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Working Paper Series

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Working Paper 2013-07
http://econbus.mines.edu/working-papers/wp201307.pdf

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August 2013

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Working Paper No. **2013-07**
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Think locally, act locally: Can decentralized planning really achieve first-best in the presence of environmental spillovers?

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ABSTRACT

Strikingly, Ogawa and Wildasin (2009) find that in a model with heterogenous jurisdictions, interjurisdictional capital flows, and interjurisdictional environmental damage spillovers, decentralized planning outcomes are equivalent to that under a single centralized planner. Taken to its extreme this result renders international agreements such as the Kyoto Protocol irrelevant. We first show the critical importance of two key assumptions (no retirement of capital, fixed environmental damages per unit of capital) in obtaining this result. Second, we consider a more general model allowing for capital retirement and abatement activities and show that generally the outcome of a decentralized market differs from the solution of a centralized planner's social welfare-maximizing problem.

1 Introduction

Delegates from numerous countries continue to hold summits in an effort to craft international agreements that address global environmental challenges, such as climate change. Based on the recent work of Ogawa and Wildasin (2009), hereafter OW, these efforts may be unnecessary. OW construct a multi-jurisdictional model showing that when production creates environmental damages, which may have interjurisdictional spillover effects (i.e., interjurisdictional externalities), the decentralized planning efforts lead to the same capital allocation as that chosen by a single centralized planner.[1] Their result holds even when the jurisdictions have heterogeneous preferences over the environmental damages and differences in production capabilities. This is an amazingly powerful result as it implies that internationally uncoordinated efforts to respond to global environmental issues will lead to efficient outcomes, negating the need for international environmental agreements such as the Kyoto protocol. The result is equally stunning because it runs contrary to much of the established public and environmental economics literature on production efficiency in the face of externalities. Taken to its logical conclusion, their result implies that there may be a fundamental error in how economists, from Pigou (1920) to Samuelson (1954) to the present, think about externalities and public goods.

However, in this short analysis, we show that this result is purely an artifact of a highly stylized and unrealistic modeling assumption. More specifically, OW assume that, regardless of whether we consider the centralized planner problem or the decentralized problem, global capital is exogenously given and fixed. Combining this assumption with their formulation of

[1] Their work builds off of Oates and Schwab (1988) who show efficiency of decentralized planning in the absence of interjurisdictional spillovers.

how environmental damages are generated leads to a fixed sum of environmental damages across jurisdictions. In other words, the centralized planner cannot reduce global environmental damages by construction. We go on to more generally characterize the conditions under which a wedge exists between the outcomes under the centralized planner model and that of the decentralized model. Allowing for capital-retirement or abatement activities leads to inefficient decentralized planning in all but the most extreme cases. Recent work by Eichner and Runkel (2012) show a special case of our more general point, whereby the central result of OW breaks down in a two-period model with capital adjustment if the elasticity of capital supply is positive.[2] However in a more general static model setting, no dynamic considerations are needed to reject the main result of OW.

2 Fixed Total Environmental Damages Assumption

Consider the set-up from OW for N jurisdictions indexed by i. Equation 1 of their paper gives the following expression for the environmental damage in a given jurisdiction e_i as:

$$e_i = ak_i + \beta \sum_{j \neq i} ak_j \tag{1}$$

where a is units of local environmental damage per unit of capital k_i, and β represents the degree of environmental damage spillovers from other jurisdictions ($\beta \in [0, 1]$). Note

[2] In brief, cumulative damages are endogenized in Eichner and Runkel (2012) as the local capital tax reduces the net rate of return to capital, which in turn affects the savings decisions of households in a two-period model. Household savings affects cumulative capital and thus cumulative environmental damages when the capital supply elasticity with respect to the net return on capital is positive. We note that the result in Eichner and Runkel (2012), whereby decentralized decisions are efficient "...for economies where the capital supply elasticity has been found to be negligible,...", is subject to the same criticism developed below in the context of the original model in OW.

e_i, a unit of environmental damage in i, is not the same as the "cost" of pollution felt by those in i. Environmental damage enters the representative utility function, so the cost of environmental damage is represented through the marginal disutility of environmental damage (u_{ei}). For example, in the global warming context e_i may represent temperature increase in i, and the harm associated with a marginal increase in temperature need not be the same across jurisdictions ($u_{ie} \neq u_{je}$).

Capital is assumed to obey the following (equation 2):

$$\sum_i \bar{k}_i = \sum_i k_i \tag{2}$$

where $\bar{k}_i$ is the endowment of capital in a jurisdiction. Thus, while capital is mobile, the cumulative capital used has to equal the sum of the initial endowments ($\bar{k} = \sum_i \bar{k}_i$). Taken together equations 1 and 2 imply:

$$e_i = ak_i + a\beta(\bar{k} - k_i). \tag{3}$$

The previous three equations restate equations (1) - (3) in OW. To calculate the *cumulative* level of environmental damage, sum across all N jurisdictions:

$$\sum_i^N e_i = \sum_i^N (ak_i + a\beta(\bar{k} - k_i)) = a\bar{k} + a\beta\bar{k}N - a\beta\bar{k} = a\bar{k}(1 + \beta(N-1)) = \bar{e}. \tag{4}$$

Though never explicitly stated in OW, their modeling assumptions imply the sum of the environmental damages is equal to an exogenous constant ($\bar{e}$). At this point, a centralized planner (or any other decision-maker) has as much control over cumulative environmental damage units as he does over the tilt of the Earth's axis or Planck's constant.

Two important points follow. First, equation 4 implies a regulator can only shift environmental damages across jurisdictions, but not reduce aggregate damages. The issue becomes even more alarming when one considers the case of global stock pollutants such as CO_2 within the context of this model. As noted in OW this case corresponds to the parameterization of $\beta = 1$. With $\beta = 1$, environmental damages (e.g., temperature increases) in all jurisdictions are equal such that $e_i = e_j = a\bar{k} \quad \forall i, j$. Combining this with the condition that the sum of environmental damages across jurisdictions is constant implies the centralized planner can do nothing to lower average temperature increases ($\frac{\bar{e}}{N}$) nor can it lower the level of environmental damage in any region. That is, the centralized planner is stuck with the business-as-usual environmental damage case. Therefore for this special case it is perhaps not surprising, and indeed follows from the first fundamental theorem of welfare economics, that the social planner would allocate capital in a way consistent with a decentralized competitive market.

Second, such a model setting appears detached from the debate on current global environmental issues. For example, when international summits on climate change are held, delegates are not simply meeting to decide how temperature increases should be distributed across countries, but rather they are primarily concerned with the appropriate *level* of average temperature increase ($\frac{\bar{e}}{N}$). Thus, while OW motivate their model in part by appealing to interjurisdictional spillovers such as CO_2 emissions, their modeling assumptions are ill-equipped to deal with the central question actually facing policymakers.[3]

In the next section, we relax the assumption that all capital must be allocated, effectively allowing for capital retirement. In the decentralized case, this corresponds to a situation where local environmental policies are sufficiently stringent to drive the net rate of return on

[3] Even with pollutants where location of the pollution matters (e.g., SO_2 and NO_X), first order policy discussions are primarily concerned about aggregate levels of abatement.

capital to zero. In the centralized case, this corresponds to a situation where a centralized planner simply chooses to not allocate the full capital endowment.

3 Capital retirement

We now relax the basic model in OW to allow for capital retirement. While the original model also includes a local public good, we abstract from this consideration as it is not relevant for this paper.[4] It should also be noted that one could augment OW to allow for environmental damage reductions in any general way beyond just capital retirement and still arrive at the same general conclusions made below. We, however, focus on the relaxation of capital retirement because as noted above, the assumption of a fixed capital stock is of fundamental importance in the OW model.

The general framework of OW remains the same. The composite private good x_i is produced with capital given by the increasing and strictly concave production function $f_i(k_i)$, where $f_{ik} > 0$, and $f_{ikk} < 0$. A representative household in each jurisdiction consumes this private good and is affected by environmental damage e_i, with utility denoted by $u_i(x_i, e_i)$ such that $u_{ix} > 0$ and $u_{ie} < 0$. We simply relax the capital constraint in equation 2 to be $\sum_i \bar{k}_i \geq \sum_i k_i$ to allow for capital retirement.

3.1 Decentralized problem

We first begin with the problem faced by decentralized policymakers. Equivalent to equation 4 in OW, private consumption in each jurisdiction is given by:

[4] OW also note that local public goods do not play a crucial role in their analysis.

$$x_i = f_i(k_i) - f_{ik}k_i + \rho\bar{k}_i + T_i \tag{5}$$

where f_{ik} is the marginal productivity of capital, and ρ is the net rate of return to capital. To allow for the fact that capital may not be fully allocated ($\sum_i \bar{k}_i \geq \sum_i k_i$), the net return to capital satisfies $\rho \geq 0$. The government in each jurisdiction can charge a tax on capital t_i such that T_i is a lump-sum subsidy (a tax to fund a local public good in OW) households receive from any tax revenues raised, where $T_i = t_i k_i$.

Because of capital mobility, the net rate of return must be equal across jurisdictions, such that equilibrium requires:

$$f_{ik} - t_i = \rho \quad \forall i, \tag{6}$$

$$\rho(\sum_i \bar{k}_i - \sum_i k_i) = 0. \tag{7}$$

The second equation reflects the possibility of capital retirement, as either the net rate of return is positive $\rho > 0$ and all capital is allocated, or $\rho = 0$ and some capital is retired. Thus, the problem for each jurisdiction is to maximize $u_i(x_i, e_i)$ by selecting the local capital tax rate t_i taking ρ as given, accounting for equations 3 and 5.

3.2 Centralized problem

Next, consider the Pareto-efficient allocation of resources:

$$\max_{x_i, k_i} u_1(x_1, e_1) \tag{8}$$

subject to

$$u_i(x_i, e_i) - \bar{u}_i = 0 \quad \forall i > 1, \tag{9}$$

$$\sum_i f_i(k_i) - \sum_i x_i = 0, \tag{10}$$

$$\lambda(\sum_i \bar{k}_i - \sum_i k_i) = 0, \tag{11}$$

and equation 1. λ represents the shadow cost associated with the capital constraint for the corresponding Lagrangian formulation, such that $\lambda > 0$ if the capital constraint holds and $\lambda = 0$ if capital is retired.

3.3 Results

We now turn to the solutions to the above problems. A priori, there are four cases to consider, corresponding to whether or not the capital constraints are binding for the decentralized and centralized problems, though as shown below, one case can be ruled out. We begin by considering the case when both capital constraints are binding, such that $\rho > 0$ and $\lambda > 0$.

Proposition 1. *When capital constraints are binding for both the decentralized and centralized problem, the decentralized allocation is efficient.*

Proof. The decentralized solution satisfies equilibrium equation 6, the optimal tax is given by

$$t_i = -a(1-\beta)\frac{u_{ie}}{u_{ix}}, \tag{12}$$

and total capital allocation satisfies $\sum_i \bar{k}_i = \sum_i k_i$. Combining this optimal tax with 6, the decentralized problem implies $f_{ik} + a(1-\beta)\frac{u_{ie}}{u_{ix}} = \rho = f_{jk} + a(1-\beta)\frac{u_{je}}{u_{jx}}$.

The centralized planner's equilibrium is characterized by:

$$f_{ik} + a\frac{u_{ie}}{u_{ix}} + \beta\sum_{l\neq i} a\frac{u_{le}}{u_{lx}} = f_{jk} + a\frac{u_{je}}{u_{jx}} + \beta\sum_{l\neq j} a\frac{u_{le}}{u_{lx}} = \lambda \quad \forall i,j \tag{13}$$

or

$$f_{ik} + a(1-\beta)\frac{u_{ie}}{u_{ix}} + \beta \sum_l a \frac{u_{le}}{u_{lx}} = f_{jk} + a(1-\beta)\frac{u_{je}}{u_{jx}} + \beta \sum_l a \frac{u_{le}}{u_{lx}} = \lambda \quad \forall i, j \tag{14}$$

and total capital allocation satisfies $\sum_i \bar{k}_i = \sum_i k_i$. Because the marginal external cost term, $\beta \sum_l a \frac{u_{le}}{u_{lx}}$, appears on both sides of the equality in equation 14 and the total capital endowment is allocated, it is clear from equations 6 and 12 that the decentralized allocation is identical to the central planner's allocation. □

This striking result is equivalent to that in OW and, indeed, it is interesting that capital allocation rules for the decentralized and centralized models coincide in this context. In particular, even though the decentralized and centralized "prices" of capital are not equal, $\lambda = \max(\rho + \beta \sum_l a \frac{u_{le}}{u_{lx}}, 0)$, the resulting decentralized allocation is nonetheless efficient.[5]

However, it is important to recognize what underlying economic conditions must be met for both $\rho > 0$ and $\lambda > 0$. Figure 1 illustrates the basic intuition. Here we plot the marginal private benefit ($\text{MPB}_i = f_{ik}$), marginal private cost ($\text{MPC}_i = -a(1-\beta)\frac{u_{ie}}{u_{ix}}$), and marginal social cost ($\text{MSC}_i = -a(1-\beta)\frac{u_{ie}}{u_{ix}} - \beta \sum_l a \frac{u_{le}}{u_{lx}}$) for jurisdiction i, given $\bar{k}$.[6] In order for both ρ and λ to be positive at the point $\sum_i \bar{k}_i$, the marginal private benefits of an additional unit of capital must exceed the marginal private (local) costs of that capital as well as the the marginal social costs. In other words, the marginal external cost $\beta \sum_l a \frac{u_{le}}{u_{lx}}$ must be sufficiently small in magnitude (recall $u_{le} < 0$) such that $\lambda = \rho + \beta \sum_l a \frac{u_{le}}{u_{lx}} > 0$, whereby the net social return on capital is still positive. A positive net social return on capital implies

[5] We reiterate that while this does seem remarkable at first glance, the fixed environmental damage assumption makes this result essentially an example of the first fundamental theorem of welfare economics.

[6] For a given $\bar{k}$ there will be a decentralized solution for $k_i \quad \forall i$. The MPB_i, MPC_i, and MSC_i curves may vary by jurisdictions, but the wedges (ρ and λ) among the curves at a given $\bar{k}$ must be the same for all jurisdictions.

that it would be welfare improving to *increase* the cumulative capital endowment $\bar{k}$ and thus cumulative environmental damages $\bar{e}$. Needless to say, this does not reflect the current international deliberations regarding potential temperature increases from anthropogenic global warming, nor does this reflect typical deliberations regarding transboundary pollution in general.

Note also that in the case of climate change, $\beta = 1$, the equivalence between the decentralized outcome ($t_i = 0$) and the centralized outcome implies that neither centralized intervention nor intervention carried out in a decentralized manner is necessary to achieve efficient capital allocation.[7] The purely decentralized outcome, which sets the marginal productivity of capital (f_{ik}) equal to the return of capital (ρ), results in efficient capital allocation with nothing at all being done to reduce global temperature increases.

Next, consider the case where the decentralized net return on capital is positive, while the centralized net return is equal to zero, such that $\rho > 0$ and $\lambda = 0$.[8]

Proposition 2. *When the capital constraint is binding for the decentralized problem but not the centralized problem, the decentralized allocation is inefficient.*

Proof. The decentralized solution satisfies equilibrium equation 6, the optimal tax is given by equation 12 and total capital allocation satisfies $\sum_i \bar{k}_i = \sum_i k_i$.

[7] The local tax rate corrects for the environmental cost created by the marginal unit of capital ($-a\frac{u_{ie}}{u_{ix}}$) and the environmental benefit of avoiding a "spillback" that would occur if that marginal unit of capital went elsewhere ($a\beta\frac{u_{ie}}{u_{ix}}$). Thus, for the case of CO_2 emissions ($\beta = 1$) the optimal tax should be zero. This makes sense because, as discussed above, with $\beta = 1$ we will have $e_i = e_j = a\bar{k} \quad \forall i, j$ regardless of where capital is distributed.

[8] Because $\lambda = \max(\rho + \beta \sum_l a\frac{u_{le}}{u_{lx}}, 0)$, this simply requires that $\beta \sum_l a\frac{u_{le}}{u_{lx}}$ be sufficiently negative. Because we have assumed $u_{le} < 0 \quad \forall l$, we can rule out the case where $\rho = 0$ and $\lambda > 0$. For the case of a positive externality, the analysis follows symmetrically with the case of $\rho > 0$ and $\lambda = 0$ ruled out.

The centralized planner's equilibrium is characterized by:

$$f_{ik} + a(1-\beta)\frac{u_{ie}}{u_{ix}} + \beta\sum_l a\frac{u_{le}}{u_{lx}} = f_{jk} + a(1-\beta)\frac{u_{je}}{u_{jx}} + \beta\sum_l a\frac{u_{le}}{u_{lx}} = 0 \quad \forall i,j \tag{15}$$

and total capital allocation satisfies $\sum_i \bar{k}_i > \sum_i k_i$. While the capital allocation rule between jurisdictions is identical for both planners, less total capital is allocated by the centralized planner, driving a wedge between the decentralized and centralized allocations. □

In this case, by allowing for capital retirement, the centralized planner chooses to not allocate further capital once the net social return is negative.[9] By contrast, the decentralized allocation results in all of the capital endowment being put to use, driving the standard wedge between the centralized planner and the decentralized solution. Furthermore, this wedge is not simply a minor, second-order concern. In the case of climate change, where $\beta = 1$ and $t_i = 0$, the decentralized allocation would *never* result in capital retirement due to the fact that $f_{ik} > 0$ implies $\rho > 0$. This is true regardless of the size of the marginal disutility (u_{ei}) from environmental damages. The centralized planner however would allocate a smaller and smaller level of cumulative capital as marginal disutility rises.

We stress that the economic forces highlighted in OW are still at work in Proposition 2. Decentralized policymakers behave atomistically, choosing polices that represent the interests of their own residents and accounting for capital mobility and spillbacks. Nonetheless, by simply allowing for the central planner to retire capital if its net social return is negative, a wedge emerges between the centralized and decentralized allocations.

[9] Equivalently, one could consider a model where the centralized planner could undertake some costly emissions abatement activities that lowers cumulative environmental damages, rather than strictly retiring capital, in order to address possible negative net social returns to capital.

The final case to consider is when the net return in both the decentralized case and the centralized case are equal to zero, such that $\rho = 0$ and $\lambda = 0$.[10]

Proposition 3. *When the capital constraint is not binding for both the decentralized and centralized problem, the decentralized allocation is inefficient.*

Proof. The decentralized solution satisfies now satisfies:

$$f_{ik} - t_i = 0 \quad \forall i. \tag{16}$$

When $\rho = 0$, any change in the tax rate does not result in a "spillback" from other jurisdictions as capital is simply voluntarily retired as the tax rate grows. Thus, the optimal tax is given by:

$$t_i = -a\frac{u_{ie}}{u_{ix}}, \tag{17}$$

and total capital allocation satisfies $\sum_i \bar{k}_i > \sum_i k_i$.

The centralized planner's equilibrium is characterized by equation 15 and total capital allocation satisfies $\sum_i \bar{k}_i > \sum_i k_i$. Comparing equation 15 with equations 16 and 17, the central planner allocation includes the additional term $-a\beta\frac{u_{ie}}{u_{ix}} + \beta\sum_l a\frac{u_{le}}{u_{lx}}$. Because the summation is over all jurisdictions (including i), this term is always strictly negative, driving a wedge between the decentralized and centralized allocations. □

This case corresponds to an example where the local environmental damages are sufficiently large such that local policy decisions create capital retirement. Nonetheless, the amount of capital retirement is less in the decentralized case than the centralized case, leading to larger cumulative capital levels and thus cumulative environmental damages.

[10] As noted above, this can only occur when $\beta < 1$ and $t_i > 0$.

Figure 2 visually illustrates the intuition behind Propositions 1-3, essentially extending the horizontal axis of Figure 1. If the total capital endowment $\bar{k}$ is sufficiently small (region I), then Proposition 1 holds and the decentralized allocation is efficient per OW. However, as the total capital endowment increases (regions II and III), the decentralized allocation is no longer efficient. If the initial capital endowment, $\bar{k}$, is such that the system is in region II, the centralized planner solution will reduce cumulative capital to $\bar{k}^C$ while the decentralized solution will keep capital at $\bar{k}$. If $\bar{k}$ is such that the system begins in region III, the centralized planner solution will again reduce capital to $\bar{k}^C$ and the decentralized solution will also result in a reduction of capital to $\bar{k}^D$. Thus, Figure 2 makes it clear that the efficiency of decentralized planning requires a corner solution, such that the socially optimal level of capital and thus environmental damages exceeds that which is allowed by the capital endowment. Outside of this special case, we appear to be stuck with the messy and imperfect solutions to externality problems identified in OW.

It should be noted that OW allude to the fact that this model can be interpreted in a tradable pollution permit context, where $\bar{k}$ represents a cap on aggregate pollution. They note that the regulator "need only determine the proper aggregate amount of pollution $\bar{k}$" and allow decentralized units to allocate individual permits k_i to reach an efficient allocation. This is simply an application of Montgomery (1972). Of course, determining the "proper" $\bar{k}$ is the crux of the environmental problem, and to imply that decentralized and centralized planning outcomes are equivalent without noting this issue skirts the primary policy debate.[11]

[11] In fact, immediately following the discussion of tradeable pollution permits, OW discuss the call for international cooperation in the Stern (2007) Report, noting that their results show decentralized policymaking can be efficient. Yet, the Stern Report is primarily concerned with the benefits and costs of cutting global emissions, a possibilty precluded by assumption in their analysis.

This is highlighted in Proposition 2, where if the "proper" amount of aggregate environmental damages is less than that produced by the endowed capital, the decentralized and centralized outcomes are no longer equivalent.

4 Conclusion

The main result in OW - with interjurisdictional environmental spillovers and heterogenous environmental preferences the decentralized policy making can be as efficient as that under a centralized planner - appears at first blush to be quite remarkable. They do, however, admit a qualification. Specifically they note that if a and β are allowed to be region specific (i.e., a and β are replaced by a_i and β_{ij}) their main result no longer holds. While they offer no specifics on why this parameter relaxation will cause their central point to be invalid, the reason, as with the extension shown here, is because this relaxation implies environmental damages are no longer fixed given a fixed total amount of capital. With an endogenous level of environmental damages, regardless of how it is brought about, one will get the more commonly derived result that there is generally a divergence between the central planner's outcome and the decentralized allocation.

They further admit that their model is stylized and results are subject to deviations from the underlying assumptions, but they maintain that "...it should be apparent that the magnitude of the efficiency losses from decentralized policymaking is modest if the assumptions of the model are approximately correct," that "The findings are not knife-edge results that disappear with small departures from the underlying assumptions...", and finally, somewhat negating their primary qualification, that "The efficiency rationale for intervention in local decision making by a higher-level authority, or for explicit coordination and bargaining among local governments, must rest not on the 'first-order' existence of spillovers but on the 'second-order' differences in the amounts of spillover damage from one jurisdiction to another (i.e., not on the fact that $\beta_{ij} > 0$ but on the fact that $\beta_{ij} \neq \beta_{kl}$ for some i, j, k, l)."

It is, however, quite apparent that their result relies on one very key assumption that goes unmentioned in their paper - cumulative environmental damages must be fixed. As we have shown, this result breaks down when capital can be retired, except in the special case where socially optimal environmental damages *exceed* the business-as-usual level. This dramatically diminishes the power of their result, as the key argument in discussions on global pollutants, and interjurisdictional pollutants more generally, is not so much how we should geographically reshuffle the environmental damages along a business-as-usual path, but rather how do we reduce the total level of environmental damages. Unfortunately, as is clear from this basic modeling exercise, we cannot simply rely on the uncoordinated policies of various decentralized jurisdictions to solve this very serious global issue. On a positive note, however, those striving to form coordinated emission reduction policies can rest easier knowing their efforts are not fundamentally unnecessary.

References

Eichner, T. and M. Runkel (2012). Interjurisdictional spillovers, decentralized policymaking, and the elasticity of capital supply. *American Economic Review 102*(5), 2349–2357.

Montgomery, W. (1972). Markets in licenses and efficient pollution control programs. *Journal of Economic Theory 5*, 395–418.

Oates, W. and R. Schwab (1988). Economic competition among jurisdictions: efficiency enhancing or distortion inducing? *Journal of Public Economics 35*(3), 333–354.

Ogawa, H. and D. Wildasin (2009). Think locally, act locally: Spillovers, spillbacks, and efficient decentralized policymaking. *American Economic Review 99*(4), 1206–1217.

Pigou, A. (1920). *The Economics Of Welfare*. Macmillan and Co., London.

Samuelson, P. (1954). The pure theory of public expenditure. *Review of Economics and Statistics 36*(4), 387–389.

Stern, N. N. H. (2007). *The economics of climate change: the Stern review*. Cambridge University Press.

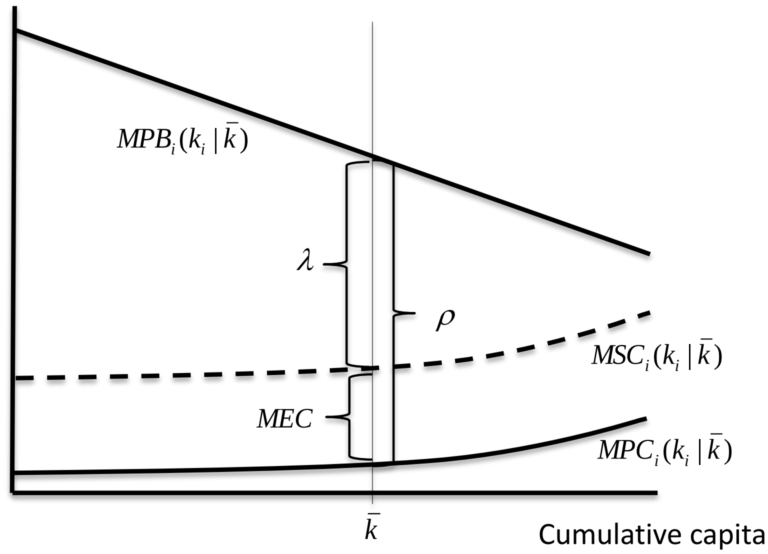

Figure 1

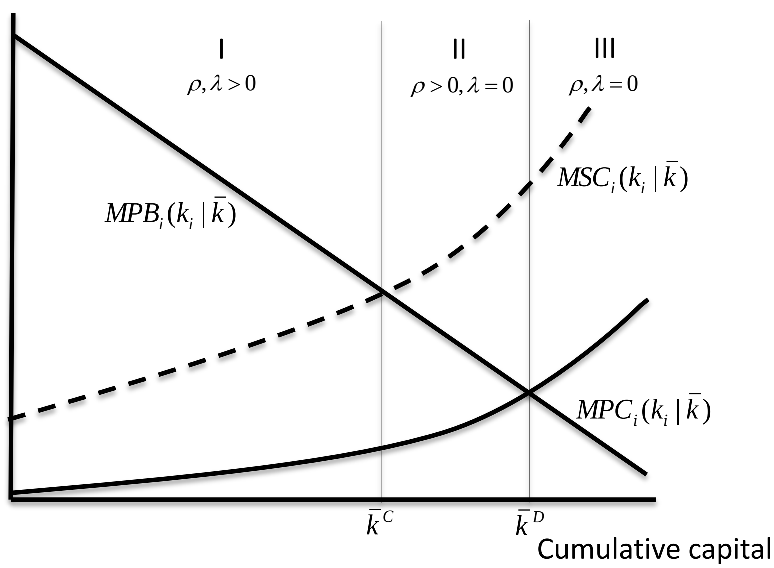

Figure 2