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Revisiting free riding in a growing economy

George Economides and Apostolis Philippopoulos

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P.O. Box 20537, 1678 Nicosia, CYPRUS Tel.: ++357-2-892430, Fax: ++357-2-892432
Web site: http://www.econ.ucy.ac.cy

NASH TAX RATES AND PUBLIC GOOD PROVISION:
Revisiting free riding in a growing economy

by

George Economides

University of Cyprus, and Athens University of Economics and Business

and

Apostolis Philippopoulos

Athens University of Economics and Business, and CESifo

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Abstract: This short paper provides an example which shows that the type of the spillover effect from one individual to another (and hence whether we under-tax, or over-tax, in a Nash equilibrium relative to a cooperative one) can be reversed when we introduce dynamics into a model with public goods. Specifically, the spillover effect changes from positive (which is the static, traditional case) to negative once the same model allows for long-term endogenous growth. Therefore, free riding is associated with too low Nash tax rates in a static economy, but with too high Nash tax rates in a growing economy. This is because, in a growing economy, free-riding and small tax contributions are achieved by relatively high tax rates, low growth and small tax bases. By contrast, in a static set-up where tax bases are exogenously given, free-riding and small tax contributions are typically achieved by relatively low tax rates.

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Correspondence to: Apostolis Philippopoulos, Associate Professor, Athens University of Economics and Business, 76 Patission street, Athens 10434, Greece. Tel. +30-1-8203415. Fax: +30-1-8214122. Email: aphil@aueb.gr

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I. INTRODUCTION

When decision-making is decentralized and voluntary, Nash tax rates - and the associated private provision of public goods - are too low. Also, this inefficiency gets worse as the size of population increases; this is because the incentive to free ride on the supply provided by others becomes stronger, and the willingness to pay taxes becomes weaker, as the number of participants increases.[1] In terms of externalities, these well-known results presuppose that the spillover effect from one individual to another is *positive*. That is, an increase in j's tax rate leads to higher tax revenues and hence higher public good provision for all $i \neq j$. Then, in the presence of positive (resp. negative) spillovers, players' actions increase (resp. decrease) when we switch from Nash to cooperative equilibria (see e.g. Cooper and John [1988]).

This short paper provides an example in which the type of the spillover effect (and hence whether we under-tax, or over-tax, in a Nash equilibrium relative to a cooperative one) is reversed, when we introduce dynamics into a fairly standard model with public goods. In particular, we show that the nature of spillover effect *changes from positive to negative*, once the same model allows for long-term endogenous growth. As a result, Nash tax rates on public good provision are inefficiently high in a growing economy. They also increase with the size of population.

We use a general equilibrium model of endogenous growth and economic policy in which the public good is renewable natural resources. Private production degrades environmental quality, but clean-up policy financed by taxes on polluting activities can improve it. We consider two "communities". In the first community, tax policy decisions are decentralized. In particular, tax contributions to clean-up policy are made privately and voluntarily by each individual. In the second community, tax policy decisions are centralized. Obviously, in the first community there is a classic free rider problem and the equilibrium is the Nash equilibrium.

In both the static and dynamic cases, there are too little tax revenues allocated to public good maintenance in a Nash equilibrium. However, free riding is associated with too low Nash tax rates when the economy is static, but with too high Nash tax rates when the economy grows. Intuitively, in a growing economy where tax bases are endogenous, individuals do not internalize the harmful effect of their own tax rates (and hence low capital accumulation, low economic growth, small tax bases and low clean-up policy) on public good maintenance; they therefore set too high tax rates. To put the point another way, in a growing economy, individuals - in their attempt to contribute little to public good provision - have an incentive to look relatively poor. They therefore go for relatively high tax rates, low capital accumulation and low growth. In other words, in a growing economy, free-riding and small tax contributions are achieved by relatively high tax rates, low growth and small tax bases. By contrast, in a static set-up where tax bases are exogenously given, free-riding and small tax contributions are typically achieved by relatively low tax rates.[2]

The rest of the paper is as follows. Section II presents the model and solves for a decentralized competitive equilibrium. Section III solves for optimal policies in a growing economy. Section IV solves for optimal policies in a static case. Section V explains the results.

II. THE MODEL AND DECENTRALIZED COMPETITIVE EQUILIBRIUM

This section presents the model and solves for a decentralized competitive equilibrium, given economic policy.

Description of the model and how we work

Consider a closed economy populated by an exogenous number of individuals, $i = 1,2,...,I$. Each individual i derives utility from streams of private consumption, c^i, and economy-wide environmental quality, N, which is a public good. Individuals

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[1] Free riding increases as the number of players expands, at least if the return to a player declines with group size (see e.g. Mueller [1989, chapter 2] and Oakland [1987, p. 514]). For more general cases in richer setups, see the survey in Drazen [2000, chapter 9.4].

[2] In Philippopoulos and Economides [2000], we derive similar results. However, there we use a world economy composed of a number of countries; in each country, the national government sets its environmental policy by either playing Nash or cooperating with other national governments. Other differences are that here: (i) we use a discrete-time model; (ii) we solve for a less restrictive long-run equilibrium; (iii) our model admits a closed-form solution and so results are clearer.

consume, save in capital, pay taxes and produce goods by using a linear AK technology.[3] Thus, at any time period, each individual i produces $y^i = Ak^i$, where $A > 0$ is the exogenous return to capital and k^i is i's capital stock. Pollution occurs as a by-product of output produced. Specifically, each i pollutes $p^i = y^i$.[4] Since individuals treat environmental quality as a public good and do not internalize the effects of their production activities on N, there is need for cleanup (or maintenance) policy.

We will consider two communities.[5] In the first community, cleanup policy is financed by voluntary contributions from the membership. Specifically, each individual i contributes $\theta^i y^i$, where $0 \leq \theta^i < 1$ is a tax rate on i's income. The choice of θ^i reflects the preferences of the ith individual, who acts selfishly by maximizing his own utility function. The equilibrium of this decentralized community will be given by the Nash equilibrium. In the second community, policy decisions are centralized. Specifically, we assume that a benevolent social planner chooses jointly all θ^i to maximize the sum of individual utilities over all $i = 1,2,...,I$.[6] The equilibrium of this centralized community will be a cooperative equilibrium. We will focus on symmetric equilibria.

We assume discrete time, infinite horizons and perfect foresight. The events are as follows in each time period.[7] First, economic policy is chosen (either by individual voters in a decentralized community, or by a social planner in a centralized community). Then, taking economic policy and public goods as given, individual investors make their consumption-saving-production choices. The rest of this section will solve for the second problem and a decentralized competitive equilibrium given economic policy. Economic policy will be chosen in the next section.

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[3] The AK model is the simplest and most popular model of endogenous growth.

[4] For simplicity, we assume that one unit of output generates one unit of pollution. This is not important.

[5] We follow the terminology of Glomm and Lagunoff [1999]. Although this is not the only way to distinguish decentralized and centralized outcomes, we think this is a particularly clear and intuitive way.

[6] There are several ways of modeling a centralized economy. For instance, we could alternatively assume that there is a uniform tax rate $0 \leq \theta < 1$, so that each i pays θAk^i, and θ is chosen by majority voting. Or that a social planner maximizes the utility of the representative individual. All of them give the same cooperative equilibrium, at least when we solve for symmetric equilibria which is the case here.

[7] See also e.g. Persson and Tabellini [1994] and Park and Philippopoulos [2001] in similar setups.

Individuals

Individual i gets utility from streams of current private consumption, c_t^i, and the average of end-of-period economy-wide natural resources, $\frac{N_{t+1}}{I}$.[8] The infinitely-lived i th individual maximizes:[9]

$$\sum_{t=0}^{\infty} \beta^t (\log c_t^i + \nu \log \frac{N_{t+1}}{I}) \qquad \text{for each } i \tag{1}$$

where the parameter $0 < \beta < 1$ is the discount rate, and the parameter $\nu > 0$ is the weight given to environmental quality relative to private consumption.

The budget constraint of the i th individual is:

$$k_{t+1}^i - k_t^i + c_t^i = (1 - \theta_t^i) A k_t^i \qquad \text{for each } i \tag{2}$$

where k_{t+1}^i is the end-of-period capital stock, k_t^i is the beginning-of-period capital stock used in current production, $A > 0$ is the exogenous return to capital, and $0 \le \theta_t^i < 1$ is the current tax rate on i ' income. The initial stock, k_0^i, is given.

When individuals maximize (1) subject to (2), they act competitively by taking economy policies, $\{\theta_t^i\}_{t=0}^{\infty}$, and public goods, $\{N_{t+1}\}_{t=0}^{\infty}$, as given. The control variables at any time t are c_t^i and k_{t+1}^i so that the first-order conditions are the budget constraint in (2) and the familiar Euler equation:

$$\frac{c_{t+1}^i}{c_t^i} = \beta [1 + (1 - \theta_{t+1}^i) A] \qquad \text{for each } i \tag{3}$$

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[8] Our results do not change if we use N_{t+1}, so that there is no congestion.

[9] For algebraic simplicity, we use an additively separable and logarithmic function.

The optimality conditions (2) and (3) are two equations in c_t^i and k_{t+1}^i for each i. It will be convenient for what we do in the next section to solve them so as to get for current consumption:[10]

$$c_t^i = (1-\beta)[1+(1-\theta_t^i)A]k_t^i \qquad \text{for each } i \tag{4}$$

which gives current consumption as a function of the current tax rate and the predetermined capital stock only.

Natural resources i.e. the public good

The stock of aggregate natural resources, N, evolves over time according to:

$$N_{t+1} - N_t = \delta N_t - \sum_{i=1}^{I} p_t^i + \sum_{i=1}^{I} \theta_t^i y_t^i \tag{5}$$

where the parameter $\delta \geq 0$ is a regeneration rate, p_t^i is current pollution emissions by individual i, and $\theta_t^i y_t^i$ is i's current contribution to cleanup policy. The initial stock, N_0, is given. Thus, natural resources are renewed by themselves and by maintenance policy, but they decrease with pollution emission.

Recall that pollution, p_t^i, is a by-product of output produced, y_t^i. Thus,

$$p_t^i = y_t^i = Ak_t^i \qquad \text{for each } i \tag{6}$$

so that (5) is rewritten as:

[10] To get (4), we solve (3) forward for c_t^i, impose a standard transversality condition and use the intertemporal budget constaint implied by the flow constraint (2). Details are available upon request; also (4) is a special case of e.g. Blanchard and Fischer [1989, p. 52] and Benhabib and Velasco [1996, equation (13)]. Notice that only the current tax rate appears in (4). This is thanks to logarithmic utility functions and Cobb-Douglas constraints. This simplifies the algebra in the next section without affecting our main results.

$$N_{t+1} - N_t = \delta N_t - \sum_{i=1}^{I} (1-\theta_t^i) A k_t^i \qquad (7)$$

Decentralized Competitive Equilibrium

Equation (4) for each individual i, and equation (7) for the motion of public good N_{t+1}, fully summarize a Decentralized Competitive Equilibrium (DCE). In this DCE, all individuals maximize utility and all markets clear. This holds for given initial conditions and any tax policies $\{\theta_t^i\}_{t=0}^{\infty}$.[11] The next section will endogenize θ^i first by assuming that economic policy is chosen by selfish individuals, and then by a centralized authority.

III. OPTIMAL ECONOMIC POLICIES IN A GROWING ECONOMY

We now endogenize economic policy, $\{\theta_t^i\}_{t=0}^{\infty}$. Assume first that economic policy decisions are decentralized. The ith individual acts selfishly, in the sense of maximizing his own objective function (1) subject to the DCE summarized by equations (4) and (7). Since all individuals act simultaneously, the ith individual takes the decisions of all others, $j \neq i$, as given. This is a Nash equilibrium in fiscal policy.

In our simple set-up, using (4) c_t^i and (7) for N_{t+1} for each time-period into the intertemporal objective function (1) reveals that it suffices to consider only the current period utility function, and so solve the problem as if it is a static one.[12]

Symmetric Nash equilibrium

We will focus on Symmetric Nash Equilibria (SNE) in policies. At a symmetric equilibrium, all individuals are alike *ex-post.* Thus, *ex post* $x^i = x^j \equiv x$, where $i \neq j$ and

[11] This equilibrium is inefficient because private agents have treated natural resources as a public good and have not internalized the effects of their production activities on the environment. This provides a rationale for policy intervention. Here, policy intervention takes the form of taxing the externality-generating activity and using the collected tax revenues to finance the maintenance of public good.

[12] Using a Hamiltonian equation, where the dynamic constraints are (2), (3) and (7) and optimizing accordingly, gives similar results. See Philippopoulos and Economides [2000] for details in a continuous-time model. Note that we do not have time inconsistency problems here. This is thanks to the functional forms used (see e.g. Benhabib and Velasco [1996]).

$x \equiv (\theta, c, k)$.[13] Differentiating the current period utility function with respect to θ_t^i, setting it equal to zero and invoking symmetry, we get (we now omit individual superscripts):

$$\frac{1}{1+(1-\theta_t)A} = \frac{\hat{\nu}}{(1+\delta)\dfrac{n_t}{k_t} - (1-\theta_t)A} \tag{8}$$

where small letters denote individual-specific variables and capital letters denote economy-wide variables, i.e. $N_t \equiv \sum_{i=1}^{I} n_t^i$ and so (in a symmetric equilibrium) $N_t = In_t$. Also, $\hat{\nu} \equiv \dfrac{\nu}{I}$ denotes the "effective" weight given to environmental quality relative to private consumption (recall that I is the exogenous number of countries).

We have therefore solved for a Symmetric Nash Equilibrium (SNE) in fiscal policies. This SNE is given by equations (2), (3), (7) and (8) in c_t, k_{t+1}, $N_{t+1}(= In_{t+1})$ and θ_t, given initial conditions.

Long-run symmetric Nash equilibrium

This subsection solves for a long-run Nash equilibrium.[14] We will study Sustainable Balanced Growth Paths (SBGPs). That is, long-run equilibria in which consumption and capital can grow at a constant positive rate without damaging the environment. Specifically, we look for a long-run equilibrium of (2), (3), (7) and (8) in which consumption and capital can grow at the same positive rate, i.e. $\dfrac{c_{t+1}}{c_t} = \dfrac{k_{t+1}}{k_t} > 1$, while renewable natural resources remain unchanged, i.e. $\dfrac{N_{t+1}}{N_t} \equiv 1$.[15]

[13] Focusing on symmetric equilibria is not restrictive for what we want to do here (i.e. to examine how spillovers and incentives are affected depending on whether the set-up is dynamic or static).
[14] We will focus on the long run. Again, this is enough for what we want to do here.
[15] In Philippopoulos and Economides [2000] we solve for a long-run equilibrium in which all per capita quantities (including renewable natural resources) grow at the same positive rate.

Setting $\frac{N_{t+1}}{N_t} \equiv 1$ in (7), we get $\frac{n_t}{k_t} = \frac{(1-\theta_t)A}{\delta}$. Using this into (8), we get for the long-run Nash tax rate (variables without time subscripts will denote long-run values):

$$\theta = 1 - \frac{\hat{\nu}\delta}{(1-\hat{\nu}\delta)A} \qquad (9)$$

so that $\theta = \theta\left(\overset{-}{\delta}, \overset{+}{A}, \overset{-}{\hat{\nu}}\right)$.[16] That is, the easier natural resources regenerate themselves (i.e. the higher is δ), the smaller the need for environmental protection. When the productivity of private capital is high (i.e. A is high), we can afford higher tax rates and lower economic growth. The more economic agents value environmental quality relative to private consumption (i.e. the higher is $\hat{\nu}$), the lower should be the long-run tax rate on polluting activities. This seemingly counter-intuitive result is explained in detail in section V below. The basic idea is that the more we value environmental quality, the higher the need for tax revenues to finance cleanup policy, and - in the long run - this can be achieved only by high growth and large tax bases (see e.g. John and Pecchenino [1994] who show that it is economies that achieve a sustained growth path that can also afford a better environment).

Finally, notice the effect of the size of population, I, on equilibrium outcomes. Since $\hat{\nu} \equiv \frac{\nu}{I}$, (9) implies that an increase in I leads *ceteris paribus* to an increase in the long-run Nash tax rate. Such a positive effect from the size of population on the Nash tax rate seems to be opposite from the standard one, which is traditionally negative (see the discussion in the Introduction and the algebra of the next section). As we argue below, this seemingly paradoxical result arises because the spillover effect across individuals is in fact negative. Then, a negative spillover effect can justify the positive effect of I on Nash tax rates. To confirm the above, we solve for a cooperative equilibrium below.

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[16] In turn, using (9) for θ into (3), we can get the SBGP, whose properties are opposite to those of θ (since the SBGP decreases with θ). In other words, any changes in the exogenous factors (δ, A and $\hat{\nu}$), that cause a rise (resp. fall) in the Nash tax rate on polluting activities, lead to lower (resp. higher) rates of

Symmetric cooperative equilibrium

Assume now that economic policy decisions are centralized. We will solve for a cooperative equilibrium defined as the solution to the problem of maximizing the sum of individual utilities. That is, now a hypothetical benevolent social planner chooses jointly all $\{\theta_t^i\}_{t=0}^{\infty}$ to maximize the sum of individual utilities in (1) subject to (4) for each i and (7) for the public good. This equilibrium is typically Pareto-optimal.

Working exactly as in the previous section, and focusing on Symmetric Cooperative Equilibria (SCE) in policies, it is straightforward to show that all previous results hold if we replace $\hat{\nu}$ with ν. To understand this, recall that the only externality present is due to public good provision, i.e. N_{t+1}. In a symmetric cooperative equilibrium (in which all actions are coordinated, all externalities are internalized and all individuals are alike), equilibrium outcomes are not affected by such public-good type problems.

Thus, under SCE, we again get (9) in the long run with ν instead of $\hat{\nu}$. Since $\nu > \hat{\nu} \equiv \frac{\nu}{I}$, the comparative static results in (9) imply that the optimal tax rate decreases when we switch from non-cooperation to cooperation, i.e. $\tilde{\theta}^{nash} > \tilde{\theta}^{coop}$. As we said above this is different from the standard result, and can happen only when the spillover effect from one individual to another is negative. To confirm this, we present below the standard static result.

IV. OPTIMAL ECONOMIC POLICIES IN A STATIC ECONOMY

We now study a special, static case. If saving is zero, equation (2) gives for i's consumption:

$$c^i = (1-\theta^i)Ak_0^i \tag{10}$$

where k_0^i is exogenously given.

Equation (7) is simply rewritten as:

economic growth. Note that the SBGP is a function of economic policy, θ, where the latter has been

$$N = (1+\delta)N_0 - \sum_{i=1}^{I}(1-\theta^i)Ak_0^i \qquad (11)$$

where N_0 is exogenously given.

In a Nash game, each individual i chooses θ^i to maximize $\log c^i + \nu \log \frac{N}{I}$, where c^i and N are given by (10) and (11) respectively. In a symmetric Nash equilibrium, the first-order condition is:

$$\frac{N}{c} = \hat{\nu} \qquad (12)$$

which is a well-known condition (see e.g. Mueller [1989, chapter 2] and Mas-Colell et al. [1995, chapter 11]). Plugging (10) and (11) back into (12) and differentiating, we get $\theta = \theta(\overset{-}{\delta}, \overset{+}{A}, \overset{+}{\hat{\nu}}, \overset{+}{k_0}, \overset{-}{N_0})$. Thus, since $\hat{\nu} \equiv \frac{\nu}{I}$, the Nash tax rate decreases with group size, I.

In a cooperative solution, the hypothetical social planner chooses all θ^i to maximize the sum of $\log c^i + \nu \log \frac{N}{I}$ over all individuals, $i = 1,2,...,I$. In a symmetric cooperative equilibrium, the first-order condition is:

$$\frac{N}{c} = \nu \qquad (13)$$

which is the Samuelson condition for Pareto optimality. Using the comparative static properties of (12) and since $\nu > \hat{\nu} \equiv \frac{\nu}{I}$, inspection of (12) and (13) reveals that $\tilde{\theta}^{nash} < \tilde{\theta}^{coop}$. That is, in the static case, a switch to coordination will lead to a higher tax rate, higher tax revenues, more cleanup policy and better environment.

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optimally chosen. This is as in all Barro-type endogenous growth models.

In summary, when the model is static, we get the standard results: Nash tax rates on public good provision are too low and decrease with the size of population. By contrast, when there is long-term endogenous growth, these results are reversed. In particular, in the model presented in sections II-III above, long-run Nash tax rates on public good provision were too high and increased with the size of population.

V. INTERPRETATION OF RESULTS AND CONCLUSIONS

In a static setup, capital tax bases are exogenously given. As a result, an increase in tax rates leads always to an increase in tax revenues and an increase in resources available for public good provision (in our example, cleanup environmental policy). This implies a positive spillover effect from one individual to another. Specifically, an increase in j's tax rate leads to higher tax revenues and higher cleanup policy; hence, there is an external welfare benefit upon $i \neq j$. In turn, a positive spillover implies that the Nash tax rate on public good provision is too low. Also, this tax rate decreases with the size of population (i.e. the Nash inefficiency increases with the size of population). These are the standard results.

By contrast, in a dynamic growing economy, economic activity, pollution and capital tax bases are all endogenous in the long run. As a result, higher tax rates lead to lower economic activity and this can generate a negative spillover effect from one individual to another. Specifically, an increase in j's tax rate lowers his capital accumulation, and this leads to smaller tax bases, lower tax revenues and lower cleanup policy; hence, there is an external welfare cost upon $i \neq j$. Since the spillover effect is negative, the Nash tax rate on public good provision is too high. Also, this tax rate increases with the size of population (i.e. again, the Nash inefficiency increases with the size of population). Therefore, the standard results have been reversed.

Consequently, in a dynamic setup, a decentralized economy can end up with too high tax rates on polluting activities, relative to the case in which there is centralized decision-making. When tax contributions to public good maintenance are decentralized and made privately and voluntarily, individuals do not internalize the harmful effect of their own tax rates (and hence low capital accumulation, low economic growth, small tax bases and low clean-up policy) on public good provision. They therefore set too high tax rates relative to the case in which tax policy decisions are centralized. In other words, in a growing economy, free-riding and small tax contributions are achieved by relatively high tax rates, low growth and small tax bases.

Therefore, the type of the spillover effect (and hence whether we under-tax, or over-tax, in a Nash equilibrium relative to a cooperative one) changes from positive to negative, once the same model allows for long-term endogenous growth. Although we have not provided a theory, we believe that we have managed to present a clear example by using a fairly standard model of public goods.

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