, with saving a function of income and perhaps the rate of return to capital. In these models, capital income taxation reduces saving, which in turn lowers the equilibrium capital—labor ratio; as a result, labor productivity falls and wages decline, implying that the tax has been at least partially shifted from capital to labor, typically by about one-third to one-half (Krzyzaniak, 1967; Feldstein, 1974; Mankiw and Weinzierl, 2005).

The extension to a variable capital stock — and to multiple consumption and production goods — was also examined in the CGE literature by Ballard *et al.* (1985), who assumed that individual utility was a function of current consumption and a composite good that captured all future consumption; this model also implied that saving was a function of the after-tax rate of return to capital, so that capital income taxes were partially or fully shifted to labor. This approach was a precursor to the more formal models of saving behavior in which individuals are effectively infinitely-lived

[3] As will be described in detail below, these applications often use somewhat different versions of the DZ model, reflecting both the evolution over time of the model and extensions that were added to address specific issues that were the focus of a particular analysis. The simulation results in the various applications are thus not strictly comparable.

that are analyzed in Chapter 8 by Jorgenson and Yun as well as many others in this Handbook.

By comparison, in this chapter we focus on analyses in which individual behavior with respect to saving and labor supply follows a many-period life-cycle model, supplemented with a bequest motive. In a typical version of the model, the economy is characterized by many overlapping generations that are alive at any given point in time, so that the effects of tax reforms can be determined in the aggregate and then distributed both across and within generations — results that cannot be captured when individuals are infinitely-lived.

11.2.2 Summers OLG Model

The use of the OLG model to analyze tax reforms was pioneered by Summers (1981) who analyzes the replacement of an income tax with two different forms of consumption-based taxation — an expenditure tax and a wage tax — using a continuous-time, single-good OLG model characterized by life-cycle savers with fixed labor supply and myopic expectations. Summers, following Hall (1968), stresses that a many-period approach, rather than the traditional two-period life-cycle model with labor earnings occurring only in the first period, is essential to modeling life-cycle effects accurately because only the former approach captures the fact that an increase in the tax rate on capital income reduces the after-tax discount rate individuals use in estimating their human wealth when making consumption and savings decisions. The resulting increase in human wealth prompts greater consumption early in life, i.e. less saving.

The simulations reported by Summers suggest that this human wealth effect results in large reductions in savings (savings elasticities with respect to the after-tax rate of return on the order of 1—3), which in turn implies that the enactment of a consumption tax reform results in large steady-state welfare gains. For example, in one central case, the enactment of a cash flow consumption tax results in a steady-state welfare gain equal to 11.2% of lifetime income. The enactment of a wage tax in the Summers model also increases steady-state welfare, but to a significantly smaller extent (7.0% of lifetime income) since existing capital is not subject to tax. This highlights the often-noted point that a significant fraction of the efficiency gains obtained from a consumption tax reform may be attributable to a one-time reduction in the value of existing capital; moreover, this 'capital levy' primarily affects the elderly generations alive at the time of enactment since they own the vast majority of existing capital — an effect that can only be captured in life-cycle OLG models.

The Summers dynamic OLG model sparked a great deal of interest. Much of the subsequent research focused on the extent to which its savings responses are sensitive to various choices about model structure, especially the treatment of bequests and parameter values (Evans, 1983; Starrett, 1988), and appear to be implausibly large, given the empirical literature (Ballard, 1990, 2002; Gravelle, 2002). In addition, Summers assumes an inelastic labor supply and wages that increase exponentially over the life cycle — assumptions that tend to inflate the human wealth effect that is the focus of his analysis and are thus especially problematical.

11.2.3 Seminal model of Auerbach and Kotlikoff

These and many other issues raised by the Summers study were addressed in the model constructed by Auerbach and Kotlikoff (1987), hereafter the AK model, which is the seminal contribution in the vast OLG-CGE literature; the book by Auerbach and Kotlikoff (1987) builds on an earlier article by Auerbach *et al.* (1983) and recent extensions of the model are described in Kotlikoff (1998). Following Summers, Auerbach and Kotlikoff model a closed economy that produces a single good with a single representative individual in each adult cohort alive at any given point in time. However, the AK model differs in five important ways from the Summers model, all of which have been followed by most subsequent researchers (including ourselves).

The first and arguably most important innovation in the AK model is that, rather than assuming myopic expectations, Auerbach and Kotlikoff assume that individuals (and firms, in some applications of the model) have perfect foresight. This naturally makes solving the model far more difficult from a computational standpoint, since all prices in the current and all future years must be determined simultaneously. However, the assumption of perfect foresight implies that firms and households systematically and rationally form expectations about the future, including all of the future effects of tax reforms — a significant improvement over earlier models that is now the standard approach in general equilibrium modeling of tax policy.[4] In particular, the assumption of perfect foresight generally results in more reasonable behavioral responses, as it implies that individuals and firms do not over-react to temporary price increases that will be reversed over time (e.g. temporary tax-induced increases in the rate of return to capital that dissipate over time with capital accumulation).

Second, rather than assuming exogenous labor supply, Auerbach and Kotlikoff allow labor—leisure choices in each period; as a result, labor income taxation distorts labor supply decisions (rather than acting as a lump sum tax) both within a given period and across the life cycle. Third, rather than assuming exponentially growing wages, Auerbach and Kotlikoff assume a 'hump-backed' wage profile over the life cycle, based on estimates from the labor economics literature. Fourth, in some applications, Auerbach and Kotlikoff assume that firms incur convex costs of adjustment when altering their capital stocks; this allows the calculation of an optimal path for investment in response to changes in the tax structure, which in turn implies the model can be used to track the

[4] The Auerbach and Kotlikoff approach is thus consistent with the micro-foundations approach to dynamic macroeconomic modeling sparked in large part by the famous Lucas (1976) critique of macroeconomic policy modeling.

economy in each period following reform until it reaches a new steady state (rather than simply comparing the steady states before and after reform). This allows a thorough analysis of the transitional effects of reform. Finally, Auerbach and Kotlikoff generally use more conservative parameter values than those utilized by Summers; among other things, their choices dampen the sensitivity of savings in response to changes in the after-tax rate of return, which addresses a common criticism of the Summers model — that it implies unreasonably large savings elasticities.

Auerbach and Kotlikoff also consider the effects of a movement from an income tax to a consumption-based tax system in their model. As a result of the five changes described above and other more minor differences from the Summers model, the welfare gains obtained from the enactment of a consumption tax reform in the AK model are more moderate. For example, in their base case analysis, the replacement of an income tax with a cash flow expenditure tax increases steady-state welfare by 2.3% of the present value of 'lifetime resources' (which is a broader measure of welfare than that used by Summers as it includes the value of leisure). By comparison — and for the same reasons as in the Summers model — the enactment of a wage tax (again without a complementary business tax) reduces steady-state welfare by 0.9% of the present value of lifetime resources. They also calculate the efficiency gains from such reforms, under the assumption that lump-sum redistributions are used so that the utility levels of all generations existing at the time of reform are held constant and all subsequent efficiency gains or losses are distributed so that future generations experience an equal percentage change in utility. Under these circumstances, enacting a cash flow expenditure tax results in an efficiency gain of 1.7% of lifetime resources, while enactment of a wage tax results in an efficiency loss of 2.3%. They note that these efficiency calculations imply that roughly 60% of the difference in the long-run welfare gains that occur with expenditure tax and wage tax reforms in the absence of such redistributions are attributable to intergenerational redistributions.

Auerbach and Kotlikoff also use their model to analyze a variety of other issues in their book. In particular, they examine the effects of increasing business tax incentives, which they show reduces the welfare of the elderly by reducing the value of their holdings of old capital (which does not benefit from the incentives), although this effect is mitigated by the presence of adjustment costs which imply that old capital earns above-normal returns until the economy reaches a new steady-state equilibrium. Auerbach and Kotlikoff also use their model to examine the efficiency costs of increased income tax progressivity, as well as the long-run effects of deficit-financed income tax cuts.

More recently, Auerbach (1996) and Jokisch and Kotlikoff (2007) have used updated versions of the AK model to analyze the effects of several consumption tax reform proposals. For example, Auerbach estimates that enactment of a flat rate comprehensive retail sales tax or a value-added tax (VAT) would increase economic efficiency by more than twice as much as enactment of the Hall–Rabushka Flat Tax with its standard deductions and personal exemptions. He also shows that adding transition rules to the Flat Tax in the form of allowing continued deductions for depreciation on existing assets further reduces long-run efficiency gains. Thus, a central message of Auerbach's analysis is that reform-induced efficiency gains vary significantly across consumption tax reforms, and are negatively affected by adding progressivity and transition rules. Indeed, Auerbach also estimates that the efficiency gains associated with implementing the USA Tax — a form of cash flow expenditure tax that provides for transition rules and multiple individual tax rates that range up to 40% as well as a variety of other features (Weidenbaum, 1996) — are negligible.

11.2.4 Extensions of the AK model

We conclude our overview of OLG-CGE models by providing a necessarily selective overview of some of the many extensions of the AK model. The models and extensions discussed are summarized in Table 11.1.

11.2.4.1 Many goods and many incomes: Fullerton and Rogers model

Two of the most important extensions of the AK model are due to Fullerton and Rogers (1993), hereafter the FR model. First, following Ballard *et al.* (1985), Fullerton and Rogers include many consumption goods (17) and production goods (19) in their model; the consumption goods are linked to the production goods with a fixed coefficients input-output matrix. This disaggregation allows the decomposition of the effects of tax reforms into those that are specific to certain industries and consumer goods. Fullerton and Rogers also require minimum purchases of each good in their formulation of individual tastes; they stress that this limits the amount of discretionary income that can be reallocated across periods and thus results in smaller savings elasticities that are more consistent with empirical evidence. They also allow five types of capital — equipment, structures, land, inventories and intangible assets — and include a simple foreign trade sector (although they ignore international factor flows).

Second, and perhaps most important, rather than assuming a single representative individual in each generation, Fullerton and Rogers include 12 representative individuals in each cohort. The 12 groups correspond to each decile of the lifetime income distribution, with the top (bottom) decile split into the top (bottom) 2% and the remaining 8%, in order to focus on the effects of reform at the very top and bottom of the income distribution. For each income and age group, Fullerton and Rogers estimate (i) wage profiles over the life cycle and across lifetime income groups, (ii) an income tax function with marginal tax rates that are constant within groups but vary across group, and (iii) a profile of government transfers received over the life cycle and across lifetime income groups. Given this detailed intragenerational framework, the FR model allows a much richer analysis of the intragenerational redistributive effects of tax

Table 11.1 Selected models based on the AK model (Auerbach and Kotlikoff, 1987)

Study	Key extensions and limitations (relative to the AK model)
Fullerton and Rogers (1993)	Multiple goods, multiple individuals in each cohort, a target bequest, minimum purchase requirements, multiple types of capital, foreign trade in goods, but myopic expectations and no adjustment costs
Auerbach (1996)	Open economy
Altig *et al.* (2001)	Multiple individuals in each cohort and a joy of giving bequest
Goulder and Summers (1989)	Explicit modeling of firm behavior, following Tobin's q-theory of investment, Kueschnigg (1990, 1991) explicit modeling of firm values, risk premium (Goulder and Summers, 1989), variable debt—equity ratio (Kueschnigg, 1990)
Engen and Gale (1996)	Uncertain earnings, an uncertain time of death and precautionary saving
Davies and Whalley (1991); Taber (2002)	Human capital accumulation
de Mooij and Devereux (2010); Bettendorf *et al.* (2010)	Open economy modeling of multiple regions, with trade and capital mobility, with two-period OLG structure
Fehr *et al.* (Chapter 27 in this Handbook)	Open economy modeling with trade and capital/labor mobility, multiple regions, multiple goods, variable population growth, endogenous retirement decisions, and uncertain earnings and lifespan

The AK model is characterized by perfect foresight, variable savings and variable labor supply with an exogenous wage profile, no bequests, progressive labor income taxation, convex costs of adjusting the capital stock, a closed economy, a single good, a single type of capital, and a single representative individual in each cohort.

reforms, while still capturing the intergenerational redistributions stressed by Auerbach and Kotlikoff.

These extensions of course significantly complicate the model. To facilitate its solution, Fullerton and Rogers assume myopic expectations for firms and consumers, no adjustment costs (so that firms reallocate factors costlessly each period), investment that is solely determined by individuals savings decisions rather than firm optimization over time, and calculate equilibria every 5 years rather than on an annual basis.

Within this context, Fullerton and Rogers examine the lifetime incidence of the US tax system as well as the effects of several tax reforms. They find that the overall tax system is quite progressive with respect to the lifetime burdens borne by the very top and very bottom lifetime income groups, with the burden on the top group (as a fraction of lifetime income) more than three times the burden on the bottom group. However, they find that the overall tax system is roughly proportional or only slightly progressive over the remaining 10 lifetime income groups.

Fullerton and Rogers (1996) use their model to analyze the effects of various fundamental tax reforms, stressing the intragenerational redistributions associated with implementing consumption tax reforms as well as their intergenerational burdens. For example, they note that the implementation of a comprehensive proportional wage tax increases saving more than does the implementation of a comprehensive proportional consumption tax (a VAT). As noted above, intergenerational redistributions imply a smaller increase in saving under a wage tax because it does not include the 'hit' on old capital that is owned primarily by the elderly who tend to consume relatively more in the latter stages of their life cycle. However, Fullerton and Rogers note that the capital levy under the consumption tax hits the lifetime rich more than the lifetime poor and the lifetime rich have a relatively high propensity to save, so that avoiding this hit under the wage tax increases saving and, in their model, this intragenerational effect more than offsets the traditional intergenerational effect. Fullerton and Rogers also show that, not surprisingly, moving to a flat rate consumption tax is a regressive reform, although much of that regressivity can be eliminated at the low end of the lifetime income distribution with a modest tax exemption. They also show that despite the intergenerational saving effect noted above, the implementation of a consumption tax generates larger efficiency gains than enacting a wage tax; these gains are on the order of 1% of lifetime income, but disappear if the intertemporal elasticity is sufficiently low.

11.2.4.2 AK model revisited, with many income groups and perfect foresight

Following Fullerton and Rogers, the AK model has been extended to include 12 income groups in each generation in Altig *et al.* (2001), hereafter the AAKSW model, while maintaining the assumptions of perfect foresight by consumers and a one-year period structure. Altig *et al.* also examine a wide variety of consumption tax reforms. Of particular interest is their analysis of the 'X-Tax' devised by Bradford (1986, 2005). The X-Tax is a multiple-rate progressive version of the Hall and Rabushka (1983, 1995) Flat Tax; the latter is a flat rate tax on labor compensation with standard deductions and personal exemptions coupled with a cash flow business tax that was the model for the 'Progressive Consumption Tax' discussed at length — but ultimately not recommended — in the report of the President's Advisory Panel on Federal Tax Reform (2005). The Altig *et al.* simulations indicate that replacement of the current income tax with an X-Tax with a top marginal rate of 30% would result in a long-run increase in output of 6.4%, coupled with long-run welfare increases for each of the 12 lifetime income classes in their model of between 1 and 2% of full lifetime resources. The Altig *et al.* results thus suggest that a progressive consumption tax reform could be designed without causing huge long-run redistributions of income across income classes.

These long-run gains, however, are accompanied by transitional losses for the elderly at the time of reform that range between 1 and 2% of remaining lifetime utility. Altig *et al.* do not analyze the effects of adding transition relief to mitigate these losses. However, they do analyze the effects of the Flat Tax, with and without transition relief in the form of allowing continued depreciation deductions on existing capital assets; they estimate that adding transition relief reduces the long-run increase in output from 4.5% to 1.9%. This suggests that adding transition relief to the X-Tax would significantly reduce, and perhaps even reverse, its long-run steady-state welfare gains, especially since the windfall loss due to the capital levy imposed on the elderly under the X-Tax is relatively large since they face a relatively high marginal tax rate.

11.2.4.3 Including explicit calculation of firm values and financial markets

Several models extend the standard OLG-CGE model to include explicit calculation of firm values, taking into account the current values of existing capital assets given the depreciation deductions taken previously on such assets (Goulder and Summers, 1989; Kueschnigg, 1990, 1991). This approach is based on the '*q*'-theory of investment developed by Tobin (1969), under which firms' investment decisions are related to the ratio of the market value to the replacement value of capital, as extended to include the costs of adjusting the capital stock by Hayashi (1982). Firms with perfect foresight are assumed to choose an optimal investment path to maximize firm value, which is defined as the discounted value of future after-tax cash flows. The debt–equity ratio is typically assumed to be fixed, although in some formulations the degree of leverage is endogenous and typically depends on a balancing of the tax advantages of debt in the form of deductible interest against the agency costs (diminished control over managers) of higher leverage (Kueschnigg, 1990).

Such models are especially well-suited to analyzing the transitional effects of reform, as firm values and thus individual asset holdings are calculated explicitly. In addition, since depreciation on existing assets is calculated explicitly, the effects of different transition rules can be analyzed explicitly. For example, the implementation of a 'pure' consumption tax would include the denial of all depreciation deductions on existing capital (Hall and Rabushka, 1983, 1995). Such a policy is likely to be too harsh to be politically feasible, and models that calculate firm values explicitly can determine the macroeconomic and distributional effects of alternative transition rules, such as full or partial continuation of such allowances.

11.2.4.4 Adding a precautionary saving motive: Engen and Gale model

As noted above, one common criticism of OLG-CGE models (that is invoked to an even greater extent with infinite-horizon models) is that they are characterized by savings responses to changes in after-tax rates of return that some perceive to be implausibly large. These responses arise because individuals are assumed to have perfect foresight, so that even small changes in the after-tax rate of return are compounded into large changes in the prices of future consumption goods, generating relatively large savings responses (Judd, 1985; Chamley, 1986).

One response to this issue has been to assume that individuals have motives for saving other than to finance retirement. In particular, Engen and Gale (1996) argue that much saving reflects a precautionary motive, as individuals attempt to protect themselves against fluctuations in earnings (note that this could also be interpreted as earnings net of uninsured medical expenses) and an uncertain lifetime. They augment a standard OLG-CGE model to include uncertain earnings, an uncertain time of death and precautionary saving, stressing that such saving is far less sensitive to rates of return than life-cycle saving; indeed, in the case of 'target' saving where individuals want to accumulate a fixed 'buffer stock' of saving, saving is inversely related to the rate of return since target savings can be more easily attained with a higher rate of return. They note that the saving elasticity with respect to the after-tax rate of return in their model is in the neighborhood of 0.25–0.40, which is far smaller than typically observed in an OLG-CGE model; they argue that such small elasticities are consistent with the empirical literature. Engen and Gale also stress that the current tax system is not a pure income tax, but a hybrid with many important features of a consumption tax, especially the treatment of much retirement saving and investments in owner-occupied housing. They argue that this implies that roughly half of saving is tax preferred (taxed as it would be under a consumption tax) under the income tax. As a result, moving toward a consumption-based tax does not represent as much of a change as it would if the initial equilibrium were a true income tax.

Within this context, Engen and Gale simulate the effects of the implementation of a flat rate consumption tax. Although this reform still generates efficiency gains, these gains – which are on the order of 1% of lifetime income in the long run – are significantly smaller than in alternative analyses that do not consider precautionary saving; they also show that allowing transition relief in the form of allowing continued depreciation deductions for existing capital reduces this efficiency gain by approximately one-half. The Engen and Gale results clearly imply that the efficiency case for consumption tax reform is weaker if the precautionary motive is a dominant factor in determining saving behavior (and to the extent that the current income tax already has consumption tax features). On the other hand, the relative importance of precautionary saving is open to debate; for example, Kennickel and Lusardi (2004) estimate that precautionary saving represents only 8% of total net worth.

11.2.4.5 Adding human capital

Another strand of this literature adds human capital to the OLG-CGE model, thus allowing life-cycle saving in the form of both physical and human capital accumulation and making future wages endogenous. This extension was prompted in part by the early partial equilibrium work of Driffill and Rosen (1983) who simulated the effects of moving from a proportional income tax to a proportional consumption-based tax within the context of a partial equilibrium life-cycle model (the rate of return to capital was assumed to be fixed) with both human capital accumulation and variable labor supply in each period. They argued that the focus of the standard OLG-CGE model on the changes in labor supply induced by such tax reforms was misplaced, as the distortions of human capital accumulation were likely to be more important. Driffill and Rosen assume that all the costs of human capital accumulation are foregone earnings, which are implicitly deductible, implying that individuals effectively receive cash flow tax treatment of human capital investment under either tax system, which in turn implies a non-distortionary marginal effective tax rate of zero on such investment. By comparison, investment in physical capital is fully taxed under an income tax and untaxed at the margin under a consumption-based tax, which implies that the income tax creates a tax bias favoring investment in human capital while the consumption tax is neutral between investment in human and physical capital. The simulations of a consumption tax reform conducted by Driffill and Rosen suggest that the efficiency costs associated with the distortion of both labor supply and human capital accumulation decisions under the income tax are roughly seven times as large as the distortion of the labor supply decision considered in isolation (35% versus 5% of revenues). The authors suggest that this provides a compelling argument for consumption-based tax reforms.

Subsequent general equilibrium analyses with endogenous rates of return on physical capital, however, have cast doubt on this conclusion. In particular, Davies and Whalley (1991) show that although the short-run negative effects on human capital accumulation of replacing a proportional income tax with a proportional consumption (or a wage) tax are significant as the relative after-tax return to physical capital spikes initially, this effect dissipates rapidly, as the after-tax rate of return to physical capital quickly falls back to roughly its initial level with additional physical capital accumulation. As a result, the tax-reform-induced effects on human capital accumulation are small in the intermediate and long runs, and the incremental efficiency gains from adding a human capital accumulation decision to the life-cycle model are small.[5]

Taber (2002) obtains broadly similar results in a model that considers progressive as well as proportional taxes. In principle, progressive taxes create a tax bias against human capital accumulation, since the implicit deductions for foregone earnings are taken at relatively low rates (since income is relatively low during human capital accumulation) while some of the subsequent returns in the form of higher future wages are taxed at relatively high rates. However, Taber finds that progressivity has relatively small effects on

5 Similar results are obtained by Lord (1989) in an analysis of the replacement of a payroll or wage tax with a consumption tax.

human capital accumulation; he also confirms the Davies and Whalley result that consumption tax reforms have only short-run effects on human capital accumulation that dissipate rather quickly.

11.2.4.6 Adding international flows of goods and factors

Much of the analysis of tax reforms using OLG-CGE models has been done within either a closed economy framework, or one in which trade in outputs and/or international factor mobility is modeled in a fairly ad hoc way. For example, the AK model is closed and the FR model includes a simple form of trade in goods but has no international movements of capital or labor. Auerbach (1996) includes some simulations in which the US economy is simply modeled as a small open economy (the international rate of return to capital is assumed to be fixed).

The need to consider open economy issues, especially international capital flows, is highlighted by the ongoing debate regarding the incidence of the corporate income tax. For example, Harberger (1995, 2008) constructs a four-sector general equilibrium model, characterized by perfectly mobile capital and tradable goods with prices that are determined on international markets, in which a tax on capital income is typically shifted more than 100% to labor. This result, however, has been questioned by Gravelle and Smetters (2006), who argue that, even if capital is perfectly mobile internationally, capital in the US will bear more of the burden of the corporate income tax than the US share of world output if domestic goods and imports are not perfect substitutes; indeed, they show that the capital share of the tax burden increases dramatically as the substitutability between domestic goods and imports falls. By comparison, Randolph (2006) shows that extending the Gravelle–Smetters model to allow a domestic corporate sector that produces two types of traded goods – some that are perfect substitutes for imports and others that are imperfectly substitutable – greatly reduces the importance of imperfect product substitutability.

Although none of these models includes an OLG structure, the issues of the appropriate way to model international factor mobility and international trade, as well as the magnitudes of the key parameters, are obviously relevant to OLG-CGE modeling as well – an issue to which we return in our discussion of the DZ model below. One recent example of explicit modeling of international capital flows in an OLG-CGE framework is de Mooij and Devereux (2010), who model the effects of various tax reforms in the EU. Their model has a simple two-period OLG structure, but is essentially a model of a 'world' economy that includes the 27 countries of the EU plus the US and Japan. Although labor is assumed to be immobile internationally, capital is perfectly mobile across all countries in the model (the overall world supply of capital is determined by the saving of each country) and the single production good in the model is traded on perfectly competitive world markets. They also consider an extension to the model in another form of capital 'mobility' — income shifting to tax havens — is allowed with the extent of income shifting determined by differences in statutory tax rates in the EU countries relative to the tax havens.

Within this context, de Mooij and Devereux analyze the effects of various EU-coordinated and single-country reforms that would eliminate current tax distinctions between debt and equity financed investments. These include the enactment of an 'allowance for corporate equity' or ACE business tax, which allows firms an extra deduction for the cost of equity, and a 'comprehensive business income tax' (CBIT) that would deny firms deductions for business interest expense. In their benchmark model, they show that a coordinated ACE reform would increase welfare in each of the EU countries, by amounts that range from 0.2 to 0.8% of GDP; however, these gains are largely or fully offset if tax havens are added to the model, as the higher ACE rate (required to maintain revenues, given the new deduction for equity capital) results in significant income shifting out of the EU. By comparison, in their benchmark model, most EU countries experience a welfare loss with a coordinated CBIT reform due to the resulting increase in the cost of capital; however, such a reform tends to increase welfare in most countries when tax havens are allowed, as the extent of income shifting declines due to the reduction in the tax rate made possible by the denial of interest deductions under the CBIT regime. The de Mooij—Devereux analysis provides an excellent example of how the standard OLG-CGE model might be extended to incorporate international trade and factor flows, even if only in the context of a two-country model of the US and the 'rest of the world'.[6]

11.3 OVERVIEW OF THE DZ MODEL

In this section, we provide an overview of the DZ model, which is a large-scale dynamic OLG-CGE model that can be used to analyze both the short-run and long-run macroeconomic and distributional effects of tax reforms. A detailed description is provided in the Appendix. We describe a fairly general version of the model; however, all of the features of the model described are not necessarily used in all applications. In particular, we describe a version of the model in which there are 12 lifetime income groups within each generation, but in many applications we assume a single representative individual in each generation.

The basic features of the model are as follows. Consumers are assumed to have perfect foresight and to maximize utility over a 55-year adult life, consisting of 45 working years

[6] See also Bettendorf *et al.* (2010), who use a similar model to analyze the effects of corporate income tax harmonization (the Common Consolidated Corporate Tax Base with formula apportionment) in the EU. See also the comprehensive multiregional model with internationally mobile capital and labor, variable population growth, multiple goods, uncertain earnings and lifespan, and endogenous retirement decisions by Fehr *et al.* in Chapter 27 of this Handbook.

followed by a 10-year retirement.[7] The model is constructed in discrete time, with each period corresponding to 1 year. Individual lifetime utility is the discounted sum of annual utility in each of the 55 periods. Annual utility is a function of leisure and an aggregate consumption good, which is in turn a composite of four goods — a non-housing composite consumption good produced by the corporate sector, a non-housing composite consumption good produced by the non-corporate sector, owner-occupied housing and rental housing. The model also includes relatively simple representations of bequests and inheritances, and tax-deferred saving under the current income tax. There are 12 lifetime income groups within each generation, each characterized by its own profiles for lifetime earnings and lifetime transfers received.[8]

Firm managers are also characterized by perfect foresight. Firms are assumed to maximize firm value and thus the discounted value of future profits. Following the well-known *q*-theory of investment behavior formulated by Tobin (1969), firm managers calculate the optimal time path of investment in response to any changes in the tax structure, taking into account convex costs of adjusting investment from its initial steady-state level. Firm behavior is modeled separately for each of the four production sectors, with individuals who own their own homes treated as the owners of private 'firms' that produce housing and then rent it to their owners (themselves), taking into account the income tax advantages of home ownership. The debt—capital ratio is assumed to be fixed in each industry.

The government must finance an exogenously specified time path of public services, which are assumed to be separable from the individual lifetime utility function, as well as income transfers, which are included in individual income. This fairly standard 'differential incidence' approach significantly simplifies the model while still allowing us to analyze a wide range of tax substitutions, as well as changes in government spending that take the form of changes in transfers payments, which are fully accounted for in the individual budget constraint. However, we cannot conduct 'balanced budget incidence' analyses, i.e. we cannot analyze an increase in government services (other than transfer payments) that is financed with a tax increase. Such an analysis would of course require a complete specification of how all government services enter individual utility functions, by age and by income group. We leave this interesting but complex extension to further research.

7 Following most of the models in this literature, we consider an economy characterized by perfect certainty. This admittedly strong assumption has been relaxed in the dynamic stochastic general equilibrium literature (see, e.g. the discussion in Kocherlakota, 2010).

8 The individual utility functions, however, are identical across the various lifetime income groups, which implies that the parameters that determine behavioral responses, including those associated with changes in labor supply and saving, are identical across the various lifetime income groups; allowing variation by lifetime income group of these parameters in order to better capture differences in their behavioral responses is a topic of future research.

The basic version of the DZ model follows the AK model in assuming a closed economy. This simplifying assumption is acceptable for some reforms that are unlikely to have large effects on rates of return to capital and thus on international capital flows, or if one believes that international capital mobility, especially with respect to capital flows in and out of the US, is less than often asserted.[9] Nevertheless, because such capital flows are of great importance in the modern economy, in several of our analyses with the DZ model, we have modified the model to allow a simple representation of capital flows, as described below.

In the initial steady-state equilibrium, the government's tax instruments include a corporate income tax and an income tax with a progressive wage income tax structure and constant rate capital income taxes. The model can be used to analyze the short-run and long-run effects of both reforms of the existing income tax system, such as base-broadening, rate-reducing reforms (BBRR) or various approaches to business—personal income tax integration, as well as various types of consumption tax reforms, including the Hall—Rabushka Flat Tax and its variants such as the Bradford X-Tax, cash flow expenditure taxes, national retail sales taxes and VATs. In general, the government must satisfy an annual budget constraint. However, the model can also accommodate federal government debt, and the government can issue debt for a finite period and then satisfy the annual budget constraint from that point forward, paying interest on the accumulated debt.

All markets are assumed to be perfectly competitive. Market equilibrium in the model requires that total consumer demand, obtained by aggregating the demands of each of the 12 types of individuals within each of the 55 generations alive at any single point in time, must equal aggregate supply in each of the four production sectors. In addition, factor demands must equal factor supplies in the labor and capital markets, the total amounts of debt and equity held as individual wealth must equal firm stocks of debt and equity, and both individual and firm expectations regarding the time paths of future prices must be satisfied. In all applications including those with government debt, the model must arrive at a steady-state equilibrium, in which all key macroeconomic variables, including GDP and output in the various sectors, the capital stock, the effective labor force, any government debt held by the public, etc., grow at the steady-state growth rate, which is defined as the sum of the long-run population growth rate and the rate of labor-augmenting technological progress, both of which are specified exogenously and assumed to remain constant. Note that because we assume a constant rate of population growth in our model, we cannot analyze the effects of demographic changes, including the fiscal imbalances that currently plague the US and many other countries due to an aging population. The model can, however, be extended to allow varying rates of population growth for a finite time period, as long as population growth eventually

[9] See, for example, Feldstein and Horioka (1980) and the voluminous subsequent literature, reviewed in Zodrow (2010).

returns to a constant steady-state growth rate; for example, Auerbach and Kotlikoff make such a modification in their analysis of reform of the social security system in the US, and Fehr *et al*. in their multiregional model in Chapter 27 of this Handbook analyze demographic changes in great detail.

The model calculates asset values in all four markets explicitly for each period after the enactment of a reform, taking into account both the effects of all changes in the tax treatment of existing capital assets, as well as their previous tax treatment under the existing tax system. As noted above, the model is thus especially well suited to analyzing the transitional effects of reform, including reform-induced changes in asset prices in all four sectors, as well as the associated redistributions within and across all generations alive at the time of reform. The model can also be used to calculate the long-run economic effects of reform, including the welfare effects of reform on future generations.

11.4 APPLICATIONS OF THE DZ MODEL

In this section, we describe the results of using the DZ model to analyze five types of potential tax reforms, including (i) fundamental tax reform in the form of replacing the income tax with a consumption-based tax (the Flat Tax), (ii) the implementation of a Flat Tax supplemented by the taxation of capital income at the individual level, (iii) reform of the existing income tax in the form of a BBRR corporate income tax reform, (iv) implementing a new VAT designed to reduce current deficits and the US national debt, and (v) deficit-financed tax reductions. The initial equilibrium for evaluating these reforms is a stylized representation of the US economy, characterized by numerous tax-induced inefficiencies that offer the potential for efficiency-enhancing reforms. These inefficiencies include the taxation of corporate income with double taxation at the business and individual levels of corporate equity income, the taxation of saving at both the business and individual levels, the taxation of labor income, and differential taxation of the corporate and non-corporate sectors as well as differential taxation of the business and housing sectors.[10] Typical parameter values used in constructing the initial equilibrium are shown in Table 11.2; for a detailed discussion of parameter choices, see Gunning *et al.* (2008).

11.4.1 Consumption-based tax reforms

In Diamond and Zodrow (2008a), we examine the short-run and long-run effects of fundamental tax reform, focusing on the transitional effects of replacing the current

[10] Note that most of these distortions would be reduced or eliminated with the replacement of the existing income tax with a consumption-based tax, especially if its base were broad enough to reduce the effective tax rates applied to labor income; as noted above, this is the main reason many of the reforms analyzed in the OLG-CGE literature examine the effects of such reforms.

Table 11.2 Typical parameter values used in the DZ model

Symbol	Description	Value
Utility function parameters		
ρ	Rate of time preference	0.004–0.01
σ_U	Intertemporal elasticity of substitution	0.25–0.35
σ_C	Intratemporal elasticity of substitution	0.60–0.80
σ_H	Elasticity of substitution between composite good, housing	0.33–0.50
σ_N	Elasticity of substitution between corporate, non-corporate good	5.0
σ_R	Elasticity of substitution between rental, owner housing	0.80
α_C	Utility weight on the composite consumption good	0.70
α_H	Utility weight on non-housing consumption good	0.72
α_N	Utility weight on corporate good	0.75
α_R	Utility weight on owner-occupied housing	0.78
Production function parameters		
ϵ_C	Elasticity of substitution for corporate good	0.5–1.0
ϵ_N	Elasticity of substitution for non-corporate good	0.5–1.0
ϵ_H, ϵ_R	Elasticities of substitution for owner and rental housing	0.25–0.80
γ_C	Capital share for corporate good	0.25–0.35
γ_N	Capital share for non-corporate good	0.25–0.50
γ_H, γ_R	Capital share for owner and rental housing	0.99
β_X, β_N, β_H	Adjustment cost parameters	0–15
ζ	Dividend payout ratio in corporate sector	0.68
b_C, b_N, b_H, b_R	Debt–asset ratio	0.35
δ_C, δ_N	Depreciation rates in the corporate and non-corporate sectors	0.088
δ_H, δ_R	Depreciation rates in the owner and rental housing sectors	0.019

income tax with a Hall–Rabushka Flat Tax.[11] Transitional issues have played an important and controversial role in the tax reform debate. Some observers argue that the prospect of large reform-induced windfall losses creates a huge impediment to the enactment of reform, while others stress that such losses, which are typically concentrated among high-lifetime-income capital owners, create the potential for larger long-run reform-induced efficiency gains while simultaneously mitigating the distributional problems associated with the lower marginal tax rates at the top of the income distribution and the generous treatment of capital income that characterize a consumption tax.

In particular, we focus on two specific transitional issues that often arise in discussions of the feasibility of consumption tax reforms. The first is the potential one-time windfall loss imposed on the owners of existing capital assets (other than owner-occupied housing). For example, under the Flat Tax, allowing expensing is equivalent in present

[11] See Diamond and Zodrow (2007b) for a similar analysis of the effects of implementing a national retail sales tax.

value to exempting from taxation the normal rate of return on all new investments. However, in the absence of transition rules under the Flat Tax, firms would not be allowed to deduct the remaining basis of existing assets, although the returns earned by such assets (and the proceeds of asset sales) would be included in the tax base. As a result, the rate of return on existing assets would fall relative to the return on new investments, and arbitrage across new and existing assets would imply that the value of existing assets would fall; Gravelle (1996) constructs a simple model in which the decline is proportional to the rate of tax. Moreover, in the likely event that the general price level remains unchanged under the Flat Tax, lenders would be insulated from this loss since the nominal value of outstanding bonds would be fixed; thus, the entire reform-induced one-time windfall loss would be borne by business equity holders.

However, as described by Zodrow (2002), this analysis ignores a wide variety of other factors associated with the implementation of a Flat Tax that would also affect existing business capital owners, most of which would act to reduce the one-time windfall tax on existing assets or offset its negative welfare effects. A partial list of these factors — all of which are considered in the DZ model — includes: (i) the costs of adjusting the capital stock, which would allow the owners of capital to earn above-normal returns on both existing assets and new investments during the period of transition to the new postreform equilibrium; (ii) a short-run (and perhaps a long-run) increase in the after-tax rate of interest, which would allow the owners of capital to earn a higher after-tax rate of return on existing assets and new investments; (iii) the reduction under a lower-rate flat tax of the expected tax on assets that were allowed accelerated depreciation allowances, including 'bonus depreciation' and expensing of investments in research and development or advertising, under the current income tax (Lyon and Merrill, 2001); and (iv) the efficiency gains obtained from eliminating distortions of saving and investment decisions and reducing distortions of the labor—leisure choices, as well as from improvements in the allocation of capital across business sectors.[12] Thus, the magnitudes of such reform-induced reductions in the prices of business equity assets are far from clear, and results presented in Auerbach (1996) and Altig *et al.* (2001) suggest they are smaller than those obtained in the Gravelle (1996) analysis.

12 The model tends to overstate transitional losses for two additional reasons. (i) To the extent the 'new view' of dividend taxation is accurate, the enactment of a consumption tax reform would benefit existing assets by removing individual level taxation of dividends that is capitalized into current asset prices (Auerbach, 1996). As the model is based on the 'traditional' view of dividend taxation, it does not capture this effect. One potential extension of the model is to allow some 'traditional view' firms and some 'new view' firms, consistent with the evidence presented in Auerbach and Hassett (2003). (ii) As stressed by Hubbard (2002), the primary difference between income and consumption taxes is that only the latter exempts normal returns to capital; by comparison, above-normal returns and the returns to risk-taking are treated similarly under income and consumption taxes. Since the model is characterized by perfect competition and certainty, it does not consider these factors. In particular, as discussed by Auerbach (2008), treating all of the return to capital as normal returns may significantly overstate the gains that could be achieved with a consumption tax reform.

The second potential windfall loss from implementing a Flat Tax is its potentially negative effect on the price of owner-occupied housing. This price decline is due to a reform-induced increase in the user cost of housing, as perceived by the owner-occupier, which arises primarily because (i) normal returns to business equity investments are effectively untaxed under the Flat Tax, making such investments relatively more attractive and raising the opportunity cost of equity-financed investment in owner-occupied housing, and (ii) deductions for mortgage interest and property taxes are eliminated. This increase in the user cost of owner-occupied housing would tend to reduce the demand for owner-occupied housing, which in turn would tend to result in a decline in the price of owner-occupied housing in the short run. In the long run, the quantity of housing and the cost of housing would return to an equilibrium reflecting production costs, including the cost of land, and the absence of taxation.

Several analysts have commented on the impact of consumption tax reforms on housing prices, and the range of predicted effects is large. An analysis conducted by Data Resources Incorporated (Brinner *et al.*, 1995) predicts that the present value of the loss of mortgage interest and property tax deductions alone would cause the aggregate value of owner-occupied housing to decline by 15%. Capozza *et al.* (1996) predict that implementing a Flat Tax would reduce owner-occupied housing prices by an average of 20%, assuming that interest rates fall by one percentage point. By comparison, Gravelle (1996), Bruce and Holtz-Eakin (1999), and Hall (1997) argue that both the short-run and the long-run effects of a Flat Tax on housing prices would be fairly small.

The housing component of the DZ model captures most of the important factors affecting the housing market discussed in these studies. The model explicitly accounts for changes in the level of new investment and the reallocation of the existing capital stock across the business and both owner-occupied and rental housing sectors, and examines the effects of the costs of adjusting the capital stock. In addition, changes in consumer demands across rental and owner-occupied housing, including those changes attributable to the elimination of deductibility of home mortgage interest and property taxes, as well as changes in demands for the composite good, are considered. It should be noted, however, that a weakness of the approach used in the model is that land is not modeled explicitly. Instead, the difficulties of converting land used initially for owner-occupied housing to other uses are captured indirectly by including the costs of adjusting the housing capital stock in the analysis. These costs are assumed to be symmetric (i.e. to follow the same quadratic pattern for both declines and increases in investment, relative to the steady-state level), and reflect the costs of reducing the level of new investment, reducing the level of replacement investment, converting owner-occupied housing to rental housing and finally, if necessary, converting owner-occupied housing to production of the composite good.

Finally, we focus on the Flat Tax because it is among the most often-discussed consumption tax proposals [e.g. the progressive 'X-Tax' variant of the Flat Tax was the consumption tax option discussed at length in the report of the President's Advisory Panel on Federal Tax Reform (2005)], its enactment is believed to raise the most troublesome transitional issues among the various consumption-based tax reform options and it is the main reform analyzed in existing studies of the effects of fundamental reform on the housing values (Capozza *et al.*, 1996; Gravelle, 1996).

The version of the DZ model used in this analysis has only three production sectors (the 'composite good' sector reflects a combination of the corporate and non-corporate sectors) and only a single representative individual in each generation, and the bequest motive assumes a target bequest (following Fullerton and Rogers). Since adjustment costs are uncertain, but are critical for analyzing transitional effects, the simulations include sensitivity analysis for various adjustment costs.

The reform simulated is the replacement of the federal income tax system with a revenue neutral Hall-Rabushka (1985, 1995) Flat Tax that applies a constant tax rate to (i) a comprehensive measure of household labor incomes, with an exemption amount that is initially set at $20,000 per household, and (ii) business real cash flow, which allows expensing of all non-financial business purchases and ignores financial flows and thus does not allow deductions for interest expense. The assumption of a comprehensive Flat Tax base, which follows the admittedly highly optimistic Hall and Rabushka approach of assuming full taxation of all fringe benefits, elimination of all deductions, and elimination of the Earned Income Tax Credit, implies that the required flat tax rate is relatively low — it ranges from 21.0% to 22.3% in the year of reform, depending on the level of adjustment costs, and gradually declines to a steady-state value of 20.1%. The reform is assumed to be unanticipated and enacted immediately.

The results of the simulations, which are presented in Table 11.3, can be summarized as follows. The enactment of the Flat Tax results in a longrun increase in GDP of nearly 5%, long-run increases in investment that range from about 2% in owner-occupied housing to 15—17% in the composite good and rental housing production sectors, a long-run increase in labor supply of roughly 1.8%, and a long-run increase in welfare of nearly 3%. The increase in labor supply occurs immediately, while the increase in the capital stock occurs slowly over time, with the capital—labor ratio nearly 9% higher, and wages 4% higher in the long run. Note that part of the increase in labor supply is attributable to the reform-induced reallocation of capital from owner-occupied housing into the much more labor-intensive production of the composite good, which stimulates the demand for labor.

Although one of the economic benefits of fundamental tax reform is a more efficient allocation of capital across the housing and composite good sectors, this naturally comes only with a reduction in investment in owner-occupied housing during a transition period following reform. The capital stocks in the composite good and rental housing sectors increase in every year after the enactment of reform, and are 16.9% and 15.0% larger, respectively, in the long run. By comparison, in the owner-occupied housing sector, the stock of capital declines initially, as capital is reallocated from the

Table 11.3 Simulation results: Flat Tax reform (% changes in variables)

	Years after reform					
	2	**5**	**10**	**20**	**50**	**150**
GDP	2.3	3.7	4.2	4.7	4.9	4.9
Output − X	2.6	3.9	4.5	5.0	5.2	5.2
Output − R	−0.3	0.5	0.7	1.1	1.2	1.2
Output − H	0.7	2.5	3.0	3.5	3.6	3.7
Capital stock − X	8.0	12.9	14.6	16.5	16.9	16.9
Capital stock − R	4.0	8.5	11.0	14.1	14.9	15.0
Capital stock − H	−5.8	−4.6	−1.9	1.4	2.2	2.3
Investment − X	21.7	18.8	17.7	16.9	17.0	16.9
Investment − R	33.1	27.9	24.2	18.0	15.4	15.0
Investment − H	−18.2	1.1	6.4	5.1	2.6	2.3
Labor supply	2.0	2.0	1.9	1.8	1.8	1.8
Asset prices − X	−11.6	−9.2	−7.5	−5.7	−5.0	−4.9
Asset prices − R	−26.6	−23.6	−21.6	−19.3	−18.4	−18.3
Asset prices − H	−5.2	−3.1	−1.2	1.2	2.2	2.3

X = corporate and non-corporate sector, R = rental housing sector, H = owner-occupied housing sector.

owner-occupied housing to the rental housing and composite good sectors. Five years after the reform is enacted, the capital stock in the owner-occupied housing sector is 1.0–6.1% smaller than in the initial steady state, depending on the level of adjustment costs, although it is 2.3% larger in the long run. (By comparison, in results not shown, in the high adjustment costs case ($\beta_x = 10$ and $\beta_h = 2$) the owner-occupied housing stock falls by 9.3% 10 years after reform, and the ensuing reform-induced growth effects are spread out over a longer transition period.) Output is 5.2% larger in the composite good sector and 1.2% larger in the rental housing sector in the long run; in the owner-occupied housing sector, the change in output ranges from 0.1 to −1.5 in the short run, but is 3.6% larger in the long-run steady state.

As discussed above, the Flat Tax results in changes in the prices of assets at the time of its enactment. The declines in the value of business equity range from 0.1% to 16.5%, depending on the size of adjustment costs, while the average value of equity in the rental housing sector (where remaining basis is relatively large) decreases by 19.9–29.9%. The effects of reform on the value of equity in the owner-occupied sector are much more modest, where home equity values initially fall by 5.1–2.9% which, with a debt-asset ratio of 0.35, is equivalent to a 3.3–1.9% decline in the total value of owner-occupied housing; equity values return to their initial levels by the fourth year after the reform. This suggests that the negative effects on house values of reducing tax preferences for owner-occupied housing under a Flat Tax would be relatively small, at least in the aggregate, once all general equilibrium effects are taken into account. Instead, the biggest transitional issue arises in the rental housing sector (and in general for long-lived assets with significant amounts of remaining basis), where a reasonably strong case can be made for transitional relief.

The gains described above come at the expense of one-time windfall losses experienced by the (primarily elderly) owners of business equity, which are moderated as adjustment costs increase. For example, the generation of age 54 in the year of enactment experiences a net welfare loss that ranges from 1.8% to 11.3% of remaining lifetime utility. These losses are larger than those predicted in some other recent studies, but not nearly as large as those predicted by partial equilibrium models that ignore a wide variety of factors that tend to mitigate asset price declines in an OLG-CGE model. In our view, these results suggest that special transition rules should be used with caution when implementing fundamental tax reform, especially since they significantly reduce the long-run gains obtained with such a reform.

Finally, it is interesting to note that the effects of adjustment costs — at least if they are symmetric across production sectors — tend to cancel, as higher adjustment costs mitigate the fall in the value of business equity but exacerbate declines in the values of owner-occupied housing, in both cases by slowing down the reallocation of capital from owner-occupied housing to the other production sectors. Thus, explicitly accounting for such differential asset price effects is essential to accurately estimating the welfare effects of fundamental tax reform.

11.4.2 Effects of a capital income tax add-on to a flat tax

Moving completely to the consumption-based Flat Tax (or its progressive variant, the X-Tax) implies completely exempting all of the normal returns to capital from taxation at the individual level. Such a reform may be undesirable for a variety of both economic and political reasons. Indeed, the 'Growth and Investment Tax' (GIT) proposed by the President's Advisory Panel on Federal Tax Reform (2005) provided for a consumption-based tax at the firm level (since expensing was allowed and deductions for interest expense were denied), but included an 'add-on' tax on capital income at the individual level.[13] In Diamond and Zodrow (2007a), we examine the economic effects of adding an individual level capital income tax to the Flat Tax.

The use of an add-on capital income tax reflects the current state of the debate regarding the relative desirability of income-based and consumption-based direct taxes. Specifically, there is widespread agreement that an 'ideal' or comprehensive 'Schanz—Haig—Simons' accrual-based tax on real economic income is not administrable,

[13] The GIT included an individual level tax on labor compensation assessed at rates of 15%, 25% and 30%, supplemented with a 15% 'add-on' capital income tax at the individual level. The DZ model was used to provide some of the simulations of the economic effects of the three tax reform proposals discussed by the tax reform panel; see the appendix to the report of the President's Advisory Panel on Federal Tax Reform (2005). Another variant of this approach is the 'dual income tax' used in the Nordic countries and elsewhere, which is characterized by a progressive tax on labor income, but taxes capital income at the lowest positive rate applied to labor income (see Sorensen, 2007).

as it would require current taxation of all changes in wealth (i.e. accrual taxation of all capital gains and losses). Moreover, there is less but still considerable agreement that the taxation of the normal returns to capital inherent to an income tax is relatively undesirable, as it creates an inefficient tax bias favoring current consumption over saving, discriminates against savers (i.e. individuals who have the same lifetime income, but save more over their life cycle, would pay more tax under an income tax), and creates considerable complexity in administration and compliance, especially given the significant difficulties in accurately measuring real capital income.[14] On the other hand, many observers remain unconvinced that movement to a full-fledged consumption tax is desirable or could be implemented, citing its distributional implications, as well as uncertainty about the magnitudes of the associated efficiency gains, improvements in administrative and compliance simplicity, and transitional problems.[15] The add-on capital income tax represents a reasonable compromise between these two ends of the tax reform spectrum.

The model we use to analyze the add-on capital income tax is essentially the same as in Diamond and Zodrow (2008a), except that bequests are modeled assuming that donors are motivated by the 'joy of giving.' We compare two reform options, involving the replacement of the current federal income tax system with either (i) a revenue-neutral Hall-Rabushka Flat Tax (hereafter the FT plan) that applies the same constant tax rate to both a comprehensive measure of household labor incomes, with an exemption amount that is initially set at $20,000 per household, and business real cash flow (which allows expensing of all non-financial business purchases and ignores financial flows including interest expense), or (ii) a revenue-neutral tax system that includes a flat tax on wages and business cash flow supplemented with a relatively low flat rate 'add-on' capital income tax at the individual level on interest, dividends, and capital gains (hereafter the AT plan).

As in the previous analysis, the assumption of a truly comprehensive FT base implies that the required tax rate under the FT plan is quite low, equal to 21.1−22.1% in the year of reform, depending on the level of adjustment costs, and gradually declines to a steady-state value of 20.2%. Under the alternative AT plan, the capital income tax rate is assumed to be 10%, roughly half of the wage tax rate,[16] which is 20.0−20.8% in the year of reform, depending on adjustment costs, and declines to a steady-state value of 19.3%.[17]

14 See Zodrow (2007) for a review of these arguments.

15 For recent collections of articles that reflect the current status of the debate on these issues, see Diamond and Zodrow (2008b), Aaron *et al*. (2007), Auerbach and Hassett (2005), and Zodrow and Mieszkowski (2002).

16 Note that this 10% 'flat rate' is the statutory tax rate applied to all capital income under the AT plan, rather than the effective tax rate. In the model, the annual accrual individual-level capital gains tax rate, taking into account the advantages of deferral and tax exemption of death and the disadvantage of the taxation of inflationary gains, is assumed to be 3.3%. All capital income tax rates are assumed to be fixed for all years after the enactment of reform.

17 Note that the lower rates under the AT plan are due to its taxation of capital income, which results in a somewhat broader base than under the FT plan.

The general patterns of the economic effects of implementing the FT plan, which are shown in Table 11.4, are of course quite similar to that described in the previous section. Accordingly, we focus our discussion on a comparison of the effects of the AT plan, relative to the FT plan. The reform-induced increase in labor supply is slightly larger under the AT plan because its additional layer of capital income taxation implies a somewhat lower tax rate on labor income and thus a higher after-tax wage rate; this effect, however, is tempered by the higher long-run capital—labor ratio and thus higher gross wages under the FT plan (the increase in wages is about 18% greater) due to its lower overall level of capital taxation. Investment responses are muted somewhat under the AT plan relative to the FT plan, as its individual level taxation of capital income implies smaller reductions in the cost of capital; this translates into a long-run increase in GDP that is 0.4 percentage points greater under the AT plan than under the FT plan. The general pattern of changes in investment is the same — large increases in investment in the composite good and rental housing sectors, but an initial decline and ultimately only a small increase in investment in the owner-occupied housing sector — but the magnitudes of these changes are reduced by as much as 15% relative to the FT plan, with similar reductions in the long-run changes in the capital stocks in each sector.

With respect to asset price changes, the tax treatment of capital income is less generous under the AT plan, which implies that the differences between the treatment of old and new business assets, including rental housing, before and after reform is smaller than under the FT plan. As a result, the changes in the prices of these assets are less

Table 11.4 Simulation results: capital income tax add-on to Flat Tax reform (% changes in variables)

	Years after reform					
	2	5	10	20	50	150
GDP	1.9	2.5	2.8	3.4	3.8	3.9
Output — X	2.0	2.6	3.0	3.6	4.0	4.1
Output — R	1.0	1.3	1.4	1.6	1.7	1.6
Output — H	1.4	2.1	2.4	3.0	3.3	3.3
Capital stock — X	1.5	4.0	5.8	8.5	10.5	10.9
Capital stock — R	1.0	2.8	4.3	6.9	9.3	9.9
Capital stock — H	−0.3	−0.4	−0.3	0.4	1.7	2.2
Investment — X	8.0	8.7	9.4	10.1	10.8	10.9
Investment — R	13.4	13.1	12.9	11.5	10.3	9.9
Investment — H	−2.5	−0.3	1.2	2.3	2.5	2.3
Labor supply	2.1	2.1	2.1	2.0	2.1	2.1
Asset prices — X	−2.9	−3.6	−3.9	−4.6	−4.9	−4.9
Asset prices — R	−16.1	−15.6	−15.2	−15.0	−15.0	−14.9
Asset prices — H	−2.1	−0.7	0.4	1.6	2.2	2.3

X = corporate and non-corporate sector, R = rental housing sector, H = owner-occupied housing sector.

pronounced. With adjustment costs, this effect is small, except for rental housing, where the decline in average equity prices is about 15% less than under the FT plan; by comparison, without adjustment costs, the declines in the equity values of all three assets are smaller by roughly 13–15% under the AT plan. In particular, this implies that implementing the AT plan would decrease the total value of owner-occupied housing by less than 3% initially. However, as discussed in the previous section, the declines in the values of rental housing are relatively large under all scenarios, suggesting the case for transition relief is strongest for rental housing. In marked contrast, with the higher level of adjustment costs, equity asset prices in the composite good sector rise slightly – reversing the 13% decline that occurs in the absence of such costs – in which case for transition relief is much weaker. The more modest changes in asset prices (and thus smaller windfall losses) under the AT plan suggest that while an add-on tax promises smaller increases in investment and capital accumulation, it is likely to be politically more feasible.

11.4.3 Corporate income tax rate reduction

Although there has been considerable interest in recent years in fundamental tax reform in the US, experience suggests that incremental reform of the existing income tax system is a much more likely possibility. In particular, there has been much recent discussion of corporate income tax reform, especially a BBRR reform along the lines of the much celebrated Tax Reform Act of 1986.[18] Diamond *et al.* (2011) uses the DZ model to examine the economic effects of such a corporate income tax reform.

The case for a BBRR corporate income tax reform is well-known: by eliminating tax preferences for certain forms of investment and lowering statutory rates, such a reform reduces costly distortions of economic decisions, and thus promotes economic growth and economic efficiency in resource allocation, simplifies tax administration and compliance, reduces incentives for tax evasion and tax avoidance, and creates both the perception and the reality of a fairer tax system. These arguments are especially compelling in the case of the corporate income tax, which has often been characterized as a singularly complex and inefficient tax instrument, as it significantly distorts a wide variety of decisions, including those regarding asset mix and thus the allocation of investment across different industries, the method of finance (debt versus equity in the form of retained earnings or new share issues), organizational form (corporate versus non-corporate), and the mix of retentions, dividends paid and share repurchases (Gravelle, 1994; US Department of the Treasury, 2007; Nicodème, 2008). Moreover, in the case of equity finance, the magnitude of these distortions is increased to the extent that the effective tax rate on corporate income is increased by the double taxation of such

18 See McLure and Zodrow (1987) for a discussion of the Tax Reform Act of 1986 as well as its predecessor, the plan prepared by the US Department of the Treasury known as 'Treasury-I'.

income at both the business level under the corporate tax and then again at the individual level as dividends or capital gains (and, to an increasingly limited extent, under the estate tax). The taxation of capital income inherent in the corporate income tax also reduces saving and investment, which in turn reduces the size of the capital stock, labor productivity, and wage growth.

Many recent proposals for corporate income tax reform have also focused on international issues, especially increasing international capital mobility, international tax competition and aggressive tax avoidance on the part of US multinationals. Proponents of such reforms argue that both statutory tax rates and the overall tax burden on capital income in the US are quite high by international standards, and that the corporate income tax should be reformed in the interest of attracting and retaining mobile capital, promoting economic growth, improving economic efficiency, reducing opportunities for tax avoidance and evasion, and reducing administrative and compliance costs. The ongoing process of globalization also implies that the tax system increasingly has important effects on the competitiveness of US multinationals and on the investment decisions of multinationals based in both the US and in other countries. All of these factors suggest that the corporate income tax is ripe for reform.

The direction that such a reform should take is, however, not obvious. Although the BBRR approach is the traditional one, a question that inevitably arises in discussions of lowering the corporate tax rate is whether maintaining a high statutory rate, coupled with investment incentives such as an investment tax credit or more accelerated depreciation allowances (including partial expensing) for new investment, is not preferable. The investment incentive approach is often touted as having more 'bang for the buck' in that the revenue cost per dollar of induced investment is lower than with a rate reduction (US Department of the Treasury, 2007), i.e. revenue losses are comparatively small because the new tax incentives apply only to new investment while the relatively high statutory rate continues to apply to the income earned by old investments.[19] In addition, the use of investment incentives implies that the effective marginal tax rate applied to normal returns is reduced, while above normal returns, including those attributable to location-specific rents, are still taxed at the statutory rate. By comparison, revenue losses are argued to be significantly higher under a reduction in the statutory tax rate because the rate reduction applies to both the income earned by old investments and by investments that generate above normal returns. Finally, to the extent that a lower statutory corporate tax rate increases a positive rate differential between the personal and corporate income tax rates, it creates incentives for shifting income from the personal tax base to the corporate tax base (Gordon and Slemrod, 2000).

[19] Note, however, that even in this case, much of the incentives for new investments will nevertheless be inframarginal and will reduce revenues for investments that would have been made without the incentive.

Although each of these arguments has some validity, there are important counter-arguments. (i) The 'bang for the buck' from rate reduction may not be as small as sometimes envisioned, because the rate cut reduces the taxation of above-normal returns that reflect firm-specific rents attributable to highly mobile investments in invention and innovation or firm-created intangible assets, and thus attracts such investments by lowering the average effective tax on such returns — a result that does not obtain under investment incentives. Thus, the desirability of taxing above-normal returns depends on whether they reflect relatively mobile firm-specific rents or relatively immobile location-specific rents. (ii) The relatively high statutory corporate tax rate under the 'tax incentives' approach encourages multinational firms to use transfer pricing and other tax planning strategies, including debt reallocation and relocation of patents and other intangible assets, to reduce the share of taxable income realized in relatively high-tax countries like the US, while increasing the share of taxable income realized in relatively low-tax countries. Such 'financial reallocation', which is much easier to put into effect than physical reallocation of capital assets, can significantly reduce taxable incomes reported in the US and thus government tax revenues. Much empirical evidence confirms that such income shifting is become increasingly prevalent (Diamond *et al.*, 2011), with one study suggesting that that the revenue increase from a unilateral increase in the statutory tax rate is on average reduced by roughly more than 65% due to income shifting solely in the form of transfer pricing (Bartelsman and Beetsma, 2003). In addition, it is difficult in practice to design an investment incentive system that is neutral across business assets, tax incentives for new investment may be perceived as unfair by firms that invested under the previous tax system and tax incentives may have a limited effect on investment if they are received by firms in a loss position that must carry forward their benefits without interest. The desirability of the traditional BBRR corporate income tax reform is thus open to question, and we attempt to shed some light on this difficult issue by simulating its economic effects.

We extend our model in several ways in order to evaluate the arguments outlined above. (i) We account explicitly for a wide variety of business tax expenditures, including rate-reducing preferences, production incentives, investment incentives, and lump sum deductions, as described by the Joint Committee on Taxation (2008), modeling in detail how their elimination would affect the cost of capital in the corporate and non-corporate sectors. (ii) In order to account for the taxation of economic rents, we extend the model to include an imperfectly competitive sector in which investments permanently earn above normal returns.[20] This is accomplished by splitting the corporate sector into two production sectors — a perfectly competitive sector characterized by normal returns and

[20] Note that, in contrast to the basic model, the extension to an imperfectly competitive sector implies that the initial equilibrium is characterized by inefficiencies other than those related to taxes and a reallocation of resources from the imperfectly competitive sector will generate an efficiency gain.

an imperfectly competitive corporate sector characterized by above-normal returns, even in the long-run steady-state equilibrium. The above-normal returns in the imperfectly competitive sector are assumed to reflect a fixed markup of the price of the goods produced in that sector. The extent of imperfect competition in the US economy — and thus the appropriate way to model the corporate sector — is of course a subject of much debate. We assume that the imperfectly competitive sector consists of large multinational corporations, which account for slightly over 20% of the US economy; also, following Bayoumi *et al*. (2004), we assume a price markup of 20%. Second, to examine the effects of corporate tax reform on international capital flows (including into the imperfectly competitive sector), we adopt an approach used by Goulder *et al*. (1983) and assume that the elasticity of supply of international capital with respect to the difference between the US and world rates of return is constant; based on the discussion in Gravelle and Smetters (2006) we make the relatively conservative assumption that this elasticity is unitary. (iii) In order to capture the benefit of a lower statutory corporate income tax rate in reducing incentives for income shifting abroad by US multinationals, we assume that one-half of the static revenue reduction in the imperfectly competitive sector that would occur with a rate reduction in the absence of income shifting is offset by reduced income shifting abroad.

We perform numerous simulations of a BBRR corporate income tax reform within the context of this expanded version of the DZ model, focusing on the macroeconomic effects of reform, especially the effects on long-run GDP (rather than aggregate efficiency gains or losses); the results of several of these simulations are reported in Table 11.5. We begin with a pure BBRR reform that eliminates all business tax expenditures (nearly $100 billion) using all the revenues for rate reduction. This reform allows a reduction in the corporate rate from 35% to roughly 20% in the long run. The effects of such a reform on GDP, however, are moderately negative in the long run, as GDP decreases by 0.56%. This reflects the classic problem with a BBRR reform of the corporate income tax: the combination of reducing the rate and eliminating tax expenditures (the vast majority of which are assumed to reduce the cost of capital at the margin in our analysis) has roughly offsetting effects on the incentives for new investment, but the rate reduction reduces revenues on income earned by existing capital. The resulting relatively large statutory rate implies a higher effective tax rate on capital, reducing investment, the capital stock, labor productivity, wages and labor supply, generating a long reduction in GDP.

These negative macroeconomic effects are exacerbated when an imperfectly competitive sector is added to the model, as the corporate rate reduction applies to the above-normal returns earned in this sector, further driving down revenues and thus further limiting the rate reductions that can be achieved with a revenue neutral reform. In this case, the corporate tax rate falls to 21.9% in the long run and GDP falls by 0.84%.

Table 11.5 Simulation results: corporate income tax rate reduction (% changes in variables)

	Years after reform					
	2	**5**	**10**	**20**	**50**	**150**
Benchmark case: base broadening						
GDP	0.08	−0.01	−0.14	−0.30	−0.51	−0.56
Capital stock	−0.19	−0.64	−1.15	−1.72	−2.22	−2.35
Investment	−2.57	−2.65	−2.76	−2.81	−2.95	−2.99
Labor supply	2.1	2.1	2.1	2.0	2.1	2.1
Consumption	0.26	0.03	−0.19	−0.33	−0.17	−0.14
Base broadening with imperfectly competitive sector, foreign capital flows and income shifting						
GDP	0.07	−0.04	−0.20	−0.40	−0.60	−0.63
Capital stock	−0.01	−0.83	−1.42	−1.66	−2.00	−2.05
Investment	−2.08	−2.48	−2.84	−2.85	−2.94	−2.95
Labor supply	−0.09	−0.12	−0.13	−0.11	−0.10	−0.10
Consumption	0.30	0.00	−0.21	−0.29	−0.15	−0.16
Base broadening to reach 25% rate, keep accelerated depreciation and 80% investment credits						
GDP	0.09	0.20	0.31	0.48	0.60	0.62
Capital stock	0.22	−0.03	−0.09	0.27	0.46	0.51
Investment	−0.34	−0.24	−0.11	0.36	0.45	0.48
Labor supply	−0.02	−0.04	−0.04	−0.03	−0.04	−0.04
Consumption	0.16	0.04	−0.01	0.12	0.59	0.80

As discussed above, several factors might mitigate these negative macroeconomic effects of a BBRR reform. However, these effects are fairly modest in our simulations. In principle, allowing for an elastic supply of foreign capital might increase the amount of reform-induced investment, especially in the imperfectly competitive sector where above-normal returns would be taxed at lower rates. However, the net effect of the reform on after-tax interest rates is very small, as the negative effects of eliminating tax expenditures that benefit capital investment roughly offset the beneficial effects of the rate cut. This in turn implies that changes in capital inflows and outflows, which are assumed to be determined by differences in relative after-tax interest rates, are similarly very small. As a result, 'opening up' the economy has virtually no effect on the results.

Somewhat more positive results occur when reform-induced reductions in income shifting are added to the model, which result in higher revenues at each tax rate. For example, in the version of the model with an imperfectly competitive and a closed economy, adding income shifting results in a long-run decline in GDP of 0.63% (rather than 0.84%).

These results may appear to be surprising, given the negligible or slightly positive effects on GDP from a BBRR reform reported by the US Department of the Treasury (2007). Although our analyses differ in numerous respects, the most important difference is that the Treasury analysis is based on the questionable assumption that all tax expenditures other than accelerated depreciation have no effects on marginal investment decisions, i.e. they do not affect the cost of capital and thus the level of investment. For purposes of comparison, we perform a simulation in which we follow Treasury in assuming a perfectly competitive, closed economy with no income shifting. In this case, the effects of eliminating all business tax expenditures and lowering the corporate tax rate are, unsurprisingly, much more positive, as GDP increases in the long run by 0.52%. However, when we extend the model to include an imperfectly competitive sector, foreign capital flows, and the income shifting response, the long-run increase in GDP declines to 0.20%.[21]

To sum up, our simulations of the economic effects of a traditional BBRR reform suggests that it results in modest declines in long-run GDP, even when one takes into account the taxation of economic rents in an imperfectly competitive sector, the possibility of international capital flows, and the potential for reduced income shifting due to a lower statutory corporate tax rate in the US. However, it is important to stress that our simulations do not fully capture one of the key benefits of a BBRR reform — the improved allocation of capital across industries within the corporate and non-corporate sectors due to the elimination of tax preferences for certain industries. Thus, one could interpret our results as suggestive of the magnitudes of the efficiency gains that would need to be obtained from such reallocations of investment and capital to generate long-run increases in economic growth.

11.4.4 Implementing a VAT for deficit reduction

All of the tax reforms considered thus far have been revenue neutral, raising the same amount of revenue as the current income tax system. However, much recent attention has been focused on the unsustainable fiscal imbalance faced by the US under currently projected spending and tax policies. For example, Auerbach and Gale (2011), drawing on the recent report of the Congressional Budget Office (2011) as well as the latest projections by the actuaries of the Social Security and Medicare programs, estimate that federal deficits will be in excess of 6% of GDP by late in the decade even with a relatively strong economy, with the debt—GDP ratio approaching 100% by 2021. The long-term budget outlook is even worse. Although the magnitude of the long-term fiscal imbalance depends on a wide variety of factors, especially the pattern of healthcare spending, Auerbach and Gale estimate that even under the most optimistic assumptions, the long-term fiscal gap, defined as the immediate and permanent increase in taxes or reduction in spending required to maintain the long-term debt—GDP ratio at its current level, will be between 6% and 7% of GDP. These projections demonstrate clearly that the US faces

21 We also show that greater GDP growth can be obtained with more carefully designed BBRR reforms, including (i) focusing on eliminating only rate-reducing, production, and lump-sum tax preferences, rather than direct investment incentives, and (ii) replacing the revenues lost with corporate tax rate reduction with higher taxes on wages.

fiscal problems of unprecedented proportions and that dramatic actions must be taken relatively quickly to avoid a catastrophic outcome (Burman *et al.*, 2010).

The reports of several recent commissions focusing on deficit and debt reduction, including the report of the National Commission on Fiscal Responsibility and Reform (the Bowles–Simpson report) and the alternative proposed by the Bipartisan Policy Center's Debt Reduction Task Force (the Rivlin–Domenici plan), have examined potential solutions to these fiscal problems. Although they differ considerably in their details, both reports recognize that additional tax revenues are assuredly going to have to play some role in solving our nation's looming fiscal problems, even if this role is secondary to spending reductions and cost-saving reforms of the Social Security, Medicare, and Medicaid programs (Diamond and Zodrow, 2011).

One often-cited proposal for partially addressing the deficit and debt problems in the US is the enactment of a new federal VAT — not as a substitute for the existing income tax as in the proposals for fundamental tax reform discussed above, but as an 'add-on' tax designed to reduce the deficit and, over time, the debt. Cline *et al.* (2010) examine the effects of such a policy using the DZ model.

We make several modifications to the basic model (which in this case assumes a target bequest) to facilitate the analysis of a deficit-reducing add-on VAT. Most importantly, we add government debt. In a steady-state equilibrium in the model — both before enactment of the add-on VAT and once the economy has fully adjusted to the VAT — the debt must grow at the steady-state growth rate of the economy; in this analysis, the model assumes a fixed population growth rate of 1.1% and a fixed productivity growth rate of 2.3%, which equal the average population and productivity growth rates in the US over both the past 50 and the past 20 years (Council of Economic Advisors, 2010). Thus, federal government debt owned by the public must grow at a 3.4% rate to maintain a constant ratio of government debt to GDP in the steady state. This in turn implies that the steady-state annual increment in the debt — the government's annual budget deficit — must equal the product of the growth rate and the steady-state level of debt.

However, the model can accommodate annual deficits and debt levels that differ from steady-state values during the transition period following the enactment of the add-on VAT. In the simulations, we assume an initial steady state with 2007 as our benchmark year and then superimpose on that year a relatively large steady-state debt of roughly 90% of GDP — as predicted by Congressional Budget Office (2010) to occur by 2020 under the Obama administration proposals — which in turn implies a steady-state deficit of 3.1% of GDP. We then introduce an add-on VAT that raises roughly 2.0% of GDP and thus, at least initially, reduces the deficit from approximately 3.1%–1.1% of GDP; the exact amounts of deficit reduction vary primarily because interest payments on the debt decline as the reduction in the deficit reduces debt accumulation.

We maintain this deficit-reducing VAT for 20 years, during which time the debt–GDP ratio declines by roughly 2–3 percentage points of GDP per year, until it reaches a level roughly half of the initial level, declining from roughly 90% to about 45% of GDP. At this point, we have to 'close' the model so that we can return to a steady-state equilibrium, i.e. we cannot continue to reduce the debt–GDP ratio indefinitely and reach a steady state, and instead have to alter fiscal policy to ensure that the deficit is consistent with a steady-state debt of 45% of GDP, which implies a steady-state deficit of roughly 1.5% of GDP.

Although this could be done in many ways, we close the model 20 years after the enactment of the VAT by increasing government transfer payments, by roughly 3.3% of GDP, to achieve the steady-state level of the deficit. This seems to be a reasonable approach, given projected increases in government transfers through the Medicare, Medicaid, and Social Security programs; in particular, we assume that these transfers are distributed uniformly on a *per capita* basis, which could be argued as corresponding roughly to the effects of a deficit-financed increase in the Medicare program. Thus, the 'add-on VAT' in the model is best interpreted as financing an approximate halving of government debt relative to GDP and then financing an increase in transfer payments that are distributed on a lump-sum basis. Our simulation results calculate the economic and distributional effects of this specific add-on VAT, relative to a baseline equilibrium in which the debt–GDP ratio is constant at 90% and the deficit–GDP ratio is constant at 3.1%.[22]

We examine several different VAT structures in our analysis, which differ in the broadness of the base and the existence of a means-tested rebate. In principle, a VAT should include all personal consumption expenditures and exclude all investment purchases, with any distributional concerns regarding the effects of the taxation of necessities addressed with a VAT rebate in the form of means-tested income transfers that refund VAT paid on consumption purchases by the poor. In practice, even in the presence of rebates, the VAT base is seldom applied to all consumption expenditures, with a variety of goods excluded from the base or given rate preferences, typically to relieve the tax burden on the poor; in addition, for social reasons, tax is often reduced or eliminated on goods such as food consumed at home, education or health care services. In our analysis, we follow Toder and Rosenberg (2010) in considering two potential bases for a US VAT – a 'Broader' base that includes all of personal consumption that might reasonably be expected to be subject to tax and includes approximately 73% of all consumption, and a 'Narrow' base that includes several additional exemptions and includes roughly 46% of consumption. We also consider a rebate that would refund tax paid on the poverty level of consumption and phases out as household income increases.

22 Note, however, that the analysis assumes that a debt–GDP ratio of 90% is sustainable in the long run, which very well may not be the case. Our analysis thus does not capture the perhaps significant benefits of moving from an unsustainable situation to a sustainable growth path.

Table 11.6 Simulation results: effects of add-on value-added tax (% changes in variables)

	Years after reform					
	2	**5**	**10**	**20**	**50**	**150**
Broader base VAT						
GDP	−0.12	−0.04	0.20	0.69	1.34	1.43
Investment	3.40	4.05	5.34	6.97	8.36	8.25
Employment/aggregate labor	−0.64	−0.63	−0.62	−0.64	−0.79	−0.82
Consumption	−1.08	−1.17	−1.24	−1.09	−0.71	−0.58
Debt−GDP	91.24	85.83	75.81	55.24	54.89	54.84
Narrow base VAT						
GDP	−0.12	−0.03	0.20	0.68	1.32	1.42
Investment	3.52	4.12	5.37	6.97	8.34	8.23
Employment/aggregate labor	−0.63	−0.62	−0.62	−0.63	−0.78	−0.81
Consumption	−1.11	−1.19	−1.26	−1.10	−0.73	−0.59
Debt−GDP	91.21	85.86	75.96	55.60	55.25	55.20

The results of our simulations, which are shown in Table 11.6, can be summarized as follows. With respect to macroeconomic effects, the VAT reduces the need for deficit finance by roughly 2% of GDP over a 20-year period in which the debt is roughly cut in half, with the deficit-reducing effect magnified over time with the decline of the debt and the associated reduction in government interest payments. Most of the private saving in the model that formerly was allocated to government bonds and used to finance government consumption or transfer payments is now diverted to private saving and used to finance investment. As a result, investment surges, as the classic ‘crowding out’ effect of government debt is reversed.

This effect is reinforced by (i) the eventual decline in interest rates that occurs because the government’s demand for debt is reduced, which in turn reduces the cost of capital, (ii) the decline in income tax rates that occurs because government revenue needs decline as interest payments decline with the reduction in the level of government debt and (iii) the fact that the VAT discourages consumption relative to saving.[23] At the same time, the government expenditures that were formerly financed with debt are now financed with the consumption-based VAT, which is assumed to be fully shifted forward as higher consumer prices.[24] As a result, private consumption falls. Moreover, by

23 This pattern is also reinforced in the short run to the extent that elderly owners of capital, who have a relatively high propensity to consume in their retirement years, suffer a windfall loss due to the implementation of the VAT, as the real value of their capital assets declines due to VAT-induced increases in consumer prices.

24 In our view, this is the most reasonable assumption regarding the incidence of the VAT; see Zodrow et al. (2011) for further discussion. Note that we adjust transfer payments for the VAT so that their real value is held constant, i.e. the VAT is increased to both cover this increase in transfer payments and reduce the deficit by 2% of GDP.

increasing consumer prices, the VAT reduces the real wage, causing labor supply to fall. Whether these negative effects on consumption and labor supply are offset in the long run depends on the strength of the investment effect; in any case, overall GDP is likely to increase in the long run due to efficiency gains, as the increase in investment is larger than any reduction in consumption. These effects, however, are secondary — the primary effect of the add-on VAT is to increase private saving and investment at the expense of private consumption by substituting government revenues that come from a consumption-based tax for revenues that were raised with deficit finance. Finally, 20 years after enactment of the VAT, government transfer payments are increased on a *per capita* basis to increase the deficit to the 1.5% of GDP level consistent with a steady-state debt of about 45% of GDP. This increases consumption, but also reduces labor supply as it has purely an income effect, increasing the demand for leisure.

With respect to distributional effects, a VAT tends to be regressive relative to annual income since consumption is a larger fraction of annual income for the poor, although this effect is mitigated by the rebate, and to a much smaller extent, any exemptions under the tax. Moreover, the VAT is less regressive when measured with respect to lifetime income, the approach we take in our analysis. This occurs because consumption and thus VAT paid relative to income is higher during youth and in old age, when income is relatively low, than it is during the prime saving years of middle age, when income is relatively high and consumption and VAT paid are relatively low; these factors imply that any annual snapshot of the incidence of a consumption-based tax relative to income will overstate regressivity, relative to our measure, which compares lifetime taxes to lifetime income (Fullerton and Rogers, 1993).

Within this context, the incidence of the VAT in our model is determined primarily by three factors. (i) As a consumption-based tax, the burden of the VAT in isolation is slightly regressive in a lifetime context (due to difference in bequest motives), but this regressivity is largely or fully offset by the rebate and, to a much smaller extent, by any exemptions. As a result, the VAT tends to be moderately progressive over the lower and middle lifetime income ranges. (ii) VAT-induced changes in interest rates have a large effect on the distribution of the burden of the VAT policy. Individuals who are near death benefit significantly from the initial short-run increase in the interest rate since it has a large positive impact on the income from their assets. Over time, however, interest rates decline, which has a negative effect on the wealthy — an effect that dominates the direct effect of the VAT, since interest rates in the simulations eventually decline by roughly a quarter. As a result, wealthy individuals who are elderly at the time of enactment of the VAT tend to benefit, but wealthy individuals who are younger tend to be hurt by the reform. (iii) The significant increase in government transfers that occurs 20 years after the enactment of the VAT (that we have chosen to close the model to return it to a steady-state equilibrium) tends to drive the incidence results for those who live long enough to benefit from the transfers. As the transfers are distributed on a *per capita* basis, they disproportionately benefit the poor and make the 'VAT plus eventual increase in transfers' policy quite progressive.

We close by reporting some of the detailed results for our simulation of the effects enacting the 'Broader' VAT with a means-tested rebate. Consumption falls immediately, by 1.4% initially, with the declines gradually increasing in absolute value, to 1.7% 10 years after enactment, and then declining moderately to 1.3% in the long run, reflecting the effects of VAT-induced capital accumulation. As described above, this decline in consumption is accompanied by an increase in investment, as private saving is diverted from purchases of government debt to private investment. Investment initially increases by 4.5% and gradually continues to rise, with an ultimate increase of 10.1% in the long run. Labor supply falls due to the reduction in the real wage, with declines of 0.6% in the short run, and 0.8% in the long run. Nevertheless, GDP still rises after enactment of the VAT, as it initially increases by slightly less than 0.3% and then gradually continues to rise, with an increase of 1.4% in the long run.

Over the 20 years of deficit reduction, government debt falls from 93.5% to 46.3% of GDP, while the deficit falls from 3.2% to 1.9% of GDP initially, and then turns to a slight surplus, before jumping to its steady-state value of 1.5% of GDP 20 years after enactment of the VAT when *per capita* transfers increase by 3.4% to close the model. Although the interest rate initially increases, from 5.4% to 6.4%,[25] the increase in the supply of private saving available for private investment quickly puts downward pressure on the interest rate, which declines to 5.1% 5 years after enactment of the VAT and to 4.1% in the long run.[26] The decline in interest rates, when coupled with the decline in debt, implies that interest payments on the debt fall considerably, enhancing the amount of deficit reduction obtained under the VAT. Specifically, interest on the debt rises initially from 5.0% to 6.0% of GDP, but quickly falls to 4.4% of GDP 5 years after enactment and to 1.9% of GDP in the long run.

The distributional analysis of the broad-based VAT with a rebate (Figure 11.1) shows the net effects of the three primary factors determining incidence in the model discussed above (the direct effects of the VAT, the indirect effects on interest rates and the eventual increase in transfers 20 years after enactment of the VAT). Note first that the very wealthy and very elderly benefit primarily from the initial reform-induced increase in interest rates; for example, for individuals of economic age 54 at the time of reform, the 11th income group experiences a gain of 3.0% of remaining lifetime

25 The initial increase in the interest rate reflects two purely transitional factors: a short period of time during which existing capital earns above-normal rents due to costs in adjusting the capital stock to its new higher level and anticipated capital gains as the value of the capital stock initially declines due to the enactment of a consumption-based tax that favors new capital over capital (which is assumed not to receive any transitional relief, e.g. in the form of expensing of existing basis), but then increases in value with time. For further discussion, see Zodrow (2002) and Auerbach and Kotlikoff (1987).

26 Note that these figures reflect the before-tax interest rate on debt in the model; in this version of the model, we incorporate an equity premium of 5%, following Goulder and Summers (1989).

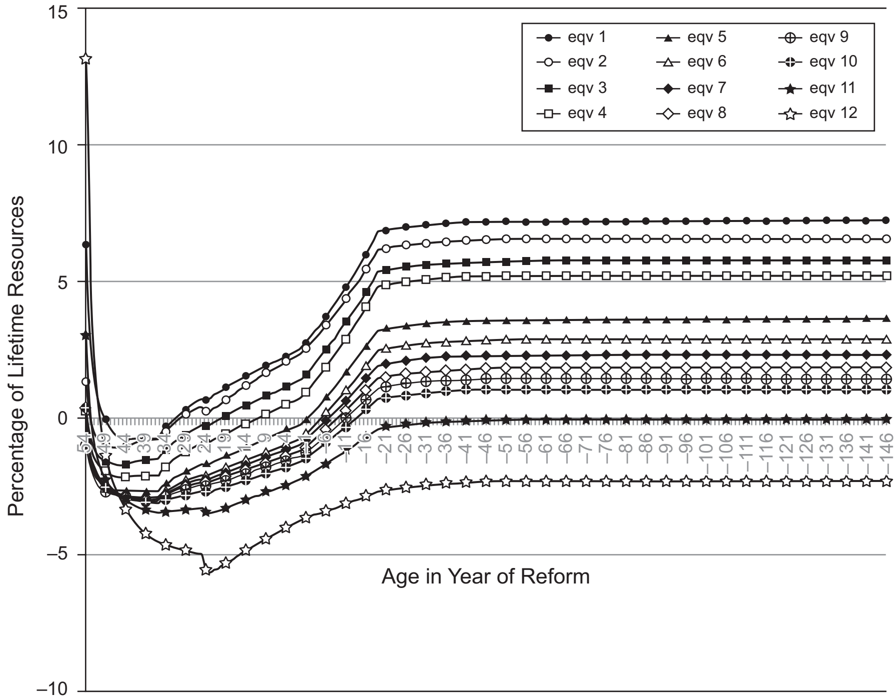

Figure 11.1 Distributional effects of a broader-base VAT with a rebate. *(Source: Authors' calculations based on results presented in Carroll et al. (2010).)*

resources and the 12th income group (the top 2%) experience an increase of 13.1% of lifetime resources. At the same time, individuals of age 54 in the first four income groups also benefit from reform, primarily because their government transfers are fully indexed and they receive VAT rebates, and also because their assets, while small in absolute terms, are large relative to income so that they benefit from the initial increase in the interest rate.

These positive effects, however, diminish rapidly as individuals live longer after reform. For example, for individuals age 51 at the time of reform, the poorest group benefits slightly (0.5% of remaining lifetime resources) and the incidence of the tax is progressive throughout lifetime income group 6, but then turns regressive due to the lingering effects of the initial increase in the interest rate. By comparison, for individuals of age 46 at the time of enactment, the incidence of the tax is progressive for the low- and high-lifetime-income groups, and roughly proportional for the middle-income groups, with losses ranging from 0.7% of remaining lifetime resources for the lowest income group to 2.8% of lifetime resources for the highest income group. Looking at an even younger group — those age 35 at the time of enactment — the tax is progressive over the entire income range except for the first two income groups (although it is still roughly proportional for the middle-income groups) with losses ranging from 0.5% of remaining lifetime resources for the lowest income group to 4.6% of lifetime resources for the highest income group. Once individuals start receiving transfers 20 years after enactment of reform (those of age 34 or less), the net effect of the fiscal policy on the low-income groups is more likely to be positive, while middle- and upper-income groups still lose from reform. In the long run, the capital accumulation benefits of the VAT increase wages modestly. For example, for individuals born 10 years after reform, individuals in the first eight income groups benefit from reform, while individuals in the top four groups are net losers, with the gains ranging from 4.2% of lifetime resources to −3.2%. In the long run, only the top two income groups lose from the reform and the tax policy is progressive at all but the very lowest income levels, with the gains ranging from 7.2% to −2.3% of lifetime resources.

In summary, our analysis provides several insights regarding the effects of implementing an add-on VAT for deficit reduction. Most importantly, it shows that reducing the deficit is a difficult task, even if the instrument used is a relatively efficient tax. The use of an add-on VAT diverts private saving from government debt to private investment and is successful in reducing the deficit and ultimately the level of debt, reducing interest rates and increasing private saving. However, these benefits come at the cost of reducing consumption in both the short run and, to only a slightly smaller extent, in the long run. Moreover, the reduction in the real wage associated with the VAT reduces labor supply, again both the short run and, to a slightly smaller extent, in the long run. These are simply costs associated with using a consumption-based tax to replace deficit-financed government spending. In addition, although most individuals ultimately benefit from the VAT reform, these benefits are long delayed, accruing primarily to those not yet alive at the time of reform — a result that demonstrates the political difficulty of dealing with the deficit problem.

The enactment of a VAT is also often believed to problematical from a distributional standpoint. Our simulation results suggest that this concern is largely misplaced, as long as the VAT includes a rebate designed to relieve its burden on the poor. Indeed, because the replacement of deficit finance with the VAT reduces interest rates over time, much of its burden is borne by the wealthy.[27]

Our results are generally consistent with a recent study by the International Monetary Fund (2010), which provides both empirical and simulation evidence that fiscal consolidation has a negative macroeconomic impact in the short run. However, the International Monetary Fund study suggests that the fact that we assume a closed economy to simplify our analysis implies that our results may overstate the increases in

[27] Results not reported confirm the conventional wisdom that the use of an income-conditioned rebate is superior to using VAT exemptions to protect the poor; indeed, to a first approximation, the distributional benefits of the broad-based VAT with a rebate can be matched by a narrow-based VAT only if also includes a rebate.

domestic investment that would occur with an add-on VAT. In an open-economy context, some of current and projected future deficits are financed with borrowing from abroad, which is associated with a trade deficit. Introduction of the VAT would reduce the government deficit, thus increasing national saving and reducing the need to borrow abroad. However, some of the reduction in the deficit would be reflected in an improvement in the trade balance, i.e. an increase in net exports rather than an increase in domestic investment; thus, domestic investment would increase less (and interest rates would decline less) than under our closed-economy scenario.

11.4.5 Macroeconomic effects of tax cuts and the financing decision

Tax cuts are often adopted with no explicit provisions for offsetting the resulting revenue losses, with the most recent examples being the Bush administration tax cuts enacted in 2001 and 2003. In this section we discuss several studies that use OLG-CGE models to analyze the effects of such tax cuts, including some using the DZ model.

11.4.5.1 Overview

The decrease in revenue from deficit-financed tax cuts initially increases the stock of government debt. However, the government's infinite-horizon budget constraint requires that measures must ultimately be adopted to service or retire that debt. Deficit-financed tax cuts have been controversial, with supporters highlighting the beneficial economic effects from reductions in distortionary taxes and opponents stressing the adverse economic effects of deficits.

In view of these conflicting economic effects, the assessment of deficit-financed tax cuts requires an estimate of the magnitudes of their various effects, including their impacts on output, consumption, labor supply and the capital stock. In addition, it is important to examine the impact of deficit-financed tax cuts on the welfare of various generations in an overlapping generations framework, and OLG-CGE models offer a natural way to obtain such estimates. As noted above, Auerbach and Kotlikoff (1987) is the pioneering work in the use of OLG-CGE models to examine the effects of deficit-financed tax cuts, as they analyze the effects of broad-based income tax cuts that last 1, 5, and 20 years, followed by income-tax increases that maintain the debt–output ratio stabilized at its new, higher level. A number of other studies have also examined the impact of deficit-financed tax cuts.[28] In general, these studies find that both the form of

[28] The Office of Tax Analysis, US Department of the Treasury (2007), the Joint Committee on Taxation (2006) and the Congressional Budget Office (2007) have all produced estimates of the effects of deficit-financed tax cuts. The Office of Tax Analysis, US Department of the Treasury (2006) uses a version of the DZ model, among others, to examine the permanent extension of the 2001 and 2003 tax cuts. The Joint Committee on Taxation (2006) also uses the DZ model to consider a rate reduction in individual income taxes accompanied by base-broadening measures, assuming two different offsets to finance the deficit, one involving changes in transfer payments and the other involving changes in individual income tax rates.

the initial tax cut and the financing method matter. An increase in steady-state output is most likely if the initial tax cut is targeted toward marginal-rate reduction, if the financing method does not raise marginal rates and has income effects that encourage work (with transfer payment reductions being ideal), and if financing is implemented quickly.

One of the major issues confronting tax policy makers is related to whether the tax provisions in the Economic Growth and Tax Reduction Reconciliation Act of 2001 (EGTRRA) and the Jobs and Growth Tax Relief Reconciliation Act of 2003 (JGTRRA) should be extended permanently. In addition, the Alternative Minimum Tax (AMT) is a subject that has been receiving widespread attention since a large number of taxpayers, including many that earn less than $100,000, will be affected by the AMT in the next several years if changes are not enacted.

The debate over permanent extension of EGTRRA and JGTRRA focuses primarily on issues of economic growth, equity, and affordability. Proponents of permanently extending the tax cuts argue that a permanent reduction in tax rates will increase individual incentives to work and save. They argue that if the extension of the 2001 and 2003 tax packages were combined with tight spending controls, then the tax-induced economic growth and the reduction in the growth of spending would reduce the size of the deficit relative to GDP to a sustainable level. The opponents of permanently extending the tax cuts argue that given the current US budget deficit the tax cuts are unaffordable. They contend that the tax cuts are unlikely to increase economic output because larger deficits would lead to higher interest rates and debt-servicing costs, thereby offsetting the potential long-run gains from tax-induced increases in labor supply and personal saving. Given this, they believe that extending the tax cuts would be detrimental to the government's ability to solve other pressing budget issues, such as the need to reform the AMT and deal with the predicted budget shortfalls related to demographic changes in the population. In addition, many of the opponents believe that the tax cuts are unfairly distributed, with most of the benefits accruing to higher income taxpayers.

Auerbach (2002) examines the effects of extending the 2001 and 2003 tax cuts. He considers a somewhat different policy experiment than most other studies, which generally assume permanent tax cuts and then add a financing mechanism to pay for the tax cuts. (Of course, when the financing mechanism is a tax rate increase, layering on the tax increase effectively undoes the tax cuts in whole or in part.) Following Auerbach and Kotlikoff (1987), Auerbach instead considers experiments in which the 2001 and 2003 tax cuts last 10, 15, or 20 years before expiring, after which the debt–output ratio is stabilized using either increases in wage taxes or capital income taxes. Output increases while the tax cuts are in effect, but falls after the tax cuts expire. The long-run output decline is greater when the tax cut lasts longer, causing more debt to be accumulated, and when the financing is done through higher taxes on capital income. These negative effects are diminished if government purchases are reduced during the time the tax cuts are in effect to offset part of the revenue loss.

11.4.5.2 Diamond (2005) analysis

Diamond (2005) uses the DZ model (with a target bequest motive) to simulate the impact on the federal deficit and economic growth of permanently extending most of the provisions in EGTRRA and JGTRRA, assuming that the baseline is present law modified to include AMT relief.[29] In 2005, permanently extending the 2001 and 2003 income tax cuts roughly corresponded to a delayed tax cut on labor income since the bulk of the reduction in income tax rates would have occurred after 2010. The capital income tax cuts were also delayed since the tax rate reductions on dividends and capital gains were effective for taxable years beginning after 2008, and the most significant tax rate reductions on interest income and non-corporate business income would have occurred for taxable years after 2010.

In addition, an offsetting federal fiscal policy must be assumed to achieve a constant debt–GDP ratio in the long run. There are an infinite number of fiscal policies that could achieve this goal, and the choice of policy has an important effect on the simulation results. The three main fiscal policy responses considered by Diamond are: (i) a cut in government transfer payments after 10 years that achieves a constant debt–GDP ratio, (ii) an increase in federal income taxes after 10 years that achieves a constant debt–GDP ratio and (iii) a federal fiscal policy that assumes the growth in real discretionary government spending increases at the population growth rate instead of the growth rate of real GDP (under this assumption an additional offsetting income tax adjustment may also be necessary to achieve a constant debt–GDP ratio). The first two scenarios are often assumed by the Joint Committee on Taxation and Congressional Budget Office in analyses of the effects of changes in tax policy. Feldstein (2004) suggests a policy similar to the third fiscal policy alternative in a commentary that supported permanent extension of the 2001 and 2003 tax cuts. By comparison, the Joint Committee on Taxation (2003) and Congressional Budget Office (2003) assume that changes in income tax rates or government consumption (or transfer payments) are implemented after 2014 – the end of the federal budget window – to insure a stable long-run equilibrium growth path.

29 The percentage changes in the average and marginal tax rates for different sources of taxable income are calculated using the Joint Committee on Taxation's individual tax model. Marginal tax rates are calculated on an income-weighted basis. Tax rates with similar patterns and percentage changes are averaged across adjacent years to simplify the presentation. From 2005 to 2010, the average wage tax rate decreases by 4%, the marginal wage tax rate decreases by 1% and the tax rate on interest income decreases by 2%. From 2011 to 2014, the average wage tax rate decreases by 20%, the marginal wage tax rate decreases by 12% and the tax rate on interest income decreases by 15%. From 2009 to 2014, the dividend tax rate decreases by 54% and capital gains tax rate decreases by 23% (there is no change in dividend or capital gains tax rates before 2009).

Table 11.7 Simulation results: permanent extension of 2001 and 2003 tax cuts with different financing options (% changes in variables)

	Years after reform					
	2005–2009	**2010–2014**	**2015–2019**	**2020–2024**	**2035–2044**	**2095**
Transfer offset after 2014						
GDP	0.1	0.6	0.8	0.9	0.8	0.8
Capital stock	0.1	0.4	0.8	0.9	1.0	0.4
Investment	0.9	1.5	1.4	1.2	0.6	0.4
Labor supply	0.1	0.7	0.8	0.8	0.8	0.9
Consumption	−0.1	0.4	0.6	0.7	0.8	0.8
Transfers increase at population growth rate 2005–2045 then income tax rates adjust						
GDP	0.1	0.6	0.8	0.8	1.2	1.2
Capital stock	0.1	0.5	0.8	0.9	1.0	4.0
Investment	1.0	1.6	1.3	1.1	3.6	4.0
Labor supply	0.1	0.7	0.8	0.8	0.9	1.2
Consumption	−0.1	0.4	0.7	0.8	0.8	2.1

The results of Diamond's simulations are reported in Table 11.7. He finds that permanently extending the 2001 and 2003 income tax cuts assuming that transfer payments are reduced after 2014 would increase employment and output by 0.1% and investment by 0.9% over the 5-year period after enactment. These effects occur because individuals increase saving in response to the lower tax rates and to offset the decrease in transfer payments in 2014 and thereafter.[30] In the long run, the permanent extension of the tax cuts increases employment and output by more than 0.8% relative to the baseline. In the long run, the capital stock increases by 0.7% and private consumption increases by 0.8%.

Beginning in 2015, transfer payments, which are 4.4% of GDP in the baseline, are reduced by roughly 44% to reach a stable fiscal policy. The remaining items that make up government spending are held constant at their baseline levels, except for net interest payments, which increase from 2 to 2.5% of GDP in the long run. This policy increases the debt-GDP ratio from 38% in 2005 to 47% in 2014 and beyond. Net interest payments increase by roughly \$70 billion in 2014. A \$262 billion reduction in real transfer payments is necessary to hold the debt-GDP ratio constant in 2015. This corresponds to a change in all real non-interesting outlays of \$314 billion.

The net welfare effects, however, paint a much different picture than do the aggregate macroeconomic variables, such as GDP, labor supply, and investment. The net welfare effects show that current old and future generations would suffer a net welfare loss if the

[30] Note that individuals are fully aware of the pending cut in transfer payments under the assumption of perfect foresight.

2001 and 2003 tax cuts were permanently extended and transfer payments were cut after 2014. The oldest six generations (of economic ages 49–55) at the time of enactment would experience a net welfare change of −0.2% to −0.5% of remaining lifetime utility. Current young and middle aged generations would experience a net welfare gain ranging from 0.1% to 0.3% of remaining lifetime utility, with the largest net welfare gains occurring for individuals of economic age six (or roughly 30 years old) in the year of enactment. Generations born more than eight years after enactment would experience a net welfare change ranging from −0.1% to −0.4% of lifetime utility. These welfare losses demonstrate the negative effects of the larger federal deficits that occur before the enactment of offsetting fiscal policy actions in 2014. If the fiscal policy response occurred in 2005, the net welfare effects would reflect gains that range from 0% to 0.4% for all generations that are younger than age 24 at the time of enactment. The labor supply responses are roughly equivalent whether the fiscal policy response occurs immediately or is delayed for 10 years. However, the investment response when the fiscal policy response is delayed is mitigated considerably. For example, in the long run, investment increases by 3.2% with an immediate fiscal policy response rather than 0.4% if the fiscal policy response is delayed 10 years. This shows the importance of enacting offsetting fiscal policy responses in a timely manner.

Diamond also shows the effects of permanently extending the 2001 and 2003 income tax cuts assuming that increases in income tax rates are enacted in 2014 to reach a stable fiscal policy. In this case, employment increases in both the short and long run. In the short run, households supply more labor because tax rates are expected to increase in the future.[31] In the long run, households must work more to maintain the same level of consumption since the burden of increased debt service costs and the reduction in the private capital stock reduces after-tax disposable income. The capital stock declines by 1.2% relative to the baseline as a result of government debt crowding out private capital.

Because the fiscal offset is not enacted until after 2014, government debt increases in the period from 2005 to 2014, as tax revenues are reduced and government expenditures net of interest payments are unchanged relative to the baseline values. The debt–GDP ratio increases from 38% in 2005 to 47% in 2014. Net interest payments on the debt increase as the government accumulates more debt, although a decline in the interest rate in the first 5 years mitigates this effect slightly in the short run. Households increase private consumption immediately by effectively borrowing from future generations. Household consumption of private goods would be roughly constant after 2020 as the increase in income tax rates, lower wage rates, and an increase in labor supply would have offsetting effects on disposable income. Current young and middle-aged generations receive small welfare benefits from the extension of the tax cuts, while older and future

31 This result is similar to the behavioral response to a delayed tax cut found in House and Shapiro (2006).

generations suffer a net welfare loss. The net welfare loss of future generations is approximately 0.4% of their remaining lifetime utility.

In the 5-year period 2015–2019, income tax rates increase by 16.5% from 2015 to 2019 levels and by approximately 19% thereafter. The net effect of the 2001 and 2003 tax cuts and the income tax increase in 2014 is different for each source of income. The net effect on dividend and capital gains tax rates is a net decrease. Interest income and the general business tax rate increase after 2014 relative to the baseline. In the long run, the marginal tax rate on wages falls by roughly 1% and the average tax rate on wages is unchanged. Thus, this could be viewed as a scenario similar to allowing the tax cuts to sunset in 2010, although the period that federal debt is accumulated would be four years shorter.

Diamond also examines the effect of assuming that the growth rates of real transfer payments and government spending, excluding Social Security and Medicare programs, are equal to the population growth rate for 50 years (after this 50-year period they grow at the growth rate of GDP).[32] In the baseline, transfer payments and government consumption are assumed to grow at the growth rate of GDP, which is determined by the growth rate of the population and technological growth.[33] Thus, this fiscal policy reduces the growth rate of real transfer payments and government spending from 2% to 1% per year for 50 years after the enactment of the permanent extension of the 2001 and 2003 income tax cuts. After 40 years, the income tax rates are allowed to adjust to stabilize the debt–GDP ratio.

The immediate impacts of this fiscal policy on labor supply and GDP are insignificant in the first 5 years after enactment. After that 5-year period, labor supply increases permanently by 0.3–0.5% relative to the baseline. GDP increases in the 15-year period from 2010 to 2024; however, this increase slowly diminishes as the stock of capital declines as the increase in the deficit relative to GDP increases interest rates and thus crowds out private investment. As the effect of moderate spending controls strengthens slowly over time, the deficit is reduced and private investment rebounds. In the long run, permanent extension of the 2001 and 2003 income tax cuts increases investment, labor supply, and GDP. In 2095, the capital stock is 1.7% higher relative to the baseline. Private consumption is higher in every period relative to the baseline.

The reductions in transfer spending and government consumption are equivalent to reductions in real non-interest spending of 6% in 2015, 16% in 2035 and 25% in the long run. The deficit–GDP ratio in the period from 2010–2034 increases above the baseline level as current generations borrow from future generations. In the long run, the

32 The 50-year period is chosen arbitrarily. Periods shorter than 50 years will decrease the gains in economic output and periods longer than 50 years will increase the gains in economic output.

33 However, it is important to note that actual transfer payments and government consumption currently are growing slower than GDP; thus, the offsetting spending cuts will reduce *per capita* spending over time.

debt–GDP ratio is roughly 9 percentage points higher than in the baseline. However, note that the income tax rate adjustment to stabilize the debt–GDP ratio, which occurs 40 years after enactment, reduces income tax rates by an additional 11.3% in the period from 2045 to 2054 and 15.4% in the long run.[34]

The simulation results presented by Diamond (2005) suggest that extending the 2001 and 2003 income tax cuts and reducing the growth rate of government spending, excluding Social Security and Medicare, would increase investment, employment, and output. In this case, the net welfare of the oldest generations alive at the time of enactment would decrease, while the net welfare of future generations would likely increase. By comparison, adopting the other fiscal policy offsets considered would decrease the net welfare of future generations. For, example, increasing future taxes to finance the 2001 and 2003 tax cuts will impose significant net welfare losses on future generations.

11.4.5.3 Diamond and Viard (2008) analysis

Diamond and Viard (2008) also use the DZ model to examine the macroeconomic and welfare effects of several alternative tax cuts under a number of different financing options. The magnitude of the tax reduction is chosen so that the decrease in revenue over the 10-year period following enactment is $500 billion with no behavioral responses. The tax cuts are permanent, unanticipated, and enacted immediately. The three main financing methods, which are announced at the time of enactment, are: (i) government transfers (other than social security benefits) are reduced immediately to finance the tax cut, (ii) government debt is used to finance the tax cut for 10 years and then government transfers (other than social security benefits) are reduced so that government debt grows at the steady-state rate of growth, and (iii) government debt is used to finance the tax cut for 10 years and then all personal income tax rates (wage, interest, dividends, and capital gains) are increased proportionately so that government debt grows at the steady-state growth rate.

Diamond and Viard (2008) simulate the macroeconomic effects of five different tax cuts paired with one of the three financing methods. The five tax cuts examined are a 3.9% reduction in average and marginal wage tax rates, a 22.1% reduction in the effective tax rate on interest income, a 50.6% reduction in the effective tax rate on dividend income, a 12.3% reduction in the effective tax rate on corporate income, and a 41% increase in personal tax credits. Some representative results of these simulations are presented in Table 11.8.

All four of the reductions in distortionary taxes increase long-run GDP when they are offset by an immediate reduction in transfer payments. The increase in GDP is largest for reductions in dividend and corporate taxes, because those taxes are more distortionary.

[34] This tax rate reduction affects wages, interest income, dividends, capital gains and pass-through business entities.

Table 11.8 Simulation results: effects of the financing decision (% changes in variables)

	Years after reform					
	2	**5**	**10**	**20**	**50**	**150**
Wage tax cut with immediate transfer offset						
GDP	0.3	0.3	0.4	0.4	0.4	0.4
Investment − X	0.4	0.4	0.5	0.5	0.5	0.5
Investment − R	0.8	0.8	0.8	0.6	0.5	0.5
Investment − H	0.8	0.8	0.8	0.6	0.5	0.5
Labor supply	0.4	0.4	0.4	0.4	0.4	0.4
Consumption	0.2	0.3	0.3	0.3	0.4	0.4
Wage tax cut with transfer offset after 10 years						
GDP	0.3	0.3	0.3	0.3	0.3	0.3
Investment − X	0.2	0.2	0.1	0.0	−0.2	−0.2
Investment − R	0.5	0.4	0.2	0.0	−0.2	−0.2
Investment − H	0.5	0.4	0.2	0.0	−0.2	−0.1
Labor supply	0.4	0.4	0.4	0.4	0.4	0.4
Consumption	0.3	0.3	0.3	0.4	0.4	0.4
Wage tax cut with tax offset after 10 years						
GDP	0.3	0.3	0.3	−0.1	−0.2	−0.3
Investment − X	0.0	−0.2	−0.7	−1.1	−1.5	−1.6
Investment − R	0.3	0.1	−0.3	−1.3	−1.4	−1.3
Investment − H	0.6	0.5	0.6	−0.6	−0.8	−0.7
Labor supply	0.4	0.4	0.4	0.1	0.1	0.1
Consumption	0.3	0.4	0.4	0.1	0.0	−0.1

X = corporate and non-corporate sector, R = rental housing sector, H = owner-occupied housing sector.

If the tax rate on wage income is reduced, GDP increases by 0.3% in the year of reform and by 0.4% in the long run. If the tax rate on interest income tax is reduced, GDP is unchanged in the short run and increases by 0.1% in the long run. GDP does not increase in the case of an increase in personal tax credits.

With an immediate reduction in transfer payments, the macroeconomic effects of reducing the dividend and corporate tax rates are similar.[35] The before-tax interest rate increases by 24 (48) basis points in the year the dividend (corporate) tax rate is cut and then gradually declines to a level that is 4 (5) basis points higher than in the initial steady state. Under both the dividend and corporate rate cuts, labor supply increases by 0.1% in every year after enactment. Under the dividend (corporate) rate cut, the before-tax wage rate is initially unchanged and increases by 0.7 (0.5)% in the long run as the capital stock increases by 2.7 (2.1)%. Non-housing investment increases by 2.6 (1.9)% in the year of enactment under the dividend (corporate) tax cut. In the long run, investment in the

[35] Recall that the DZ model assumes the validity of the traditional view of the effects of dividend taxation.

non-housing sector increases by 2.7 (2.1)% under the dividend (corporate) rate cut. Investment in the owner and rental housing sectors decreases by 2.3–3.2% in the year of enactment, and is roughly unchanged in the long run. Consumption decreases by 0.1–0.2% in the year of enactment, but increases by 0.3–0.4% in the long run. In this case, cutting the dividend (corporate) tax rate increases GDP by 0.7 (0.5)% in the long run.

When the reduction in transfer payments is delayed by 10 years, however, the long-run effects are less beneficial. In each case, the increase in GDP is diminished by 0.1 or 0.2 percentage points. This implies that the reduction in the tax rate on interest income has no effect or a slightly negative effect on GDP; however, a noticeable increase in GDP still occurs if corporate, dividend, or wage tax rates are reduced. The long-run gains are smaller because the increase in debt crowds out private investment (there is virtually no change in labor supply). Notably, long-run non-housing investment is increased by cuts in wage taxes and interest taxes when the transfer payment cut is immediate, but such investment is reduced in the case of a 10-year deficit financing strategy. The dividend and corporate rate cuts, which are more directly targeted to investment, still increase long-run non-housing investment with 10-year deficit financing, but by significantly less than with an immediate transfer cut to hold the deficit constant.

The macroeconomic effects are much worse if an across-the-board tax increase is enacted after ten years to finance the deficit and increased interest costs. In the long run, GDP is unchanged if the dividend tax rate is reduced, decreases by 0.2% if the corporate tax rate is reduced, decreases by 0.5% if the tax rate on interest income is reduced, and decreases by 0.8% if personal tax credits are increased. Non-housing investment falls in every case, except the dividend tax cut. Long-run labor supply falls in every case, except for the wage-tax reduction. With the across-the-board tax increase used as the method of financing, the distortionary effects of the tax increases reinforce crowding out.

Estimates of the macroeconomic effects of tax policy changes have become an important tool for tax policy analysts in the 2000s. However, macroeconomic aggregates are not always reliable indicators of whether certain policies make individuals better off, are not sufficient to compare alternative policies, and do not allow policy makers to examine the effects of policies across various income or age groups. Diamond and Viard (2008) present estimates of the intergenerational welfare effects of the various policies they examine. They show that welfare gains for the generations alive at the time of reform, assuming that government transfers are cut immediately so that government debt grows at the steady-state rate of the economy, are largest under the corporate rate cut, the dividend rate cut, and the interest income tax cut. With the immediate cut in transfer payments, the well-being of future generations is increased under all of the policies except for the decrease in the tax rate on interest income. Notably, the increase in the well-being of future generations is 4–8 times larger (measured as a percentage of lifetime resources) under a decrease in the wage tax rate than under the alternative tax decreases.

The deficit-financed tax cuts uniformly reduce the well-being of future generations — a result that occurs even though these generations benefit from a more efficient tax system — as deficit financing redistributes income from current generations to future generations. As expected, deficit-financed tax cuts almost uniformly benefit the generations alive at the time of the reform. Diamond and Viard also calculate the intergenerational welfare effects of reducing the wage and dividend tax rates when government transfers are reduced 20 years after the reform rather than 10. In this case, welfare losses are much larger for future generations. For the wage tax cut, the long-run welfare loss is 2% of lifetime resources instead of the 0.08% loss for the 10-year deficit finance approach. For the dividend tax cut, the long-run welfare loss is 2.4% of lifetime resources instead of 0.32%. Confirming the findings of Auerbach and Kotlikoff (1987), these welfare losses increase non-linearly with the period of deficit finance.

Diamond and Viard conclude that deficit-financed tax cuts can increase long-run output if the financing mechanism is less distortionary than the tax that is initially reduced and if the financing begins relatively soon after the tax cut is adopted. Even then, however, the shift in fiscal burdens generally reduces the well-being of future generations while increasing that of current generations.

11.5 CONCLUSION

In this chapter, we have examined the use of dynamic, OLG-CGE models to analyze the macroeconomic and distributional effects of tax reforms, using as a paradigm a model that we have constructed — the DZ model. Although the use of such models is not without controversy — as illustrated by the exchange between Gravelle (2006) and Diamond and Zodrow (2006) — in our view, OLG-CGE models are an excellent tool for illustrating the potential effects of tax reforms in a general equilibrium setting. In particular, OLG-CGE models characterized by perfect foresight are especially well-suited to analyzing both the short-run transitional and the long-run dynamic macroeconomic effects of tax reforms, including the time paths of reform-induced changes in labor supply, saving and investment, as well as the redistributional effects of reforms both across and within generations. Our paper provides both a historical overview of the development of OLG-CGE models for tax analysis and a discussion of numerous applications of such models, using as a paradigm our own DZ model.

Analyses using OLG-CGE models have thus provided policy makers with much useful information for gauging the effects of various tax reforms. However, much remains to be done, especially in terms of treating in a single model all of the issues of most current concern to policy analysts, including complete specifications of international trade and factor flows, involuntary unemployment, business financial decisions, and the role of financial institutions in the world economy. It is clear that OLG-CGE modeling will be a fruitful research area for many years to come.

APPENDIX

In this Appendix, we provide a fairly detailed description of the DZ model. We begin with a discussion of timing conventions, and then consider in turn the behavior of households, firms, and the government, and the nature of the market equilibrium in the model.

A.1 Timing conventions

It will be useful to begin by specifying the timing conventions used in the model, which is constructed in discrete time, with each period reflecting a year. In each period, all flow variables, including labor supply, saving, consumption, investment, and the associated issuance of debt and new equity shares, government spending, taxation, and the accumulation of any deficits, occur at the end of the period. Individual utility levels, which are based on current and future flows of consumption and leisure, are thus calculated at the end of the period, as is the lifetime budget constraint. The prices related to all flow variables are also determined at the end of the period. In contrast, all stock variables, including capital stocks in all four sectors, individual wealth including all asset values, and the stocks of private and public debt are measured at the beginning of the period. That is, stock values at the beginning of a period reflect the effects of the flow values that occurred at the end of the previous period.

Births and deaths occur at the beginning of the period, as do inheritances and bequests. Thus, an individual is of age zero all of the birth period and age one all of the following period. Age a is defined at the beginning of a specific time period t and thus changes with time. For example, an individual of age $a=10$ at the beginning of period $t=1$ is age $a=30$ at the beginning of period $t=21$. In general, individual age is specified with respect to period $t=1$, as the enactment of reform is typically assumed to occur at the beginning of period $t=1$. Since the enactment of reform is assumed to be unexpected, reform affects only consumption C_1, saving S_1 and investment I_1 decisions made at the end of period $t=1$ and thereafter, but has no effect on these values in the initial pretax equilibrium in period $t=0$. Thus, period zero C_0, S_0, I_0, capital stock K_0, asset value A_0 and period $t=1$ capital stock K_1 are all determined in the initial income tax equilibrium. The first postreform values are thus flows C_1, S_1, and I_1, and the capital stock K_2. However, asset values A_1, which are calculated when reform is announced at the beginning of period $t=1$, instantaneously reflects the anticipated effects of the reform.

A.2 Individual behavior

A.2.1 Setting up the life-cycle optimization problem

Individual behavior is modeled using an overlapping generations framework that consists of 55 cohorts, with an exogenous population growth rate n. Individual cohorts alive at the time of reform $t = 1$ are identified by ages that range from $a = 0$ to $a = 54$, as the economic life span, which is assumed to begin at age 23, is known (with certainty) to be 55 years, reflecting an average life expectancy of 78 years. Each individual works for the first 45 years of the 55-year economic lifespan and is retired for the last 10 years. Generations who are unborn at the time of reform $t = 1$ are identified by negative ages.[36]

All individuals share the same utility function. In the multi-income-group version of the model, each generation is divided into 12 different types of individuals, classified by lifetime income, with $\gamma = 1$ representing the bottom 2% of population cohort a in terms of lifetime income, $\gamma = 2$ representing the rest of the first lifetime income decile, $\gamma = 3$ through $\gamma = 10$ representing the next eight deciles by lifetime income, $\gamma = 11$ representing the bottom four-fifths of the top decile, and $\gamma = 12$ representing the top 2% of individuals in the cohort. Each type of individual within a cohort has a unique exogenous endowment of human capital and a 'humped-back' dynamic wage profile over the lifetime.[37]

An individual of age a and lifetime income type γ at the beginning of any period t over the life cycle has assets $A_t(a,\gamma)$ that have been accumulated from the time of 'economic birth' and are used to help finance both consumption over the subsequent years of the individual's lifetime, including during the retirement period and the making of a bequest. Accumulated assets include inheritances received (or the present value of anticipated inheritances), which are assumed to be received at economic age $a = 25$ (actual age $a = 48$). Bequests are given at the time of death (age $a = 55$) and total assets at death $A_t(55,\gamma)$ are just sufficient to fund the bequest $BQ_t(55,\gamma)$, which becomes the inheritance of the recipient $INH_t(25,\gamma)$. Following Altig *et al.* — and consistent with the empirical results of Kopczuk and Lupton (2007) — the model utilizes the 'joy of giving' model of bequests, under which individuals receive utility directly from the making of bequests.[38]

The model assumes that individuals have perfect foresight and optimize over their life cycles. The (remaining) lifetime utility of an individual of age a and lifetime income type γ calculated at the end of period t, $LU_t(a,\gamma)$, is assumed to be a time-separable aggregation of individual utility in each period over the remainder of the life cycle and the bequest, or:

36 For individuals who are not yet born at the time of reform, the t subscript in the expressions derived below should be interpreted as their year of birth.

37 As will be discussed further below, endowments and wages vary across individuals, and individual wages are a multiplicative function of a single economy-wide equilibrium wage. We use the wage profiles estimated by Altig *et al.*, which imply that wages peak around ages 45—50, and the peak wages of the highest income group are approximately 20 times the peak wages of the lowest income group. In the single-income-group version of the model, there is a single value of γ for each generation.

38 One can interpret the joy of giving bequest motive as including the benefits from holding wealth while accumulating resources sufficient to finance the bequest.

$$LU_t(a,\gamma) = \frac{1}{(1-1/\sigma_U)}\left[\begin{array}{l}\sum_{s=t}^{t+54-a}\left(\frac{U_s(a,\gamma)^{(1-1/\sigma_U)}}{(1+\rho)^{s-t}}\right) \\ +\frac{1}{(1+\rho)^{54-a}}[\alpha_B(\gamma)][BQ_{t+54-a}(a,\gamma)]^{1-1/\sigma_U}\end{array}\right], \quad (11.1)$$

where σ_U is the intertemporal elasticity of substitution, ρ is the pure rate of time preference, $U_s(a,\gamma)$ is utility in period s of an individual of age a of lifetime income type γ, $\alpha_B(\gamma)$ is the utility function weight placed on bequests due to the joy of giving bequest motive by an individual of lifetime income type γ and $BQ_{t+54-a}(a,\gamma)$ is the bequest that will be made in period $t+54-a$ by an individual of lifetime income type γ who is of age a at the time of enactment of reform.

Utility within each period (other than that attributable to the bequest) is defined as $U_s(a,\gamma)$ and is modeled as a constant elasticity of substitution (CES) function of a composite consumption good (which aggregates all non-housing consumption goods and housing services) $CH_s(a,\gamma)$ and leisure $LE_s(a,\gamma)$:

$$\begin{aligned} U_s(a,\gamma) &= \left[(\alpha_C)^{1/\sigma_C} CH_s(a,\gamma)^{(\sigma_C-1)/\sigma_C} + (1-\alpha_C)^{1/\sigma_C} LE_s(a,\gamma)^{(\sigma_C-1)/\sigma_C}\right]^{\sigma_C/(\sigma_C-1)} \\ &= \left[U_s^*(a,\gamma)\right]^{\sigma_C/(\sigma_C-1)}, \end{aligned} \quad (11.2)$$

where σ_C is the intratemporal elasticity of substitution between the composite consumption good and leisure in any period, α_C and $(1-\alpha_C)$ are the utility weights on the composite consumption good and leisure, and leisure is defined as $LE_s(a,\gamma) = HT_s(a,\gamma) - L_s(a,\gamma)$, where $HT_s(a,\gamma)$ is the time endowment or the total number of hours available in period s for either labor supply $L_s(a,\gamma)$ or leisure. The time endowment $HT_s(a,\gamma)$ varies across individuals of different lifetime income types, reflecting differences in initial human capital. To keep the ratio of labor supply to time endowment constant in the steady state, the time endowment for each generation is assumed to be larger by a factor equal to $(1+g)$, where g is the exogenous productivity growth rate. The $[U_s^*(a,\gamma)]$ notation, and similar notation defined below, is introduced simply to facilitate exposition.

The composite consumption good is modeled as a CES function of (non-housing) consumption goods and housing services:

$$\begin{aligned} CH_s(a,\gamma) &= \left\{\begin{array}{l}(\alpha_H)^{1/\sigma_H}[CN_s(a,\gamma)]^{(\sigma_H-1)/\sigma_H} \\ +(1-\alpha_H)^{1/\sigma_H}[HR_s(a,\gamma)]^{(\sigma_H-1)/\sigma_H}\end{array}\right\}^{\sigma_H/(\sigma_H-1)} \\ &= \left[CH_s^*(a,\gamma)\right]^{\sigma_H/(\sigma_H-1)}, \end{aligned} \quad (11.3)$$

where $CN_s(a,y)$ is consumption of non-housing consumption goods in period s by individuals of age a and lifetime income type y, $HR_s(a,y)$ is the analogous consumption of housing services, α_H and $(1-\alpha_H)$ are the utility weights on the non-housing consumption goods and housing services, and σ_H is the elasticity of substitution between consumption goods and housing.

The non-housing consumption good is modeled as a CES function of consumption in period s by individuals of age a and lifetime income type y of the goods produced by the corporate sector $C_s(a,y)$ and the goods produced by the non-corporate sector $N_s(a,y)$, with the option of specifying minimum required purchases of each good for each type of individual, $b_s^C(a,y)$ and $b_s^N(a,y)$ (which are assumed to grow at the productivity growth rate g), or:

$$\begin{aligned} CN_s(a,y) &= \left\{ \begin{array}{l} (\alpha_N)^{1/\sigma_N}\left[C_s(a,y)-b_s^C(a,y)\right]^{(\sigma_N-1)/\sigma_N} \\ +(1-\alpha_N)^{1/\sigma_N}\left[N_s(a,y)-b_s^N(a,y)\right]^{(\sigma_N-1)/\sigma_N} \end{array} \right\}^{\sigma_N/(\sigma_N-1)} \\ &= \left[CN_s^*(a,y)\right]^{\sigma_N/(\sigma_N-1)}, \end{aligned} \tag{11.4}$$

where α_N and $(1-\alpha_H)$ are the utility weights for corporate and non-corporate goods, and σ_N is the elasticity of substitution between above-minimum quantities of the corporate and non-corporate goods.

Housing services $HR_s(a,y)$ are also modeled as a CES function of the quantities of owner-occupied housing services $H_s(a,y)$ and rental housing services $R_s(a,y)$, in excess of the minimum required purchases $b_s^H(a,y)$ and $b_s^R(a,y)$:

$$\dot{H}R_s(a,y) = \left\{ \begin{array}{l} (\alpha_R)^{1/\sigma_R}\left[H_s(a,y)-b_s^H(a,y)\right]^{(\sigma_R-1)/\sigma_R} \\ +(1-\alpha_R)^{1/\sigma_R}\left[R_s(a,y)-b_s^R(a,y)\right]^{(\sigma_R-1)/\sigma_R} \end{array} \right\}^{\sigma_R/(\sigma_R-1)}, \tag{11.5}$$

where σ_R is the elasticity of substitution between the discretionary or above-minimum quantities of owner-occupied housing and rental housing services, and α_R and $(1-\alpha_R)$ are the utility weights for owner-occupied and rental housing.

We turn next to the lifetime budget constraint, simplifying notation by dropping the age and lifetime income type subscripts where it is possible to do so without creating ambiguity. Individuals are assumed to discount future cash flows at the after-tax interest rate r_u for the relevant period u, which implies that marginal savings are taxable (and that marginal borrowing is deductible, e.g. investment interest or borrowing in the form of a home mortgage or a home equity loan), $r_u = i_u(1-\tau_{iu})$, where τ_{iu} is the tax rate on interest income under the income tax in future period u. In principle, marginal tax rates on capital income should vary with income. However, primarily for analytical tractability, the model assumes the various elements of capital income are taxed at differing proportional rates that do not vary across income types, an approach that ensures that all individuals use the same discount rate. This approach is justifiable because most saving is done by individuals in the top bracket, and the differentials in effective capital income tax rates across income types are relatively moderate due to the narrowing of marginal income tax rates since the 1980s, the recent reductions in tax rates on capital gains and dividends, and the greater access to tax sheltering opportunities available to the wealthy, which lowers their effective capital income tax rates; this approach follows the FR and AAKSW models.

Each individual maximizes lifetime utility subject to a lifetime budget constraint:

$$TDW_t(a,\gamma) = TDE_t(a,\gamma) = \sum_{s=t}^{t+54-a} \frac{p_s^{\mathrm{c}}\left(1+\tau_{vs}^{\mathrm{c}}\right)\left(C_s-b_s^{\mathrm{c}}\right)+p_s^{\mathrm{n}}\left(1+\tau_{vs}^{\mathrm{n}}\right)\left(N_s-b_s^{\mathrm{n}}\right)}{\Pi_{u=t+1}^{s}\left(1+r_u\right)}$$
$$+\sum_{s=t}^{t+54-a} \frac{p_s^{\mathrm{h}}\left(1+\tau_{vs}^{\mathrm{h}}\right)\left(H_s-b_s^{\mathrm{h}}\right)+p_s^{\mathrm{r}}\left(1+\tau_{vs}^{\mathrm{r}}\right)\left(R_s-b_s^{\mathrm{r}}\right)}{\Pi_{u=t+1}^{s}\left(1+r_u\right)}+\frac{\left(1+\tau_{vs}^{\mathrm{b}}\right)BQ_{t+54-a}}{\Pi_{u=t+1}^{t+54-a}\left(1+r_u\right)}, \tag{11.6}$$

where $TDW_t(a,\gamma)$ is the total discretionary wealth for an individual of age a and income type γ at the end of period t that is available to spend on total discretionary expenditures $TDE_t(a,\gamma)$, defined as the present value of lifetime consumption of the four goods in excess of minimum required levels and the bequest BQ_{t+54-a}, p_s^{c} is the producer price of the corporate good, which is chosen to be the numéraire so that $p_s^{\mathrm{c}} = 1$ in each period s, p_s^{n} is the producer price of the non-corporate good, p_s^{h} is the unit price of owner-occupied housing services received by individuals in their role as producers of owner-occupied housing and p_s^{r} is the unit price of rental housing services received by the producers of rental housing.

Note that consumer prices include any sales or VATs imposed on a destination basis by either the national or subnational governments, as reflected in the various τ_{v} terms. For example, the consumer price of the corporate good is $p_s^{\mathrm{c}}(1+\tau_{vs}^{\mathrm{c}})$, $\tau_{vs}^{\mathrm{c}} = \tau_{vs}f_{vs}^{\mathrm{c}}$, where f_{vs}^{c} is the fraction of the corporate consumption good that is included in the VAT base (under a comprehensive VAT $f_{vs}^{\mathrm{c}} = 1$, but VATs typically exempt certain goods for administrative, social or political reasons). Similarly, $p_s^{\mathrm{n}}(1+\tau_{vs}^{\mathrm{n}})$, $\tau_{vs}^{\mathrm{n}} = \tau_{vs}f_{vs}^{\mathrm{n}}$, $p_s^{\mathrm{h}}(1+\tau_{vs}^{\mathrm{h}})$, $\tau_{vs}^{\mathrm{h}} = \tau_{vs}f_{vs}^{\mathrm{h}}$, and $p_s^{\mathrm{r}}(1+\tau_{vs}^{\mathrm{r}})$, $\tau_{vs}^{\mathrm{r}} = \tau_{vs}f_{vs}^{\mathrm{r}}$. In the case of owner-occupied housing, if f_{vs}^{h} is non-zero, it is typically defined as the ratio of purchases of new housing to the imputed rental value of the existing stock of owner-occupied housing (Carroll *et al.*, 2010). The denominator of this expression reflects the theoretically correct VAT base – the value of the housing services generated by the existing stock of housing. However, taxing this imputed value is widely believed to be impossible for both administrative and political reasons. It may, however, be possible to apply some tax to the services provided by owner-occupied housing by taxing new housing construction, which effectively taxes currently all the future rents that will be generated by such housing. The value of f^{h}_{vs} simply reflects the fraction of imputed rents on existing housing captured by this indirect approach to taxing owner-occupied housing.

To define total discretionary wealth, options for saving must be specified. Individuals can save to accumulate both taxable assets $A_t(a,y)$ and tax-preferred 'total retirement assets' $TRA_t(a,y)$ that accumulate at the after-tax interest rate i_u. 'Retirement saving' is assumed to be mechanical, both because pension saving is relatively non-discretionary and because in many cases our primary concern is simply to determine the extent of tax-favored assets held in the initial equilibrium. Specifically, retirement saving is assumed to consist of a fixed annual contribution that varies by lifetime income level, with all discretionary saving and dis-saving occurring in taxable accounts. Individuals are assumed to allocate a fixed dollar amount $RS_s(y) = RS$ to retirement saving each year of their working lives, ages $0 \leq a \leq 44$, with all additional saving going into taxable accounts.

Total retirement assets $TRA_t(a, y)$ consist primarily of tax-deferred assets $\mathrm{TDA}_t(a, y)$, such as pension plans (assumed to be owned by the individual), traditional IRAs, and 401(k) and 403(b) plans, all of which receive cash flow or 'tax postpaid' treatment, i.e. contributions are deductible and all withdrawals are fully taxable, by assumption at a proportional rate specific to each income type $\tau_{rt}(y)$. However, individuals can also save in the form of 'tax prepaid' assets $TPA_t(a,y)$, such as Roth IRAs, for which contributions are not deductible and all withdrawals are tax free, so that at the time of the enactment of reform $t = 1$, individuals will have accumulated $TRA_t(a,y) = TDA_t(a,y) + TPA_t(a,y)$. The ratio of retirement saving in each period in tax-deferred assets to total retirement assets $s_d(y)$ is assumed to be constant for individuals at each lifetime income level.

Withdrawals $WD_s(a,y)$ from retirement accounts in period s start upon reaching retirement at age $a = 45$. These withdrawals are assumed to occur at the end of the period in each of the 10 years of retirement in the following pattern. For a person who is in the first year of retirement in period s at age $a = 45$, one-tenth of the balance of both tax-deferred and tax-prepaid accounts is assumed to be withdrawn. At the end of the second year of retirement, at age $a = 46$, one-ninth of the remaining balance of the retirement account is withdrawn, and this process continues until all of the remaining balance of the retirement account is spent at the end of the period when the individual is age $a = 54$.

Total discretionary wealth at the end of period t, $TDW_t(a,y)$, is defined as the total physical and human wealth, net of current and future taxes, available over the rest of the lifetime for discretionary lifetime consumption expenditures (those in excess of any minimum required consumption expenditures) and for the bequest, or:

$$
\begin{aligned}
TDW_t(a,\gamma) = {} & A_t(a,\gamma)(1+r_t) + [TRA_t(a,\gamma)](1+i_t) \\
& + \sum_{s=t}^{t+54-a} \frac{w_s(a,\gamma)[HT_s(a,\gamma) - LE_s(a,\gamma)] - LIT_s(a,\gamma) - SST_s(a,\gamma)}{\Pi_{u=t+1}^{s}(1+r_u)} \\
& + \sum_{s=t}^{t+54-a} \frac{SSB_s(a,\gamma)[1-\tau_{bs}(\gamma)] - RS_s(a,\gamma)}{\Pi_{u=t+1}^{s}(1+r_u)} \\
& + \sum_{s=t}^{t+54-a} \frac{WD_s(a,\gamma)[(1-s_d\tau_{rs}(\gamma)] + TR_s(a,\gamma) + LSR_s(a,\gamma)}{\Pi_{u=t+1}^{s}(1+r_u)} \\
& - \sum_{s=t}^{t+54-a} \frac{p_s^{\mathrm{c}}(1+\tau_{vs}^{\mathrm{c}})b_s^{\mathrm{c}} + p_s^{\mathrm{n}}(1+\tau_{vs}^{\mathrm{n}})b_s^{\mathrm{n}} + p_s^{\mathrm{h}}(1+\tau_{vs}^{\mathrm{h}})b_s^{\mathrm{h}} + p_s^{\mathrm{r}}(1+\tau_{vs}^{\mathrm{r}})b_s^{\mathrm{r}}}{\Pi_{u=t+1}^{s}(1+r_u)},
\end{aligned}
\tag{11.7}
$$

where $A_t(a,\gamma)$ is the value of taxable assets including the present value of the inheritance if not yet received and the value of individual ownership of business equity and debt and government debt in period t for an individual age a and income type γ, $TRA_t(a,\gamma)$ is the value of tax-preferred retirement assets at the beginning of period t, $LIT_s(a,\gamma)$ is the labor income tax component of the individual income tax for an individual of age a and income type γ in period s, $SST_s(a,\gamma)$ is the social security payroll tax paid on labor income, $SSB_s(a,\gamma)$ represents any social security benefits received which are subject to tax at rate $\tau_{bs}(\gamma)$, $TR_s(a,\gamma)$ is transfers received, $LSR_s(a,\gamma)$ equals any lump sum rebates received (which may include VAT rebates, which for simplicity are assumed to be lump sum and uniform across each lifetime income group and declining as lifetime income increases), and $p_s^{\mathrm{i}}b_s^{\mathrm{i}}$ is the cost, including the VAT, of meeting the minimum purchase requirement for the consumption good $i=$ c, n, h, r in period s.

The individual income tax is modeled as a progressive tax on labor income, coupled with the taxation of the various forms of capital income as described above. The AMT is modeled implicitly as changes in the tax rates applied to labor income at each income level. The calculation of the labor income base $LIB_s(a,\gamma)$ begins with total wage income $w_s(a,\gamma)[HT_s(a,\gamma) - LE_s(a,\gamma)]$, defined broadly to include all labor compensation including fringe benefits. This base is then reduced by $DED_s(a,\gamma)$, which reflects the standard deduction and other itemized deductions (other than home mortgage interest or property taxes, which are treated in the calculation of capital income earned in the owner-occupied housing production sector described below), personal exemptions and exclusions from income including fringe benefits such as employer-provided health insurance. Individual tax credits, the most important of which is the earned income tax credit, are modeled implicitly by adjusting the labor income tax rates. The base of the tax on labor income is also reduced by saving in the tax-deferred component of retirement savings, $s_d[RS_s(a,y)]$, so that the labor income base is:

$$LIB_s(a,\gamma) = w_s[HT_s(a,\gamma) - LE_s(a,\gamma)] - DED_s(a,\gamma) - s_d[RS_s(a,\gamma)]. \tag{11.8}$$

Taxable labor income is assumed to be taxed at progressive rates. Following Fullerton and Rogers (1993), we approximate the existing progressive income tax system as a piecewise linear system characterized by a constant marginal tax rate $\tau_{\text{wm}s}(\gamma)$ for each lifetime income group, with marginal tax rates that increase with lifetime income. Specifically, revenues from labor income taxation of an individual of age a and lifetime income type γ in period s are:

$$LIT_s(a,\gamma) = \psi_s LIB_s(a,\gamma) + (\chi_s/2)[LIB_s(a,\gamma)]^2, \tag{11.9}$$

where $\tau_{\text{wm}s}(\gamma) = \chi_s(\gamma) > 0$ and $\psi_s(\gamma) > 0$ is set so that the average revenue collected from the income group γ in period s is correct.

Capital income is assumed to be taxed at flat rates τ_{ds} on dividends, τ_{is} on interest, and τ_{gs} on capital gains. The tax rate on capital gains is an effective annual accrual rate, taking into account the benefits of tax deferral until gains are realized and the tax exemption of gains transferred at death, as well as the cost in an inflationary environment of taxing nominal rather than real gains. The tax rate on withdrawals from the retirement saving account is $\tau_{rs}(a,\gamma)$. The effective social security tax rate is τ_{ss} and the tax rate on social security benefits is $\tau_{bs}(\gamma)$; the modeling of social security is discussed further below.

Substituting from the definitions of the various components of $TDW_t(a,\gamma)$, isolating the LE_s terms, and dropping the age and lifetime income subscripts to simplify notation yields:

$$\begin{aligned}
TDW_t &= A_t(1+r_t) + TRA_t(1+i_t) + \sum_{s=t}^{t+54-a} \frac{w_s HT_s}{\Pi_{u=t+1}^{s}(1+r_u)} \\
&\quad - \sum_{s=t}^{t+54-a} \frac{\chi_s[w_s HT_s - DED_s - s_d RS_s] - \psi_s}{\Pi_{u=t+1}^{s}(1+r_u)} - \sum_{s=t}^{t+54-a} \frac{\tau_{ss}[w_s HT_s - DED_s - s_d RS_s]}{\Pi_{u=t+1}^{s}(1+r_u)} \\
&\quad + \sum_{s=t}^{t+54-a} \frac{SSB_s(1-\tau_{bs}) - RS_s + WD_s[(1-s_d\tau_{rs}(\gamma))] + TR_s + LSR_s}{\Pi_{u=t+1}^{s}(1+r_u)} \\
&\quad - \sum_{s=t}^{t+54-a} \frac{p_s^{\text{c}}(1+\tau_{vs}^{\text{c}})b_s^{\text{c}} + p_s^{\text{n}}(1+\tau_{vs}^{\text{n}})b_s^{\text{n}} + p_s^{\text{h}}(1+\tau_{vs}^{\text{h}})b_s^{\text{h}} + p_s^{\text{r}}(1+\tau_{vs}^{\text{r}})b_s^{\text{r}}}{\Pi_{u=t+1}^{s}(1+r_u)} \\
&\quad - \sum_{s=t}^{t+54-a} \frac{w_s LE_s(1-\chi_s-\tau_{ss})}{\Pi_{u=t+1}^{s}(1+r_u)} \\
&= TDEW_t - \sum_{s=t}^{t+54-a} \frac{w_s LE_s(1-\chi_s-\tau_{ss})}{\Pi_{u=t+1}^{s}(1+r_u)},
\end{aligned} \tag{11.10}$$

where $TDEW_t$ is total discretionary *endowment* wealth, including the value of leisure, and is a function only of variables and parameters that are exogenous to the individual optimization problem in period t.

Following the FR and AAKSW models, the wage rate for an individual of age a and lifetime income y is defined as $w_s(a,y) = (weq_s)[h(a,y)]$, where weq_s is the economy-wide equilibrium wage in period s and $h(a,y)$ is a labor efficiency parameter that reflects both the exogenous accumulation of individual human capital and the exogenous rate of economy-wide productivity growth. The labor efficiency parameter varies in a 'hump-backed' fashion over the individual life cycle, reflecting increasing productivity during middle age and decreasing productivity in the final earning years, as described above. Exogenous productivity growth over time at rate g is modeled as exogenous growth of the time endowment $HT_s(a,y)$, so that the economy-wide equilibrium wage weq_s exhibits no time trend.

A.2.2 Individual behavior: solving the optimization problem

The individual consumer demand functions for the four consumer goods are calculated under the assumption of maximization of the nested individual lifetime utility function subject to the lifetime budget constraint. Solving the first order conditions with respect to C_s and N_s in the innermost nest of the individual utility function yields:

$$\left(C_s - b_s^{\mathrm{c}}\right) = \frac{F_s^{\mathrm{c}} CN_s}{p_s^{\mathrm{c}}} \tag{11.11}$$

$$\left(N_s - b_s^{\mathrm{n}}\right) = \frac{F_s^{\mathrm{n}} CN_s}{p_s^{\mathrm{n}}}, \tag{11.12}$$

where:

$$F_s^{\mathrm{c}} = \frac{(\alpha_{\mathrm{N}})\left[\left(p_s^{\mathrm{c}}\right)^{1-\sigma_{\mathrm{N}}}\right]}{\left[(\alpha_{\mathrm{N}})\left(p_s^{\mathrm{c}}\right)^{(1-\sigma_{\mathrm{N}})} + (1-\alpha_{\mathrm{N}})\left(p_s^{\mathrm{n}}\right)^{(1-\sigma_{\mathrm{N}})}\right]^{\sigma_{\mathrm{N}}/(\sigma_{\mathrm{N}}-1)}}$$

$$F_s^{\mathrm{n}} = \frac{(1-\alpha_{\mathrm{N}})\left[\left(p_s^{\mathrm{n}}\right)^{1-\sigma_{\mathrm{N}}}\right]}{\left[(\alpha_N)\left(p_s^{\mathrm{c}}\right)^{(1-\sigma_{\mathrm{N}})} + (1-\alpha_{\mathrm{N}})\left(p_s^{\mathrm{n}}\right)^{(1-\sigma_{\mathrm{N}})}\right]^{\sigma_{\mathrm{N}}/(1-\sigma_{\mathrm{N}})}},$$

are factors that are functions only of prices and tastes and are thus exogenous to the consumer. Note that if $p_s^{\mathrm{c}} = p_s^{\mathrm{n}}$, $(F_s^{\mathrm{c}} + F_s^{\mathrm{n}})$ reduces to p_s^{c}. More generally:

$$F_s^{\mathrm{c+n}} = F_s^{\mathrm{c}} + F_s^{\mathrm{n}} = \left[(\alpha_{\mathrm{N}})\left(p_s^{\mathrm{c}}\right)^{(1-\sigma_{\mathrm{N}})} + (1-\alpha_{\mathrm{N}})\left(p_s^{\mathrm{n}}\right)^{(1-\sigma_{\mathrm{N}})}\right]^{1/(1-\sigma_{\mathrm{N}})}.$$

The analogous derivations for H_s and R_s imply:

$$\left(H_s - b_s^{\mathrm{h}}\right) = \frac{F_s^{\mathrm{h}} HR_s}{p_s^{\mathrm{h}}} \tag{11.13}$$

$$\left(R_s - b_s^{\mathrm{r}}\right) = \frac{F_s^{\mathrm{r}} HR_s}{p_s^{\mathrm{r}}}, \tag{11.14}$$

where:

$$F_s^{\mathrm{h}} = \frac{(\alpha_{\mathrm{R}})\left(p_s^{\mathrm{h}}\right)^{(1-\sigma_{\mathrm{R}})}}{\left[(\alpha_{\mathrm{R}})\left(p_s^{\mathrm{h}}\right)^{(1-\sigma_{\mathrm{R}})}+(1-\alpha_{\mathrm{R}})\left(p_s^{\mathrm{r}}\right)^{(1-\sigma_{\mathrm{R}})}\right]^{\sigma_{\mathrm{R}}/(\sigma_{\mathrm{R}}-1)}}$$

$$F_s^{\mathrm{r}} = \frac{(1-\alpha_{\mathrm{R}})\left(p_s^{\mathrm{r}}\right)^{(1-\sigma_{\mathrm{R}})}}{\left[(\alpha_{\mathrm{R}})\left(p_s^{\mathrm{h}}\right)^{(1-\sigma_{\mathrm{R}})}+(1-\alpha_{\mathrm{R}})\left(p_s^{\mathrm{r}}\right)^{(1-\sigma_{\mathrm{R}})}\right]^{\sigma_{\mathrm{R}}/(\sigma_{\mathrm{R}}-1)}}$$

$$F_s^{\mathrm{h+r}} = F_s^{\mathrm{h}} + F_s^{\mathrm{r}} = \left[(\alpha_{\mathrm{R}})\left(p_s^{\mathrm{h}}\right)^{(1-\sigma_{\mathrm{R}})}+(1-\alpha_{\mathrm{R}})\left(p_s^{\mathrm{r}}\right)^{(1-\sigma_{\mathrm{R}})}\right]^{1/(1-\sigma_{\mathrm{R}})}.$$

The determination of the optimal amounts of the non-housing and housing composite goods, obtained by maximizing lifetime utility with respect to CN_s and HR_s, yield:

$$CN_s = \frac{\left(F_s^{cn}\right) CH_s}{\left(F_s^{\mathrm{c+n}}\right)} \tag{11.15}$$

$$HR_s = \frac{\left(F_s^{hr}\right) CH_s}{\left(F_s^{\mathrm{h+r}}\right)}, \tag{11.16}$$

where:

$$F_s^{cn} = \frac{(\alpha_{\mathrm{H}})\left(F_s^{\mathrm{c+n}}\right)^{(1-\sigma_{\mathrm{H}})}}{\left[(\alpha_{\mathrm{H}})\left(F_s^{\mathrm{c+n}}\right)^{(1-\sigma_{\mathrm{H}})}+(1-\alpha_{\mathrm{H}})\left(F_s^{\mathrm{h+r}}\right)^{(1-\sigma_{\mathrm{H}})}\right]^{\sigma_{\mathrm{H}}/(\sigma_{\mathrm{H}}-1)}}$$

$$F_s^{hr} = \frac{(1-\alpha_{\mathrm{H}})\left(F_s^{\mathrm{h+r}}\right)^{(1-\sigma_{\mathrm{H}})}}{\left[(\alpha_{\mathrm{H}})\left(F_s^{\mathrm{c+n}}\right)^{(1-\sigma_{\mathrm{H}})}+(1-\alpha_{\mathrm{H}})\left(F_s^{\mathrm{h+r}}\right)^{(1-\sigma_{\mathrm{H}})}\right]^{\sigma_{\mathrm{H}}/(\sigma_{\mathrm{H}}-1)}}.$$

Substituting into the expression for total discretionary expenditures yields:

$$TDE_t = \left[\sum_{s=t}^{t+54-a} \frac{\left(F_s^{\mathrm{c+h}}\right)CH_s}{\Pi_{u=t+1}^{s}(1+r_u)}\right] + \frac{BQ_{t+54-a}}{\Pi_{u=t+1}^{t+54-a}(1+r_u)},$$

where:

$$F_s^{\mathrm{c+h}} = F_s^{cn} + F_s^{hr} = \left[(\alpha_{\mathrm{H}})\left(F_s^{\mathrm{c+n}}\right)^{(1-\sigma_{\mathrm{H}})} + (1-\alpha_{\mathrm{H}})\left(F_s^{\mathrm{h+r}}\right)^{(1-\sigma_{\mathrm{H}})}\right]^{1/(1-\sigma_{\mathrm{H}})}.$$

Finally, optimizing lifetime utility with respect to the aggregate consumption good CH_s, leisure LE_s (and thus labor supply $L_s = HT_s - LE_s$), and the bequest BQ_{t+54-a} yields

$$CH_t(a,\gamma) = \Psi_t^{\mathrm{ch}}(a,\gamma)\,TDEW_t(a,\gamma) \tag{11.17}$$

$$LE_s = \Psi_t^{\mathrm{le}}(a,\gamma)\,TDEW_t(a,\gamma) \tag{11.18}$$

$$BQ = \Psi_t^{\mathrm{b}}(a,\gamma)\,TDEW_t(a,\gamma), \tag{11.19}$$

where

$$F_s^{\mathrm{b}} = \left[\left(F_s^{u}\right)^{(1/\sigma_{\mathrm{U}}-1/\sigma_{\mathrm{C}})(\sigma_{\mathrm{C}}/(\sigma_{\mathrm{C}}-1))}\left(F_s^{\mathrm{c+h}}\right)\frac{(\alpha_{\mathrm{B}})}{(\alpha_{\mathrm{C}})^{1/\sigma_{\mathrm{C}}}}\frac{(1+\rho)^{s-t}}{(1+\rho)^{54-a}}\prod_{u=s}^{t+54-a}(1+r_u)\right]^{\sigma_{\mathrm{U}}}$$

$$F_s^{\mathrm{le}} = \frac{(1-\alpha_{\mathrm{C}})}{(\alpha_{\mathrm{C}})}\left[\frac{F_s^{\mathrm{c+h}}}{w_s(1-\chi_s-\tau_{ss})}\right]^{\sigma_{\mathrm{C}}}$$

$$\Psi_t^{\mathrm{ch}}(a,\gamma) = \left[\sum_{s=t}^{t+54-a}\frac{\left(F_s^{\mathrm{c+h}}\right)}{\prod_{u=t+1}^{s}(1+r_u)} + \sum_{s=t}^{t+54-a}\frac{w_s(1-\chi_s-\tau_{ss})}{\Pi_{u=t+1}^{s}(1+r_u)}\left(F_s^{\mathrm{le}}\right) + \frac{\left(F_t^{\mathrm{b}}\right)}{\prod_{u=t+1}^{t+54-a}(1+r_u)}\right]^{-1},$$

i.e. that all consumer demands are multiplicative functions of $TDEW_t(a,\gamma)$.

Given individual labor supply, the aggregate effective labor force (EL_s) depends on the exogenous population growth rate n. Thus, the size of the population of age a in years, $P_s(a)$, is $P_s(a) = P_t(a)(1+n)^{s-t}$, where $P_t(a)$ is the size of this population in some reference time period, typically the initial period ($t = 0$). This implies that in any period s, the total effective labor force is:

$$EL_s = \sum_{a=0}^{44} P_s(a)L_s(a), \tag{11.20}$$

where $L_s(a)$ is labor supply of an individual of age a in period s. Initial values for EL_s and K_s are established at the beginning of period zero ($s = 0$) as the steady-state values under the existing tax system.

A.2.3 Modeling the social security program

The DZ model includes a simple if somewhat unrealistic modeling of Social Security. Social Security taxes paid $SST_s(a,y)$ are assumed to be assessed on the same base as the labor income component of the personal income tax base $LIB_s(a,y)$. With an effective Social Security tax rate of τ_{ss}, this implies that the Social Security taxes paid by an individual of age a and lifetime income level y are $SST_s(a,y) = \tau_{ss}[LIB_s(a,y)]$. Social security benefits $SSB_s(a,y)$ are received by individuals of lifetime income y who reach an economic age $a = 45$ in years and continue until death at age $a = 54$.

The model assumes that social security is financed on a 'pay-as-you-go' basis; any accumulation or decumulation of the Social Security trust fund is ignored, as is any link between marginal additional taxes paid and additional future benefits.[39] To calculate the budget constraint of the Social Security system, recall that population growth at rate n is assumed to be uniform across all types of individuals.[40] Thus, the population of age a of lifetime income group y in period s is $P_s(a,y) = P_t(a,y)(1+n)^{s-t}$, where $P_t(a,y)$ is the size of this population in some reference time period, typically the initial period ($t = 0$), just before the enactment of reform at the beginning of period one ($t = 1$). Hence, assuming that the revenues raised from taxing social security benefits go into general revenues, the government's social security budget constraint requires that annual social security taxes must equal annual benefit payments or:

$$\sum_{a=0}^{44}\sum_{y=1}^{12} P_s(a,y)SST_s(a,y) = \sum_{a=45}^{54}\sum_{y=1}^{12} P_s(a,y)SSB_s(a,y). \tag{11.21}$$

This expression determines the social security tax rate τ_{ss}. Social security benefits are then allocated across the lifetime income groups so that the fraction received by each lifetime income group is consistent with current data.

A.3 Firm behavior

The DZ model has four production sectors, which use all of the supplies of capital and labor, as derived above. Production of all goods other than housing is divided into two sectors, the 'corporate' sector (X^c) and the 'non-corporate' sector (X^n). Both sectors are assumed to have CES production functions. A third sector comprised of landlords, who

39 This link is fairly minimal; for example, AK argue that additional benefits offset only 25% of marginal Social Security taxes.

40 Thus in its current form the DZ model cannot be used to analyze the problems faced by the Social Security system due to an aging population.

are also non-corporate entities, produces rental housing (X^{r}), and the fourth sector is individual home owners who effectively produce (and consume) owner-occupied housing (X^{h}). Both types of housing are produced with the same CES production function.

In each sector, the model assumes that firm managers, including landlords and the owners of owner-occupied housing, act to maximize the value of their firm in a perfectly competitive environment in the absence of uncertainty. The approach utilized is based on Tobin's 'q'-theory of investment, as extended to include investment adjustment costs by Hayashi (1982). The firm modeling approach is similar to those utilized by Goulder and Summers (1989) and Kueschnigg (1990).

A.3.1 Corporate sector

The corporate sector is characterized by a CES production function:

$$X_s^{\mathrm{c}} = \left[(\gamma_c)^{1/\epsilon_{\mathrm{C}}}\left(K_s^{\mathrm{c}}\right)^{(\epsilon_{\mathrm{C}}-1)/\epsilon_{\mathrm{C}}}+(1-\gamma_c)^{1/\epsilon_{\mathrm{C}}}\left(EL_s^{\mathrm{c}}\right)^{(\epsilon_{\mathrm{C}}-1)/\epsilon_{\mathrm{C}}}\right]^{\epsilon_{\mathrm{C}}/(\epsilon_{\mathrm{C}}-1)}, \tag{11.22}$$

where K_s^{c} denotes inputs of capital used for corporate production in period s, EL_s^{c} denotes effective labor used for corporate production in period s and γ_{C} is the capital weighting parameter in the CES production function in the corporate sector.

Gross investment in the corporate sector in period s, I_s^{c}, equals:

$$I_s^{\mathrm{c}} = K_{s+1}^{\mathrm{c}} - (1-\delta^{\mathrm{c}})K_s^{\mathrm{c}}, \tag{11.23}$$

where δ^{c} is the rate of depreciation of the capital stock in the corporate sector. The investment good and the corporate good are assumed to be identical. The price of the corporate good p_s^{c} is assumed to be the numéraire, or $p_s^{\mathrm{c}} = 1$.

Following Goulder and Summers (1989), adjustment costs per unit of investment are:

$$\Phi_s^{\mathrm{c}}\left(I_s^{\mathrm{c}}/K_s^{\mathrm{c}}\right) = \frac{p_s^{\mathrm{c}}(\beta^{\mathrm{c}}/2)\left(I_s^{\mathrm{c}}/K_s^{\mathrm{c}}-\mu^{\mathrm{c}}\right)^2}{\left(I_s^{\mathrm{c}}/K_s^{\mathrm{c}}\right)}, \tag{11.24}$$

where β^{c} and μ^{c} are adjustment cost parameters that are specific to the corporate sector. The parameterμ^{c} is equal to the steady-state ratio of gross investment to capital in the corporate sector; that is, $\mu^{\mathrm{c}} = \delta^{\mathrm{c}} + n + g + ng$.

Investment can be financed with either debt or equity. Firms in the corporate sector are assumed to maintain a constant debt-capital ratio, b^{c}, so that:

$$B_s^{\mathrm{c}} = b^{\mathrm{c}}K_s^{\mathrm{c}}, \tag{11.25}$$

where B_s^{c} is the stock of outstanding corporate sector debt at time s. New bond issues in the corporate sector in period s, BN_s^{c}, are the difference in bonds outstanding in two consecutive periods, or $BN_s^{\mathrm{c}} = B_{s+1}^{\mathrm{c}} - B_s^{\mathrm{c}}$, which implies:

$$BN_s^{\mathrm{c}} = b^{\mathrm{c}}\left(K_{s+1}^{\mathrm{c}} - K_s^{\mathrm{c}}\right) = b^{\mathrm{c}}\left(I_s^{\mathrm{c}} - \delta^{\mathrm{c}}K_s^{\mathrm{c}}\right). \tag{11.26}$$

Note that this implies that existing loans are repaid at the rate of depreciation of the existing capital stock, so that the existing stock of outstanding corporate debt always equals $b^c K_s^c$.

Total gross equity earnings in the corporate sector (before depreciation and corporate taxes, but after local property taxes assessed at rate τ^{pc}) in period s, $EARN_s^c$, are:

$$EARN_s^c = p_s^c X_s^c - w_s EL_s^c - i_s B_s^c - \tau^{pc} K_s^c. \quad (11.27)$$

Dividends paid are assumed to equal a constant fraction (ζ^c) of the corporation's after-tax earnings net of economic depreciation, or:

$$DIV_s^c = \zeta^c \left(EARN_s^c - TE_s^c - p_s^c \delta^c K_s^c \right), \quad (11.28)$$

where TE_s^c denotes total corporate taxes paid in period s. Assuming that adjustment costs are fully deductible and that the corporate business tax rate is τ_{bs}, total corporate taxes are defined as:

$$\begin{aligned} TE_s^c = \tau_{bs} \Big[& p_s^c X_s^c - w_s EL_s^c - f_e I_s^c - \Phi_s^c I_s^c - f_i i_s B_s^c - f_p \delta^c b^c K_s^c \\ & + f_b b^c I_s^c - f_d \delta^{\tau c} K_s^{\tau c} - \tau^{pc} K_s^c \Big], \end{aligned} \quad (11.29)$$

where $\delta^{\tau c}$ is the depreciation rate for tax purposes in the corporate sector and $K_s^{\tau c}$ is tax basis under the corporate income tax. This formulation accommodates a wide variety of alternative income-based or consumption-based tax regimes, depending on the values of the various f parameters, which equal zero or one. Assuming no cash accumulation on the part of the corporation, cash inflows in period s must equal total disbursements, or:

$$EARN_s^c + BN_s^c + VN_s^c = DIV_s^c + I_s^c (1 + \Phi_s^c) + TE_s^c, \quad (11.30)$$

where VN_s^c is corporate new share issues in period s.

Following Auerbach and Kotlikoff and Fullerton and Rogers, the model assumes individual level arbitrage. The after-tax nominal return on bonds is $r_s = (1 - \tau_{is}) i_s$ so that individual level arbitrage[41] implies:

$$r_s = (1 - \tau_{is})\ i_s = \frac{(1 - \tau_{ds}) DIV_s^c + \left(1 - \tau_{gs}\right)\left(V_{s+1}^c - V_s^c - VN_s^c\right)}{V_s^c}, \quad (11.31)$$

where V_s^c is the value of the firm, $\left(V_{s+1}^c - V_s^c - VN_s^c\right)$ is the capital gain on outstanding shares, and DIV_s^c is dividends paid; note that the return on equity income is the sum of the return on dividends after dividend taxation at rate τ_{ds} and the return on capital gains, after capital gains taxation at an annual accrual tax rate τ_{gs}. This treatment of equity

41 In this formulation, after-tax returns to debt and equity are identical. However, it is straightforward to add an equity premium, which in principle could vary across sectors (Goulder and Summers, 1989); such an approach facilitates calibrating the model as it realistically allows after-tax returns to equity to exceed after-tax returns to debt.

finance follows the traditional view of the effects of dividend taxes, which are assumed to increase the cost of capital for investment financed with retained earnings. As noted above, dividends are a fixed fraction of earnings after taxes and depreciation. Investments are financed from the remaining retained earnings, or with new share issues if retained earnings are insufficient to finance the desired level of investment. (If desired investment is less than retained earnings, the firm repurchases shares without paying a dividend tax). Rearranging and simplifying yields:

$$V_{s+1}^{c} = V_{s}^{c}(1+\theta_{s}) + VN_{s}^{c} - \left(\frac{1-\tau_{ds}}{1-\tau_{gs}}\right)DIV_{s}^{c}, \tag{11.32}$$

where $\theta_s = (1-\tau_{is})i_s/(1-\tau_{gs})$.

This expression can be used to obtain the value of the firm by repeatedly substituting for V_{s+i-1}^{c} and solving for V_s^c, imposing the transversality condition, and substituting to yield:

$$V_s^c = \sum_{u=s}^{\infty}\left\{\begin{array}{l}\left[\prod\limits_{v=s}^{u}\dfrac{1}{(1+\theta_v)}\right]\left[\begin{array}{l}(1-\tau_{bs})\Omega_u^c\left(p_s^cX_s^c - w_sL_s^c\right) - (1-\tau_{bs}f_i)\Omega_u^c i_s b^c K_s^c\\ +f_e\tau_{bs}\Omega_u^c I_s^c(1+\Phi_s^c) - f_b\tau_{bs}\Omega_u^c b^c I_s^c\\ +f_p\tau_{bs}\Omega_u^c\delta^c b^c K_s^c + f_d\tau_{bs}\Omega_u^c\delta^{\tau_C}K_s^{\tau_C} - p_s^c\Omega_u^c\delta^c K_s^c\end{array}\right]\\ -I_u^c(1+\Phi_u) + \delta^c K_u^c + b^c\left(I_u^c - \delta^c K_u^c\right)\end{array}\right\}, \tag{11.33}$$

where:

$$\Omega_u^c = \left[\zeta^c(1-\tau_{du}) + (1-\zeta^c)(1-\tau_{gu})\right]/(1-\tau_{gu}).$$

The term $f_d\tau_{bs}\Omega_u^c\delta^{\tau_C}K_s^{\tau_C}$ reflects the tax savings from depreciation allowances, which include both those attributable to past investments and those attributable to future investments made after time t. It is useful to distinguish between the present value of depreciation allowances on old capital, which are irrelevant to the investment decision, and the present value of depreciation allowances on future investments. Separating these two effects yields:

$$V_s^c = \sum_{u=s}^{\infty}\prod_{v=s}^{u}\frac{1}{(1+\theta_v)}\Gamma_u^c + f_dX_t^c, \tag{11.34}$$

where:

$$\begin{aligned}\Gamma_u^c = {} & (1-\tau_{bu})\Omega_u^c\left[p_u^cX_u^c - w_uL_u^c\right]\\ & - K_u^c\left\{\Omega_u^c(1-\tau_{bu}f_i)i_u b^c - \delta^c\left[1-b^c-\Omega_u^c\left(1-f_p\tau_{bs}b^c\right)\right]\right\}\\ & - I_u^c\left[1-b^c-\Omega_u^c\tau_{bs}(f_e - f_b b^c) - f_dZ_u^c + \Phi_u^c(1-\tau_{bu}\Omega_u^c)\right]\end{aligned}$$

$$Z_j^c = \sum_{u=j}^{\infty}\left[\tau_{bu}\Omega_u^c\delta^{\tau_C}(1-\delta^{\tau_C})^{u-j}\prod_{v=j}^{u}\frac{1}{(1+\theta_v)}\right],$$

where $X_t^c = Z_t^c K_t^{\tau c}$ is the value of future depreciation deductions on old capital existing at the time of enactment of reform.

The corporation maximizes firm value subject to $K_{s+1}^c = I_s^c + (1-\delta^c)K_s^c$ and $\lim_{T\to\infty} K_T^c \geq 0$. Defining $(q_{u+1}^c)^* = \prod_{v=s}^{u}[1/(1+\theta_v)]q_{u+1}^c$, the necessary conditions for a maximum are:

$$w_s = p_s^c F_{uL}^c, \tag{11.35}$$

i.e. the wage rate must equal the value of the marginal product of labor, $p_s^c F_{uL}^c$, and:

$$q_{s+1}^c = 1 - b^c - f_d Z_{s+1}^c - \Omega_u^c \tau_{bs}(f_e - f_b b^c) + (1-\tau_{bs}\Omega_s^c)\left[\Phi_s^c + \left(I_s^c/K_s^c\right)(\Phi_s^c)'\right], \tag{11.36}$$

which describes the variable commonly known as Tobin's q, the ratio of the market value of a marginal unit of capital to its replacement cost. Thus, the shadow price of additional capital goods (q_{s+1}^c) must equal the after-tax marginal cost of capital goods (the right-hand side). Since the investment good is the numéraire, the first term in the equation indicates that the shadow price is simply one in the absence of debt and taxes. The second term reflects the financing of a fraction b^c of the cost of the investment with debt. The third term reflects the reduction in the shadow price of new capital goods due to tax deductions for depreciation. The fourth term reflects the effects of either expensing or the inclusion of the proceeds of debt under the consumption tax options. The last term reflects the costs of installing new capital goods with immediate expensing of adjustment costs. This expression yields the standard optimal investment equation for the firm, expressed as a function of Tobin's q, or:

$$\frac{I_s^c}{K_s^c} = \frac{q_{s+1}^c - 1 + b^c + f_d Z_{s+1}^c + \Omega_u^c \tau_{bs}(f_e - f_b b^c)}{p_s^c \beta^c (1-\tau_{bs}\Omega_s^c)} + \mu^c \tag{11.37}$$

It is, however, convenient to express investment demand as a function of the value of the corporation, V_s^c, rather than of q_{s+1}^c. To do this, note that, as shown by Hayashi (1982), the relationship between marginal q and average q denoted as Q, is:

$$q_s = \frac{[V_s - X_s]}{K_s}, \quad Q_s = \frac{V_s}{K_s}. \tag{11.38}$$

Thus, the investment demand function can be written as:

$$\frac{I_s^c}{K_s^c} = \frac{\left(V_{s+1}^c - X_{s+1}^c\right)/K_{s+1}^c - 1 + b^c + f_d Z_{s+1}^c + \Omega_u^c \tau_{bs}(f_e - f_b b^c)}{p_s^c \beta^c (1-\tau_{bs}\Omega_s^c)} + \mu^c \tag{11.39}$$

The third necessary condition is the Euler equation:

$$i_s = \frac{\Omega_s^c(1-\tau_{bs})p_s^c \dfrac{\partial F_s^c}{\partial K_s^c} + \delta^c\left[1 - b - \Omega_s^c\left(1 - f_p\tau_{bs}b^c\right)\right] + q_{s+1}^c(1-\delta^c) - q_s^c}{\Omega_s^c(1-\tau_{bs}f_i)b^c + q_s^c(1-\tau_{is})/\left(1-\tau_{gs}\right)} \tag{11.40}$$

$$+\frac{(1-\tau_{bs}\Omega_s^c)p_s^c(\beta^c/2)\left[\left(I_s^c/K_s^c\right)^2 - \mu^2\right]}{\Omega_s^c(1-\tau_{bs}f_i)b^c + q_s^c(1-\tau_{is})/\left(1-\tau_{gs}\right)},$$

which can be written as a difference equation in q_s^c, and solved to yield:

$$q_s^c = \sum_{u=s}^{\infty}\left\{\begin{array}{l} \displaystyle\prod_{v=s}^{u}\frac{1}{(1+\theta_v)}(1-\delta^c)^{u-t}\left[\Omega_u^c(1-\tau_{bu})\, p_u^c\frac{\partial F_s^c}{\partial K_s^c} - \Omega_u^c(1-\tau_{bu}f_i)i_u b^c\right] \\ +\delta^c\left(1 - b^c - \Omega_u^c\left(1 - f_p\tau_{bs}b^c\right)\right) + (1-\tau_{bu}\Omega_u^c)p_u^c(\beta/2)\left[\left(I_s^c/K_s^c\right)^2 - (\mu^c)^2\right] \end{array}\right\}. \tag{11.41}$$

This equation implies that the shadow price of new capital in the corporate sector, q_s^c, equals the present value of future income, reflecting the productivity of the asset, depreciation allowances, savings future installation costs and future interest payments. From, $Q_s^c = q_s^c + X_s^c/K_s^c$, that is, average Q equals marginal q plus an adjustment for future depreciation deductions on existing assets. Also, can be solved for the user cost of capital developed by Jorgenson (1963), the minimum return an investment must yield in order to provide the investor with the same rate of return that would be received from lending at the after-tax interest rate, or:

$$\frac{\partial F_u^c}{\partial K_u^c} = \frac{\Omega_u^c(1-\tau_{bu}f_i)i_u b^c - \delta^c\left[1 - b^c - \Omega_u^c\left(1 - f_p\tau_{bs}b^c\right)\right] + q_s^c(1+\theta_s)}{\Omega_s^c(1-\tau_{bs})p_s^c} \tag{11.42}$$

$$+\frac{-q_{s+1}^c(1-\delta^c) - (1-\tau_{bu}\Omega_u^c)p_u^c(\beta/2)\left[\left(I_s^c/K_s^c\right)^2 - (\mu^c)^2\right]}{\Omega_s^c(1-\tau_{bs})p_s^c}.$$

Finally, the optimal solution must satisfy:

$$\lim_{T\to\infty} K_{T+1}^c \geq 0, \quad \lim_{T\to\infty}\left(q_{T+1}^c\right)^* \geq 0, \text{ and } \lim_{T\to\infty} K_{T+1}^c\left(q_{T+1}^c\right)^* = 0. \tag{11.43}$$

The equations for the remaining three production sectors in the DZ model are generally similar to those for the corporate sector, and are thus not replicated in detail below. The following three subsections highlight the special features of each of these sectors.

A.3.2 Non-corporate sector

The primary difference between the corporate and non-corporate sectors is that dividends and new share issues are not modeled explicitly. Instead, the value of the non-corporate firm is determined by the net cash flow (*NCF*) accruing to the owners of the business in each period, defined as gross equity earnings less the individual-level business taxes paid by the owners of the non-corporate business and less the portion of new investment that is financed with new equity contributions by the owners. Letting 'n' superscripts denote the non-corporate sector and defining all variables as above, net cash flow is:

$$NCF_s^{\mathrm{n}} = EARN_s^{\mathrm{n}} - TE_s^{\mathrm{n}} - \left[I_s^{\mathrm{n}}(1+\Phi_s^{\mathrm{n}}) - BN_s^{\mathrm{n}}\right]. \tag{11.44}$$

This term replaces the dividend term in the numerator of the non-corporate analog of the expression defining the value of the firm, with new share issues by definition equal to zero. The business tax rate is the average individual tax rate applied to business income that is 'passed through' to individual owners of non-corporate business owners. Thus, although in reality all non-corporate earnings are passed through to individual owners, in the model these earnings are nominally taxed at the business level, but at the appropriate individual tax rate.

A.3.3 Two housing sectors

The framework for determining the value of housing services to homeowners or landlords is similar to that utilized for the non-corporate firm. In particular, housing sector 'dividends' take the form of the service flows from the housing stock and thus are paid out in full, as either imputed or actual rents; in addition, new share issues are assumed to be unavailable. Thus, investment in the housing sector is all financed by either debt or equity in the form of retained earnings (or new equity if retained earnings are insufficient). Homeowners and landlords maintain constant debt to capital ratios, and existing loans are repaid at the rate of depreciation of the housing existing capital stock.

Earnings in the owner-occupied and rental housing sectors are defined as the value of housing services less labor cost (used in the production or maintenance of the capital that generates housing services), real interest payments on total indebtedness, and property tax payments. However, the tax treatment of housing differs across the owner-occupied and rental housing sectors. Earnings in the owner-occupied housing sector (imputed rents) are not taxed, but owner-occupiers who are itemizers receive income tax deductions for mortgage interest and property tax payments (but not for maintenance and repair expenditures). The net service flow of owner-occupied or rental housing, S_s^j, is:

$$S_s^j = EARN_s^j + BN_s^j - I_s^j(1+\Phi_s^j) - TE_s^j, \tag{11.45}$$

where variables are defined as above, and the $j-\mathrm{h}$, r superscripts refer to housing that is owner-occupied and rental housing.

A.4 Market equilibria

Finally, prices must adjust so that equilibrium is obtained in all periods in all markets. This requires that aggregate demand (including investment demands, inclusive of adjustment costs, and government demands) equal aggregate supply for all four goods, that aggregate demand equal aggregate supply in the markets for capital and labor, and that the government budget (including both national and state governments) be balanced in each period (with the option of increasing government debt for a finite period). Asset market equilibrium requires that the total equity holdings of individuals equals total firm values for all four types of firms and that the total debt holdings of individuals equals the amount of debt issued by all four types of firms. Implicit in the calculation of these equilibria is that the expectations regarding all future prices by all individuals and firms must be satisfied.

The model is solved using the method developed by Fair and Taylor (1983). This method uses an initial guess to calculate actual values for all forward looking variables, and then updates the guess using a combination of the initial guess and the actual value. This procedure iterates until the model converges to a fixed point, where the difference between the revised guess and actual value is sufficiently small for each endogenous variable.

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