A Bargaining Model of Local Growth and the Environment

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Abstract: This paper establishes a simple bargaining model of local growth and the environment in which firms and residents in potentially polluted regions bargain cooperatively to settle environmental concerns. While economic development affects the extent of the negotiation outcomes, the bargaining results also influence firms' incentive to undertake R&D and thus the growth of the local economy. Contrasting to growth-promoting policies, policies that create barriers to firm entry/matching may reduce pollution without hindering growth. Thus, depending on the underlying driving forces, the equilibrium level of pollution and the endogenous rate of growth need not be positively correlated. Depending on the severity of pollution spillovers and the magnitude of firms' share of the joint surplus accrued from establishing the polluting plant, the decentralized equilibrium may feature over or under-pollution, compared to the social optimum outcome..

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1 Introduction

While the establishment of a dirty industry may create job opportunities and enhance tax revenues in the local economy, community residents would suffer from the accompanied degradation of the local environment. The conventional view emphasizes that there is no free lunch as pollution is an inevitable by-product of the process of economic advancement. A more recent view, best represented by the World Bank Development Report (1992) and Grossman and Krueger (1995), suggests however that there may exist an inverted-U relationship between income and environmental degradation of certain types.[1] That is, the relationship between pollution and growth is in general non-monotone: pollution increases with income at the early stage of economic development and decreases with income at the later stage. Since then, there has been a growing literature studying economic growth and the environment.[2]

Despite its insight toward understanding "green budget" allocations and pollution regulations, the conventional static framework of environmental economics ignores an important fact that the decision of environmental protection over time is after all a matter of intertemporal redistribution.[3] This motives the studies of the environmental issues in a dynamic setting, either under an overlapping-generations framework [e.g., John and Pecchenino (1994) and Jones and Manuelli (2001)] or under an infinite-lifetime endogenous-growth setup [e.g., Stokey (1998)].[4] This literature proposes three decision mechanisms of the level of pollution: intergenerational collective choice (John and Pecchenino and Jones and Manuelli), majority voting (Jones and Manuelli) and central planning (Stokey). Our paper contributes to this literature by considering another plausible decision mechanism, a *cooperative settlement*, that governs an intertemporal collective choice between potentially polluting firms and local residents.[5]

[1] More precisely, an inverted-U relationship exists for most (but not all) pollution indicators, including smoke in cities and oxygen in rivers as well as fecal and arsenic metal contamination of rivers.

[2] In the U.S., increased concerns about environmental quality are reflected by the passage of the 1965 Clean Air Act and the 1972 Clean Water Act. The reader is referred to Jeffe, Peterson, Portney and Stavins (1995) for a comprehensive survey on environmental regulations - in particular, see Section 5 which summarizes important empirical evidence concerning the possible growth effects of environmental control.

[3] For example, Howarth and Norgaard (1992) argue that environmental concern is usually the interest of future generations.

[4] For brevity, we suppress the discussion of other dynamic models of economic growth and the environment that are remotely related to ours.

[5] Shibata (1971) suggests that the bargaining framework may be very relevant for public goods and goods imposing

In his empirical study, Hamilton (1993) emphasizes that in making their decision on establishing a new plant or expanding an existing plant, firms count the variations of collective actions of neighboring residents to raise the demand for pollution compensation. Our paper provides a formal theory elaborating how such calculation is integrated into firms' decision on R&D investment and production. In addition to the decision by new entry firms/plants and incumbents that undertake major expansions, our model also account for the possibility that jurisdictions (cities/townships), under the support of their residents, are actively seeking for more job creation and tax revenues by compromising on their environmental quality. Consider the petroleum industry that has been frequently opposed by environmentalists, including both petroleum refining and oil/natural gas exploring firms. Back to a decade or two ago, petroleum firms obtained local right-of-way via the political channel by only dealing with local officers or political leaders. In recent years, there has been increased community awareness in that local residents, together with the legislators, have involved extensively in negotiating with those petroleum companies (which has been frequently referred to as "fighting fire with fire" by news media).[6] These negotiations have led to compensations of various forms, from cash payments to communal benefits, such as schools and clinics.[7] In these cases, the determination of pollution controls and firm establishments are not by government central planner, intergenerational collective choice, or majority voting. Rather, it is the cooperative settlements between firms and residents of potential sites that serve as the self-regulating mechanism.

To explain the above-mentioned phenomena, we develop a simple *bargaining model* of economic growth and the environment where firms and local residents in potentially polluted areas bargain cooperatively to settle their environmental concerns and where the main driving force of growth is firms' investment in R&D for manufacturing products with pollution.[8] We argue that the interplay

externalities. In particular, he uses diagrammatic analysis of bilateral monopoly to determine public expenditure and the distribution of taxes. Although our paper considers a very different bargaining method, his insight motivates our study.

[6]Examples include, to name but a few, Shell Canada Ltd. at Fort McMurray (Alberta, Canada) in 1992, Trans Mountain Pipe Line Co. Ltd. at Port Angeles (Washington State, U.S.A.) in 1999, as well as many cases in less-developed countries, such as BP in Colombia, Mobil in Peru and Arco in Ecuador, over the past 15 years.

[7]Wasserstrom and Reider (1998) provide a comprehensive report on how several petroleum companies negotiated with Latin American communities. They indicate that those companies usually hire community relations specialists, visiting and consulting communities before and during the environmental impact assessment, developing guidelines for contact with local residents, as well as working out cash payments, community support programs and deals to employ local residents.

[8]While we acknowledge other important growth-enhancing forces (such as human capital and general knowledge),

between *endogenous settlements* and *endogenous growth* may provide better understanding of the process of environmental development and evaluating the effects of relevant public policies. Moreover, our framework allows us to compare a decentralized equilibrium allocation with the socially optimal allocation, adding new insights to the existing literature. Specifically, while the stage of economic development affects the extent of the negotiation outcomes, the bargaining results feed back to influence firms' incentives to undertake R&D and thus the rate of growth of the local economy. Thus, the primary benefit of employing this matching framework is not only to simplify the settlement of pollution compensation but to allow market conditions (precisely, the extent of entry and matching frictions), in addition to conventionally considered preference and technology parameters, to play a role in affecting pollution and growth.

The main findings of our paper can be summarized as follows. First, in the absence of endogenous R&D, pollution co-moves with income whereas a local tax or environmental regulation that discourages firm entry or matching can reduce the level of pollution. Second, with endogenous R&D, changes in firms' entry cost or residents' social acceptability parameters result in a negative relationship between growth and pollution, whereas changes in production technology parameters lead to a positive relationship. As a consequence, any growth-promoting policy (such as a production subsidy or a capital investment tax credit) will enhance growth at the expense of increased pollution; yet, a policy that creates barriers to firm entry or matching or a policy that requires a minimum pollution compensation ratio may reduce pollution *without* harming growth. Thus, depending on the underlying driving forces, the equilibrium level of pollution and the endogenous rate of local growth need not be positively correlated. Third, in examining the social inefficiency of the decentralized equilibrium, there exist opposing effects of "capitalized R&D cost" and "pollution externality" versus "thick matching" net of "effective discounting," which depend crucially on the severity of pollution spillovers and the magnitude of firms' share of the joint surplus accrued from establishing the polluting plant, As a consequence, the decentralized equilibrium may feature *over or under-pollution*, compared to the social optimum outcome.

Related literature

It is informative to contrast our paper with three related studies on growth and the environment

the R&D framework considered herein provides the most parsimonious structure allowing us to examine the feedbacks between growth and pollution analytically. Also, one could easily add a clean local industry, which simply changes local residents' outside option without affecting the main conclusions of the paper.

– John and Pecchenino (1994), Jones and Manuelli (2001) and Stokey (1998) – in the table below.

Key Features	Decision Mechanism	Growth-Pollution Relationship	Equilibrium Compared to Social Optimum
John-Pecchenino	collective choice	N/A	under-polluted
Jones-Manuelli	collective choice or voting	inverted-U due to endogenous taxes	under-polluted
Stokey	central planing	inverted-U with low intertemporal elasticity	N/A
Chang-Huang-Wang	cooperative settlement	inverted-U due to interplay between bargaining and R&D	under- or over-polluted

First, the cooperative settlement mechanism in our paper, via bargaining between potential firms and local residents, differs from intergenerational collective choice, majority voting or central planning. Second, within the infinite lifetime framework, Stokey obtains the time-series inverted-U relationship between environmental degradation and income growth based on a direct trade-off between environmental quality and final goods output through individual preferences, which depends crucially on the functional forms of utility (for example, the elasticity of marginal utility) and pollution generating activity.[9] In our paper, it is the endogenous cooperative settlement that interacts with endogenous investment in R&D, leading to a non-monotonic relationship across various development stages. More specifically, in less-developed areas, regional prosperity is given higher priority than pollution considerations. Thus, with higher technology growth, pollution accompanies economic growth. However, the economy becomes more advanced, the increasing community awareness on the environmental issues reduces potential matches and results in a lower effective discounting rate, which encourages R&D; so a reduction in pollution is associated with higher economic growth. Third, with an intergenerational collective choice mechanism as in John and Pecchenino and Jones and Manuelli, the economy under a decentralized equilibrium is always insufficiently polluted in the

[9] It requires that the intertemporal elasticity of substitution for the composite good be sufficiently low.

absence of an accumulation of the pollution stock. This is because individuals fail to account for the positive effect of investment in physical capital on future generations' welfare and as a result under-invest in productive capital, leading to an insufficiently polluted equilibrium. In our paper, we show that even without the accumulation of the pollution stock, it is still possible to have an overly polluted decentralized equilibrium, depending crucially on the severity of pollution spillovers and the magnitude of firms' share of the joint surplus accrued from establishing the polluting plant.

2 Basic Environments

We consider an economy which is populated with a continuum of potential firms of mass V and a continuum of potential residential regions of mass R. By normalizing the total population to unity, each region has a continuum of residents of mass $0 < n < 1$, where $nR = 1$. As its residents wish, each region can be opened to polluting firms in exchange local income creation and direct pollution compensation. Each firm is endowed with a production technology, seeking for a possible region to operate its polluting plant. To allow for endogenous cooperative settlements between firms and local residents, we adopt a simple continuous-time matching framework where time is indexed by t. Assume that matches are one-for-one (one firm per region) and permanent (in the sense that an established firm in a region would continue its operation over time). Under our continuum setup, matching is anonymous, which helps circumvent some technical difficulties.[10] Before describing the behaviors of firms and residents and specifying their value functions in matched and unmatched states, we summarize the structure of the basic environment in Figure 1.

2.1 Firms

Upon establishing a plant, each firm can produce a certain amount of the final good at the expenses of environmental pollution. Denote the discount rate as r and the endogenous R&D effort of a representative firm as q. It is assumed, for technical reasons to be specified below, that q is a one-time investment prior to production (or, equivalently, a constant path of R&D investment flows). Each firm, upon paying an entry (or setup) cost, accumulates "productive knowledge" K at rate

[10] Under a finite (countable) setup, matching becomes a dynamic assignment game, involving much more complicated mathematical analysis.

$\theta = \theta(q)$:[11]

$$K(t) = k_0 e^{\theta(q)t}, \tag{1}$$

where $k_0 > 0$ is the initial knowledge capital stock. The growth rate of productive knowledge is characterized as follows:

Assumption 1: $\theta' > 0$, $\theta'' < 0$, $\theta(0) = \theta_0 \geq 0$ and $\sup_q \theta(q) = \overline{\theta} < r$.

Thus, R&D enhances knowledge growth at a diminishing rate. While θ_0 may be viewed as the exogenous component of knowledge growth (possibly zero), the last inequality is usually referred to as the Brock-Gale condition to guarantee bounded optimization.

The setup costs may be thought of as establishing the background or basic structure of the particular production activity. The higher the R&D effort is, the more effectively a firm can accumulate product-specific knowledge. Since the focus of our paper is on the interaction between bargaining in establishing a production plan and the environment, we ignore the labor market by assuming inelastic labor normalized to one.[12] Consider a constant-returns-to-scale production technology with a scaling parameter $A > 0$, so the instantaneous flow of output at any point in time is AK. Utilizing (1), we can then specify the capitalized value of production to each firm from time t and on as:

$$Y(t) = \int_t^\infty AK(\tau)e^{-r(\tau-t)}d\tau = \frac{Ak_0}{r-\theta(q)}e^{\theta t},$$

which is integrable under the Brock-Gale condition given in Assumption 1.

It is important to transform perpetually growing variables into stationary ones (in effective units) such that the conventional stationary bargaining theory can be applied. Defining the stationary value of production per effective unit as $y = Y(t)/e^{\theta t}$, shortly referred to as effective output, we therefore have:

$$y = y(q) = \frac{Ak_0}{r-\theta(q)}. \tag{2}$$

Note that the Brock-Gale condition also ensures the positiveness of the value of effective output. Thus, this value is increasing in the production scaling factor, the initial knowledge capital stock

[11] Technically speaking, should q be continuous time-varying flows, denoted $q(t)$, (1) must be rewritten as: $K(t) = k_o e^{\int_0^t \theta(q(\tau))d\tau}$, which generates unnecessarily complication without additional insights. The reader may find our assumption analogous to the constant aggregate expenditure assumption in Grossman and Helpman (1992, p.28) which implies a constant discount factor and simplifies the analysis greatly.

[12] This assumption is innocuous, as an inclusion of variable employment would not change the main conclusion of the paper.

and the R&D effort, and decreasing in the discount rate.

Pollution is a by-product of manufacturing the final good. When a firm establishes a plant in a region to undertake production activity, it creates a pollution flow (to be specified later), which in turn harms the quality of life of residents in the polluted area. Thus, to induce the residents in this region to agree upon the establishment of the production site, firms can provide pollution-compensation, which is modeled as a one-time transfer from the firm to the local residents to obtain the legal right to produce the dirty good.[13] Denote the amount of pollution-compensation provided to each resident (per effective unit) as x, the (fixed) entry cost (per effective unit) as ν_0, and the (capitalized) utility cost of R&D effort (per effective unit) as $c(q)$. While the entry cost is pecuniary, the R&D cost is measured in utils so as to simplify the feasibility condition concerning resources costs. Then, under a pollution compensation schedule $x = x^*$, a representative firm's optimization problem can be written as:

$$\max_q (y(q) - nx^* - c(q)), \tag{PF}$$

subject to the technology specified in (2) and the non-negativity constraint $y(q) - nx^* \geq \nu_0$ (i.e., the value of production is sufficient to pay for pollution-compensation and fixed entry costs; otherwise, the equilibrium degenerates with no production activity in the area.

2.2 Residents

Consider a continuum of potential sites that may be suitable for a firm to establish a factory.[14] Consider now a polluted region. Given the level of pollution flows potentially generated by a firm, each resident would potentially suffer from a pollution damage (per effective unit), denoted by z. We follow the conventional wisdom regarding *local pollution* as a by-product of production, which implies z is an increasing function of y. Additionally, we allow *global pollution* to play a role to

[13] In general, this pollution-compensation may include both direct compensation and indirect benefits from job creation. This would not change the structure of the setup if job creation is specified as a fraction of the value of production.

[14] For example, in the early 1980s, Texas opened the costal line between Texas City and Corpus Christi – a continuum of potential sites – for potential petroleum refining firms (known to be one of the dirtiest industries) to enter. Among others, the Formosa Plastic Corp. (the largest petroleum refinery in Taiwan and one of the Fortune 500 businesses), after a succession of negotiations with local residents and Texas government, established a refinery plant at Point Comfort, Texas, which created over 10 thousand jobs. As another example, the authorities of several regions in Mainland China, such as Soo-Chow and Poo-Don, compete for new firms to establish their plants by provide cheap land and utilities as well as other business operation related benefits.

capture cross-region pollution spillovers by assuming that z is also increasing in the amount of pollutant generated in adjacent areas, p.[15] We thus have,

$$z = Z(p, y), \tag{3}$$

where Z is increasing in both arguments. To simplify the analysis, we assume Z to take a simple form, $Z(p, y) = \delta(p)y$, where the unit pollution damage, δ, satisfies the following properties:

Assumption 2: $\delta' > 0$, $\delta'' < 0$, $\delta(0) = 0$ and $\sup_p \delta(p) \leq 1$.

While the strict concavity of δ is imposed to ensure the second-order condition, the last inequality guarantee that the pollution damage will not exceed the total value of production. The main benefit of setting up this functional form is to summarize the entirety of the *pollution externality effect* in $\delta(p)$, which will become handy when we conduct welfare analysis below.[16]

A representative resident's decision is simple: he/she will allow a firm to establish a production site in the neighborhood if the net value of the pollution compensation subtracting the damage, $x - z$, is strictly positive. Otherwise, the autarky case will emerge, in which the economic activity degenerates ($y = 0$).

2.3 Value Functions

There are two separate states: matched (M) and unmatched (U). A region could be occupied (matched) or unoccupied (unmatched) and a firm could be operative (matched) or non-operative (unmatched). Let Π_i denote the value of a firm (per effective unit) in state i and J_i be the value of a resident (per effective unit) in state i ($i = M, U$). Denote the flow probability for a firm to locate a region as η and the flow probability for a region to attract a firm as μ.

We can now specify the values as follows:

$$\Pi_M = \max\{y - nx, 0\} = y - nx, \tag{4}$$

$$\Pi_U = \int_t^{\infty} \eta \max\{y - nx, 0\} e^{-(r+\eta)(\tau - t)} d\tau = \frac{\eta}{\eta + r}(y - nx), \tag{5}$$

[15] The assumption that pollution is a "public bad" fails to account for the possibility that the pollution externality from a closer neighborhood may be more severe than from a distant area.

[16] This functional form specification implies that without production, a region will not suffer from pollution as a result of cross-region spillovers, which may seem unreasonable. Yet, this assumption is innoculous because we will only focus on characterizing an *ex post* symmetric equilibrium in which the local and global levels of pollution are identical ex post in equilibrium (i.e., both are measured by p).

$$J_M = \max\{x - z, 0\} = x - z, \tag{6}$$

$$J_U = \int_t^\infty \mu \max\{x - z, 0\} e^{-(r+\mu)(\tau - t)} d\tau = \frac{\mu}{\mu + r}(x - z). \tag{7}$$

While the matched values are obvious, the unmatched values deserve further comments. In (5), the flow value for a firm to be operative (by locating in a region) is $\eta \max\{y - nx, 0\}$. To obtain the present value, this must be discounted by the effective discount rate, $r + \eta$, where the exogenous discount rate r is augmented by η as the latter measures the probability of exiting the unmatched state. The unmatched value of a representative resident in (7) follows a similar interpretation, where relevant contact rate is μ and the associated effective discount rate is $r + \mu$.

Obviously, the unmatched values depend positively on their corresponding contact rates and values of matching, and negatively on the discount rate. Moreover, it is easily seen that both matched values are higher than the associated unmatched values, as their multipliers, $\eta/(\eta + r)$ and $\mu/(\mu + r)$ are strictly less than unity. The gives rise to a positive incentive for firms and residents to seek for a match, as long as both unmatched values are positive (to be verified later).

2.4 The Flow of Pollutant

An immediate question arises is how to determine the pollution flows. In the steady state, the pollution flows are determined by the mass of potential firms and the mass of potential regions. All agents are atomistic, behaving competitively by taking matching parameters as given. We can then employ the constant-returns-to-scale random matching technology developed in Diamond (1982) to derive the overall pollution flows:

$$p = p_0 P(V, R),$$

where $p_0 > 0$ is a matching scaling factor and $P(V, R)$ satisfies the following properties:

Assumption 3: $P_V > 0$, $P_R > 0$, $P_{VV} < 0$, $P_{RR} < 0$, $P(0, R) = P(V, 0) = 0$, and Inada conditions hold.

That is, an increase in either the mass of potential firms or the mass of potential regions to accept the entry of polluting firms results in more matches and hence larger pollution flows. Since the mass of regions is fixed, the flow matches depend crucially on the mass of potential firms, which is in turn driven by endogenous contact rates. The absence of either side of the parties yields no match and zero pollutant. The Inada conditions and the property of constant returns are imposed to ensure the existence of a nondegenerate steady-state equilibrium.

The matching scaling factor p_0 may be thought of as an indicator of the degree of social acceptability of environmental pollution (in a capitalism regime) or effectiveness for the government to coordinate social conflicts (in a socialism regime). Baumol and Oates (1988) argue that the social acceptability of pollution may vary in different countries and result in different environmental policies. They further suggest that social acceptability may be related to income class: "[pollution may] produce anguished cries from middle- and upper-income inhabitants of a potential site and yet be welcomed as a source of more remunerative jobs by residents whose earnings are low" (p. 191).

3 Steady-State Equilibrium

The sequence of actions in our economy can be divided into three stages: (i) stage 1: R&D investment, (ii) stage 2: firm entry, search and matching, and (iii) stage 3: Nash bargaining, production and pollution compensation. To ensure subgame perfection, we solve the equilibrium backward. Specifically, we begin with stage 3 solving the Nash bargaining game between a potential firm and local residents in a region of our concern to determine the pollution-compensation offer function. We then go backward to stage 2, using pollution market equilibrium and equilibrium entry relationships, combined with the compensation offer function, to derive the flow of pollutant as well as the contact rate schedules. At this stage, we shall check the conditions under which firm's entry is profitable. Finally, we solve the firm's optimal R&D effort in stage 1.

3.1 Stage 3: Bargaining

Upon a successful meeting, each pair of region representative and potential firm undertakes cooperative Nash bargaining. Precisely, a firm and a region representative take their unmatched values (Π_U and J_U) as the threat points and given these, seek to split the surplus accrued from a successful matching. To a firm, the surplus is measured by $\Pi_M - \Pi_U$, whereas the surplus to a region representative is $J_M - J_U$. Following Laing, Palivos and Wang (1995), we assume that each atomistic competitive firm takes Π_U as parametrically given. Let β denote the share of the surplus going to the firm in negotiation (so the remaining fraction $1 - \beta$ goes to the residents in the selected region). Each pair of the matching party desires to maximize the joint surplus to determine pollution compensation:

$$\max_x (\Pi_M - \Pi_U)^\beta [n(J_M - J_U)]^{1-\beta}.$$

Joint surplus maximization produces the following Nash bargaining rule:

$$\frac{\Pi_M - \Pi_U}{\beta} = \frac{(J_M - J_U)\, n}{1-\beta}. \tag{8}$$

Substituting the value functions in (4), (6) and (7) into (8), we obtain the pollution-compensation offer function:

$$x = \frac{(1-\beta)(r+\mu)(y-\Pi_U)/n + \beta r\delta(\mu R)y}{r+\mu(1-\beta)}. \tag{9}$$

This pollution-compensation offer function is well-defined as long as the total output exceeds the unmatched value for firms: $y > \Pi_U$. Thus, the pollution-compensation offer depends positively on residents' contact rate, and firm's potential output, but negatively on firm's outside option measured by its unmatched value. We defer any further characterization to Section 4 below.

3.2 Stage 2: Matching and Equilibrium Entry

We begin by combining a transformed version of the steady-state matching condition with the equilibrium entry condition to determine the steady-state equilibrium contact rates, η and μ. We then substitute these equilibrium contact rates into the steady-state matching relationships to solve for the equilibrium level of pollution flows (p) and the endogenous population of potential firms (V).

Given the masses and the contact rates of both sides of the matching party, the flow matches of firms and regions are ηV and μR, respectively. Under one-for-one matching, these two flow matches must both be equal to the overall pollution flows generated in the steady state:

$$\eta V = \mu R = p. \tag{10}$$

By the constant-returns-to-scale property, the steady-state pollution market equilibrium relationship (10) can be rewritten as:

$$\eta^{SS} = \mu(R/V) = p_0 P(1, \eta/\mu), \tag{11}$$

which can be referred to as the SS (steady-state pollution market equilibrium) locus. This locus can be plotted in (μ, η) space: it is downward sloping, with both axes as asymptotes (which is a consequence of the Inada conditions).[17] When social acceptability is higher or government coordination becomes more effective (i.e., a higher value of p_0), the SS locus will shift outward.

We next turn to examining the equilibrium entry relationship. In particular, we postulate that competitive firms continue to enter the market searching for a region to establish their production site until their ex ante (unmatched) value equates with the fixed entry cost, ν_0:

$$\Pi_U = \nu_0. \tag{12}$$

Substituting (5) and (9) into (12) then yields the equilibrium entry condition, referred to as the EE (equilibrium entry) locus, which depends only on the two endogenous contact rates:

$$\eta^{EE} = \frac{\nu_0(r + \mu(1-\beta))}{\beta(y - \nu_0 - n\delta(\mu R)y)}. \tag{13}$$

It is tedious but straightforward to show that the RHS of (13) is strictly increasing and strictly concave in μ and thus the EE locus is upward sloping in (μ, η) space with a vertical intercept $\eta_o = \nu_0 r/[\beta(y - \nu_0)]$ (see the Appendix). Obviously, an increase in output (y) or in firm's bargaining power (β), or a decrease in the mass of potential regions (R), the population of residents in each region (n) or the fixed entry cost (ν_o) will shift the EE locus rightward.

We impose:

Assumption 4: $\frac{Ak_0}{r-\theta_0}(1-n) > v_0$.

Since $\theta(q) \geq \theta_0$ and $\delta \leq 1$, Assumption 4 is sufficient to guarantee $\frac{Ak_0}{r-\theta(q)}(1-\delta n) > v_0$, which subsequently ensures positive matching surplus ($\Pi_M = y(q^*) - nx^* > \nu_0 = \Pi_U$) and acceptability of firms by local residents ($x^* > z^*$).

The steady-state equilibrium contact rates and pollutant flows can be solved in a recursive manner. First, combining the SS and EE loci, (11) and (13), the (unique) steady-state equilibrium values of the contact rates (μ^*, η^*) can be obtained (for a diagrammatic illustration, see Figure 1). Next, utilizing these contact rates μ^* and η^*, the steady-state equilibrium level of pollution flows p^* and the steady-state equilibrium mass of potential firms V^* can be pinned down using (10):

$$p^* = \mu^* R, \tag{14}$$

$$V^* = \mu^* R/\eta^*. \tag{15}$$

[17] This relationship is parallel to the concept of the Beveridge curve in the labor-market matching literature, which illustrates the steady-state matching condition in the conventional space of the unmatched populations.

It is clear that a higher resident's contact rate or mass of potential regions raises the level of pollution and potential firm entrants, whereas an increase in the firm's contact rate reduces the mass of potential firms.

3.3 Stage 1: R&D Investment

We now solve the equilibrium R&D effort (q) based on the optimization problem specified in (PF). A potential firm decides endogenous R&D effort taking as given its unmatched value (Π_U) and the region's contact rate (μ). In this optimization problem, the rate of growth of output is endogenous, depending positively on q. Utilizing (2), (9), (11) and (13), we can derive the first-order condition as:

$$\frac{Ak_0\beta r\left[1-n\delta(\mu R)\right]\theta'(q)}{\left[r+\mu(1-\beta)\right]\left[r-\theta(q)\right]^2}=c'(q). \tag{16}$$

To guarantee the second-order condition, the following inequality is imposed:

Assumption 5: $-\theta''(q)(r-\theta(q))>2(\theta'(q))^2$ for all $q>0$.

We use this stronger global condition (rather than a local condition around equilibrium q^*) such that the equilibrium level of R&D effort is unique. This claim will be verified in Section 4 below.

3.4 Equilibrium

We are now prepared to define the equilibrium formally.

Definition: *A non-degenerate steady-state equilibrium is a pollution compensation offer function x^*, a R&D effort function q^* and a quadruple of matching variables $\{\mu^*, \eta^*, p^*, V^*\}$, satisfying the following conditions:*

(i) *cooperative Nash bargain, (9);*

(ii) *pollution market equilibrium (11), (14) and (15);*

(iii) *equilibrium entry, (13)*;

(iv) *optimal R&D investment (16);*

(v) *operative production: $y(q^*)-nx^*\geq\nu_0$.*

Notably, part (v) above ensures that in the steady-state, $y > \Pi_U$ and $(1-\delta n)y > \Pi_U$. The latter two inequalities are required to guarantee that $x - z$ is positive and that x is increasing in q, respectively.

4 Characterization of the Steady State

To characterize the steady-state equilibrium, we follow the solution steps (backward from stage 3 to stage 1) to study the pollution compensation offer function, the steady-state contact rates and pollutant flows, and the R&D effort function.

Lemma 1: (Pollution-Compensation Offer). *Under Assumption 1-4, the (per capita) pollution-compensation offer function,* $x^* = X(y,\ \beta,\ \mu,\ r,\ n,\ \delta(\mu R),\ \Pi_U)$*, is increasing in local and global pollution(*y *and* δ*) and residents' flow contact rate (*μ*), but decreasing in firms's bargaining share (*β*), population density (*n*), and firms's outside options (*Π_U*).*

Obviously, an increase in R&D (q) that raises local output (y) has a positive wealth effect on pollution-compensation, while a higher bargaining share for firms (β) reduces their compensation offered to residents in polluted areas. An increase in the resident's flow contact rate (μ), on the one hand, strengthens the resident's relative bargaining power due to thick matching, which results in a higher pollution-compensation to residents. It, on the other hand, raises the effective discount rate ($r + \mu(1-\beta)$), thus reducing the matching surplus and pollution compensation. It is easily seen from (9) that the *thick matching effect* always dominates the *effective discounting effect.* As a consequence, an increase in the resident's contact rate leads to a larger pollution-compensation. Next, consider a higher pollution cost per unit of output (δ) that reflects an increased severity of pollution externalities and hence requires a higher compensation in order to maintain a fixed proportion of surplus to each side of the bargaining party. As the population in each region (n) increases, it is more costly to compensate the residents to operate the factory; thus, to maintain a fixed proportion of surplus for firms, per capita pollution-compensation must be lower. Finally, a higher Π_U enhances firm's outside option, thus resulting in lower pollution-compensation to the residents.

Utilizing Figure 1, the properties of the EE and SS loci and equations (14) and (15), we have::

Lemma 2: (Steady-State Equilibrium Contact Rates). *Under Assumption 1-4, an increase in output (*y*) or firm's share of matching surplus (*β*), or a decrease in population density (*n*), the* *mass of potential regions (R) or the firm entry cost (ν_0) will raise resident's contact rate but suppress firm's contact rate. The matching scaling factor (p_0), on the other hand, has positive effects on both resident's and firm's steady-state equilibrium contact rates.*

Lemma 3: (Steady-State Equilibrium Level of Pollution Flows). *Under Assumption 1-4, an increase in output (y), firm's share of matching surplus (β) or the matching scaling factor (p_0), or a decrease in the population density (n) or the firm entry cost (ν_0) will raise the level of pollution flows.*

The effect of the scaling factor in Lemma 2 is straightforward: an increase in social acceptability of pollution or government coordination effectiveness raises both firm's and potential region's contact rates. The effect of a higher output, a greater firm's share of matching surplus or a lower firm entry cost is to encourage firm entry, thus raising the probability for a region to locate a firm but reducing that for a firm to locate a region. A lower mass of potential regions or population in each region increases firm competition for a production site and thereby enhances potential region's contact rates but suppresses firm's contact rates.

Since the level of pollution in the steady state is measured by $p^* = \mu^* R$, any autonomous changes that raise the potential region's contact rate – except for a reduction in R – will generate more pollutants. That is, the level of pollution flows p depends positively on output, the firm's bargaining power and the matching scaling parameter, but negatively on the population density and the firm entry cost. The mass of potential regions for accepting a polluting factory (R) has an ambiguous effect on pollution: while its direct effect is to raise pollution, the indirect effect through a reduced resident's contact rate is to decrease it.

Lemmas 2 and 3 together therefore lead to some intriguing implications. First, pollution (measured by the society's pollutant, p) co-moves with income (measured by the value of output per effective unit, y) *in the absence of endogenous R&D effort*, due primarily to an increase in firm entry. Second, an increase in government coordination effectiveness (measured by p_0) as in socially planned, growth-oriented countries tends to produce more environmental problems. However, if the degree of social acceptability of pollution (also measured by p_0) is higher in low income regions, then the low income regions may or may not be associated with higher levels of pollution, as a consequence of the conflicting effects of output and social acceptability. Finally, a local tax or environmental regulation that discourages firm entry or matching can reduce the level of pollution.

Furthermore, we can study the R&D effort function. We begin by verifying that the second-order condition to (PF) is met. Notice that the marginal benefit of R&D, the LHS of (16), is decreasing in μ. By Lemma 2, μ, in the steady state, depends positively on y and thus q [recall equation (2)]. Under the above condition, both the direct (via θ and θ') and indirect (via μ) effects of q are to reduce the marginal benefit of R&D. On the other hand, the marginal cost, the RHS of (16), is strictly increasing in q. Thus, the uniqueness of an interior solution of equilibrium R&D is obtained.[18] This optimizing R&D effort function is now ready to be characterized:

Lemma 4: (Optimizing R&D Effort). *Under Assumption1-5, the R&D effort, $q^* = Q(Ak_0, \beta, n, R, \nu_0, p_0)$, is decreasing in the matching scaling factor (p_0), but increasing the firm entry cost (ν_0). Moreover, if the direct effect of the technology parameters (A and k_0) dominates, a technological advancement encourages firms to undertake more R&D investment. The effect of firm's share of matching surplus (β), the population density (n) or the mass of potential regions (R) on the endogenous R&D effort is in general ambiguous.*

From Lemma 2, an increase in the matching scaling factor or a decrease in the firm entry cost increase the resident's flow contact rate (μ). A higher resident's contact rate raises the effective discount rate ($r + \mu(1-\beta)$) as well as the level of pollution ($p = \mu R$) which subsequently increases the environmental damage due to negative pollution externalities (via δ). As a consequence, the net value of firm is lower, thus discouraging the R&D activity. Concerning the comparative-static results with respect to the firm's share of matching surplus, the population density or the mass of potential regions, each has a direct effect on the marginal benefit of R&D and an opposing indirect effect via its influence on the resident's contact rate, thus leading to ambiguity outcomes. However, one may expect that such a direct effect for technology advancement – the *productivity effect* – is likely to dominate, in particular if the flow matches are insensitive to the mass of firms so that the SS locus is very steep (i.e., μ becomes insensitive to technological changes).[19] In this case, improvements in the production technology encourage investment in R&D.

Recall that the rate of growth of the local economy θ depends positively on firm's R&D effort. An important implication of Lemmas 3 and 4 is that the relationship between the level of pollution and the growth of the local economy depends crucially on the underlying driving forces. Specifically,

[18] An example is in order. Consider a bounded function: $\theta(q) = \Theta[1 - (1/\alpha)e^{-\alpha q}]$, where $\alpha > 1$. When $\Theta < \frac{\alpha}{1+\alpha} r$, not only $r - \theta(q)$ is always positive but the sufficient condition for a unique interior solution is also met.

[19] More precisely, let $P(V, R) = [\phi V^{\sigma} + (1-\phi)R^{\sigma}]^{1/\sigma}$ where $\sigma < 0$. Then, flow matches are insensitive to the mass of firms if ϕ is sufficiently close to zero.

we can conclude:

Theorem 1: (Growth versus Pollution). *Under Assumptions 1-5, changes in the matching scaling factor (p_0), the population density (n) or the firm entry cost (ν_0) result in a negative relationship between growth and pollution. Conversely, changes in the production technological parameters (A and k_0) lead to a positive relationship.*

Theorem 1 delivers an important message: with endogenous pollution settlements and endogenous R&D effort, pollution and growth need not be positively related. One may imagine that at the early stage of economic development, technological advancements are more feasible through imitation (i.e., uncompensated knowledge spillovers) and income creation is more likely the main concern. At the later stage of development, technical progress becomes difficult and, as the pollution problem becomes more severe, it is more costly to establish a new firm and matching becomes more restricted as a result of environmental regulations (via reductions in ν_0 or p_0). Thus, the role of technology diminishes whereas the role of social acceptance or entry barriers enhances. These underlying structural changes may therefore result in an inverted-U relationship between environmental degradation and output growth, as documented in Grossman and Krueger (1995). Notably, it is the endogenous cooperative settlement that interacts with endogenous investment in R&D, leading to such a non-monotone relationship.

5 Policy Implications and Social Inefficiency

Upon completing a positive analysis of a cooperative settlement model of pollution and growth, we now turn to examining normative issues. We begin by discussing some intriguing policy implications. We then illustrate the sources of social inefficiency associated with the decentralized equilibrium under a framework that is particularly suitable for evaluating social welfare in our local economy.

5.1 Policy Implications

The results in Theorem 1 suggest that any growth-promoting policy, such as a production subsidy or a capital investment tax credit, will enhance economic growth at the expense of an increased level of pollution. Nor can a Pigovian tax be implemented to correct this problem due to the presence of *matching externalities* between potential firms and local residents. However, a policy that creates barriers to firm entry or matching (by increasing ν_o or reducing p_o) may reduce pollution without harming growth. The latter type of policy is not of the conventional Pigovian type - it can be implemented in an economy with market (entry and matching) frictions in which pollution compensation is settled by cooperative Nash bargains. For example, a direct regulation controlling the entry of dirty firms or an administrative red tape delaying the match between residents and firms may serve the purpose. Moreover, one may consider a policy that requires a minimum compensation to matching surplus ratio, which sets a ceiling for firm's share, β. Notice that from Lemma 2, a lower β discourages firm's entry and hence reduces the resident's contact rate as well as the equilibrium level of pollutant. Lemma 4 suggests that although a decrease in β has a direct effect to lower the R&D effort, it also creates a positive indirect effect via the contact rate (i.e., what is called the thick matching effect). When the thick matching effect is strong, a reduction in β need not discourage firm's incentive to undertake R&D. Thus, such a policy may reduce pollution without retarding growth.

5.2 Social Optimality

To study social optimality, one must inquire how to construct a sensible social welfare function. In our model, each firm's welfare at time 0 is given by $\Pi_U(0) - c(q)$ (recall that is the capitalized cost of R&D effort measured in utils), or, substituting in the equilibrium entry condition, $\nu_0 - c(q)$. This measures the net expected value of firm upon entry. Also, at time 0, all residents are unmatched and from (7), a resident's unmatched value $J_U(0)$ is exactly the expected value of lifetime utility based on expected future matches. We suppose that the government cannot change the bargaining mechanism, so the cooperative Nash bargain still follows (8). Since the mass of residents is given at nR and the mass of firms is $V = \frac{\mu R}{\eta}$, the social planner's equally weighted social welfare maximization problem can therefore be specified as: $\max_q \left[nRJ_U(0) + \frac{\mu R}{\eta} (\nu_0 - c(q)) \right]$, or,

$$\max_q \frac{(1-\beta)\mu R}{r + \mu(1-\beta)} \left\{ [1 - n\delta(\mu R)] \frac{Ak_0}{r - \theta(q)} - \nu_0 \right\} + \frac{\mu R}{\eta} [\nu_0 - c(q)], \tag{PS}$$

where μ is determined by the steady-state pollution market equilibrium and the equilibrium entry conditions, (12)-(15). This yields a constrained optimum given the nature of the cooperative game and unrestricted entry. Particularly, any effects of R&D via the resident's contact rate considered by the social planner in (PS) are not taken into account in the decentralized equilibrium, which are the main sources of social inefficiency.

To facilitate the analysis, we derive the first-order conditions for (PS) as follows:

$$\begin{aligned}
&(1-n\delta(\mu R))\frac{dy}{dq}+\frac{1}{\mu}\left\{\frac{r\left[(1-n\delta)\,y-\nu_0\right]}{r+\mu(1-\beta)}+\frac{(\nu_0-c)\left[r+\mu(1-\beta)\right]}{(1-\beta)\,\eta}(1-\frac{\mu d\eta}{\eta d\mu})\right\}\frac{d\mu}{dq} \\
=\;& \frac{\left[r+\mu(1-\beta)\right]}{(1-\beta)\,\eta}c'(q)+nRy\delta'(\mu R)\frac{d\mu}{dq} \qquad (17)
\end{aligned}$$

which equates the social marginal benefits with the social marginal cost. We can also rewrite (PF) as follows:

$$\max_q \frac{1}{r+\mu(1-\beta)}\left[\beta r(1-n\delta)\frac{Ak_0}{r-\theta(q)}-(1-\beta)(r+\mu)\nu_0\right]-c(q)$$

where the reader should be reminded that μ is taken as parametrically given in this optimization problem. By manipulating the first-order condition for (PF) in a comparable manner to that for (PS), we have:

$$(1-n\delta(\mu R))\frac{dy}{dq}=\frac{r+\mu(1-\beta)}{\beta r}c'(q) \qquad (18)$$

Comparing (17) and (18) where they have a common marginal benefit term (the first term on the LHS of both equations), we can identify four effects that cause social inefficiency: (i) a thick matching effect (via μ in the numerator of each term in (PS) and η in the denominator of the second term in (PS)), (ii) an effective discounting effect (via the effective discount rate in the denominator of the first term in (PS)), (iii) a capitalized R&D cost effect (via $c(q)$ in both (PS) and (PF)), and (iv) a pollution externality effect (via δ in (PS)).

We can see that since individuals ignore the positive thick matching effect, they tend to under-invest in R&D and the decentralized equilibrium features under-pollution. Individual also ignore the negative effective discounting effect, resulting in over-pollution in decentralized equilibrium. From the second term on the LHS of (17), one can see that the effective discounting effect is entirely dominated by the thick matching effect, i.e., the thick matching net of effective discounting effect is always positive, which adds to the marginal social benefit of R&D. Thus, these two effects together yields a source of under-pollution in decentralized equilibrium. Concerning the capitalized R&D cost effect, the result is ambiguous (see the RHS of (18) and the first term on the RHS of (17)). When firms' share of the surplus accrued (β) is sufficiently small, the capitalized R&D cost effect adds an additional source of under-investment in R&D. However, when the share of the surplus accrued going to firms is sufficiently large, the capitalized R&D cost effect leads to over-investment in R&D. Lastly, the ignorance of the pollution externality effect by individuals yields another source of over-pollution (see the second term on the RHS of (17) that adds to the marginal social cost).

Should the capitalized R&D cost and the pollution exteranlity effects outweigh the thick matching net of the effective discounting effect, over-pollution in equilibrium emerges as compared to the social optimum.

Summarizing,

Theorem 2: (Equilibrium versus Optimum). *Under Assumption 1-5, the decentralized Nash equilibrium may be characterized by under-investment in R&D and under-pollution if the thick matching net of the effective discounting effect is strong or if firms' share of joint surplus accrued from establishing a polluting plant is sufficiently small. The reverse is true if the pollution externality effect is strong or if firms have a sufficiently large share of joint surplus.*

The contrast between decentralized equilibrium and social optimum has been examined by John and Pecchenino (1994) and Jones and Manuelli (2001), in which the economy under decentralized equilibrium is always insufficiently polluted in the absence of an on-going accumulation of the pollution stock. This is because individuals fail to account for the positive effect of investment in physical capital on future generation's welfare and hence under-investment occurs. Thus, a reallocation from physical capital to pollution abatement investment results in an insufficiently polluted equilibrium. In our paper, we show that even without accumulation of pollution stock, it is possible to have an overly polluted decentralized equilibrium, depending crucially on the severity of pollution spillovers and the magnitude of firms' share of the joint surplus accrued from establishing the polluting plant.

6 Concluding Remarks

This paper establishes a model pollution and growth in which firms and residents in potentially polluted areas bargain cooperatively to settle their environmental concerns. While the stage of economic development affects the extent of the negotiation outcomes, the bargaining results feed back to influence firms' incentive to undertake R&D and thus the rate of growth of the local economy. Depending on the underlying driving forces, the relationship between environmental degradation and local growth need not be monotone. We find that a policy that creates barriers to firm entry or matching or a policy that requires a minimum pollution-compensation ratio may reduce pollution without harming growth. Due to the opposing effects of thick matching (net of effective discounting) versus capitalized R&D cost and pollution externality, the decentralized equilibrium may be excessively or insufficiently polluted.

Along these research lines, the first natural extension is to employ the dynamic search framework developed by Chen, Mo and Wang (2002) so that the patterns of pollution and growth along the transition path can be fully characterized. Second, one may perform simulation analysis to assess quantitatively the welfare implications of the environmental policies. It may be of particular interest to contrast the conventional Pigovian tax policy with environmental regulations that influence the entry or matching of potential firms. Third, it may also be interesting to consider two production sectors (dirty and clean) where there are pollution spillovers from the dirty to the clean sector. Similar pollution compensation schedules may be derived based on cooperative settlement between firms from different sectors. Fourth, one may consider heterogeneous residents with regards to their preferences over a clean environment, which can be simply captured by different thread points in our bargaining framework. One may then examine by free migration whether endogenous segregation will occur in which clean-air lovers agglomerate geographically. Finally, a possible line of future research is to generalize the setup of the aggregate negative pollution externality by considering explicitly a spatial structure that allows for distance-dependent pollution spillovers. This will enable a characterization of the spatial patterns of pollution, depending on the external benefit from production clustering and the gradient of pollution spillovers.

Appendix

Derivation of the EE Locus: Substitution of (5) into (12) leads to:

$$\frac{\eta}{r+\eta}(y-nx)=\nu_0,$$

which can be combined with (9) to produce:

$$\frac{\eta}{r+\eta}\left(y-\frac{(r+\mu)(1-\beta)(y-\nu_0)+\beta nrz}{r+\mu(1-\beta)}\right)=\nu_0.$$

Straightforward manipulation of the above expression gives the EE locus (13). Next, differentiating the EE locus with respect to μ and manipulating yields:

$$\begin{aligned}\frac{\partial\eta^{EE}}{\partial\mu} &\propto (1-\beta)[y-\nu_0-n\delta(\mu R)y]+n\delta'(\mu R)yR[r+\mu(1-\beta)]>0,\\ \frac{\partial^2\eta^{EE}}{\partial\mu^2} &\propto -\left\{2(1-\beta)-n\delta'(\mu R)yR^2[r+\mu(1-\beta)]\right\}[y-\nu_0-n\delta(\mu R)y]\\ &\quad +2n\delta'(\mu R)yR[r+\mu(1-\beta)]<0.\end{aligned}$$

This implies that the EE locus is strictly increasing and strictly concave.■

Proof of Lemma 1: Substitution of (4), (6) and (7) into (8) gives:

$$(1-\beta)(y-nx-\Pi_U)=\beta n(x-z)\frac{r}{r+\mu},$$

which reduces to (9). Straightforward differentiation then leads to the comparative static results with respect to y, n, δ and Π_U. For μ, we have:

$$\frac{\partial X}{\partial q}\propto(1-\delta n)y-\Pi_U,$$

which is positive (the validity of this assumption is based on the free entry condition that $\Pi_U=\nu_0$ and the operative production condition that $y-nx-c(q)\geq\nu_0$ to be discussed in the Section 4 below). For β, we have:

$$\frac{\partial X}{\partial\beta}\propto-\left\{[(1-\delta n)y-\Pi_U]-(1-\beta)\left(\frac{\mu}{\mu+r}\right)n\delta y\right\},$$

which is negative if the first term in the bracket dominates the second (i.e., the direct effect is dominant).■

Proof of Lemma 2: The maximization problem is:

$$\max_q \{y - nx^* - c(q)\},$$
$$s.t. \qquad y - nx^* - c(q) \geq \nu_0.$$

Notice first that

$$\begin{aligned} & y - nx^* - c(q) \\ = \quad & \frac{(r+\mu(1-\beta))\nu_0 - \beta r \Pi_u + \beta r y(1 - n\delta(\mu R))}{r + \mu(1-\beta)} - c(q) \\ = \quad & \frac{Ak_0 \beta r(1 - n\delta(\mu R))}{(r+\mu(1-\beta))(r - \theta(q))} - c(q). \end{aligned}$$

Differentiating this expression with respect to q gives:

$$\frac{\theta'(q) Ak_0 \beta r(1 - n\delta(\mu R))}{(r+\mu(1-\beta))(r-\theta(q))^2} - c'(q) = 0,$$

which yields (16).■

Social Welfare Function: First, from (9), (12) and the definition of z, we have:

$$\begin{aligned} & x - z \\ = \quad & \frac{(1-\beta)(r+\mu)(y - \Pi_u) + \beta n r \delta y - n r \delta y - n\mu(1-\beta)\delta y}{n\left[r + \mu(1-\beta)\right]} \\ = \quad & \frac{(1-\beta)(r+\mu)(y - \Pi_u - n\delta y)}{n\left[r+\mu(1-\beta)\right]} \\ = \quad & \frac{(1-\beta)(r+\mu)\left\{\left[1 - n\delta(\mu R)\right] y - \nu_0\right\}}{n\left[r+\mu(1-\beta)\right]}. \end{aligned}$$

Substituting this into (7) yields (PS).■

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Figure 1: The Basic Environment of the Economy

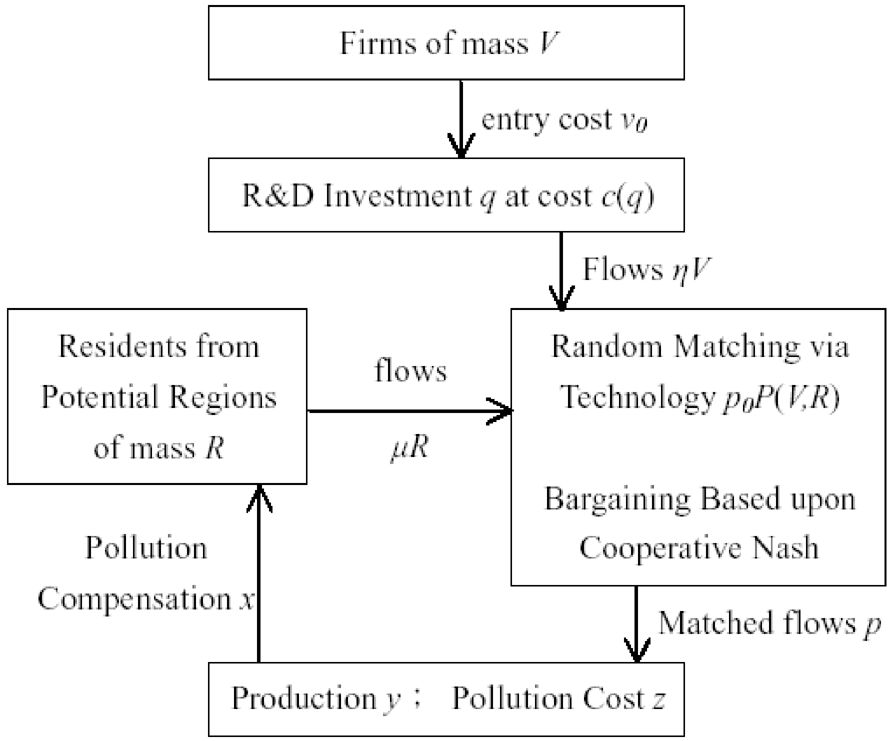

Figure 2: Determination of Steady-State Equilibrium Contact Rates