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Abstract

This paper studies environmental policy in a two-country economy with transboundary pollution and perfectly or imperfectly mobile households. We show that the policies the countries adopt in equilibrium vary significantly depending on instrument choice, and the ensuing allocation of pollution rents. If the rents are collected by the local public sector, which redistributes them evenly between all residents (also new immigrants), perfect household mobility provides a remedy to transboundary pollution problems, while impefect mobility reinforces the countries' incentives to overpollute. On the other hand, if command and control is used and the rent accrues to natives, who, say, own the local land, neither perfect nor imperfect household mobility has any effect. These results are derived from simple models with constant returns to scale and no explicit congestion externalities. If congestion is explicitly introduced into the utility function, household mobility is never neutral.

JEL Classification: Q28, R23

Keywords: transboundary pollution, household mobility, instrument choice

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1 Introduction

Recent research has indicated that perfect household mobility can generate a disciplinary mechanism which induces individual jurisdictions to internalize interregional externalities caused by transboundary pollution[1]. Wellisch (1994, 1995, 2000, Chapter 7) shows that the non-cooperative equilibrium of the environmental policy game is socially efficient, if households are perfectly mobile and jurisdictions can set a head tax for the residents in the region and also give non-negative transfers to the residents of other regions.[2] Silva (1997), and Hoel and Shapiro (2000,2003) demonstrate that the decentralized outcome is second best constrained efficient, even when interjurisdictional transfers are ruled out: given the set of instruments, a social planner, or a central government, can do no better than local governments.[3]

The gist of the efficiency result presented in the literature lies in the observation that perfect household mobility levels down regional welfare differences: in equilibrium no jurisdiction can be better off than any other jurisdiction. Then socially harmful policies cannot be individually rational. If a jurisdiction tries to free-ride through transboundary pollution, the resulting welfare difference triggers immigration. Because fixed resources, e.g. land or the carrying capacity of the environment, are scarce, there is congestion, and an increase in population lowers welfare. Thus household mobility creates a feed-back effect which eliminates the payoffs from selfish policy. Rational local governments correctly anticipate this feed-back, and do not even try to free-ride. To put it differently, due to perfect household mobility, the objectives of different regions coincide. One way to visualize the argument is to compare the economy to an expedition of alpinists, connected by a rope. Because of the rope, the alpinists have to show solidarity to each other: if one of them falls, the life of the others is in danger as well. Migration is like a rope connecting countries' and regions' fortunes together.

The efficiency result is established in static models with perfect mobility. It is not necessarily robust when migration costs and real time dynamics are introduced. In a recent paper Haavio (2004) demonstrates that the combination of stock pollution, costly migration and time consistent environmental policies implies a major departure: Rather than neutralizing distortions from transboundary pollution, household mobility reinforces the incentives to overemit. Environmental damages are excessive even when pollution is local. Moreover these intertemporal externalities get worse as the degree of household mobility increases. As migration costs approach zero (but do not reach it), the econ-

[1] Transboundary pollution problems have received a great deal of attention in the literature since the 1970's. For a recent survey, see e.g. Hoel (1999).

[2] In an economy with mobile population, there are two policy goals: the quality of the environment, and the right regional allocation of population, resulting in production efficiency. Thus two policy instruments are usually needed to reach the social optimum.

[3] There is also an interesting recent paper by Sandmo and Wildasin (1999). In contrast to the rest of the literature, however, this paper concentrates entirely on the optimal policies of a small country. This focus then makes it hard to compare the paper to our model, where the emphasis is on economywide implications of household mobility.

omy becomes as distorted as under global pollution. However, if households are perfectly mobile, the efficiency result established in the static literature is replicated.

Stock pollution introduces the tragedy of the commons[4]. As consumption and environmental damages are temporally separated, it is possible to first enjoy consumption and then escape the damages. This is not feasible in a static model where benefits and costs occur simultaneously. Viewed from another angle, the pollution stock has the strategic value of curbing future immigration. Sluggish migration and the requirement of time consistency then eliminate implicit cooperation. When migration takes time, the higher consumption today can be fully enjoyed by current residents. Under perfect household mobility there would be an immediate surge of immigration, and the extra consumption would be shared with newcomers. Therefore under imperfect household mobility, unlike under perfect mobility, there is an incentive to consume more today than is socially optimal. This incentive, however, exists not just today but at any time in the future if there is no commitment to a Nash strategy.[5]

Both in the static literature and in the dynamic model by Haavio (2004) it is assumed that the pollution rent is collected by the local public sector, which either uses emission fees or auctions tradable pollution permits. The papers further stipulate that public authorities treat natives and immigrants equally when using public funds. These assumptions then introduce open access to the pollution rents: by immigrating foreigners can get their share.

This paper shows that the choice of policy instruments, and the ensueing allocation of pollution rents, influences the interaction between household mobility and environmental policy. The paper has three interlinked goals. First, we reinterpret the earlier results in a way which illustrates that open access to pollution rents is an important element both in the mechanism leading to social efficiency, under perfect household mobility, and in the tragedy of the commons emerging in dynamic settings with imperfect mobility. Second, we demonstrate that both the beneficial effects of perfect household mobility and the harmful consequences of imperfect mobility vanish, if policy-makers use command and control, and the pollution rent accrues to natives, who, say, own the local land. Finally, we show that the efficiency and inefficiency results are nevertheless in a certain way robust with respect to alternative assumptions concerning policy

[4] A tragedy of the commons occurs when property rights over an asset are ill defined or cannot be enforced. Typically, the literature shows that open access leads to overconsumption and underinvestment. Fisheries are analysed in the classic article by Gordon (1954) and in Levihari and Mirman (1980). Lancaster (1973) and Tornell and Velasco (1992) study the accumulation of capital and economic growth in an economy with ill defined property rights.

[5] There is also some empirical evidence suggesting that mobility may encourage people to disregard their environment. Probably the best-known observations concern the role of shifting cultivation and nomadism in the process of deforestation in the tropics and in that of desertification in sub-Saharan Africa. (See e.g. Bilsborrow (1992), Bilsborrow and DeLargy (1990), Cruz and Cruz (1990), Talbot (1986), Peters (1988)). Other examples where high demographic turnover and environmental problems have coincided include military bases, with their regularly changing population, mining communities) , where people seldom plan to stay for the rest of their life (see e.g. Smith et al. (1995)), and refugee camps , with inhabitants waiting for an opportunity to leave(see e.g. UNHCR (1997)).

instruments and rent allocation. A crucial role of the assumption of open access to the pollution rent is that it provides a simple way to model congestion: as immigrants can grab a part of resources, increases in population are bad. If congestion is directly introduced into the utility function, as in Silva (1997), both the blessings of perfect household mobility and the detrimental effects of imperfect mobility reemerge, albeit in a weaker form, even under command and control.

The structure of the paper is as follows: Section 2 develops a one-eriod model to illustrate that under transboundary pollution and perfect household mobility, the socially optimal outcome is achieved if the pollution rent is collected by the local public sector, which redistributes it evenly between all residents (also new migrants). On the other hand, if command control is used and the rent accrues natives (who, say own, the local land), household mobility does not provide a remedy. Section 3 augments the framework to include two periods, and examines the situation studied in Haavio (2004), with stock pollution, sluggish migration and time-consistent environmental policy. Also in this case the allocation of pollution rents is crucial. If the rent goes to all residents, household mobility introduces new distortions; if it accrues to natives, only, there are no new externalities. Section 4 then shows how the results change, when disutility from congestion is explicitly introduced: the beneficial and harmful effects of household mobility do not disappear even if natives get the pollution rents. Some concluding remarks are given in Section 5.

2 One-period model

This section studies the potential role of household mobility in internalizing externalities caused by transboundary pollution. The economy consists of two countries $i = 1, 2$. The total population of the economy is fixed to unity and the number of consumer-laborers living in country i is denoted by N^i. Consumers are identical and derive utility out of consumption (C) and environmental amenities (E), $U = U(C, E)$. The representative consumption good is produced by constant returns to scale, and using labor (N) and pollution emissions (S)

$$Y^i = F(N^i, S^i) = N^i f(\sigma^i) \tag{1}$$

where

$$\sigma^i = \frac{S^i}{N^i}$$

(In the two-period model, analyzed below, s and S denote first and second period emissions.) The quality of the environment in country $i = 1, 2$ is given by

$$E^i = \omega - (1 - q)S^i - qS^j$$

where $q \in [0, \frac{1}{2}]$ is the measure of transboundary pollution.

The sequence of moves in the environmental policy migration game is the following:

- (0) At the outset of the game there is an equal number of people in both countries $n^1 = n^2 = \frac{1}{2}$.
- (1) The countries set their environmental policies (S_1, S_2).
- (2) People can migrate from one country to another.
- (3) Production, consumption, pollution.

The social optimum of the model is easy to characterize. There is an equal number of people in both countries; extra utility from consumption is balanced by environmental damages:

$$U_{C^i} f'(\sigma^i) = N^i U_{E^i} \tag{2}$$

In the absence of household mobility, national policy-makers would ignore damages occurring abroad and overemit:

$$U_{C^i} f'(\sigma^i) = (1-q) N^i U_{E^i} \tag{3}$$

Next we proceed to decentralized decision making under household mobility. It turns out that the incentives facing mobile consumers and policy-makers depend on instrument choice, and on how pollution rents are allocated. Denote by C_i^i and C_i^j the consumption of a native of country $i = 1, 2$, if he stays in country i and moves to country $j \neq i$, respectively. A consumer always earns wages $w^m = f(\sigma^m) - \sigma^m f'(\sigma^m)$ in the country where he resides. As to pollution rents $\pi^m = N^m \sigma^m f'(\sigma^m)$, we assume that a share $\delta \in [0, 1]$ is distributed to current residents, whereas the remaining share $(1-\delta)$ is reserved to natives. $\delta = 1$ corresponds to environmental taxation, combined with equal treatment of all residents; potential land rents are taxed away and distributed back in equal shares[6]. $\delta = 0$ is command and control, with pollution (and land) rents accruing to natives (who own the land). If an agent stays in his native country (i) his rent income is $\delta\sigma^i f'(\sigma^i) + (1-\delta)\sigma^i f'(\sigma^i)\frac{N^i}{n^i}$. If he migrates to country j, he receives $\delta\sigma^j f'(\sigma^j) + (1-\delta)\sigma^i f'(\sigma^i)\frac{N^i}{n^i}$. Then we can write

$$C_i^i = f(\sigma^i) - (1-\delta)\sigma^i f'(\sigma^i)[1 - \frac{N^i}{n^i}] \tag{4}$$

$$C_i^j = f(\sigma^j) - (1-\delta)[\sigma^j f'(\sigma^j) - \sigma^i f'(\sigma^i)\frac{N^i}{n^i}] \tag{5}$$

It is easy to see that only when the pollution rent is taxed and redistrubed by impartial local authorities $(\delta = 1)$, $C_i^i \equiv C_j^i \equiv f(\sigma^i)$ and $C_j^j \equiv C_i^j \equiv f(\sigma^j)$, and natives and immigrants necessarily get the same level of consumption. It is also

[6] Land could be easily included into the model as third factor of production. However, as this would increase notational clutter without changing the qualitative results, we have decided not to do so.

useful to analyze how consumption depends on the distribution of population. In the symmetric equilibrium we have[7]

$$\frac{\partial C_i^i}{\partial N^i} = -\delta f' \sigma^i f'(\sigma^i)/N^i \leq 0 \quad (6)$$

$$\frac{\partial C_i^j}{\partial N^i} = \delta \sigma^i f'(\sigma^i)/N^i - 2(1-\delta)(\sigma^i)^2 f''(\sigma^i)/N^i > 0 \quad (7)$$

Notice in particular that immigration decreases the consumption of a representative native, only if immigrants get a share of pollution rents, $\delta > 0$.

Next we turn to migration. People move from one country to the other only if it is profitable to do so. Perfect household mobility implies that

$$U(C_i^i, E^i) \geq U(C_i^j, E^j),\ i, j \in \{1, 2\},\ i \neq j \quad (8)$$

where equality holds if some people migrate from i to j. Notice that in general (8) does *not* imply that both countries should necessarily have the same level of welfare, not even in the case where there actually is migration.[8] If $\delta = 1$, and the rent is collected in taxes, $C_i^i = C_j^i \equiv C^i$, and we get the more familiar condition

$$U(C^i, E^i) = U(C^j, E^j) \quad (9)$$

stating that migration equalizes welfare between the two countries. Totally differentiating (8) tells how an increase in emissions in country i affects migration flows. Suppose people migrate from j to i. Then we have

$$\frac{dN^i}{dS^i} = \frac{U_{C_i^j} \frac{\partial C_j^i}{dS^i} - (1-q)U_{E^i} + qU_{E^j}}{U_{C_j^j} \frac{\partial C_j^j}{\partial N^i} - U_{C_j^i} \frac{\partial C_j^i}{\partial N^i}} \quad (10)$$

Suppose next that people migrate from i to j

$$\frac{dN^i}{dS^i} = \frac{U_{C_i^i} \frac{\partial C_i^i}{\partial S^i} - U_{C_i^j} \frac{\partial C_i^j}{\partial S^i} - (1-q)U_{E^i} + qU_{E^j}}{U_{C_i^j} \frac{\partial C_i^j}{\partial N^i} - U_{C_i^i} \frac{\partial C_i^i}{\partial dN^i}} \quad (11)$$

In the symmetric equilibrium both (10) and (11) become.

$$\frac{dN^i}{dS^i} = \frac{1}{2} \frac{\delta f'(\sigma^i)/N^i - (1-\delta)\sigma^i f''(\sigma^i)/N^i - (1-2q)\frac{U_{E^i}}{U_{C_i^i}}}{\delta \sigma^i f'(\sigma^i)/N^i - (1-\delta)(\sigma^i)^2 f''(\sigma^i)/N^i} \quad (12)$$

If $\delta = 1$ (or $q = \frac{1}{2}$), $\frac{dN^i}{dS^i} > 0$, and an increase in emissions triggers immigration; otherwise however the sign is ambiguous.

[7] In what follows we also need the relations $\frac{\partial C_i^i}{\partial S^i} = f'(\sigma^i)/N^i$, $\frac{\partial C_i^j}{\partial S^i} = (1-\delta)\left[f'(\sigma^i) + f''(\sigma^i)\sigma^i\right]/N^i$, $\frac{\partial C_i^j}{\partial S^j} = \left[\delta f'(\sigma^j) - (1-\delta)f''(\sigma^j)\sigma^j\right]/N^j$ and $\frac{\partial C_j^j}{\partial S^i} = 0$.

[8] With arbitrary policies, household mobility does not in general equalize welfare. In the symmetric equilibrium of the model both countries are of course equally well off.

National policy makers in country i choose S^i so as to maximize the welfare of a representative domestic consumer:

$$\max_{S_i} U(C_i^i, E^i)$$

When designing their policies, national authorities take into account the effects on migration (12). The first order condition is

$$U_{C_i^i}[\frac{\partial C_i^i}{\partial S^i} + \frac{\partial C_i^i}{\partial N^i}\frac{dN^i}{dS^i}] = (1-q)U_{E^i}$$

where $\frac{\partial C_i^i}{\partial N^i}\frac{dN^i}{dS^i}$ is the (potential) co-operation inducing feed-back effect . The symmetric equilibrium of the game is then characterized by

$$(1-\frac{1}{2}\delta)U_{C_i^i}f'(\sigma^i) = \left[1-\frac{1}{2}\mu-(1-\mu)q\right]N^iU_{E^i} \quad i=1,2 \tag{13}$$

where

$$\mu = \frac{\delta f'(\sigma^i)}{\delta f'(\sigma^i)-(1-\delta)\sigma^i f''(\sigma^i)}; \quad \mu \in [0,1] \tag{14}$$

The conditions (13) indicate that the properties of the decentralized outcome depend crucially on instrument choice and on how pollution rents are allocated. The equilibrium is efficient only when all residents get an equal share of the rent. Under taxation (or auctioned tradable permits), $\delta = 1$, $\mu = 1$, and (13) assumes the form (2). Under command and control, if the rents accrue to natives only, we have $\delta = 0$, $\mu = 0$ and (13) becomes (3): national policies are as distorted as under no household mobility.

To interpret the result, remember from (6) that immigration lowers natives' consumption level only when newcomers get a share of rents. Thus rent-sharing is also a necessary condition for the feed-back effect to be operative. Likewise, notice form (8) and (9) that household mobility levels off all regional welfare differences, only when natives and migrants have the same sources of income, and thus get the same consumption level. It is well established in the literature that welfare equalization through migration makes private and social goals coincide.

The distinction between private access and open access resources provides yet another key. Due to transboundary pollution, there is open access to the assimilating capacity of the environment; this then encourages overpollution. However, if there is perfect household mobility and pollution rents are redistributed to all residents, there is also open access to the fruits of pollution. As demonstrated by Wellisch (1994,1995,2000), Silva (1997), and Hoel and Shapiro (2000,2003), under these circumstances of two-sided open access, overpollution does not pay off. However, if natives have (implicit) property rights over pollution rents, open access is eliminated on the benefit side, and the incentives to overpollute remain.

3 Two-period model

In this section we construct a two period model capturing the essential features of Haavio (2004).[9] As in the previous section, our aim is to illustrate that instrument choice, and the resulting allocation of pollution rents, matters: If the rent goes to all residents (also immigrants), household mobility introduces new distortions; if it accrues to natives (who own the land), there are no new externalities.

The key ingredients of Haavio (2004) are stock pollution, sluggish migration and time consistent environmental policy. The assumptions of imperfect household mobility and constant reoptimization imply that at each moment of time national decision makers can take the regional distribution of population as given. Then higher consumption today can be fully enjoyed by current residents. However, there is a link (through state variables) from environmental policy to future population movements.

The basic setup is as above. The economy consists of two countries, and identical consumers derive utility out of consumption and environmental amenities. The economy lasts for two periods; we denote first period variables by lower-case letters and second period variables by upper-case letters. The trade-off between first period consumption (c) and emissions (s) is[10]

$$c^i = \frac{s^i}{n^i} \tag{15}$$

Second period production uses technology (1). Finally, intertemporal utility is given by

$$u(c,e) + U(C,E)$$

We assume that there is stock pollution. The quality of the environment in the first period (e) is exogenous. The quality of second period amenities (E) is affected by first period emissions (s).

$$E^i = \omega - (1-q)s^i - qs^j \tag{16}$$

As E is unaffected by S, in the second period both countries emit the maximum amount $S_1 = S_2 = \overline{S}$. Thus in what follows we do not have to analyze second period environmental policies.

The sequence of events in the environmental policy-migration game is the following

First period

- (0) At the beginning of the game there is an equal number of people in both countries. We assume that (i) migration is sluggish and (ii) the

[9] Haavio (2004) develops a continuous time, infinete horizon model. Here we try to capture the essential features of that framework using the simplest possible setup, with two periods.

[10] As first period population is given, this cake-eating technology can be used without any loss of generality.

first period (today) is so short that nobody has the time to move.[11,12] Thus in the first period the regional allocation of people can be taken as given: $n_1 = n_2 = \frac{1}{2}$. This assumption also implies that first period consumption can be enjoyed by natives, only.[13]

- (1) The countries choose their first period environmental policies (s_1, s_2)
- (2) Production and consumption. (Pollution occurs in the second period)

Second period

- (3) People can migrate from one country to another. In our two period model, the second period represents the whole future. Thus there is enough time to move. To keep the model as simple as possible, we do not introduce shifting costs.
- (4) Production and consumption; damages due to first period emissions.

In the socially optimal outcome, first period environmental policy is characterized by

$$u_{c^i} = N^i U^i_{E^i} \tag{17}$$

In the absence of household mobility, national policy-makers ignore foreign damages and overemit

$$u_{c^i} = (1-q)N^i U^i_{E^i} \tag{18}$$

In particular, under global pollution we have

$$u_{c^i} = \frac{1}{2} N^i U^i_{E^i} \tag{19}$$

As in the previous section, the way in which pollution rents are allocated plays an important role. The connection between the allocation rule and second period consumption is given by (4) and (5); interpretations are as above. (First

[11] To keep the model as simple as possible we simply assume that there is no mobility in the first period. This shortcut could however be justified by a more fullbodied model with shifting costs. When period becomes short enough, migration approaches zero.

[12] Given that the first period is short, it may seem odd that the second period pollution stock is determined by first period emissions, as stated by equation (16). However, our modelling strategy can be seen, and justified, as a shortcut. We could explicitly introduce the length of the period h into equation (16), making it $E^i = \omega - \left[(1-q)\,s^i + qs^j\right] h$. However the shortness of the period should also show up on the benefit side, and we should express first period consumption by ch. But then the h terms appearing on both sides of the maximization problem cancel out each other, and the basic structure of the problem and its solution remain unaltered.

[13] Under perfect household mobility, first period migration would be implicitly defined by the conditions $u(c^i_i, e^i) \geq u(c^j_i, e^j)$, $i, j \in \{1, 2\}$, $i \neq j$. The resulting outcome would be equivalent to that derived in the previous section: (i) If pollution rents are distributed to all resident, the decentralized outcome is socially efficient. (ii) If the rents accrue to natives only, perfect household mobility has no effect.

period consumption is given by (15).) At the beginning of the second period people choose the location offering the highest second period utility. Then in equilibrium the condition (8) holds. Totally differentiating we can then see how first period emissions affect migration. In the symmetric equilibrium we have

$$\frac{dN^i}{ds^i} = -\frac{1}{2}\frac{(1-2q)\frac{U_{E^i}}{U_{C_i^i}}}{\delta\sigma^i f'(\sigma^i)/N^i - (1-\delta)(\sigma^i)^2 f''(\sigma^i)/N^i} < 0 \tag{20}$$

Thus an increase in first period emissions discourages second period immigration.

In the first period national policy makers design their environmental policies so as to maximize the intertemporal welfare a representative resident

$$\max_{s^i} u(c^i, e^i) + U(C_i^i, E^i)$$

The first order condition is of the form

$$u_{c^i} = (1-q)N^i U_{E^i} - U_{C^i}\frac{\partial C^i}{\partial N^i}\frac{dN^i}{ds^i}N^i$$

where the term $-U_{C^i}\frac{\partial C^i}{\partial N^i}\frac{dN^i}{ds^i}N^i$ captures the distortions due to household mobility: first period emissions provide a means to decrease second period population. Then the conditions characterizing the decentralized outcome are of the form

$$u_{c^i} = \left[1 - \frac{1}{2}\mu - (1-\mu)q\right] N^i U_{E^i} \quad i = 1, 2 \tag{21}$$

where $\mu \in [0, 1]$ is given by (14).

The conditions (21) indicate that the properties of the decentralized outcome depend crucially on how pollution rents are allocated. If the rent is taxed away by local authorities, which treat all residents equally, $\delta = 1$, $\mu = 1$ and (21) becomes (19): the equilibrium is as distorted as under global pollution.[14] On the other hand if command and control is applied, and the rents accrue to natives $\delta = 0$, $\mu = 0$, and household mobility introduces no new distortions.

To interpret the result, remember from (6) that outmigration raises consumption in the source country only when emigrants get a smaller share of domestic rents than those who stay. Thus a system where the allocation of rents is (at least partially) conditional on residence is also a necessary condition for the emergence of new externalities.[15]

On the other hand the distinction between private and open access provides a key. As migration is sluggish, current residents have private access to today's pollution rents. By contrast, from today's perspective future rents are subject

[14] This rather extreme property follows from the assumption that in the second period people can migrate without incurring any costs. If migration costs were introduced, the resulting distortions would be less severe.

[15] To be more precise, this claim holds in a situation where land is owned by natives. It can be shown that if land is partially in foreign ownership, new externalities arise also under command and control.

to open access. Then - even under local pollution - there is an incentive to emit today more than is socially optimal. However, if pollution rents accrue to natives only, private access applies also in the future, and the migration-induced incentives to overemit disappear.

4 Adding a congestion externality

The previous two sections have demonstrated that household mobility has no effect if pollution rents accrue to natives only. This is because in equilibrium a small change in population leaves the level of consumption (C_i^i) intact; see expression (6). To put it differently, there is no disutility from congestion. In this section we show that household mobility is never neutral, if an explicit congestion externality is introduced.

Following Silva (1997), assume that (second period) utility is given by

$$U = U(C, E, N)$$

and $U_N < 0$ so that congestion lowers welfare. Then migration is determined by the relations

$$U(C_i^i, E^i, N^i) \geq U(C_i^j, E^j, N^j) \quad i, j \in \{1, 2\}, \ i \neq j \tag{22}$$

4.1 One period model

In the symmetric equilibrium of the one period model, the effect of environmental policy on migration is given by

$$\frac{dN^i}{dS^i} = \frac{1}{2} \frac{\delta f'(\sigma^i)/N^i - (1-\delta)\sigma^i f''(\sigma^i)/N^i - (1-2q)\frac{U_{E^i}}{U_{C_i^i}}}{\delta \sigma^i f'(\sigma^i)/N^i - (1-\delta)(\sigma^i)^2 f''(\sigma^i)/N^i - \frac{U_{N^i}}{U_{C_i^i}}} \tag{23}$$

When $\delta = 1$ (or $q = \frac{1}{2}$), $\frac{dN^i}{dS^i} > 0$; otherwise however the sign is ambiguous. First order conditions characterizing environmental policy then take the form

$$U_{C_i^i} f'(\sigma^i) + \left[U_{C_i^i} \frac{\partial C_i^i}{\partial N^i} + U_{N^i} \right] \frac{dN^i}{dS^i} N^i = (1-q) N^i U_{E^i}$$

where $\frac{dC_i^i}{dN^i} \leq 0$ is given by (6). Now the feed-back effect $\left[U_{C_i^i} \frac{\partial C_i^i}{\partial N^i} + U_{N^i} \right] \frac{dN^i}{dS^i} N^i$ consists of two parts: immigration may (i) lower consumption and (ii) cause disutility due to congestion. In the symmetric equilibrium we have

$$U_{C^i} \left[(1 - \frac{1}{2}\delta) f'(\sigma^i) + \frac{1}{2}(1-\widehat{\mu}) \frac{U_{N^i}}{U_{C^i}} \frac{N^i}{\sigma^i} \right] = \left[1 - (1-\widehat{\mu})q - \frac{1}{2}\widehat{\mu} \right] N^i U_{E^i} \tag{24}$$

where

$$\widehat{\mu} = \frac{\delta f'(\sigma^i)/N^i - \frac{U_{N^i}}{U_{C_i^i}} \frac{N^i}{\sigma^i}}{\delta f'(\sigma^i)/N^i - (1-\delta)\sigma^i f''(\sigma^i)/N^i - \frac{U_{N^i}}{U_{C_i^i}} \frac{N^i}{\sigma^i}} \quad ; \widehat{\mu} \in (0, 1] \tag{25}$$

When $\delta = 1$, $\widehat{\mu} = 1$ and the decentralized outcome is efficient: as migration levels off all interregional welfare differences, socially non-optimal policies do not pay off. Unlike in the previous sections, household mobility does not become neutral when natives obtain all rents: with $\delta = 0$ (24) takes the form

$$U_{C_i^i}\left[f'(\sigma^i) + \frac{1}{2}(1-\widehat{\mu})\frac{U_{N^i}}{U_{C^i}}\frac{N^i}{\sigma^i}\right] = \left[1 - \frac{1}{2}\widehat{\mu} - (1-\widehat{\mu})q\right]N^i U_{E^i} \quad i = 1,2 \quad (26)$$

where

$$\widehat{\mu} = \frac{\frac{U_{N^i}}{U_{C_i^i}}\frac{N^i}{\sigma^i}}{\sigma^i f''(\sigma^i) + \frac{U_{N^i}}{U_{C_i^i}}\frac{N^i}{\sigma^i}};\ \widehat{\mu} \in (0,1) \quad (27)$$

When transboundary pollution problems are severe (q is large), household mobility always decreases equilibrium emission. For example under global pollution, $q = \frac{1}{2}$, (24) takes the form $U_{C_i^i}\left[f'(\sigma^i) + \frac{1}{2}(1-\widehat{\mu})\frac{U_{N^i}}{U_{C^i}}\frac{N^i}{\sigma^i}\right] = (1-q)N^i U_{E^i}$. Due to immigration and congestion, household mobility lowers national benefits from pollution, while national costs remain intact; thus equilibrium emissions decrease. However, with less transboundary pollution the mobility of people may sometimes actually increase emissions. As an example consider the case with local pollution, $q = 0$. With no household mobility the decentralized outcome would be socially optimal. Now the first order condition (24) becomes $U_{C_i^i}\left[f'(\sigma^i) + \frac{1}{2}(1-\widehat{\mu})\frac{U_{N^i}}{U_{C^i}}\frac{N^i}{\sigma^i}\right] = (1 - \frac{1}{2}\widehat{\mu})N^i U_{E^i}$. If $-\sigma^i f''(\sigma^i)$ (the effect of an emission increase on wages) is small, $\widehat{\mu} \approx 1$. Then national benefits from pollution fall proportionally less than national costs, and as a result emissions increase. To understand this perhaps somewhat paradoxical finding, notice from (23) that when $\delta = 0$, and q and $-\sigma^i f''(\sigma^i)$ are small, an increase in emissions triggers outmigration. Then a country may overemit to alleviate congestion.[16]

4.2 Two period model

In the symmetric equilibrium of the two period model, the effect of first period environmental policy on second period migration is given by

$$\frac{dN^i}{ds^i} = -\frac{1}{2}\frac{(1-2q)\frac{U_{E^i}}{U_{C_i^i}}}{\delta\sigma^i f'(\sigma^i)/N^i - (1-\delta)(\sigma^i)^2 f''(\sigma^i)/N^i - \frac{U_{N^i}}{U_{C_i^i}}} < 0$$

[16] With local pollution, an increase in emissions has three effects. (i) The domestic pollution rent increses. With $\delta = 0$ all natives (also emigrants) get an equal share of the rent. (ii) Domestic wages rise. (iii) The domestic environment becomes more polluted. Now we can draw the following conclusions. (a) If (ii) is weak compared to (iii) an increase in emissions triggers outmigration. (b) As emigrants get their share of the pollution rent, an increase in emissions, ceteris paribus, raises their welfare.(c) In equilibrium the welfare of emigrants and those who stay must be the same. (d) Due to congestion externalities, outmigration raises domestic welfare. (e) Thus if emissions trigger outmigration, it is optimal to overemit.

and first period emissions decrease second period immigration. The first order conditions characterizing decentralized environmental policy then take the form

$$u_{c^i} = (1-q)N^i U_{E^i} - \left[U_{C_i^i} \frac{\partial C_i^i}{\partial N^i} + U_{N^i} \right] \frac{dN^i}{ds^i} N^i$$

The term $-\left[U_{C_i^i} \frac{\partial C_i^i}{\partial N^i} + U_{N^i} \right] \frac{dN^i}{ds^i} N^i$ capturing new distortions consists of two elements: a smaller second period population (i) increases per capita consumption and (ii) decreases disutility due to congestion. In the symmetric equilibrium we have

$$u_{c^i} = \left[1 - \frac{1}{2}\widehat{\mu} - q(1-\widehat{\mu}) \right] N^i U_{E^i} \;\; i = 1,2 \tag{28}$$

where $\widehat{\mu}$ is given by (25). If $\delta = 1$, $\widehat{\mu} = 1$, and national policies are as distorted as under global pollution: when the pollution rent is collected by the local public sector, we get the same result as above in Section 3. $\delta = 0$, corresponding to command and control, is the more interesting case. When $U_{N^i} < 0$, we can conclude from (27) that $\widehat{\mu} > 0$. Thus as long as there are congestion externalities, the exacerbated incentives to overemit do not vanish when pollution rents accrue to natives

5 Concluding remarks

Recent research has shown that while perfect household mobility may induce individual jurisdictions to internalize interregional externalities caused by transboundary pollution, the combination of imperfect mobility and real time dynamics may quite the contrary be harmful for the environment. These results are obtained by assuming that the pollution rent is collected by the local public sector, which treats natives and immigrants equally.

This paper demonstrated that the choice of policy instruments and the allocation of pollution rents influences the interaction between household mobility and environmental policy. The message of the paper was threefold. First we illustrated that the assumption that there is open access to pollution rents is a crucial element both in implicit cooperation, emerging under perfect mobility, and the tragedy of the commons, generated in dynamic settings by imperfect mobility. Second, we showed that both the beneficial and the harmful effects of household mobility vanish, if pollution rents accrue to natives only, and open access is eliminated. Third, we demonstrated that the results obtained in earlier studies are however robust in a certain sense: if disutility from congestion is directly modeled, household mobility is never neutral.

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