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The Macroeconomic Effects of Environmental Taxes: A Closer Look at the Feasibility of "Win-Win" Outcomes

Prepared by Jenny E. Ligthart[1]

Authorized for distribution by Liam P. Ebrill

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Abstract

This paper reviews recent literature on the macroeconomic effects of environmental taxes. It attempts to delineate the conditions under which a cleaner environment is compatible with attaining macroeconomic objectives, such as more employment and economic growth. The analysis reveals that an environmentally motivated fiscal reform—using the revenues from environmental taxes to cut labor taxes—may yield employment and environmental dividends if the tax burden can be shifted to agents outside the labor market, such as capitalists, transfer recipients, and foreigners. A cleaner environment and a higher rate of economic growth go hand in hand if the environment is considered an important public input into production.

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Author's E-mail address: jligthart@imf.org

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SUMMARY

The linkages between environmental protection, public finance instruments, and macroeconomic objectives have been barely addressed in the literature until this last decade. This paper surveys recent developments in the theoretical and empirical literature on the macroeconomic effects of environmental taxes. An attempt is made to delineate the conditions under which environmentally motivated fiscal policies yield "win-win" outcomes in the sense that they improve environment quality as well as attain macroeconomic objectives, such as more employment or a higher rate of economic growth.

Traditional theoretical work on environmental policy starts from a microeconomic framework focusing on a particular market that features an environmental externality. Various policy instruments are discussed and evaluated in terms of economic efficiency. Compared with standards, environmental taxes are a lower cost instrument to achieve a given level of pollution. In this type of model, however, the revenues of environmental taxes are rebated to consumers in a lump-sum fashion.

Revenues from environmental taxes may be employed in a more productive way by using them to lower distortionary taxes on labor in a revenue-neutral manner. Such a green fiscal reform may yield a "double dividend"—boosting both environmental quality and employment—if the burden of taxation can be shifted to agents outside the labor market, such as capital owners, transfer recipients, and foreigners.

I. Introduction

Even before it became a separate area of interest, environmental topics had long been a part of microeconomic theory.[2] Accordingly, early theoretical studies on environmental policy had a strong microeconomic orientation and were predominantly partial equilibrium in nature. Typically, the effects of environmental policy were studied for a particular firm, household, or market. From the 1960s onwards, a large volume of literature emerged on the theory of externalities and comparative analysis of environmental policy instruments. Most empirical studies conducted in the 1970s also had a strong partial equilibrium character. They mainly focused on the design and application of methods to measure society's benefits of particular (nonmarketed) environmental commodities (e.g., recreation sites, whooping cranes, etc.). Policymakers used the estimated benefits—expressed in monetary terms—as inputs in cost-benefit analyses to evaluate the soundness of proposed policy changes.

Environmental policy, however, has important economy-wide and international effects although little work has been done in this area until the late 1980s. Recently, there have been a number of studies dealing with environmental problems from a macroeconomic point of view. The aim of this paper is to give an overview of recent contributions to this literature. In particular, it reviews the effects of environmental policy on resource allocation—with a focus on employment—and on the rate of economic growth. A general equilibrium approach is taken in which traditional fiscal and environmental policies are studied in an integrated fashion.

Several developments at the end of the 1980s have led to an increased interest in addressing environmental issues from a macroeconomic viewpoint. First, environmental problems with an international dimension, such as ozone layer depletion and deforestation, materialized. To analyze these problems economists made use of (dynamic) game-theory to model the strategic interaction between countries (see Carraro and Filar, 1995). Second, there has been a growing realization that national environmental problems cannot be studied apart from macroeconomic problems such as high rates of involuntary unemployment and low rates of economic growth.[3] Trade-offs between public policy goals may be present. In particular, policies targeted at protecting the environment may well worsen the prospects of reaching other macroeconomic

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[2]Cropper and Oates (1992) date the "environmental revolution" in the late 1960s. Two events in the early 1970s gave a major boost to the development of environmental economics as a separate discipline of economics. First, the Club of Rome report (Meadows, and others, 1972) which stressed the limits to continued economic growth. Second, the first oil crisis which raised questions concerning the pricing and optimal depletion of natural resources.

[3]See, for example, the 1994 report of the Commission of the European Communities (CEC) which synthesizes both environmental and economic analyses to draw conclusions on the potential double benefits of policy integration. Proposals for policy integration were made in view of both the high levels of unemployment and labor taxes in many European countries.

goals such as full employment and sustained economic growth. An integrated study of (traditional) fiscal and environmental policy was called for that, in particular, takes account of the government's budget constraint. Without government debt, the government budget constraint dictates that spending on public goods needs to be financed by a mix of taxes on commodities and labor, the subject matter of optimal tax theory. It is well known that taxes on labor raise public funds at the cost of discouraging labor supply, depending on the labor supply elasticity (cf. Auerbach, 1985). Environmental taxes, however, correct environmental externalities, but also confer the supplementary benefit of raising public revenues that can be used to cut labor taxes in a revenue-neutral fashion. Accordingly, the burden of taxation is shifted away from socially desirable activities such as employment toward "public bad" such as pollution, which may yield two "dividends": (i) reduced pollution, and (ii) a higher level of employment. In the literature this notion is called the "double-dividend" hypothesis (Ulph, 1992; Bovenberg and van der Ploeg, 1994a).

There are divided opinions concerning the validity of the double-dividend hypothesis. The CEC, for example, strongly supports a "green tax reform" in which revenues of carbon taxes are used to cut payroll taxes (social security taxes paid by employees) in a revenue-neutral way (CEC, 1993, 1994).[4] In its 1996 Annual Report, the IMF is more cautious concerning the beneficial effects of green tax reforms although employment effects are not specifically referred to: "Green taxes were found desirable by some Directors for correcting negative externalities, but the base of these taxes was considered too narrow to fully replace payroll taxes; moreover, energy taxes were already high in many industrial countries" (IMF, 1996, p. 32). This raises the question under what circumstances a double dividend is likely to occur. The aim of this paper is to clarify the preconditions which need to be satisfied to realize a double dividend.

The analysis of the dynamic macroeconomic impact of environmental policy was facilitated by developments in growth theory which made it possible to endogenize the rate of economic growth. This endogenous or "New Growth" theory (see Romer, 1986; Barro and Sala-i-Martin, 1995) allows for the effect of public policy, preferences, and technology, on the steady-state rate of economic growth. In this framework, there are nondecreasing returns with respect to a broad measure of capital which includes physical as well as human capital and knowledge. As a result, economies can grow without bound.[5] Recently, however, the first

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[4]The 1993 "White Paper" of the European Commission also incorporates the notion of revenue recycling but departs from an across-the-board cut in labor costs by proposing a reduction aimed at semi- and unskilled labor. Two arguments are given to support this idea: (i) social security contributions are relatively large for low incomes, and (ii) unemployment is concentrated among these groups.

[5]In the preceding neoclassical growth theory (see Solow, 1956), the long-run rate of economic growth—usually equal to the sum of population growth and technological progress—is

(continued...)

studies on endogenous growth with environment considerations have appeared. These studies allow one to consider the question whether a clean environment and economic growth are compatible goals of economic policy. Against that background, this paper considers the conditions where "win-win" policy results may be obtained.

More specifically, then, the paper surveys the literature and delineates the conditions under which environmental taxes act as "win-win" policies in the sense that both environmental and economic benefits—such as a higher level of employment and more economic growth—are reaped. It will be argued that this matter cannot be settled generally as it strongly depends on the specific circumstances. As a result, each policy proposal should be evaluated individually. The positive employment and growth effects of green tax reforms are shown to be strongly dependent on the initial tax system and presence of factors of production or households who cannot avoid taxes.

The rest of the paper is structured as follows. Section II gives an overview of the policy instruments the government can employ to protect the environment and analyzes their main efficiency characteristics. In Section III the literature on environmental taxes and the double-dividend hypothesis is surveyed and the conditions under which a double dividend may be reaped are studied. Section IV analyzes the effects of a stricter environmental policy on the rate of economic growth and identifies the conditions under which environmental protection and economic growth are compatible goals of public policy. Section V summarizes and presents some conclusions.

II. Environmental Policy: Alternative Instruments and their Relative Efficiency

In the presence of environmental externalities, the allocation of resources in the decentralized market economy is often suboptimal. A pollution externality generated on the production (or consumption) side yields a market outcome with too much production (consumption) given the associated pollution. Without clearly defined property rights some form of government intervention is needed to arrive at the social optimum. This section gives an overview of the

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[5](...continued)
assumed to be exogenously determined. Given decreasing returns with respect to reproducible factors of production, growth will peter out absent population growth or technological progress. In such a framework, environmental policy could not affect the *rate* of economic growth in the long run, only the *levels* of economic variables may be affected. Therefore, this framework cannot allow for the effect of environmental policy on the long-run rate of economic growth.

main policy instruments that can be used to protect the environment.[6] Before looking at the various instruments, the Coasian solution is studied in which market participants solve the externality problem themselves.

A. Bilateral Negotiations

Coase (1960) argues that when private property rights[7] for a clean environment are clearly defined and enforceable, the polluter and the sufferer can through bilateral negotiations achieve a Pareto-efficient outcome. If the sufferer holds the property rights, the polluter offers the sufferer a compensating payment to be able to pollute. However, if the polluter holds the property rights, the sufferer offers the polluter a side payment to induce him to reduce pollution. The optimal allocation is achieved irrespective of who holds the property rights. This is known as the *Coase theorem*. In practice, however, these market bargains are unlikely to take place since agents do not live in a Panglossian universe in which markets are working perfectly (see Mishan, 1971). High legal and transaction costs may form an obstacle to bargaining, particularly when externalities are felt by many agents who are widely dispersed and difficult to identify.

B. Environmental Standards

In the absence of private property rights for a clean environment, the government can employ its policy instruments to obtain Pareto improvements. Several approaches to environmental policy can be distinguished. The most common form of government intervention is a command-and-control approach based on environmental standards.[8] Standards impose a quantitative limit (or a quota) on polluting substances (e.g., emissions) which, for example, can be expressed in terms of concentrations in emitted gas. Ideally, standards need to be set in such a way that firms supply the optimal quantities of output and pollution.[9] This requires that the regulator has detailed information on firms' marginal costs and benefits of emission reduction. Compliance with the standard needs to be monitored by a regulatory monitoring

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[6]For ease of exposition the analysis is restricted to production externalities, but can without loss of generality also be applied to consumption externalities.

[7]Property rights are the legal rules which determine what individuals or firms may do with their property. A well-defined system of property rights is completely specified and exclusive, costlessly transferable, and costlessly enforced.

[8]Emission standards are the most prominent in the literature. Besides setting standards on emissions, governments may set standards which apply to products (e.g., prescribe the sulfur content of fuels) and production processes (e.g., prescribe the temperature of combustion processes).

[9]In this case, the level of "economic pollution" lies below the physical level of pollution. Zero pollution is unlikely to be the optimal level as this requires a zero level of economic activity.

agency and is enforced through a penalty system. Monitoring of emissions may be a rather costly procedure, particularly if there are a large number of nonpoint[10] and mobile sources.

C. Environmental Taxes

A second approach to environmental policy is market based. Pigou (1924) proposed the use of taxes levied on discharges of pollution during production to bring the private marginal costs in line with the social marginal costs of production. In theory, the optimal Pigovian tax is equal to the sum of the marginal environmental damages (at the optimal level of pollution). By "internalizing" the cost of pollution into private decision making, Pigovian taxes give firms an incentive to pollute less. This approach is in line with the "polluter pays principle" which states that the polluter is directly responsible for caused damages. Compared with standards, Pigovian taxes are a lower-cost method of achieving a given reduction in pollution (Baumol and Oates, 1988). When faced with a Pigovian tax, firms are encouraged to install abatement equipment (e.g., installing scrubbers and filters in outlets or sewage treatment) to reduce pollution while such incentives are absent with standards.[11] From a dynamic point of view, Pigovian taxes are also more desirable than standards. Taxes stimulate firms to search continually for pollution-saving technologies. The revenue potential of pollution taxes may be another reason to prefer taxes to standards. Governments face different options in using ecotax revenues: reducing public deficits, increasing spending on "traditional" public goods, earmarking for specific environmental projects or reducing distortionary taxes on labor or capital.

D. Tradeable Pollution Permits

A third approach is to create a market for pollution permits (as proposed by Dales, 1968). The idea of tradeable (or marketable) pollution permits is that the regulating authority sets a quantitative limit on total pollution in a specific area and issues permits for this amount. The allocation of permits to individual firms may be based on criteria such as historical emissions, current emissions or an auction process. Firms can trade these permits freely on an open permit market.

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[10]Nonpoint pollution enters the environment from many dispersed sources rather than a single, easily identifiable source such as a chimney. Actual measurement of these sources of pollution is very difficult.

[11]For firms with abatement costs below the Pigovian tax, it is more profitable to clean up pollution. Accordingly, the Pigovian tax determines the highest marginal abatement cost a firm is willing to pay.

In a setting of perfect certainty Pigovian taxes and marketable emission permits are equivalent instruments to obtain a desired level of emission reduction.[12] Intuitively, given the optimal level of permits their price will be bid up until it is exactly equal to the level of the Pigovian tax. For firms with relatively low abatement costs, reducing pollution through private abatement is easier than buying emission permits. Conversely, firms with relatively high abatement costs will buy emission permits instead of spending resources on abating pollution. Marketable pollution permits are flexible instruments to control pollution. With new entrants, the industry standard does not have to be adjusted to take into account prospective higher levels of pollution.[13] New entrants in the polluting industry will demand permits which push the permit price upward and thus raises the "implicit tax" on pollution. When Pigovian taxes are employed, however, entry and exit of firms requires an adjustment of the tax level to maintain the optimum amount of pollution. Moreover, governments may influence the permit price in the desired direction by engaging in permit market operations (i.e., buying or selling permits). The government can, for example, sell permits to make anti-pollution policy less stringent. Besides firms and the government, nonpolluters such as green lobby groups can buy permits with the objective to reduce pollution.

E. Subsidies and Tax Incentives

All instruments discussed to this point use the "stick" to induce a desirable level of environmental quality. Alternatively, the regulator can use the "carrot" to affect behavior by employing subsidy schemes as an incentive to promote pollution control. Various types of subsidy schemes can be discerned. First, firms may be given direct subsidies for units of emission reduced to encourage private abatement activities. Second, governments can assist firms by granting subsidies on investments in pollution-saving equipment and spending on research and development through tax credits. Alternatively, governments can provide "soft loans"—with a rate of interest below the market rate—to firms undertaking green investments. Subsidy schemes do not comply with the polluter pays principle and put additional strain on the government budget. Furthermore, subsidies attract new entrants to the polluting industry due to the lower production costs. Consequently, emissions of the whole

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[12]Weitzman (1974) shows that under uncertainty about the benefits or costs of emission reduction, the two policy measures are no longer equivalent and neither are likely to be optimal.

[13]As Buchanan and Tullock (1975) have shown, firms themselves may prefer standards to Pigovian taxes thereby explaining the observed frequency of direct regulation. They argue that the assignment of emission quotas to existing firms in the industry, raises the price of output—through a restriction of output—above marginal cost in the industry. As a result, incumbent firms earn rents although each firm will produce at somewhat higher average costs. Note that this argument only holds for the range of output values over which the ex post price is above average costs. If potential entrants are able to obtain a share in the industry's quota, it is profitable for them to enter the market thereby eliminating any above normal returns.

industry expand compared with the initial equilibrium although emissions of individual firms are reduced.

F. Moral Suasion

In the last two decades, European countries have started using "voluntary" agreements (or covenants) between industries and the government as an alternative way to protect the environment.[14] These negotiations are a form of self-regulation rather than regulation imposed by the government. For example, in the 1980s, the Dutch government negotiated with the detergents industry to reduce and ultimately remove phosphorus from detergents. However, industries are often persuaded to agree to a reduction in pollution by the threat of a financial penalty if no agreement is reached. Advantages of negotiations are twofold. First, there is a higher likelihood of compliance than with taxes or standards since firms agree with the cut in pollution instead of having to carry out a policy imposed from above. Second, negotiations offer more flexibility than command-and-control regulation (OECD, 1989).

To conclude this section, market-based instruments such as environmental taxes and tradeable emission permits are the most efficient (in economic terms), but certainly not always the best solution to all pollution problems. The choice of instrument to apply also depends on the specific circumstances such as the nature of the pollution, the number of polluters, the available technologies, and the costs of monitoring and enforcement. For example, in a situation of a few large polluters with similar abatement costs, direct regulation may be efficient. However, when the differences between abatement costs are large and there are many dispersed polluters (and thus large monitoring costs), governments may prefer to employ pollution taxes.

In the next two sections models are surveyed in which environmental policy—especially environmental taxes—is studied in a more general equilibrium setting. In particular, attention is paid to the effect of environmental taxes on macroeconomic variables such as output and employment.

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[14]In addition to the covenants discussed in this section, the government can also provide information to consumers with the objective to create environmental awareness. Awareness building may contribute to environmental friendly behavior.

III. Environmental Policy and Resource Allocation: Do Environmental Taxes Yield a Double Dividend?

A. The Double-Dividend Hypothesis

Environmental taxes were shown to possess the ability to improve upon the allocation of resources by charging polluters with a price for the true cost of the damages. As an additional benefit, environmental taxes generate public revenues while alleviating distortions whereas traditional taxes (such as capital and labor taxes)—which are primarily designed to raise revenues—distort private behavior and cause efficiency losses. Terkla (1984) and Lee and Misiolek (1986) were one of the first to suggest that substituting environmental taxes for traditional taxes may yield a net welfare gain to society. This claim revives in the recently launched "double-dividend" hypothesis. By using the revenues from environmental taxes to cut distortionary labor taxes in a revenue-neutral way, governments may reap two "dividends:" (i) environmental quality improves, and (ii) public revenues are raised in a less distortionary way (Pearce, 1991; Ulph, 1992; Bovenberg and de Mooij, 1994; Oates, 1995).[15]

Alternative definitions of the second dividend have led to some confusion in the double-dividend debate. European authors usually define the second dividend as an increase in employment and refer to an "employment double dividend" (Bovenberg and van der Ploeg, 1994a; Ligthart and van der Ploeg, 1996; Carraro, and others, 1996). Also, alternative dividends were distinguished, in addition, to the employment dividend, such as increases in public spending and higher profits.[16] American authors (e.g., Goulder, 1995; Parry, 1995) define the second dividend in terms of a reduction in the distortionary cost of the tax system. Goulder (1995) introduces the concept of *gross costs* which measures the reduction in individual welfare excluding the benefits derived from changes in environmental quality. Accordingly, a second dividend is obtained if the gross costs associated with a green tax reform are negative. Unlike European authors, the various economic variables contributing to a change in welfare (such as employment, profits, public consumption, and environmental quality) cannot be discerned in Goulder's approach.

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[15]Terkla's empirical study considers a tax swap starting from a zero initial environmental tax. He then tries to find the environmental tax rate that matches the marginal cost of reducing the same amount of emissions as allowed by existing environmental regulations. Terkla does not allow for feedback effects of environmental taxes on the labor tax base and designed the experiment in such a way that environmental quality is unaffected precluding a first dividend.

[16]Bovenberg and van der Ploeg (1996) speak of a "triple dividend" which is defined as an improvement in environmental quality coupled with an increase in profits. Some studies that assume an optimal tax system from the outset distinguish a "social double dividend" which materializes if both environmental quality and public consumption rise (see Ligthart and van der Ploeg, 1996).

Goulder (1995) abstracts from the first dividend and distributional concerns and focuses entirely on the efficiency costs of environmental taxation. He distinguishes a strong and a weak form of the double-dividend hypothesis. The *weak version* states that gross costs are lower if the environmental tax revenues are recycled through cuts in distortionary taxes rather than rebated in a lump-sum fashion. Given the nature of distortionary taxes this claim will hold by definition. The *strong version* asserts that substituting environmental taxes for a "representative" distortionary tax yields zero or negative gross welfare costs. Intuitively, the total excess burden of the tax system is reduced since the avoided distortions stemming from a lower level of distortionary taxes outweigh the welfare costs associated with the higher environmental tax. Parry (1995) decomposes the total welfare effect of a green tax swap in a *revenue effect* and a *tax interaction effect*. The revenue effect refers to the welfare gain derived from using environmental taxes to lower distortionary taxes compared with recycling in a lump-sum manner. The tax interaction effect measures the efficiency losses due to the exacerbation of prior tax distortions caused by a rise in environmental taxes. Clearly, the strong double dividend fails to hold if the tax-interaction effect exceeds the revenue effect.

From the early 1990s onwards the double-dividend hypothesis gained popularity among academics as well as politicians. Politicians eagerly embraced the double-dividend premise as an ideal marketing device to push politically unpopular environmental taxes. Environmental taxes were sold as "no-regret" policies. Even if the environmental benefits (or the first dividend) turn out to be small or absent, environmental taxes are still desirable on account of the benefits of a less distortionary tax system. This is appealing since the uncertain environmental benefits are difficult and costly to measure. However, political opposition to green taxes due to the uncertainty about the net benefits is only one side of the story. More important is the resistance provoked by the effect of environmental taxes on: (i) the (inter)national competitiveness of firms,[17] and (ii) the distribution of income. An energy tax levied on large firms will redistribute income from the energy-intensive to the nonenergy sector. If the energy tax is levied on energy consumers, the distributional impact is generally

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[17]Environmental regulation raises firms' production costs which weakens their competitiveness (as measured by the average productivity of industry which depends on the quality value of products and the efficiency with which they are produced). Jaffe, and others (1995) argue in a survey of environmental regulation and competitiveness of the U.S. manufacturing industry that the majority of the evidence provides support for the view that environmental regulation tends to depress the industry's average productivity. However, some economists have suggested (cf. Porter, 1991; Porter and van der Linde, 1995) that a tougher environmental policy may stimulate growth and competitiveness. According to this so-called "Porter hypothesis," environmental regulation induces firms to improve upon the efficiency of their production process by discovering innovative approaches to reducing pollution which more than fully offset the cost of compliance. Alternatively, environmental regulation may push firms into producing less pollution-intensive products. This may give firms an absolute advantage (or "first-mover"advantage) over foreign firms which were not subject to regulation.

regressive (Smith, 1992). Low income groups—which spend a relatively large share of their income on energy—will be hurt the most. Introducing an environmental tax as part of a revenue-neutral "package" of policy instruments in which the tax burden is shifted from labor to public "bads" such as pollution is likely to enhance the political acceptability of environmentally motivated taxes.[18]

The weak double-dividend claim will hold in a representative agent model since it is based on the insight that distortionary taxes yield welfare losses. Most contributions to the debate concern studies on the strong double-dividend claim and are theoretical, although empirical studies based on applied general equilibrium models are growing in number. The strong double-dividend claim is rather controversial. Results derived from theoretical models depend strongly on the specific assumptions made about preference and production structures. Subsections C and D elaborate further on this issue.

B. Theoretical Studies: Some Key Results

The basic model to analyze a green tax reform has been developed by Bovenberg and de Mooij (1994). They show, using a simple analytical general equilibrium model which features a representative household, that an environmental tax reform—in which the revenues of green taxes are used to cut labor taxes in a revenue-neutral fashion—cannot yield a strong double dividend. The starting point is where the pollution tax equals the Pigovian tax rate.[19] Their model features a linear production technology with labor as the only factor of production. Households derive positive utility from two types of goods, "clean" and "dirty" consumption,[20] environmental quality and public consumption, but disutility from working. Private consumption and leisure are (weakly) separable[21] from environmental quality and public

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[18]This popular phrasing of the argument is somewhat misleading. The tax burden is not borne by pollution itself since only people can bear the burden of environmental taxes.

[19]Note that lump-sum taxes are not available to balance the government budget implying that revenues of labor and pollution taxes are used to finance public consumption.

[20]Goods that generate an external effect in production or consumption are referred to as "dirty goods" (e.g., oil and gas consumption) as opposed to "clean" goods which cause no (or only a negligible) external effect.

[21]Separability imposes a restriction on the utility structure. *Weak* separability implies that the choice about how much private goods to consume can be analyzed independently of the amount of environmental quality and public consumption that is consumed. As a result, changes in the supply of public consumption and environmental quality exert no feedback effects on the household's labor supply decision, but do affect the level of household welfare. *Strong* (or strict) separability implies that subgroups of goods enter the utility function in an additive fashion (cf. Ligthart and van der Ploeg, 1996). This allows the environmental and

(continued...)

consumption in social welfare. Households pay a tax on labor income and a pollution tax is levied on dirty consumption. In this model, a green fiscal reform reduces employment if the uncompensated labor supply elasticity is positive.[22] Intuitively, the higher pollution tax erodes the pollution tax base since consumers substitute to clean commodities in response to relative price changes. The reduction in pollution and the resulting erosion of the dirt tax base (i.e., dirty consumption) is particularly large when dirty and clean commodities substitute easily. If the government wants to keep total public revenues constant, it is unable to lower the labor tax sufficiently to compensate for the negative effect of the pollution tax—through an increase in the consumer price index—on the after-tax real wage. As a result, households will supply less labor. Intuitively, the pollution tax amounts to an *implicit* tax on labor that is substituted for a more efficient (and thus lower) *explicit* labor tax. Labor is the only factor of production and is assumed to be immobile implying that it always bears the full brunt of the tax burden. As a result, environmental taxes exacerbate rather than alleviate pre-existing tax distortions.

Bovenberg and de Mooij (1994) show that the optimal second-best pollution tax is below the first-best Pigovian tax which equals the marginal environmental damage. As Bovenberg and van der Ploeg (1994a) demonstrate, the second-best optimal pollution tax is equal to the first-best Pigovian tax scaled by the marginal cost of public funds. Accordingly, if public funds become more valuable, as indicated by a higher marginal cost of public funds, the government can afford less to internalize environmental externalities. In this case, environmental taxes exacerbate preexisting tax distortions to a larger extent. In the early literature, some authors, e.g., Lee and Misiolek (1986), came to the mistaken conclusion that the optimal pollution tax should exceed the Pigovian tax rate as long as increasing the pollution tax would generate revenues. Due to the partial equilibrium nature of the exercise they did not take into account the adverse effects of higher pollution taxes on labor supply. Fullerton (1997) shows that Bovenberg and de Mooij's view does not generally hold either, since it depends on the chosen normalization (i.e., the tax on the clean good is assumed to be zero). More specifically, it is the difference between the tax on the dirty good and the tax on the clean good that is less than the Pigovian rate.

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[21](...continued)
nonenvironmental (or private) component of social welfare to be studied separately. Without the above separability assumptions, the analysis becomes much more complicated. For example, better environmental quality may induce people to consume more leisure if environmental quality and leisure are assumed to be complements.

[22]This elasticity is derived from an uncompensated labor supply curve which traces out hours worked as wages vary for a given level of income. Labor supply is upward sloping if the positive substitution effect of a wage change dominates the negative income effect. The compensated labor supply curve depicts the income-compensated effect of a wage rise (i.e., holds utility constant) and thus focuses on the pure substitution effect.

The robustness of the pessimistic result of Bovenberg and de Mooij (1994) can be investigated by studying some extensions. The assumptions made about the functioning of the labor market and the structure of production turn out to be crucial in this respect. Bovenberg and van der Ploeg (1994a) use the same framework as in Bovenberg and de Mooij (1994) but start from an already optimal tax system.[23] Their analysis does not support the strong double-dividend claim. Ligthart and van der Ploeg (1996) include both labor and a fixed factor (e.g., land or capital)[24] in a general equilibrium model in which pollution is generated on the production side. They study the issue of tax incidence and show that the main result is not affected by the presence of a fixed factor. Bovenberg and van der Ploeg (1996) also include a fixed factor in a one-sector model, but pay much attention to a third distortion induced by a nonclearing labor market. In their framework, a positive employment effect fails to materialize.

C. Preconditions for Getting a Double Dividend

Goulder (1995) specifies several conditions under which the likelihood of a strong double dividend is increased. First, the marginal excess burdens of prior taxes must differ a lot. This implies a suboptimal initial tax system. Such a suboptimal tax system does not necessarily imply that a green tax reform yields a strong double dividend since the burden of the environmental tax may, for a large part, fall on the factor with the relatively high marginal excess burden. Therefore, a second condition requires that the burden of the environmental tax should fall primarily on the factor with a relatively low marginal excess burden (e.g., a fixed factor). For example, if the excess burden of capital taxes is much lower than that for labor and if the burden of the pollution tax falls primarily on capital, then a revenue-neutral pollution-labor tax swap may yield negative gross costs. Finally, the environmental tax should be broadly based. A narrowly defined environmental tax would tend to generate a lot of distortions in other markets which reduce social welfare. In practice this means that the key condition to obtain a strong double dividend is the presence of production factors or households to whom the burden of taxation can be shifted. Three types of tax burden recipients (or "sitting ducks") can be distinguished: (i) fixed factors of production, (ii) households who consume out of transfer income (such a retirees and unemployed workers), and (iii) foreign countries that cannot influence their terms of trade.

The role of fixed factors of production in generating a double dividend was first stressed in Bovenberg and van der Ploeg (1996) and later also by Ligthart and van der Ploeg (1996). The former authors develop a model in which substitution between labor, a fixed factor, and

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[23]A tax system is considered to be optimal if for each taxed good the utility cost of raising the tax rate on that particular good is equal to the marginal revenue raised by the tax rise. For a more formal exposition see Atkinson and Stiglitz (1980).

[24]This study considers the short run in which capital is assumed to be fixed in supply and thus cannot capture the long run when capital is fully mobile.

polluting natural resources (e.g., imported energy) is allowed for.[25] An exogenously given wage above the market clearing level causes involuntary unemployment. If society cares more for the environment—starting from an already optimal tax system—a double dividend may be obtained if the share of the fixed factor in production is large and labor is a better substitute for natural resources than the fixed factor. Intuitively, the burden of the environmental tax is then easily shifted from labor toward the owners of the fixed factor.[26] The improvement in environmental quality is obtained by producing in a more labor-intensive fashion rather than a lower level of production. When capital is internationally mobile, it can escape the burden of taxation by relocating abroad, which causes the double-dividend claim to fail (Bovenberg and van der Ploeg, 1994b).

In a later paper Bovenberg and van der Ploeg (1995) underscored the role of transfer recipients as possible bearers of the tax burden. A model is developed for a small open economy with perfectly mobile physical capital and search frictions in the labor market arising from hiring costs (as in Pissarides, 1990). Rather than assuming a fixed wage above the market clearing level as in Bovenberg and van der Ploeg (1996), wages are set as a mark-up on the productivity of labor.[27] Matching jobs and vacancies is assumed to be a costly and time-consuming activity, which yields rents on realized job matches. Workers in the informal sector receive unemployment benefits that are indexed to the consumer wage in the formal sector. A strong double dividend may be obtained if the burden of environmental taxes is shifted toward unemployed households who consume out of transfer income provided by the government. Higher environmental taxes reduce the purchasing power of both workers and unemployed households. Unlike employed workers, unemployed workers are not compensated for the real income loss through a lower labor tax rate. Hence, income is redistributed from unemployed to employed households. Consequently, the distribution of income becomes less equitable.[28]

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[25]A general production structure is considered in which three different ways of nesting of labor, capital, and natural resources are studied. These assumptions on the particular form of nesting determine whether labor and natural resources are cooperant or noncooperant factors of production.

[26]The double-dividend issue has not yet been analyzed in a dynamic, closed economy model with capital and labor. Since the burden of pollution taxes will always fall on labor in such a setting, it is unlikely to get a double dividend.

[27]In Brunello (1996) wages are endogenously determined by a bargaining process between firms and local trade unions.

[28]This shift of the tax burden from employed to unemployed yields a double dividend at the expense of a third negative dividend, namely a less equitable distribution of income. To date only a few theoretical papers have addressed distributional issues. See Johansson (1996) and Bovenberg and van Hagen (1997).

In an open economy, a country may shift a part of the environmental tax burden abroad if it is large enough to affect world market prices (i.e., has some monopsony power). Under these circumstances, an environmental tax reform may yield a double dividend. When a country is a net importer of energy, an environmentally motivated tax on energy use (e.g., fossil fuels) causes world-wide energy demand to decline, which depresses the before-tax price of energy on the world market. As a result, the terms of trade of the energy-importing country improve, particularly if the price elasticities of trade are small. In this way, oil-producing countries suffer a terms of trade loss so that they bear the burden of energy taxes rather than the consumers in the oil-importing country. Similarly, a country may improve its terms of trade by raising the price of the commodities it supplies on the world market if higher environmental taxes restrict the supply of these goods.

D. Empirical Evidence

Numerical studies on the double-dividend hypothesis usually abstract from estimating changes in welfare associated with improvements in environmental quality (i.e., the first dividend).[29] In line with Goulder (1995), they measure the gross costs of an environmental tax reform to assess whether the second dividend can be realized. Numerical findings obtained from large computable general equilibrium models and macroeconometric models vary across different models and the various assumptions made on the key parameters. Goulder (1995) has surveyed a number of studies[30] on the double-dividend hypothesis and concludes that in most cases environmentally motivated tax reforms reduce gross welfare. A study by the OECD (1997) indicates that simulations with macroeconometric models for various European countries yield small but positive employment effects. The empirical evidence on the double-dividend hypothesis is thus mixed.

Although the weak double dividend is generally assumed to hold, Proost and van Regemorter (1995) show—using a two-period applied dynamic general equilibrium model for the Belgian economy—that even the weak double-dividend claim may fail when distributional concerns are taken into account. Their model captures two features that are neglected in the literature on green tax reform. First, environmental benefits are explicitly measured in monetary terms.

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[29]Notable exceptions are the computational general equilibrium models as developed by Proost and van Regemorter (1995), and Carraro, and others (1996).

[30]These are the Goulder and Jorgenson-Wilcoxen intertemporal general equilibrium models for the United States, the LINK and DRI macroeconometric models of the United States, and the Shah-Larsen model applied to India, Indonesia, Japan, Pakistan, and the United States. See Goulder (1995) for a more detailed description of these models. Most models consider a carbon tax, the revenues of which are recycled through a cut in the personal income tax. A systematic study explaining the differences across models is lacking due to a shortage of information on parameters and simulation outcomes.

Second, the model assumes heterogeneous agents[31] which enables them to analyze distributional effects of various revenue recycling schemes. They compare the recycling of energy tax revenues via a rise in lump-sum transfers with recycling through a reduction in social security contributions of employers. The strong double dividend is rejected. Although the weak double dividend is generally accepted to hold in representative agent models, it is shown to fail when equity effects are taken into account. If welfare payments accrue relatively more to the poor, a rise in lump-sum subsidies causes benefits associated with more equity which exceed the efficiency losses of a higher distortionary tax.

Bovenberg and Goulder (1997) employ a dynamic numerical general equilibrium model calibrated to the U.S. economy to study the strong double-dividend hypothesis. Their model closely links to the existing analytical models, which enables them to study the channels underlying overall effects better. In contrast to the simple analytical models, a rich production structure is considered incorporating among others labor, capital, energy, and intermediate goods as productive inputs. In the model the consumption-saving and consumption-leisure choices of a representative household are explicitly treated. A revenue-neutral substitution of a consumer gasoline tax (or a tax on fossil fuel use in production) for typical income taxes yields positive gross costs, which indicates that a strong double dividend cannot be obtained. Swapping a gasoline tax for income taxes is shown to yield lower gross costs than that of a fossil fuel tax despite the narrower base of the former. Intuitively, the burden of gasoline taxes falls primarily on (relatively lightly taxed) labor while a tax imposed on energy inputs into production reduces the return on new capital (as energy is an important input into the production of capital).

IV. Environmental Policy and Economic Growth: Do Environmental Policies Curtail Economic Growth?

A. Two Opposing Viewpoints

In policy debates on economic growth[32] and the environment, we can distinguish two opposing views. Pessimists (e.g., Mishan, 1967; Meadows, and others, 1972; Daly, 1977,

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[31]Households differ in labor productivity, in the probability to become unemployed, and in their shares of the initial capital stock and the received welfare payments.

[32]Economic growth is defined in terms of an increased output of goods and services within a nation (i.e., a rise in GDP). Some environmental economists (e.g., Repetto, and others, 1992) plea for a "greening" of the national accounts. In this approach, natural resources should be counted as a part of GDP. The use of natural resources results in a flow of income, but also leads to a decline in a nation's natural capital. Second, abatement activities, which are currently included in GDP, should not be regarded as part of GDP since pollution does not count as a reduction in output either.

1993), believe in a trade-off between economic growth and the preservation of environmental quality. Protection of environmental quality can only be accomplished at zero or even negative rates of economic growth. They argue that a higher level of economic activity, obtained through economic growth, leads to increased extraction of natural resources and more emissions. This is the scale effect. Eventually, a doomsday scenario may occur in which continued economic growth inevitably destroys our natural environment. Well known is Daly's portrayal of the ecosystem as a fixed-size box. The edges of the "box" express the limited capacity of the environment to provide materials as inputs in production and to function as a "waste sink." Accordingly, Daly (1977) vehemently pleads for a "steady-state" economy in which constant physical stocks are maintained by a minimized flow of throughput (i.e., matter and energy). In this view, a reduction in GDP is totally acceptable if this is required for minimizing throughput.

Optimists or pro-growth economists (e.g., Page, 1973; World Bank, 1992) argue that environmental quality and sustained economic growth go hand in hand. They believe in "win-win" scenarios in the sense that economic growth is needed to solve the environmental problem rather than being the cause of it. The scale effect is merely one determinant of a change in environmental quality. Economic growth also causes shifts in the sectoral composition of output toward less dirty and less resource-intensive sectors. Furthermore, economic growth generates technological progress, which causes cleaner technologies to be substituted for dirtier technologies so that emissions per unit of output fall, over time, in all sectors. Pollution-saving technological progress may be market induced—through a rise in the relative price of marketed natural resources—or can be induced through tighter environmental policy. As a result, the edges of Daly's box may shift over time. Economic growth can continue without threatening our life-support system if the scale effect is dominated by the sum of the sectoral composition and pollution-saving effect. In addition, Page (1973) mentions resource discoveries and recycling as considerations which may positively affect the edges of Daly's box.[33]

B. Traditional Growth Models and the Environment

From the 1970s onwards economists have tried to formalize the relationship between growth and the environment. The early theoretical models are based on a Solow (1956) type (or neoclassical) production structure. Output is produced according to a production function that features constant returns to scale, but diminishing returns with respect to each factor of production—typically capital and labor. In the steady state, economic variables do not grow

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[33]Page (1973) criticizes the resource depletion predicted by the *Limits to Growth* economists. The fixed economically available resources and diminishing returns in resource technology are not historically valid according to Page: "If the sum of annual rates of increase of resource discovery, of recycling, and of economy of use in industry add up to more than around 2 percent, then the resource mode of collapse will be avoided and there will not be any net drain on 'available' reserves" (p. 41).

unless effective labor supply grows to compensate for the diminishing returns in physical capital accumulation. Effective labor supply is assumed to grow at a constant rate equal to the sum of population growth and technological progress. Consequently, the long-run rate of growth is entirely determined by exogenous forces. Environmental policy can thus never affect the long-run rate of economic growth in this type of model. Of course, during the transition toward the steady state the growth rates of economic variables may well be influenced by public policy (see the discussion below).[34]

Some authors have extended the classical growth model as developed by Ramsey (1928) and further refined by Cass (1965) and Koopmans (1965) to analyze the macroeconomic effects of a stricter environmental policy (see Forster, 1973; Gruver, 1976; van der Ploeg and Withagen, 1991). In the Ramsey model, social welfare is given by the utility of a representative household that lives forever.[35] Individual utility is assumed to depend on private consumption. To derive the command economy outcome a social planner maximizes instantaneous utility by choosing the entire time path of consumption subject to the economy-wide budget constraint. This yields the Ramsey rule which says that consumption is postponed if the social rate of interest exceeds the pure rate of time preference. As a result, the savings rate (i.e., the ratio of savings and national income) is no longer constant as in the Solow model, but varies with the per capita capital stock. In most studies the environment enters the Ramsey model as an argument of the social welfare function. Environmental damages are usually assumed to emanate from the production side and cause disutility to society. Most studies assume separability of social welfare in nonenvironmental welfare (i.e., private consumption) and environmental welfare (which is negatively affected by pollution). Consequently, the value assigned to future consumption is not affected by the level of pollution.[36] The main conclusion to be drawn from these studies is that a social planner who internalizes pollution externalities chooses a lower capital-output ratio than without any environmental concern.

Environmental damages can be modeled as a flow as well as a stock. In the *flow* approach, the level of environmental quality is damaged directly by emissions (e.g., air pollution). In this case, the environment can recover quite rapidly when the source of emissions is removed as is evident from the experience with air pollution reduction programs in large cities. In the *stock*

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[34]The transition dynamics show how the per capita income converges to its new steady-state value. Growth models that are consistent with empirical evidence imply lengthy transitions, typically in the order of several generations (Barro and Sala-i-Martin, 1995).

[35]Utility is assumed to be a weighted sum of all future flows of utility. The rate of time preference is used as a weighing factor in such a way that utils received far in the future receive a lower weight. Ramsey (1928) assumed a rate of time preference equal to zero in his model since discounting could not be ethically justified.

[36]Gradus and Smulders (1993) show for the nonseparable case that the value assigned to future consumption is reduced by pollution if it is assumed that pollution depresses the marginal utility of private consumption.

approach, pollution slowly affects environment quality through its effect on the regenerative capacity of the environment. Think of acid rain which is purported to cause a gradual die off of trees and deterioration of soil and water quality. Van der Ploeg and Withagen (1991) consider both the flow and the stock aspect of pollution. Their model assumes a decentralized market economy in which the government curbs environmental damages by employing a Pigovian tax. A higher Pigovian pollution tax does not affect the rate of economic growth in the new steady state (since this is exogenously given), but lowers the output to capital ratio. A higher tax rate depresses the after-tax marginal product of capital which discourages capital accumulation and thus yields a less capital-intensive production process. This result holds irrespective of the stock or flow nature of pollution. Growth models based on a neoclassical production structure all share the property that environmental policy can affect the rate of change of variables during transition toward the new steady state, but cannot influence the long-run rate of growth. Immediately after the introduction of a stricter environmental policy the rate of growth is reduced caused by a downward jump in the return on capital. Due to the decline in the capital stock the rate of interest gradually recovers until it equals its new steady-state value. Consequently, the rate of economic growth returns to its old steady-state value.

Environmental quality also deteriorates if natural resources are used as inputs in production. Natural resources are distinguished in renewable resources which have the capacity to regenerate themselves (e.g., fish populations, forests, the ozone layer, etc.) and exhaustible resources (e.g., coal and oil) the supply of which is essentially fixed. Tahvonen and Kuuluvainen (1991) consider a neoclassical growth model with renewable resources while Stiglitz (1974) allows for exhaustible natural resources. The fixed supply of the stock of exhaustible resources poses the question whether consumption per capita may be maintained forever. Stiglitz (1974) shows that the use of exhaustible resources in production does not imply that the economy necessarily stagnates due to two offsetting forces: (i) natural resource-saving technical progress, and (ii) physical capital accumulation. Sustained growth in per capita consumption on an efficient growth path requires that resource-saving technical progress exceeds the rate of population growth. Resource-saving technical progress is formally analogous to that of a renewable resource which rejuvenates itself at a fixed rate. New knowledge compensates for the resource loss due to extraction without reducing the stock of effective resources per unit of effective labor. By investing in man-made capital which substitutes for natural resource use the economy depends less and less on natural resources, particularly if natural resources and capital substitute easily.[37] Consequently, the rate of resource depletion falls and exhaustion of natural resources does not occur.

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[37]In fact the elasticity of substitution between capital and natural resources needs to be larger than unity. In this case, natural resources are not essential and unnecessary in the production process. Resources are not essential if a positive constant rate of per capita consumption can be maintained forever. Unnecessary means that production is possible without the natural resource.

C. New Growth Models and the Environment: The Case of a First-Best World

A prominent feature of neoclassical growth models is the exogenously determined rate of economic growth in the steady state. Therefore, these models are considered to be not well suited to study the trade-off between economic growth and environmental preservation. The "New Growth Theory" offers a much more flexible framework to study the environment-economy interaction.[38] The rate of economic growth is no longer assumed to be constant but is endogenized to allow for the effects of preferences, production technology, and public policy. Economic and environmental policies now affect the *level* and *rate* of growth of economic variables. In the current decade the main endogenous growth models have been extended to incorporate environmental quality to analyze the effects of environmental policy on the long-run rate of growth. Some of these contributions are discussed below. It is assumed that the government can resort to lump-sum taxes/subsidies to balance its budget.

Several authors take the AK model[39] of Rebelo (1991) and allow for a flow of pollution as by-product of production (see Ligthart and van der Ploeg, 1994; Gradus and Smulders, 1993). In the AK model capital is broadly measured to include physical as well as knowledge capital. Consequently, diminishing returns to capital are absent which yields a positive long-run rate of economic growth even without technological progress. Ligthart and van der Ploeg (1994) study the decentralized market outcome rather than the command optimum (Gradus and Smulders, 1993) and focus on the determination of optimal environmental taxes. The government levies a tax on output to internalize the pollution externality and devotes resources to public abatement. In both the command and market economy, a shift toward greener preferences harms the steady-state rate of economic growth while the capital-output ratio remains constant. A higher priority given to environmental quality means that more resources are devoted to public abatement which crowds out resources available for private investments and consumption. With capital as the only factor of production, factor substitution is not possible which precludes changes in the capital-output ratio. With more factors of production, factor substitution may compensate for crowding-out effects and yield more optimistic conclusions concerning the compatibility between growth and environmental concern.

Another widely accepted framework for endogenous growth theory is the Lucas (1988) model in which not only physical capital but also human capital can be accumulated. Gradus and Smulders (1993) extend the Lucas (1988) model by assuming that production generates a

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[38]Some economists find it hard to get excited about new growth theory, as neoclassical growth models allow for an endogenously determined rate of growth during transition, which is estimated to take 50-70 years (see Barro and Sala-i-Martin, 1995).

[39]The name of this model originates from the typical form of the production function, $Y=AK$, where Y, A, and K, respectively, stand for output, a measure of the production efficiency, and the capital stock which is assumed to be measured broadly.

flow of pollution that yields disutility to consumers. Pollution can be reduced by devoting resources to public abatement. The model features two sectors: (i) a production sector that produces consumption and investment goods, and (ii) an education sector where human capital is accumulated. Output is produced according to a Cobb-Douglas production function which implies constant returns to scale in physical and human capital taken together. Agents devote a constant fraction of their time to learning, which is assumed to have a fixed productivity. Knowledge is a private good. The build up of human capital compensates for the fall in the marginal product caused by physical capital accumulation. More environmental concern lowers the return to physical capital accumulation, which leads to a shift in investment away from physical toward human capital. So, private capital becomes scarcer than public capital. Arbitrage ensures that the rate of return to physical capital is equated to the exogenously given return to human capital. Environmental taxes thus do not affect the steady-state rate of economic growth in the extended Lucas (1988) model, but only lower the physical capital and pollution intensity of the production process.

Environmental issues can be incorporated in the Lucas (1988) model by assuming that labor productivity and utility are negatively affected by pollution. A heightened concern for the environment then supports the view of the optimists and may raise both environment quality and the rate of economic growth. In this type of model, pollution is assumed to reduce the health of workers, which lowers their learning ability and productivity (Gradus and Smulders, 1993; van Ewijk and van Wijnbergen, 1995). This idea is empirically supported by Margulis (1992) who found in a study for Mexico that a higher concentration of lead (Pb) in the blood of children (caused by lead in polluted air) reduces their intellectual development. Gradus and Smulders (1993) show that for a command economy, a shift toward greener preferences raises public abatement, which has two counteracting effects on the rate of economic growth. On the one hand, more abatement reduces pollution, and a cleaner environment in turn raises the return to schooling which increases human capital formation and boosts economic growth. On the other hand, more public abatement crowds out private investments which lowers the rate of growth. If the former effect dominates the latter effect, a "win-win" situation results, characterized by an increase in both the rate of economic growth and environmental quality.

Van Ewijk and van Wijnbergen (1995) allow for private rather than public abatement as in Gradus and Smulders (1993) and assume a positive rate of technological progress in abatement and production. Both technologies can be developed by devoting time to learning. In the decentralized market outcome a pollution tax is levied per unit of emissions to internalize the pollution externality.[40] The firm decides about its optimal abatement expenses by weighing the tax payment against the net costs of abatement which include the abatement outlays minus the improvement in productivity due to a cleaner environment. Both Gradus and Smulders (1993) and van Ewijk and van Wijnbergen (1995) derive the result that a more restrictive environmental policy improves environmental quality and raises the long-run rate of growth.

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[40]The firm is assumed to internalize the effect of the pollution it generates on the productivity of its own workers.

The environment can also be modeled as a renewable resource that accumulates over time due to its regenerative capacity but declines through its services as an input in production. Ligthart and van der Ploeg (1995) consider renewable resources in a Romer type of endogenous growth model in which knowledge externalities are the source of nondecreasing returns to capital. They focus on the pure extractive use of the environment.[41] The production technology is Cobb-Douglas with a unitary elasticity of substitution between inputs. In this type of model an increased environmental concern implies less use of natural resources which reduces the productivity of reproducible inputs and thus harms the long-run rate of economic growth. Endogenous growth models with renewable resources are a suitable framework to study the conditions necessary to obtain sustainable growth. The issue of (ecologically) sustainable growth is not a very recent one but goes back to the "Limits to Growth" debate of the 1970s initiated by Meadows, and others (1972). Sustainable economic growth requires that the use of natural resources should match the biological rejuvenation rate.[42]

Besides providing pure extractive services the environment is also productive in a nonextractive fashion. This is formalized by including the stock of renewable resources rather than the flow of resource services as input in production (see den Butter and Hofkes, 1995; Bovenberg and Smulders, 1995). A higher stock of natural resources is assumed to raise the productivity of the growth generating factors. When a tougher environmental policy is enacted, the long-run rate of economic growth may rise if the positive impact on productivity of a better environmental quality is large enough to dominate the adverse effect on productivity of less use of natural resources (or less pollution).[43] If the extractive use does not enter in the production of final goods environmental policy unambiguously raises the long-run rate of growth.

Bovenberg and Smulders (1995) develop a two-sector endogenous growth model which integrates several of the above-mentioned features. They model the natural environment as a renewable resource and capture both the extractive use (i.e., pollution as a factor of

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[41]As in den Butter and Hofkes (1995), a distinction is made between extractive use (rival use of the environment in production which causes a deterioration of environmental quality) and nonextractive use (the environment as a public good which use does not lead to environmental degradation).

[42]The literature discerns various definitions of sustainability. Pezzey (1992) defines sustainability as a situation of nondeclining utility of a representative member of society for millennia into the future (p. 323). Atkinson and Pearce (1993) distinguish a strong and weak sustainability criterion. The strong version specifies, as in the text above, that a nation's stock of environmental resources should not decrease. In the weak version, sustainability is obtained if the nation's total per capita stock of capital—physical, human, and environmental capital—is constant.

[43]Use of the environment as a "waste sink" is assumed to increase productivity for a given level of the other inputs.

production) and nonextractive use of the environment in production. One sector produces final output with physical capital, the *total* stock of natural resources, and harvested natural resources—the flow of services—or alternatively pollution. The other sector is a learning sector as in Lucas which generates knowledge about pollution-saving techniques. A tougher environmental policy is shown to stimulate the creation of pollution-saving knowledge and shifts more resources in the knowledge sector. Long-run economic growth rises if the reduced stock of pollution strongly enhances the absorption capacity of nature while the nonextractive use of the environment is relatively important in production.[44]

Transitional dynamics are usually ignored by focusing solely on the steady-state results of policy changes or by studying endogenous growth models that do not feature transition effects. Notable exceptions are Smulders (1995) and Bovenberg and Smulders (1996) who derive analytically the transition dynamics of the two-sector endogenous growth model. If the environment mainly acts as a public production good, the short-run effects of a more ambitious environmental policy on the rate of economic growth are negative. Households raise short-run consumption in anticipation of the long-run productivity gains of a cleaner environment thereby hurting the short-run rate of economic growth.

D. New Growth Models and the Environment: The Case of a Second-Best World

In the previous section it was assumed that the government can employ lump-sum taxes and subsidies to balance its budget. Without lump-sum taxes the government has to resort to distortionary taxes to finance public spending. The task of the government is twofold. On the one hand, it has to take care of the environment by imposing environmental taxes on pollution activities, and on the other hand it has to provide public goods that act as growth catalysts (e.g., material infrastructure). Various authors—Ligthart and van der Ploeg (1994, 1995); van Marrewijk, and others (1994); Bovenberg and de Mooij (1997)—have studied the trade-off between growth and the environment in a second-best world. They build on the work of Barro (1990) who stresses the productive role of government spending by including it as an argument in a Cobb-Douglas production function.[45] Public services are assumed to be complementary with private inputs. In this way an increased level of public spending raises the marginal productivity of capital in a narrow sense and thus compensates for diminishing returns associated with capital accumulation.

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[44]Technology is shown to be more pollution saving, if the environment has a small productive role and substitution between capital and polluting inputs is difficult.

[45]Production depends on the *flow* of government purchases. This specification is rather peculiar since the government can induce a zero level of production in the private sector by setting public spending to zero. An alternative approach which circumvents this problem is to include the accumulated *stock* of public spending. Including an additional stock variable, however, complicates the model considerably often precluding an analytical solution.

van Marrewijk, and others (1993) consider the flow as well as the stock approach to model the impact of pollution on the environment. Environmental quality enters the utility function in a nonseparable fashion with an intratemporal elasticity of substitution equal to unity. The government provides ordinary public goods and engages in abatement to clean up pollution. They find that a stricter environmental policy may yield a win-win outcome in the stock approach if intertemporal elasticity of substitution in consumption is larger than unity. Then current and future consumption and environmental quality can be easily substituted so that consumers postpone consumption to invest in physical capital and abatement to enjoy a higher level of consumption and environmental quality in the future. In the flow approach win-win outcomes can never be obtained.

Ligthart and van der Ploeg (1994) consider the setting of optimal environmental taxes in an endogenous growth model with a flow of pollution which is related to the scale of output. Environmental quality only has a role as public consumption good. The government levies a distortionary tax on output for the twofold task of: (i) raising revenues to finance public spending, and (ii) internalizing environmental externalities. A higher amenity value of the environment is shown to be associated with a lower long-run rate of economic growth and a lower marginal cost of public funds. The decline in the growth rate caused by the higher environmental tax is less costly (in terms of public funds) if society assigns a larger preference to environmental quality. Since the above model only features a single tax rate, the welfare effects of a green tax reform cannot be studied.

With two separate tax rates—a pollution tax and output tax—endogenous growth models incorporating the environment can also be employed to study a tax reform analysis. Bovenberg and de Mooij (1997) show that a rise in pollution taxes, the revenues of which are used to cut taxes on output, may yield a double dividend. Now the second benefit is defined as a rise in the long-run rate of economic growth. As in den Butter and Hofkes (1995) and Bovenberg and Smulders (1995) environmental quality acts both as a public consumption good and as a public input into production. Pollution damages environmental quality but also directly contributes to the productivity of private inputs. Bovenberg and de Mooij (1997) show that a double dividend can be reaped if the substitution between pollution and physical capital is relatively difficult and the adverse productivity effect of a reduction in pollution is not too large. Pollution is here a relatively fixed factor. Consequently, the pollution tax is less powerful in cutting pollution but is an efficient device to raise public revenues which can be used to lower taxes on output. Shifting the tax burden from capital toward profits (i.e., the quasi-rents from pollution) stimulates steady-state economic growth. If these conditions are met, the second-best Pigovian tax on pollution exceeds the first-best Pigovian tax. Bovenberg and van der Ploeg (1996) have shown in a static model that an environmental tax reform may boost employment if the burden of environmental taxes can be shifted on a fixed factor. However, in their framework the second-best Pigovian tax always lies below the first-best level since raising public revenues is costly (reflected by a marginal cost of public funds above unity).

By abstracting from labor as a separate factor of production, all endogenous growth models discussed implicitly assume full employment. Nielsen, and others (1995), however, develop an endogenous growth model which features unemployment caused by labor unions which set a wage above the market clearing wage. Labor unions are assumed to maximize the expected life-time utility of their members which depends on the after-tax wages and unemployment benefits. Final output is produced according to a (constant returns) Cobb-Douglas function which includes capital, labor, and the firm's level of pollution as private factors of production. Public spending on education and abatement yield positive externalities in production while the aggregate flow of pollution yields a negative external productivity effect. The government finances public spending by a distortionary tax on labor and an emission tax. Nielsen, and others (1995) show that a shift toward greener preferences raises employment but depresses the long-run rate of growth. Greener preferences raise the pollution tax and curb pollution which makes public abatement less productive. Lower taxes on labor made possible by lower abatement expenses, induce labor unions to moderate their pretax wage demands. With smaller union wage mark-ups employment expands, yielding an employment double dividend.

E. Empirical Evidence

Cross-sectional evidence suggests an inverse U-shaped relationship between pollution per capita and GDP per capita (Selden and Song, 1994; Grossman and Krueger, 1995). At early stages of development pollution per capita rises with GDP per capita and falls with GDP per capita after a certain turning point is reached. This pattern is referred to as the Environmental Kuznets Curve (EKC).[46] A serious limitation of EKC studies is that the estimated relationship is not derived from theoretical models that explain the role of environmental policy. Only speculative notions are available. For example, countries with a low GDP per capita are assumed to depend heavily on industrial production in the development process, which indicates that the scale effect may be a prominent source of pollution. Many of these developing countries are therefore likely to be located on the upward sloping part of the EKC. High income countries are likely to be found on the downward sloping section of the EKC curve possibly reflecting the large share of services in final output. Moreover, it is claimed that countries with a high GDP per capita usually have tighter environmental regulations and have governments that spend large amounts to cure environmental damage control (cf. Radetzki, 1992).

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[46]The EKC is observable for several air pollutants such as sulphur dioxides, nitrogen dioxides, and carbon dioxides. The estimated turning points vary greatly across the various pollutants. Emissions of sulphur dioxides (which are emitted by the burning of fossil fuels with a high sulphur content such as coal) seem to be worst in low- and middle-income countries. The emission of greenhouse gases such as carbon dioxides is the highest in high-income countries (Selden and Song, 1994).

F. Preconditions for "Win-Win" Outcomes

The debate on economic growth and the environment is still unresolved. Some optimists have suggested that growth and maintenance of environmental quality can go hand in hand. They believe that pollution saving technological change and shifts toward a cleaner composition of economic activity will more than compensate for the deterioration of environmental quality stemming from the higher level of output (also known as the scale effect). Theoretical models show that if the environment is mainly used as a public consumption good (e.g., recreation etc.), tighter environmental policies typically depress long-run economic growth. However, if environmental quality is used as a public consumption *and* public production good, a more ambitious environmental policy may yield win-win results. Intuitively, the better environmental quality raises the productivity of private capital and/or contributes to a higher productivity of broad capital through the positive effect of the environment on the stock of human capital.

V. Conclusions

In this paper the effects of environmental taxation have been surveyed from a macroeconomic perspective. In particular, an attempt has been made to delineate the conditions under which environmental taxes act as "win-win" policies in the sense that both environmental and economic benefits are reaped. Economic benefits may consist of a better resource allocation and a larger resource base through a higher rate of economic growth. Recently, the number of studies dealing with environmental policies in an integrated environment-economy framework has increased rapidly.

Studies dealing with the effects on resource allocation mainly focus on employment. The question is addressed whether a green tax reform—in which environmental taxes are raised to cut taxes on labor in a revenue-neutral fashion—may yield a "double dividend." Not only the environment improves but also a less distortionary tax system and a higher level of employment is obtained. The existence of an environmental dividend is commonly acknowledged. However, the employment dividend has been subject to controversy. Studies based on a single factor of production (i.e., labor) and a representative household show that employment effects are negative because tax substitution amounts to replacing a more efficient *explicit* tax on labor by a less efficient *implicit* tax on labor (i.e., the pollution tax). By studying more elaborate models it can be concluded that a positive employment effect may materialize if the burden of environmental taxes can be shifted to: (i) owners of production that are inelastically supplied, (ii) households consuming out of transfer income (i.e., unemployed and pensioners), and (iii) foreign countries—through the terms of trade. As a marketing device, package deals such as green tax reforms are politically more acceptable than a rise solely in eco-taxes. However, it should be noted that green tax reforms are not a free lunch as positive employment effects can only be realized at the expense of a less equitable income distribution.

No definite conclusions can be drawn from studies dealing with the long-run effects of environmental policy on the rate of economic growth. Empirical evidence suggests an inverse U-shaped relationship between pollution per capita and income per capita. Consequently, at high levels of income per capita there is a negative correlation between pollution per capita and income per capita which may be attributed to a higher share of services in output and cleaner production technologies. These two effects may be linked to tighter environmental policies but no formal proofs exist. Evidence from theoretical models is mixed. The long-run effect on economic growth of a more ambitious environmental policy is not clear cut, but depends on the specific assumptions made on the production structure. If the environment is purely a public consumption good (i.e., recreation), environmental protection is generally shown to depress the long-run rate of economic growth. However, if environmental quality is both a public consumption and a public production good, a stricter environmental policy may yield win-win results. Environmental quality increases and the long-run rate of economic growth is boosted.

References

Atkinson, A.B., and J.E. Stiglitz, 1980, *Lectures on Public Economics* (London: McGraw-Hill).

Atkinson, A.B., and D.W. Pearce, 1993, "Measuring Sustainable Development," *The Globe*, Issue No. 13 (Swindon, England: GER Office).

Auerbach, A.J., 1985, "The Theory of Excess Burden and Optimal Taxation," in *Handbook of Public Economics*, ed. by A.J. Auerbach and M. Feldstein, Vol. I (Amsterdam: North-Holland).

Barro, R.J., 1990, "Government Spending in a Simple Model of Endogenous Growth," *Journal of Political Economy*, Vol. 98, pp. S103-25.

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

Baumol, W.J., and W.E. Oates, 1988, *The Theory of Environmental Policy* (New York: Cambridge University Press).

Bovenberg, A.L., and R.A. de Mooij, 1994, "Environmental Levies and Distortionary Taxation," *American Economic Review*, Vol. 84, pp. 1085-89.

———, 1997, "Environmental Tax Reform and Endogenous Growth," *Journal of Public Economics*, Vol. 63, pp. 207-37.

Bovenberg, A.L., and L. Goulder, 1997, "Costs of Environmentally Motivated Taxes in the Presence of Other Taxes: General Equilibrium Analysis," *National Tax Journal*, Vol. 50, pp. 59-87.

Bovenberg, A.L., and G.H.A. van Hagen, 1997, "Environmental Levies, Pre-existing Tax Distortions and Distributional Concern," paper presented at the annual conference of the American Economic Association (AEA), New Orleans.

Bovenberg, A.L., and F. van der Ploeg, 1994a, "Environmental Policy, Public Finance and the Labor Market in a Second-best World," *Journal of Public Economics*, Vol. 55, pp. 349-90.

———, 1994b, "Green Policies and Public Finance in an Open Economy," *Scandinavian Journal of Economics*, Vol. 96, pp. 343-63.

———, 1995, "Tax Reform, Structural Unemployment and the Environment," Nota di Lavoro 95.6 (Milan: FEEM).

———, 1996, "Optimal Taxation, Public Goods and Environmental Policy with Involuntary Unemployment," *Journal of Public Economics*, Vol. 62, pp. 59-83.

Bovenberg, A.L., and S. Smulders, 1995, "Environmental Quality and Pollution-Augmenting Technological Change in a Two-Sector Growth Model," *Journal of Public Economics*, Vol. 57, pp. 369-91.

———, 1996, "Transitional Impacts of Environmental Policy in an Endogenous Growth Model," *International Economic Review*, Vol. 37, pp. 861-93.

Brunello, G., 1996, "Labor Market Institutions and the Double-Dividend Hypothesis: An Application of the WARM Model," in *Environmental Fiscal Reform and Unemployment*, ed. by C. Carraro and D. Siniscalco (Dodrecht, the Netherlands: Kluwer Academic Press).

Buchanan, J., and G. Tullock, 1975, "Polluters' Profits and Political Response: Direct Control Versus Taxes," *American Economic Review*, Vol. 65, pp. 139-47.

Carraro, C., M. Galeotti, and M. Gallo, 1996, "Environmental Taxes and Unemployment: Some Evidence on the Double-Dividend Hypothesis," *Journal of Public Economics*, Vol. 62, pp. 141-81.

Carraro, C., and J.A. Filar, eds., 1995, *Control and Game-Theoretic Models of the Environment*, Annals of the International Society of Dynamic Games (Boston: Birkhäuser).

Cass, D., 1965, "Optimum Growth in an Aggregative Model of Capital Accumulation," *Review of Economic Studies*, Vol. 32, pp. 233-40.

Coase, R.H., 1960, "The Problem of Social Cost," *Journal of Law and Economics*, Vol. 3, pp. 1-44.

Commission of the European Communities, 1993, "White Paper on Growth, Competitiveness, and Employment" (Luxembourg: Office for Official Publications of the European Communities).

———, 1994, *Potential Benefits of Integration of Environmental and Economic Policy* (London: Graham and Trotman).

Cropper, M.L., and W.E. Oates, 1992, "Environmental Economics: A Survey," *Journal of Economic Literature*, Vol. 30, pp. 675-740.

Dales, J.H., 1968, *Pollution, Property, and Prices* (Toronto: University of Toronto Press).

Daly, H.E., 1977, *Steady-state Economics: The Economics of Biophysical Equilibrium and Moral Growth* (San Francisco: Freeman).

———, 1993, "Problems with Free Trade: Neoclassical and Steady-State Perspectives," in *Trade and the Environment: Law, Economics, and Policy*, ed. by D. Zaelke and others (Washington: Island Press).

den Butter, F., and M.W. Hofkes, 1995, "Sustainable Development with Extractive and Nonextractive Use of the Environment in Production," *Environmental and Resource Economics*, Vol. 6, pp. 341-58.

Ewijk, C. van, and S. van Wijnbergen, 1995, "Can Abatement Overcome the Conflict Between the Environment and Economic Growth?," *De Economist*, Vol. 143, pp. 197-216.

Forster, B.A., 1973, "Optimal Capital Accumulation in a Polluted Environment," *Southern Economic Journal*, Vol. 39, pp. 544-47.

Fullerton, D., 1997, "Environmental Levies and Distortionary Taxation: Comment," *American Economic Review*, Vol. 87, pp. 245-51.

Goulder, L.H., 1995, "Environmental Taxation and the Double Dividend: A Reader's Guide," *International Tax and Public Finance*, Vol. 2, pp. 157-83.

Gradus, R., and S. Smulders, 1993, "The Trade-Off Between Environmental Care and Long-Term Growth: Pollution in Three Prototype Growth Models," *Journal of Economics*, Vol. 58, pp. 25-51.

Grossman, G.M., and A.B. Krueger, 1995, "Economic Growth and the Environment," *Quarterly Journal of Economics*, Vol. 110, pp. 353-77.

Gruver, G., 1976, "Optimal Investment and Pollution Control in a Neoclassical Growth Context," *Journal of Economic Management and Control*, Vol. 5, pp. 165-77.

Heijdra, B.J., and F. van der Ploeg, 1995, "Fiscal and Environmental Policy Under Monopolistic Competition," *De Economist*, Vol. 143, pp. 217-48.

International Monetary Fund, 1996, *Annual Report 1996* (Washington).

Jaffe, A.B., S.R. Peterson, P.R. Portney, and R.N. Stavins, 1995, "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?," *Journal of Economic Literature*, Vol. 33, pp. 132-63.

Johansson, O., 1996, "Optimal Taxation with Regard to Externalities and Distributional Concerns" (mimeo; Göteborg: Göteborg University).

Koopmans, T.C., 1965, "On the Concept of Optimal Economic Growth," in *The Econometric Approach to Development Planning* (Amsterdam: North-Holland).

Lee, D.R., and W.S. Misiolek, 1986, "Substituting Pollution Taxation for General Taxation: Some Implications for Efficiency in Pollution Taxation," *Journal of Environmental Economics and Management*, Vol. 13, pp. 338-47.

Ligthart, J.E., and F. van der Ploeg, 1994, "Pollution, the Cost of Public Funds and Endogenous Growth," *Economics Letters*, Vol. 46, pp. 351-61.

———, 1995, "Environmental Quality, Public Finance and Sustainable Growth," in *Control and Game-Theoretic Models of the Environment*, ed. by C. Carraro and J.A. Filar, Annals of the International Society of Dynamic Games (Boston: Birkhäuser).

———, 1996, "Optimal Government Policy, the Environment, Employment and Tax Shifting," in *Environmental Fiscal Reform and Unemployment*, ed. by C. Carraro and D. Siniscalco (Dordrecht, the Netherlands: Kluwer Academic Press).

Lucas, R., 1988, "On the Mechanics of Economic Development," *Journal of Monetary Economics*, Vol. 58, pp. 25-52.

Margulis, S., 1992, "Back-of-the-Envelope Estimates of Environmental Damage Costs in Mexico," Policy Research Working Paper WPS 824 (Washington: World Bank).

Marrewijk, C. van, F. van der Ploeg, and J. Verbeek, 1993, "Is Growth Bad for the Environment? Pollution, Abatement and Endogenous Growth," Policy Research Working Paper WPS 1151 (Washington: World Bank).

Meadows, D.H., and others, 1972, *The Limits to Growth* (New York: Universe Books).

Mishan, E.J., 1967, *The Cost of Economic Growth* (London: Staples Press).

———, 1971, "Pangloss on Pollution," *Swedish Journal of Economics*, Vol. 73, pp. 113-20.

Nielsen, S.B., L.H. Pedersen, and P.B. Sørensen, 1995, "Environmental Policy, Pollution, Unemployment, and Endogenous Growth," *International Tax and Public Finance*, Vol. 2, pp. 185-205.

Oates, W.E., 1995, "Green Taxes: Can We Protect the Environment and Improve the Tax System at the Same Time?," *Southern Economic Journal*, Vol. 61, pp. 915-22.

Organization for Economic Cooperation and Development, 1989, *Economic Instruments for Environmental Protection* (Paris: OECD).

———, 1997, *Environmental Taxes and Green Tax Reform* (Paris: OECD).

Page, T., 1973, "The Nonrenewable Resources Subsystem," in *Thinking About the Future: A Critique of the Limits to Growth,* ed. by H.S.D. Cole and others (London: Sussex University Press).

Parry, I.W.H., 1995, "Pollution Taxes and Revenue Recycling, *Journal of Environmental Economics and Management*, Vol. 29, pp. S64-77.

Pearce, D.W., 1991, "The Role of Carbon Taxes in Adjusting to Global Warming," *Economic Journal,* Vol. 101, pp. 938-48.

Pezzey, J., 1992, "Sustainable Development Concepts: An Economic Analysis," World Bank Environment Paper No. 2 (Washington: World Bank).

Pigou, A.C., 1924, *The Economics of Welfare* (London: Weidenfeld and Nicolson, 2nd ed.).

Pissarides, C.A., 1990, *Equilibrium Unemployment Theory* (Oxford: Basil Blackwell).

Ploeg, F. van der, and C. Withagen, 1991, "Pollution Control and the Ramsey Problem," *Environmental and Resource Economics*, Vol. 1, pp. 215-30.

Porter, M.E., 1991, "America's Green Strategy," *Scientific American*, p. 168.

Porter, M.E., and C. van der Linde, 1995, "Toward a New Concept of the Environment Competitiveness Relationship," *Journal of Economic Perspectives*, Vol. 9, pp. 97-118.

Proost, S., and D. van Regemorter, 1995, "The Double Dividend and the Role of Inequality Aversion and Macroeconomic Regimes," *International Tax and Public Finance*, Vol. 2, pp. 207-19.

Radetzki, M., 1992, "Economic Growth and the Environment," in *International Trade and the Environment*, ed. by P. Low, World Bank Discussion Paper No. 159 (Washington: World Bank).

Ramsey, F., 1928, "A Mathematical Theory of Saving," *Economic Journal*, Vol. 38, pp. 543-59.

Rebelo, S., 1991, "Long-Run Policy Analysis and Long-Run Growth," *Journal of Political Economy*, Vol. 99, pp. 500-21.

Repetto, R.E., and others, 1992, "Wasting Assets: Natural Resources in the National Income Accounts," in *Environmental Economics: A Reader*, ed. by A. Markandya and J. Richardson (New York: St. Martin's Press).

Romer, P.M., 1986, "Increasing Returns and Long-Run Growth," *Journal of Political Economy*, Vol. 94, pp. 1002-37.

Selden, T.M., and D. Song, 1994, "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution?," *Journal of Environmental Economics and Management*, Vol. 27, pp. 147-62.

Smith, S., 1992, "Taxation and the Environment: A Survey," *Fiscal Studies*, Vol. 13, pp. 21-57.

Smulders, S., 1995, "Entropy, Environment, and Endogenous Economic Growth," *International Tax and Public Finance*, Vol. 2, pp. 319-40.

Solow, R.M., 1956, "A Contribution to the Theory of Growth," *Quarterly Journal of Economics*, Vol. 70, pp. 65-94.

Stiglitz, J. 1974, "Growth with Exhaustible Resources: Efficient and Optimal Growth Paths," *Review of Economic Studies*, Symposium, pp. 123-37.

Tahvonen, O., and J. Kuuluvainen, 1991, "Optimal Growth with Renewable Resources and Pollution, *European Economic Review*, Vol. 35, pp. 650-61.

Terkla, D., 1984, "The Efficiency Value of Effluent Tax Revenues," *Journal of Environmental Economics Management*, Vol. 11, pp. 107-23.

Ulph, D., 1992, "A Note on the "Double Benefit" of Pollution Taxes," Discussion Paper No. 92-317 (Bristol, England: University of Bristol).

Weitzman, M.L., 1974, "Prices Versus Quantities," *Review of Economic Studies*, Vol. 16, pp. 477-549.

World Bank, 1992, *World Development Report 1992: Development and the Environment* (Washington: World Bank).