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TAX SHIFTING AND THE LIKELIHOOD OF DOUBLE DIVIDENDS:

Theoretical and Computational Issues

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I. INTRODUCTION

While arguably a landmark in environmental policy, the recent international agreement on global climate policy reached in Kyoto did not resolve continuing policy and political controversy over the economics of climate change. The Kyoto agreement notwithstanding, such issues as the economic costs of carbon abatement, the proper division of responsibility for climate protection between the developed and developing worlds, and the correct economic balancing of costs and benefits will continue to impede efforts to reach national and international consensus on the climate problem.

By contrast, there is a considerable degree of agreement within mainstream economic circles on at least the general character, if not the precise details, of economically rational climate policy. Among economists, there is virtually universal agreement on, among other elements, the benefits of market-based (as opposed to command and control) approaches to carbon mitigation in order to obtain climate protection at minimum cost. One specific component of this consensus is the desirability, from the standpoint of economic efficiency, of using revenues accruing from carbon taxes or tradable permit schemes to reduce other, preexisting distortionary taxes.

This approach is referred to as "revenue recycling" or "tax shifting." It is a well-established result in environmental economics that this approach maximizes gains in economic efficiency, and is thus preferable not just to direct regulation of emissions, but also to other taxation or permit schemes that do not involve the offsetting use of revenue. This conclusion is one form of what is often referred to as the "double-dividend" hypothesis.

A more controversial, "strong" double-dividend hypothesis has also received considerable attention in recent years. This is the idea that, even without environmental benefits, using environmental tax or permit revenues—particularly those focusing on energy use and/or carbon emissions—to offset other, distortionary taxes will *always* result in overall gains in economic efficiency. As noted by Goulder (1996) and many others, this hypothesis, were it true, would have profound implications for climate policy. It would represent, at least in the realm of analysis, a true "win-win" approach to the protection of the global climate. Following some

degree of early optimism on the topic, however, many economists have recently concluded that theory and computational evidence indicate that the strong double-dividend hypothesis is incorrect. Although double-dividend (win-win) outcomes are *possible*, they are not automatic.

The purpose of this paper is twofold. First, we review the theoretical underpinnings of the analysis of the strong double-dividend hypothesis. Because this is a topic of considerable theoretical complexity and its treatment in the technical literature has been of limited accessibility to nonspecialists, we aim to present the key points in a nonmathematical fashion. We will pay particular attention to the conditions under which revenue-neutral environmental tax reform will or will not create double dividends. Recent theoretical research suggests that skepticism regarding the likelihood of double dividends was premature, and that the likelihood issue cannot be resolved by theoretical analysis alone.

Our second aim is to examine the double-dividend issue in the context of the quantitative analysis of climate policy. Economists involved in the climate debate have increasingly relied on large-scale numerical simulation models to formulate and analyze alternative climate policies. This approach, however, has translated very imperfectly into the arena of actual decisionmaking by policymakers. There are, no doubt, a number of reasons for this gap between modeling and successful policy analysis. Among them are that no generally agreed-upon protocol exists for reconciling outputs of different models when these outputs differ, and that fundamental issues involving model design and underlying principles are often the true, but insufficiently examined, objects of policy disputes (Repetto and Austin 1997; Sanstad and Greening 1998).

In the present context, these problems are manifest by differing quantitative results of different models regarding the double-dividend issue. Simply put, some models have found that a double dividend exists, and some have not. Why these contradictory findings occur is not entirely clear at present, but are extremely important. Fully answering this question is beyond the scope of this paper. We will, however, examine two well-known and well-regarded computable general-equilibrium (CGE) models that give different answers to the double-dividend question and review key aspects of their structure that are relevant to their results.

Our key findings are twofold. First, on a theoretical level, the likelihood of a double dividend remains an open question, contrary to the negative conclusion that many analysts appear to have reached in the past several years. Second, in the realm of CGE modeling, to fully understand both pro and con findings reported to date on the double dividend will require considerably more attention to the underlying details of the simulation models, and their potential effects on empirical findings. Hence,

although the strong form of the double-dividend hypothesis has been disproved (double dividends will not *always* result from environmental tax reform), the question of when an environmental tax reform might yield double dividends is still an open question, and should be a central focus of additional research.

II. BACKGROUND: THEORETICAL ASPECTS OF THE STRONG DOUBLE-DIVIDEND QUESTION

The quantitative economic analysis of climate policy in general, and tax shifting in particular, represents a convergence of several long-standing research areas. First, it builds on the theory of environmental taxation, pioneered by British economist Arthur Pigou in the 1920s. It also incorporates the theory of optimal taxation in the public finance literature, which in turn has roots in the work of Frank Ramsey, also in the 1920s. Finally, it applies the tools of computable or applied general-equilibrium analysis, which is in essence a numerical realization of the general-equilibrium theory of Arrow and Debreu.

In this section we focus on the key results from the theories of optimal, secondbest, and environmental taxation, presenting a series of benchmark research efforts in chronological order. Work in this area has proceeded according to the standard economic methodology, in which a set of simple but generally plausible assumptions are made about individual behavior, the workings of policy, and the structure of production. These assumptions are expressed in mathematical form. Conclusions regarding most desirable or "optimal" policies are then derived, which show how (under the maintained assumptions) the government can accomplish policy objectives while simultaneously ensuring that individual well-being or "utility" is maximized.

Among the advantages of this abstract approach (as with much of economic research) is that it enables general and frequently significant conclusions to be reached starting from a minimum of assumptions, and without need for extensive empirical study. A potential pitfall, however, is that simplifying assumptions may profoundly influence the conclusions in ways that are not readily apparent. In the present case, for example, the exact nature of the assumptions regarding individual preferences turns out to be, as we describe below, particularly significant. As with virtually all economic research, work in this area assumes "utility maximization" by consumers. For example, individuals choose among goods and services to maximize their personal well-being, subject to their available resources (or budget constraint).

Some theoretical work on the double dividend has further specialized this model by imposing an additional assumption, which is that utility is "homothetically separable." Intuitively, homotheticity of a utility function means that the consumer's distribution of expenditure on different commodities is independent of his or her income level. While overwhelmingly rejected by empirical evidence, homotheticity is widely assumed in research for reasons of simplicity and analytical tractability.

THE BASIC MODEL

The problem addressed by Ramsey (1927) was that of how a government should raise a given amount of revenue while minimizing the loss of economic well-being, or utility, to the consumer (taxpayer). More precisely, the government employs excise taxes on each of N produced goods to satisfy a fixed revenue constraint, assuming fixed producer prices. Distributional considerations are not treated; instead, a (budget constrained) utility-maximizing representative individual is assumed. The government's optimization problem is then that of maximizing individual welfare subject to the revenue requirement and the constraint of individual utility maximization. There are no externalities in the model.

Under the usual assumptions, this problem's solution yields a set of first-order conditions that can be shown to yield the following conclusion: the optimum is characterized by equal marginal rates of reduction in demand for all commodities. With further restrictions on the structure of preferences, other conclusions can be drawn. For example, the assumption of zero cross-price effects yields the well-known "inverse elasticity" rule that commodities should be taxed inversely to their price elasticity of demand, which will minimize economic distortions resulting from taxation. It is important to note, however, that absent such additional assumptions, the sole conclusion of the basic model is equal marginal rates of reduction in demand for each commodity at the optimum.

THE BASIC MODEL WITH ENVIRONMENTAL EXTERNALITIES

Sandmo (1975) combined the Ramsey problem with the problem of placing a Pigouvian tax on a specific externality or pollution-generating commodity. He analyzed a model in which there are again N commodities, with the Nth, say, creating a consumption externality. The model also incorporates a representative utility-maximizing consumer, and the government faces a revenue constraint. The problem

^{1.} A Pigouvian tax is a charge on the externality that equates its marginal cost with the marginal social damage it causes.

is then to analyze the structure of optimal taxes that serve both the "Ramsey," revenue-raising function and the "Pigou," externality-correction function.

Sandmo derives implicit solutions for the optimal tax rates, and demonstrates that the optimal taxes appear to display a type of independence characteristic. A marginal damage resulting from consumption of the externality-creating commodity enters the tax formula for that commodity additively, but does not enter the formulae for the other commodities.² This result appears to imply a useful way of independently analyzing the externality-correcting and revenue-raising aspects of taxation. As Sandmo points out, however, this mathematical decomposition does not imply that the set or vector of optimal taxes when the externality is taken into account differs from the Ramsey optimal tax vector only with the addition of the corrective, "Pigouvian" term. This means that the change in optimal taxes required to correct for a single externality that has just "been discovered" to exist is, in general, a change in all optimal tax rates including that on the good that generates the previously unrecognized externality. The common but incorrect interpretation of Sandmo's result—that only the tax on the good that generates the externality need change—is a special case. As Auerbach (1985) puts it, "this independence is present only analytically, since the actual level of the externality, and hence the Pigouvian tax, depends on the actual equilibrium and hence the optimal tax rates; the same is true in the other direction."

THE WOLFF ANALYSIS

Wolff (1997) extends Sandmo's analysis to a more general model that includes taxes on factors of production such as labor, and varying producer prices. This model is a variation of that of Diamond and Mirrlees (1971), with externalities added. Wolff studies the nature of the welfare change resulting from moving from a starting point other than the Ramsey equilibrium to equilibria in which taxes are used both to raise revenue and to partially correct one or more externalities. His central conclusion is that imposition of a tax on a "dirty" good and adjustment of some other

^{2.} Deaton (1979) shows that optimal taxes on a group of goods are uniform whenever that group is separable in the distance function. The distance function is the dual of the usual expenditure function. Separability of the distance and expenditure functions (if one is separable, so is the other) is known as implicit separability. Deaton's analysis includes the case of multiple endowed goods and a subset of produced goods being separable from all others. Deaton (1981) extends this analysis to show that uniform commodity taxation is optimal when utility is homothetically separable between goods and leisure. That is, homothetic separability implies implicit separability.

tax to maintain revenue neutrality has an ambiguous effect in general on the nonenvironmental component of utility.

Further, Wolff's analysis provides an explanation for the generally negative results on the likelihood of double dividends that have appeared in the past several years. He shows that these results can be traced to the specific assumptions regarding the budget constraint, the structure of production, the structure of preferences, and which goods are involved in the tax reform. In short, these results depend on assumptions that ensure that increasing the tax on a produced dirty good and adjusting the tax on labor to maintain revenue neutrality moves the economy away from Ramsey optimality. Such movement means that nonenvironmental utility unambiguously decreases.³ We now turn to a discussion of these previous results.

BOVENBERG AND VAN DER PLOEG

Bovenberg and Van Der Ploeg (1994) devise a general-equilibrium model in which a labor supply tax is adjusted to maintain revenue neutrality when an environmental tax is introduced. They find that utility, abstracting from environmental benefits, declines; that is, the double dividend does not materialize in this model. Wolff shows that the particular form of utility they assume—known as "homothetically separable" utility—plus the absence of income other than labor income in their model implies that their ex ante tax is Ramsey second-best optimal.⁴ That is, the introduction of the environmental tax moves the optimum away from the Ramsey equilibrium, so that under these preference assumptions the tax shift cannot increase nonenvironmental utility.

^{3.} Wolff's analysis exemplifies a well-known result developed by Green and Sheshinski (1979) within the theory of the second best; that is, that the welfare impact of changes in tax regime is ambiguous when first-best intuition suggests that it should not be. Laffont (1994) describes this result as follows: "If n distortions (where n is greater than or equal to 2) exist, we cannot claim that the competitive equilibrium with n-1 distortions is preferable to the competitive equilibrium with n distortions."

By contrast, previous research on the double-dividend issue has characteristically proceeded by imposing special restrictions that ensure, in fact, that the equilibrium with more distortions is indeed preferable. Wolffs point is that these unambiguous results, which are counterintuitive from a first-best perspective, do not hold when one analyzes the second-best problem assuming utility-maximizing households and competitive cost minimizing firms that are restricted only in the most fundamental ways normally used in neoclassical analysis (quasiconcavity, etc.).

^{4.} Utility is defined to be "homothetically separable" if (a) a group of goods is weakly separable from all other goods in utility (i.e., a subutility function for this group exists), and (b) this subutility function is homothetic.

BOVENBERG AND DE MOOIJ

Bovenberg and de Mooij (1994) analyze a general-equilibrium model in which the ex ante, i.e., preexisting, taxes are on labor income and a dirty good, and there are no sources of income other than labor income. The dirty good tax is at the first-best, Pigouvian level. Following some initial results with unrestricted utility, they impose homothetically separable utility. In this model, the consequence of this utility form is to force the Ramsey optimum to be a uniform tax on clean and dirty consumption. They study the welfare effect on the ex ante tax base of a small reduction in the "dirt" tax, and find that utility rises.

Wolff shows that in this case, as well, the conclusion follows specifically from the assumption of homothetically separable utility. The Pigouvian tax has a cost in the nonenvironmental or revenue-raising dimension, so that the second-best optimum is a balance between the Pigouvian tax and the labor income tax. Thus, due to these preference assumptions, their tax shift moves the equilibrium from a second-best suboptimal point toward a point where both indirect utility and the tax base are maximized.

Bovenberg and de Mooij's result is sometimes interpreted as a rejection of the *possibility* of double dividends. This is an incorrect interpretation, as described below.⁵ Although there will always exist a region in tax space in which movement toward the social optimum (the Sandmo tax optimum) will be away from the Ramsey tax optimum—i.e., a region in which environmental gains are obtained only in exchange for nonenvironmental losses—there must also exist regions in which one can move toward both the Ramsey and social optimum simultaneously. In these latter regions, tax reforms yield double dividends. The relationship between the optimal first- and second-best taxes at the social optimum says nothing about whether double dividends will occur on part of or all of the path to that optimum. What is important is the relative location of the before-tax-reform equilibrium and the Ramsey and social optima.

PARRY

Using a somewhat different approach, Parry (1994) also concludes that revenue recycling will usually fail to improve nonenvironmental utility. In Parry's model, the sole ex ante tax is on labor, and a revenue-neutral tax is imposed on a dirty good with

5. Fullerton and Metcalf (1998, 224) reach this conclusion, but explain it differently than above.

revenue returned to the representative agent as a transfer payment, so that lump-sum income is positive. As in the previous analyses, utility is initially unrestricted.

Parry distinguishes three types of welfare impacts resulting from the revenueneutral tax shift.

- First, there is the welfare gain arising from a decrease in the environmental externality.
- Second, there is the welfare gain resulting from the offset of the ex ante distortionary tax.
- Third, there is what Parry calls the "tax interaction" effect, which is the
 welfare loss (in Parry's analysis) resulting from exacerbation of the labor
 market distortion by interaction between leisure demand and the dirty goods
 tax.

Parry's central conclusion is that this interaction effect usually exceeds the gain associated with revenue recycling, thereby precluding a nonenvironmental dividend (the sum of the second and third effects).

Parry extends the previous analysis by relaxing the assumption of homothetically separable utility. He shows that what was true for every good in the previous model is also true for a "central" case when this assumption is removed. By central he apparently means a produced good that behaves like the center of mass of the distribution of expenditures. Parry's result is consistent with Wolff's point and the theory of the second best: What was always the case in the homothetically separable model is only sometimes the case when the restriction is relaxed. As restrictions are removed one by one, the welfare effect of a dirty goods/labor tax reform eventually becomes entirely ambiguous.

A recent paper by Parry and Bento (1998) that extends upon Parry's 1995 paper is also consistent with Wolff's analysis. Parry and Bento show that the revenue recycling effect will be stronger than the tax interaction effect, even in the "central" case, when labor income is reduced by a tax exempt category of consumption expenditure prior to taxation. That is, if all labor income is not taxed, one can achieve double dividends by taxing a dirty good and using the revenues to reduce the labor income tax.

DISCUSSION

How should these results be interpreted? The following comment of Bovenberg and de Mooij (1994) is representative of much current thinking on the double-dividend quandry: "Environmental taxes typically exacerbate, rather than alleviate,

preexisting tax distortions—even if revenues are employed to cut preexisting distortionary taxes."

The key issue is the appropriateness of the term "typically" in this context. Given the discussion above, there would appear to be no well-defined sense, in general, in which the results could be labeled typical. Is a world in which labor income is the only type of income typical? Is the mathematical center of mass of the expenditure distribution also the empirical center of mass? (It is only if the actual expenditure distribution is unskewed.) In any case, the researchers who have made this and related claims do not define clearly what they mean by typically or central. Is the result of Parry and Bento (1998) any less typical than that of Parry (1995)? Indeed, the model in the 1998 paper is closer to the real tax code than the simpler model employed in the 1995 paper.

The most straightforward way to put this issue is, in our view, to simply note that the assumptions of rational behavior and competitive markets alone do not yield a negative answer to the double-dividend question. Under these general assumptions, neither a negative nor a positive conclusion can be drawn. Fullerton and Metcalf (1998) have pointed out, similarly, that whether a tax reform yields double dividends or not is an empirical issue, not a theoretical one. Thus, in the theoretical dimension, the double-dividend question remains open, and will continue to remain open. What is typical or usual depends on empirical facts that are worthy of more investigation.

III. CGE ANALYSES OF TAX SHIFTING

Theoretical and simulation-modeling studies of the double-dividend issue have in recent years proceeded simultaneously. Simulation modeling uses empirical information and a mathematical representation of the real economy to quantify the types of impacts that might result from various tax reforms. Simulation modeling is, therefore, closer to reality than pure theory, although the underlying model structure, of necessity, represents the real economy in a highly condensed and imperfect way. In this section we discuss some issues that are relevant to CGE modeling of tax shifting in the U.S. economy.

A benchmark for the quantitative analysis of tax shifting was the study by Stanford University's Energy Modeling Forum (EMF) of "revenue recycling" scenarios using a suite of numerical models (Shackleton et al. 1996). The EMF study demonstrated that revenue recycling—that is, tax shifting—substantially lowered estimates of costs of large-scale carbon abatement in the U.S. economy. Not all of the models predicted the existence of double-dividend outcomes, but there was consistent finding that revenue recycling yields efficiency gains relative to a policy of lump-sum rebates of carbon emissions revenues (or the use of such revenues to reduce the federal deficit). In any case, these findings stimulated hopes that the tax shifting approach might indeed allow relatively low, or even zero or negative, cost carbon abatement through reductions in existing distortions in the tax system. In particular, given both political hurdles to climate policy and the substantial difficulties in conducting rigorous cost-benefit analyses of this issue, these findings gave some hope that cost-benefit analysis of climate protection might ultimately be obviated.

However, numerical simulation analysis of climate policy in general, and tax shifting in particular, has focused attention on the problem of accounting for contrasting results (on the double dividend and other problems) from different quantitative models. As we noted in the Introduction, there is no standard methodology for this kind of effort; to date, much more attention has typically been given to the output of simulation models than to underlying features of their design and implementation that may be the sources of particular conclusions. An emerging literature is confronting this "meta-analysis" problem directly.

Repetto and Austin (1997) demonstrate how underlying structural features of a host of simulation models—including their treatment of tax shifting—are related to their predictions of the costs and benefits of climate policy. Engen et al. (1997) conducted a comparison of a set of models applied to fiscal policy, and studied how structural features and the values of key parameters relate to the models' outputs and policy predictions.

In this section we aim to contribute to this type of meta-analysis by discussing two specific simulation models of the U.S. economy, that of Goulder (1994, 1995) and that of Jorgenson and Wilcoxen (1993), and how both have been applied to analysis of the double dividend. Both models are well-known exemplars of the dynamic computable general-equilibrium approach, and are distinguished by their careful construction and extensive documentation. Moreover, their findings on tax shifting differ in interesting ways, and which have been discussed in depth by the researchers themselves. These aspects make them uniquely suited to the present purpose.

Although the lexicon of simulation modeling is sometimes imprecise, the Goulder and Jorgenson-Wilcoxen models are truly dynamic and general equilibrium in structure.⁶ Both include detailed representations of the production and consumption sides of the economy, with the two meeting in markets for commodities, and with price-taking and rational expectations (or "perfect foresight" in this deterministic context) on the part of consumers (and firms in the Goulder model).⁷ The models are

6. Numerical simulation models applied to climate policy in general and tax shifting in particular have three primary historical and technical sources (Sanstad and Greening 1998): The Ramsey model of economic growth, the Arrow-Debreu theory of general equilibrium, and the energy forecasting models that were developed during the 1970s.

Computable general-equilibrium (CGE) models constitute the quantitative application of the Arrow-Debreu paradigm, and are thus microeconomic in character. CGE models explicitly represent markets for energy and nonenergy commodities at varying levels of aggregation. Demand and supply arise from the decisions of utility-maximizing consumers and profit-maximizing firms, and solution of the models proceeds by finding a set of market clearing prices.

An alternative approach to modeling savings behavior in a general-equilibrium context is the overlapping generations (OLG) model of Samuelson (1958). This approach has been used extensively in public finance, and has been developed in computational form by Auerbach and Kotlikoff (1987). The OLG approach has also been applied to environmental economics—particularly questions of intergenerational equity—by Howarth (1998) and Howarth and Norgaard (1995).

It would be an extremely interesting exercise to apply the OLG approach to the tax shift issue, analogous to the extensive applications of the infinitely lived agent approach embodied in the Goulder and Jorgenson-Wilcoxen models. However, for example, the Auerbach-Kotlikoff model in its present form contains a preference structure that is homothetic over leisure and composite consumption, and does not disaggregate consumption. (That is, the model does not contain explicit representations of markets for energy or energy commodities.) The Howarth model in it present form does not contain sufficient detail for such analysis. Thus, a computational OLG analysis of tax shifting must await further development of existing models, or the construction of new ones with appropriate elements.

7. Several key features of the models not discussed in the text are as follows. The Goulder model incorporates 13 industries and 17 consumer goods. Particular detail is afforded six energy industries: coal mining, oil and gas, petroleum refining, synthetic fuels (a "backstop" industry producing shale oil as a perfect substitute for oil and gas), electric utilities, and gas utilities. Production is represented in terms of nested constant elasticity of substitution (CES) production functions of a modified "KLEM" type (i.e., each

solved for intertemporal paths of outputs and prices. We now turn to describing several applications of these models to analysis of tax shifting.

TAX SHIFTING SCENARIOS

Goulder Scenarios

Goulder (1994) compared the effects of an energy tax modeled on the Clinton Administration's 1993 Btu tax proposal with an increase in personal income tax and the imposition of a value-added tax (VAT), when revenues from each were, in turn, applied to federal deficit reduction. In these scenarios, revenue was recycled through future tax cuts, either in personal income taxes or returned in a lump-sum fashion, in such a way as to maintain intertemporal revenue neutrality.

Goulder found that in terms of time paths of real GNP, real consumption, and real, private fixed investment, both the income and the VAT dominated the energy tax. Indeed, in the scenarios in which the VAT or the income tax—but not the energy tax—were followed by future cuts in personal tax rates, long-run GNP, consumption and investment were higher than in the baseline.

In a second analysis, Goulder (1995) studied the effects of a carbon tax of \$25 per ton, offset by reductions in period-by-period marginal tax rates (and compared with lump-sum reductions). The result of revenue recycling relative to lump-sum rebates was significant: in terms of GDP, losses from the carbon tax were reduced by 40 to 55 percent in the long run, with the largest offset obtained through cuts in personal taxes. In terms of welfare effects (measured in terms of equivalent variation), welfare losses were reduced from 36 percent to 53 percent (relative to the baseline), depending on the form of recycling (the highest via cuts in payroll taxes).

These results clearly demonstrate the "weak" double-dividend effect of reductions in economic losses from energy or carbon taxes by means of using revenues to reduce

industry's output is a function of capital, labor, an energy composite, and a materials composite, as well as convex adjustment costs.) Firms are assumed to maximize equity value, i.e., the discounted value of after-tax dividends net of share issues. Data for the model were obtained from government sources. Production elasticities were obtained from Jorgenson and Wilcoxen, modified to fit the CES form of the model.

The Jorgenson-Wilcoxen model contains 35 industries and 35 distinct commodities. As with the Goulder model, several energy industries are distinguished: coal mining, oil and gas extraction, petroleum refining, electric utilities, and gas utilities. For each industry, output within each period is assumed to be a function of capital, labor, an energy and a materials composite, and noncompetitive imports. A nested translog (price dual) form is applied to each industry, and econometrically estimated from timeseries data on U.S. industries. A distinguishing feature of this model is the incorporation of "factor price biases" of technological change for each industry, that is, technological change responds to changes in relative factor prices.

other, distortionary taxes. In none of these cases, however, did Goulder find a double-dividend outcome in which economic losses were completely offset by this mechanism.⁸

Jorgenson-Wilcoxen Scenarios

In an analysis based on one of the EMF 12 scenarios (scenario 7), Jorgenson and Wilcoxen (1993) studied the effects on real GNP in year 2020 of a carbon tax of \$15 per ton imposed in 1990, rising by 5 percent annually. Relative to lump-sum rebating, cuts in a labor tax reduced GNP loss by 60 percent—from a 1.7 percent to a .69 percent reduction from the baseline GNP forecast. In the case of recycling through taxes on capital, 2020 GNP is actually increased above the baseline by 1.1 percent—a double-dividend outcome.

In a further analysis, Jorgenson et al. (1996) apply the model to a full analysis of "social cost pricing" of energy-related externalities coupled with different revenue-recycling schemes. They apply various estimates of both damages arising from climate change and damages arising from pollutant effects, such as increased mortality and reduced visibility from various categories of fossil fuel combustion. Combining the two types of externalities allows for cost-benefit analysis of using the tax system to internalize damages.

For the present purpose, the interesting feature of their analysis is the economic cost of internalization independent of environmental benefits, and as a function of the revenue recycling approach used. This is what we have referred to previously as the nonenvironmental dividend. For each combination of climate and pollutant damage estimates—using energy tax revenues to offset property or capital taxes—yields an increase in consumers' economic welfare (measured as lifetime equivalent variation over consumption of goods, services and leisure) even without inclusion of environmental gains; that is, the model yields double-dividend outcomes. For recycling via reductions in average or marginal labor taxes or nonenergy sales taxes, by contrast, there is a welfare loss if environmental gains are not included.

^{8.} Goulder does, in fact, indicate one such result, when intertemporal elasticity of substitution is set very high. This was, however, essentially a sensitivity analysis run. It also supports the point made in footnote 8; that is, that the "uniformity bias" present in the model structure can be overcome if parameter values are sufficiently extreme.

DISCUSSION

Why do these two models give different results on the double dividend in the case of cuts on capital investment taxes? Accounting for the contrasting results is a key question for the policy applications of the two models. In addition, because they serve as a type of benchmark for quantitative economic studies of carbon policy, this question has somewhat broader significance. Below we discuss several possible explanations.

We first discuss the structure of consumer preference representations in the models, in light of the results of section 2 on static, theoretical analyses of the double-dividend problem. There, we showed how particular assumptions on preferences are strongly related to theoretical conclusions regarding the double dividend. Because the numerical models also include specific assumptions regarding preferences, it is important to examine whether a corresponding relationship might exist in this applied context.

Preference Representations

We described in section 2 recent theoretical counter arguments to the likelihood of double dividends, and saw that these counterarguments are not sufficiently general to allow a firm conclusion on the issue. We begin here by noting that this theoretical situation would appear to present something of a quandary for numerical modeling of tax shifting. Some researchers (e.g., Goulder 1995; Bovenberg and Goulder 1996) have viewed quantitative simulation models as providing, in a sense, tests of the theoretical results. They have argued that numerical findings against the double dividend provide a form of verification of the corresponding theoretical results. However, given the demonstration that the theoretical case is, in general, ambiguous, the relation between analytic and numerical results is more problematic.

Essentially by definition, a simulation model must assume particular functional forms for preferences (and other elements) to instantiate the theory. Given the finding that certain such assumptions will ensure particular conclusions regarding the double-dividend hypothesis, regardless of the values of the parameters contained in the model, it is natural to wonder whether these assumptions are at work in those numerical models that have been applied to the issue.⁹ This question requires, in turn, attention to the theoretical consequences of extending the static optimal tax

^{9.} This is a slight overstatement; extreme values of specific parameters can in some cases cause model outputs to "switch" patterns of outputs. This does not detract from the point we are making.

results we reviewed above to the kinds of intertemporal settings that are included in the simulation models.

The general result of Deaton (1981; see footnote 2) regarding the optimality of uniform commodity taxation given homothetically separable preferences can be extended intertemporally via suitable indexing and reinterpretation of variables (that is, for example, commodities are identified in part by the date of their consumption). The conclusion is that uniform taxation, both across time periods and by implication across goods within each time period, is optimal. Hence, in the absence of capital, it appears that homothetically separable or implicitly separable structures have the same effect in at least some forms of intertemporal analysis as they do in static analysis.

However, the above result is obtained in a model without capital accumulation. The situation becomes considerably more complex in models with capital in which interest income can also be taxed, such as the Goulder and Jorgenson-Wilcoxen models. An illustrative analysis is that of Aschauer and Greenwood (1985): in the context of a small-dimensional CGE model that includes capital accumulation and that can be analytically manipulated as well as solved computationally, they note that, if the government is restricted to labor taxation, labor taxes across time periods (and by implication across goods within each time period) should be uniform as above. When the government is allowed to employ both labor and interest income taxes, however, optimal policies become more complicated and involve numerical approximation of analytically intractable open form solutions even in this small model. This example illustrates the fact that theory does not provide a singular answer to the questions of optimal taxation in an intertemporal setting with the full range of distortionary taxes, just as theory does not do so in the general, static setting.¹²

With these qualifications, however, it is still instructive to consider how the consumer preference structure of the two models under discussion might be related to their results. To begin, both models contain an infinitely lived representative household maximizing an additively separable utility function. Both contain an intertemporal elasticity of substitution parameter that influences how the consumer trades off consumption in different time periods. The magnitude of this parameter in

^{10.} See Blanchard and Fischer (1989, chapter 11) for a discussion.

^{11.} This result is known as "tax smoothing"; see Blanchard and Fischer (1989).

^{12.} In some models of the optimal taxation of savings, for example, it is possible to show that stringent restrictions on preferences imply the optimality of zero taxation of interest (Atkinson and Stiglitz 1980). Another example is the problem of "dynamic inconsistency" (Kydland and Prescott 1977).

the Jorgenson-Wilcoxen model is approximately twice that in the Goulder model. As Engen et al. (1997) discuss, this difference accounts at least in part for the more rapid short-run adjustments to policy changes in the Jorgenson-Wilcoxen than Goulder models. However, as they also note, this parameter cannot have an effect on the long-run, steady-state results.

In the Goulder model, the representative household maximizes intertemporal utility as a function in each period of a CES function of a composite commodity and leisure, subject to an intertemporal budget constraint. The representative household is endowed with an exogenously determined time endowment. The composite consumption good is Cobb-Douglas, which is homothetic, so that the static utility of the representative agent is homothetically separable. Thus, the within-period preference structure of the model is subject to the issues we raised in section 2.

On the consumer side of the Jorgenson-Wilcoxen model, an infinitely lived representative household maximizes an intertemporal utility function, in a multistage nesting scheme. At the top level, discounted utility of full (per capita) consumption is maximized subject to an intertemporal budget constraint. In the second level, full consumption within each period is allocated between consumption and leisure, and at the third level, the consumption composite is in turn aggregated from five intermediate composite commodities. At a fourth level, these 5 are in turn aggregated from the full 35 commodities of the model. At the top level, utility is strongly separable, while at the second level, static utility is represented by a homothetic indirect utility function. (Savings appear in the budget constraint, and are determined indirectly.) The composite commodity is not homothetic, so homothetic separability is not present at the second level of the decision tree. But the expenditure share function for the composite commodity may be implicitly separable. If so, this would imply that uniform taxation of the five groups of commodities (into which the 35 commodities are organized) is optimal. The five groups of goods within the composite commodity are not homothetic, so homothetic separability is not present at the third level of the decision tree. But the expenditure share functions for each of the five subgroups of goods may be implicitly separable. If so, this would analogously imply that uniform taxation of the commodities within each of the five groups is optimal (even if the expenditure share function at the higher level is not implicitly separable). The fourth level of decisionmaking, representing the lowest stage of commodity aggregation, is homothetic at the household level. So homothetic separability is present at the fourth level of the decision tree. This implies that uniform taxation of the subgoods within each of the 35 commodities is optimal (even if implicit separability is not present at the higher levels).

Fully assessing the role these functional structures play in the outputs of the models is a task for further research. It is worth noting, however, a general problem related to this question that is inherent in the application of CGE models to the tax shifting issue. As Ho (1989) notes, fundamental data limitations imply that modelers "cannot easily estimate and use a disaggregated model of consumption-savings or consumption-leisure choice." Thus, there is no alternative to the use of multiple-stage, aggregated representations. However, the goal of consistent aggregation imposes potentially severe restrictions on the structure of such representations. For example, homothetic separability is necessary and sufficient for consistent commodity aggregation in which each composite commodity satisfies the theory of demand (Green 1964), but as discussed above, this implies in a static context the Ramsey optimality of uniform taxation of goods in each homothetically separable group. Again, this type of restriction does not dictate the results in a full CGE setting, but may significantly affect results. It raises questions regarding the tendency of the models toward certain conclusions due to structural rather than empirical features. ¹³

This issue underlies not just CGE analysis, but also econometric analysis of data. As Deaton (1981) notes, "Econometricians estimating commodity demand and labor supply equations make generous use of separability assumptions to enable estimation at all. . . . It is . . . of central importance that empirical work directed toward providing parameters for evaluating optimal tax formulae should employ functional forms sufficiently general to allow measurement rather than assumption to determine the structure of taxes." Understanding the currently unknown effects of the preference structure in the Jorgenson-Wilcoxen and Goulder models upon their patterns of output is not a trivial task. Comprehensive research is needed about separability structures in which dirty goods are "carefully placed" to avoid welfare impacts due to structural specification of a Ramsey optimum (e.g., the optimality of uniform commodity taxes) that may be necessary for other reasons (e.g., to ensure that the multiple-stage decision process is consistent).¹⁴

^{13.} It is interesting to note that analyses using the DRI and Wharton Econometric macro models of the U.S. economy have found positive results from carbon tax/labor tax shifting. Without endorsing these models, we observe that the contrast in results between the CGE models with uniform tax bias and macro models without this bias suggests that the magnitude of the uniformity bias is important to understand. On the other hand, it is not clear how dynamic preferences are represented in detail in the current versions of these models.

^{14.} Consistent commodity aggregation is possible without homothetically separable structure, but then other highly restrictive structures are necessary. Green (1964) describes these structures in Theorem 3.1. They involve weak or strong separability, at minimum; and both weak and strong separability have implications for optimal tax structures (Auerbach 1985). In addition, the ability to construct quantity or price aggregates does not exist in general; e.g., such construction requires, in the case of strong price aggregation (Blackorby et al. 1978), that the conditional indirect utility functions for each separable sector may be written in the Gorman Generalized Polar Form (this differs from the Gorman form relevant to aggregation across consumers).

Capital Dynamics and Other Issues

To explain his results, Goulder (1995) appeals to results in the optimal tax literature that treat issues associated with production efficiency, particularly the work of Diamond and Mirrlees (1971). In particular, he argues, these findings demonstrate that "taxes on intermediate inputs have larger welfare costs (apart from environmental benefits) than do equal-revenue taxes on primary factors or final goods." However, the Diamond and Mirrlees result is based on a model in which externalities do not exist. That is, their result does not take account of second-best considerations in the presence of an environmental externality, so it is not clear that comparison with their result is appropriate. We also note that the Diamond and Mirrlees result in fact states that, if a full set of taxes can be levied on primary factors and final goods then taxes on intermediate goods are unnecessary, as opposed to welfare-reducing, so that its practical significance is somewhat unclear.

Wilcoxen (1994) proposes an alternative source of the difference between the two models' results, arguing that the different ranking of energy and income taxes in the two models could be due to the treatment of capital goods production. In particular, he notes that in the Jorgenson-Wilcoxen model, new capital goods are labor, rather than energy, intensive. Thus, increasing energy taxes has little effect on the price of such goods. He suggests that, by contrast, new capital goods being energy, rather than labor, intensive, could account for Goulder's results: higher energy prices would raise the cost of new capital goods, lowering the rate of return on investment, and thus reducing investment, GNP and consumption growth—the effects Goulder reports.

At the same time, there is another difference in the models' treatment of capital that could also bear on their differing assessment of revenue recycling outcomes. The Jorgenson-Wilcoxen model represents capital as perfectly mobile across sectors, while the Goulder model assumes partially sector-specific capital by means of an adjustment cost framework. Thus, all else being equal, the model will exhibit greater short-run flexibility of capital stock adjustment to such policies as reducing taxes on investment.

Some have questioned the Jorgenson-Wilcoxen results in light of this capital mobility assumption. The standard interpretation of this approach is that the model represents long-term equilibria; that is, the state of the economy after shorter-term adjustments have occurred. This does raise questions about the interpretation of dynamic paths; in effect, "time" in the model should not be taken to literally correspond to "time" in the real world. In any case, it is also true that use of the capital mobility assumption rather than other possible specifications does not

15. See for example Joskow (1992).

translate in a straightforward way to interpretation of long-run effects. It should also be noted that there are corresponding problems with the convex adjustment-cost approach employed by Goulder; an increasing body of research demonstrates that this adjustment cost specification is inconsistent with microlevel data on firm behavior (Hamermesh and Pfann 1996).

The degree to which the contrasting assumptions on capital explain their different predictions could conceivably be explored by appropriately designed simulations. For example, counterfactual analyses in which capital taxes alone are employed to satisfy given revenue requirements could be used to compare these effects directly. Here again, however, it is important to note that the models both employ reasonable assumptions whose differences reflect the current state of underlying theory and empirical work. What we are suggesting is that careful comparison of the way capital is treated in the both models may be very helpful in identifying future empirical work that would bear significantly on the double-dividend question. Specifically, such a comparison could bring into sharper focus why these two prominent CGE models yield different answers to this question.

IV. CONCLUDING REMARKS

The use of large-scale, economy-wide tax shifting as a means of dealing with climate change or other environmental problems may seem a distant prospect. However, we believe that the potential impacts of climate (and other environmental) change on human society may well eventually open the way for ambitious—indeed unprecedented—policies of this type. Hence, the double-dividend debate is far from an academic exercise. It is vital that the underlying mathematical content of the current theoretical state of the art on this issue be clearly understood. As we have shown, the possibility of double-dividend outcomes from environmental tax shifting remains an open question. Further theoretical research to clarify the nature of cases in which the double dividend does and does not hold would contribute substantially to the policy debate.

Computable general-equilibrium models are an important tool for assessing the quantitative character of potential tax shift policies. These models serve both as research platforms and as practical tools for helping to design and evaluate real-world policies. Thus, further careful analysis of the relations among their underlying structure, empirical features, and quantitative output is needed to ensure their effective application to policy design. The complexity of the models makes this analysis a challenging task. In the case of the two models we examined, it remains a subject of debate why different double-dividend outcomes are predicted. For the assessment of this and other such issues, the further development of rigorous protocols for model comparisons would yield both research and policy benefits.

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