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A Search Model for Joint Implementation

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Summary

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Keywords: Environmental economics, Search theory, Market failures

JEL Classification: C61, O13, Q26

I would like to thank professors and colleagues of my department at the University of Cagliari for their support and discussions we had on the issues regarding Dynamic Programming and Search Theory. Obviously, I take responsibility for all errors.

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A search model for Joint Implementation*

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Abstract

The aim of this paper is to present a search model in the field of environmental economics, where so-called *clean* and *dirty* producers enter the trading market, both looking for a partner with whom to exchange the goods they are endowed with. The model derived in this paper is rather simple. Nevertheless, it is able to produce a series of interesting results and useful insights, and is conveniently used here as a framework to explain the functioning of Joint Implementation programmes for polluting emissions' reduction.

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1 Introduction

Equilibrium search models were first introduced by Diamond (1982) as a basic framework to illustrate how multiple equilibria might eventually arise in economics. In the simplest version of the model there is only one good, but it is assumed that producers do not consume their own output. In fact, they move suddenly to an exchange sector where they meet bilaterally, hence trade, consume, and finally move back to the production sector again, "searching" for new inventories to pursue continuously the aforementioned economic behavior. Obviously, this simple framework can be complicated in a number of different ways. We can, for example, include more than one type of commodity, or rather consider agents with different tastes. In this case, exchange itself becomes more difficult, since you not only have to meet another trader, but you have to meet the one who both has what you want, and wants what you have (commonly referred to as the *double coincidence of wants*, after Jevons, 1875).

It is a basic issue in *search models* to assume any investment decision to be made ex-ante, before entering the market. In this case, when matching frictions exist, bargaining agents are not able to get together, and conclude a stable agreement, such that the Coase theorem cannot be applied anymore. The problem here is that agents do not know who to talk with (i.e., they do not know who is in the market, who the traders are), and free-riding problems are obviously very near. Room is left consequently for a governmental intervention to make the socially efficient outcome be eventually enforced.[1]

The bulk of literature dealing with *search models* mainly concentrates on those markets where an inefficient outcome due to market imperfections occurs. In this light, many studies have particularly focused on the frictions arising in job market unemployment analysis (e.g., Coles-Burdett, 2003; and Wright, 1986), or rather in monetary economics (e.g., Kiyotaki-Wright, 1989; and Corbae et al., 2003), though the same technique is suitable for many other different issues.

The aim of this paper is to present a search model in the field of environmental economics, where two type of producers, broadly referred to as firms belonging to developed (DC) and developing (LDC) countries, enter

[1] So-called *co-ordination failures* finally arise, because each person is trying to anticipate the action of others (make a decision now by anticipating the future), commonly defined as "matching frictions" either (see, for example, Acemoglu-Shimer, 1999; and Burdett et al., 2001).

the exchange sector, face traders' preferences towards their goods (henceforth, named projects), and achieve a particular market solution. The model derived in this paper is rather simple. Nevertheless, it is able to produce a series of interesting results and useful insights. In particular, we attempt to use the presented framework to model the market for Joint Implementation (*JI*) projects, and explain the reasons for which search theory can be applied to such programmes generating emissions' reductions (see, Liski-Virrankoski, 2004).

The rest of the paper is organized as follows. In section 2 we describe the main characteristic of a market for Joint Implementation projects, and its similarities with a search market. In section 3, we derive the model, taking advantage of Diamond's (1982) "coconut parable", and determine the steady state equilibrium strategies. In section 4, we examine the results obtained, and make a comparative static analysis to better understand what policy intervention to increase social welfare is to be preferred. We finally show that a subsidizing policy to promote clean production processes is the preferred instrument to solve the market imperfections, whenever the Coase theorem might not be of help. A final section concludes, and a subsequent Appendix provides all the necessary proofs.

2 Joint Implementation as a search market

Briefly, Joint Implementation (*JI*) occurs when a *donor* country invests in pollution abatement projects in a *host* country in return for a number of "credits" to comply its own pollution abatement targets. As a corollary effect, the recipient nation will gain some foreign direct investment and a stock of advanced technologies. Lastly, the atmosphere will benefit as these reductions are met.[2]

In reality, some problems arise when dealing with *JI* projects. *LDC* nations are, in fact, generally hostile towards *JI*, since transaction costs for these projects might be prohibitively high, and above all fear that it will threaten their sovereignty, reduce potential flows of foreign aid, and thus finally impose an indirect control on the total amount of polluting emissions being realized.

[2]Broadly, Joint Implementation is a programme under the Kyoto Protocol that allows industrialised countries to meet part of their cuts in greenhouse-gas emissions by paying for projects that reduce the level of polluting emissions in other countries.

The rise of different interests between *DC* and *LDC* countries is the core of each international negotiation on environmental concerns. Indeed, *LDC* countries often claim that environmental protection policies are unfair because impose a burden on these countries that are not responsible for the existing global level of polluting emissions. On the other hand, *DC* countries prefer to avoid any home made emissions' reduction that might also possibly lower their economic growth. To solve this problem, the Kyoto Protocol suggests the set up of a *JI* project.

As we can easily notice, an agreement on an acceptable *JI* project can be viewed as a search problem, at least for the following reasons. First, emissions' reductions are difficult to verify, and cannot coincide with the ex ante investment decisions. This depends also on a variety of project-specific factors which are only learned in negotiations. Second, the *donor* country is typically an energy producer investor endowed with some advanced home-made technologies, whereas the *host* partner typically offers abatement opportunities which are best materialized using a particular low-level technology. Consequently, a provider with a given technology needs to search for a project that best matches his own technology.

In the next section, we present a model where a *DC* firm and a *LDC* firm might agree on a *JI* programme in order to comply with their emissions target. That is to say, each host firm cannot undertake its own project alone, and therefore needs to search for a partner, the donor firm, with whom to sing a contract. Once the host and the provider firms have met, they bargain over the size of the project, and the potential output to be exchanged. Therefore, if both firms agree on the project, and the contract is signed, the donor firm finances the project, joint with a technological transfer, and leaves the pool of unmatched firms.[3]

In the next section, for the sake of simplicity, we restrict the analysis to two type of producers, henceforth called *clean* and *dirty*, the former broadly referred to as developed (*DC*) countries firms, the latter to developing (*LDC*) countries ones. We also set up a basic search model and justify each assumption, and the terminology used, in the light of the aforementioned *JI* programme.

[3] Once the project is realised, and the emissions' reductions are verified, firms may enter the permit market, commonly assumed to be perfect and frictionless, and therefore left out of our analysis.

3 The "environmental" *coconut model*

The basic Diamond's model (1982) we will be referring to throughout the paper takes advantage of the so-called *coconut* parable to illustrate all the fundamental properties of an economy affected by problematic "matching frictions" to achieve an efficient solution (see, for example, Mortensen-Wright, 2002).

The economy consists of islands, on some of which there are palm trees of various height bearing coconuts of different size. Individuals search for an acceptable tree to climb in order to pick a desired nut.

Remark 1 *To clarify the terminology used, we assume that*
1. A clean production is called clean/dirty according to its compliance with polluting emissions' reduction.
2. Each coconut is a potential production opportunity.
3. Only ripe nuts represent a suitable JI project.
4. Consuming the coconut means the set up of the JI project.

Unfortunately, two strict laws in force in the archipelago cannot be amended. The one states that no burden (i.e., tax) can be levied on whatever production process in the market (*free entry condition*). The other one prescribes a prohibition against consuming one's own coconut (*free trading condition*). Agents are thus forced to travel to a trading island on which they look for others in a similar position with whom to trade. The key decision is then: how much would be one willing to pay (which is the optimal size of a tree one should accept to climb onto) to enter the exchange sector?

As noticed in section 2, we characterize our model by assuming two type of producers, the clean (N_c) and the dirty (N_d) ones. The former are supposed to respectfully interact with the environment, and pick up the nuts within the carrying capacity of the tree, though the latter are mainly interested in exploiting any palm as much as they can, thoughtlessly acting to the detriment of future harvests. Moreover, we consider an economy containing a continuum of infinitely lived agents, with a total population normalized to unity. To simplify, we can thus write $N_d = N$, and $N_c = 1 - N$.

An agent with no goods in inventory, either clean or dirty, enters a production sector, where potential projects arrive according to a Poisson process with constant arrival rate given by $\alpha > 0$ for the dirty, and by $\alpha\theta > 0$ for the clean ones (with $0 < \theta < 1$). That is to say, dirty productions occur at a greater probability, since harvest takes place despite the size of the nuts. On the contrary, clean producers do particularly care about the nut to be caught, leaving those still unripe fruits to future crops. Moreover, each potential project yields one unit of the good, but while dirty productions arise costlessly, clean productions require a nonnegative cost, denoted by c, randomly distributed according to a distribution function, $F(c)$. The value of c is observed before the individuals decide whether or not to undertake the project. A clean producer is then expected to choose an optimizing strategy between incurring the cost of picking up the coconut, thus becoming a trader, as opposed to remaining a producer, so delaying any action to future occurrences. The utility of consuming one unit of whatever good is $u > 0$, with an exception: an agent receives no utility from consuming a good he has produced himself (i.e., there is no possibility to undertake a *JI* project by one agent alone). Therefore, after producing, an agent proceeds to an exchange sector where he looks to trade for something that he can consume.[4]

Remark 2 *Only those agents that enter a clean production sector, by choosing the appropriate coconut (project) are thus supposed to move and search for another clean partner with whom to conclude a JI project to reduce their total amount of polluting emissions.*

In the exchange sector, agents meet trading partners bilaterally, according to a Poisson process with arrival rate $\beta > 0$. When two traders meet they always exchange inventories one-for-one, after which they consume, enjoy utility u, and proceed back to the production sector. Moreover, if agents pessimistically believe that trading opportunities will be poor because β is relatively low, they will not be willing to pay a lot to move from production to exchange. This implies a relatively slow flow into the exchange sector. On the other hand, if they optimistically believe trading opportunities to be good because β is relatively high, they will be willing to pay more to move from production to exchange. This implies a relatively fast flow into the exchange sector. Consequently, in this model we not only have to determine agents' production strategies but also their trading strategies. To make things more interesting, we shall complicate the model, and consider the different outcome arising in trade when exchange takes place either with a clean or a dirty partner, and try to suggest a policy action to move the system towards a "clean" oriented solution.

[4]To simplify, let assume sailing to the exchange island be costless.

Bearing in mind the assumptions made so far, we can formulate the problem faced by our agents through a standard backward induction analysis, that is typical of each dynamic programming study. Let then i denote the agent's state. That is, $i = d$, if the agent is a dirty producer; $i = c$, if he is a clean one; and $i = t$, if the agent enters the exchange sector, thus becoming a trader. Consequently, we assume V_i represent the optimal value function, discounted by a constant rate of time preference, henceforth called r, and finally derive the expected pay-off of whatever agent's state by means of some useful Bellman's equations. To begin with, we shall derive the expected value in steady state of being a dirty producer

$$rV_d = \alpha(V_t - V_d - \eta) = \alpha(k - \eta) \tag{1}$$

where $k = V_t - V_d$ represents the reservation strategy of a dirty producer to become a trader. In other words, the closer is k to zero, the higher is the probability that a dirty producer will become a trader. Moreover, parameter η measures an externality that might negatively affect the expected pay-off, as indiscriminate harvest of nuts will necessarily reduce future disposal of this natural resource.[5]

Secondly, we derive the expected pay-off of being a clean producer, that is

$$rV_c = \alpha\theta E_{\max}\left[0, V_t - V_c - c + \varepsilon\right] = \alpha\theta \int_0^g (g - c + \varepsilon) dF(c) \tag{2}$$

where $g = V_t - V_c$, as before, is the reservation cost of a clean producer to become a trader, while ε, as opposed to the above η, measures a positive effect from embarking on clean productions, when agents do pay attention on the nuts to be harvested within the capacity of the tree, whose reproduction process shall be consequently bequeathed to future generations.[6]

Remark 3 *Parameter η represents a negative external effect (e.g., environmental quality reduction) derived from not embarking on a JI project.*

Remark 4 *Parameter ε represents a positive external effect (e.g., environmental quality improvement) derived from embarking on a JI project.*

[5] Let consider, for example, the damage arising from cutting down the palm tree at once instead of climbing onto it to pick up the nuts, thus preventing from further production occurrences.

[6] As commonly found in dynamic programming models $E_{\max}[x, y]$ is the expected value of the maximum pay-off strategy to be chosen between x or y.

Finally, we present the expected value of being a trader, when producers decide to enter the exchange sector, and wait for meeting, with a probability β, someone to deal with. Hence

$$rV_t = \beta[(1-\mu)(u-k) + \mu(u-g-\delta)] \tag{3}$$

Assuming that exchange among traders always takes place, the problem is that we may encounter someone either carrying a dirty or a clean good, being $(1-\mu)$ the probability of meeting a dirty producer and μ the probability of meeting a clean one. Each agent will consequently eat the obtained coconut (so deriving utility, u), finally moving back to the dirty or clean production sector, depending on the swapping previously made. Our scope must be then to determine whether an appropriate policy intervention could be set to increase clean production processes, and drive a society towards natural resource preservation. Particularly, we consider δ as a potentially small but still positive transaction cost, in terms of disutility, an agent may incur each time he accepts any clean good in trade (i.e., to undertake a *JI* project). That is, for example, a case where agents are willing to pay a cost to make any recycling policy be undertaken to clean up the environment, as an entry fee for moving back to the clean production sector either.

Definition 1 *A steady state equilibrium for the environmental coconut model is a triplet (k, g, N) satisfying the expected pay-off equations for V_d, V_c, and V_t, and the flow movements of agents among sectors.*

Furthermore, we ought to determine the steady state number of agents devoted to whatever sector. To do so, we need to characterize our solution in terms of flow movements from a state to another. That is, in equilibrium, the flow into a sector must necessarily equal the flow out from that sector, as depicted in the following Fig. 1.[7]

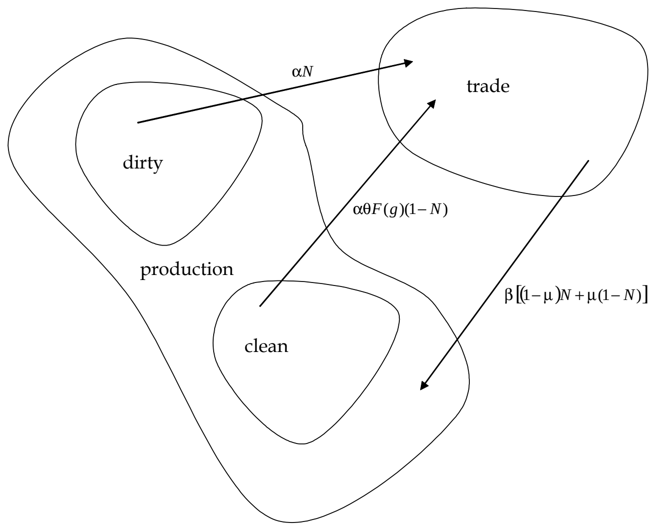

Fig. 1: Coconuts' archipelago

Mathematically, we should then write

$$\alpha N + \alpha\theta g(1-N) = \beta\left[(1-\mu)N + \mu(1-N)\right] \tag{4}$$

that is, solving for N,

$$N = \frac{\beta\mu - \alpha\theta g}{\alpha(1-\theta g) - \beta(1-2\mu)} \tag{5}$$

or rather we can interpret the number of dirty producers (N) depending on

[7]The flow out from a sector (i.e., the flow into another sector) can be interpreted as the number of agents that decide to switch their state at the probability they have to change their status.

the reservation cost of being a clean one (g), as clearly depicted in Fig. 2.[8]

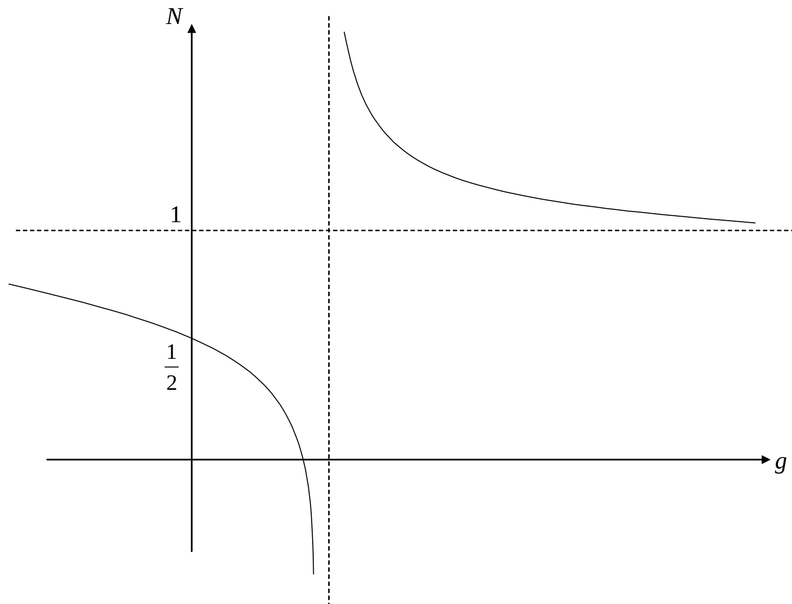

Fig. 2: Evolution of N

Since economic significance merely holds for $N \in [0, 1]$, we may then easily confirm that as convenience to become a clean producer raises (g increases), the number of agents that decide to remain in the dirty sector necessarily lowers (N decreases).[9].

4 Comparative Statics

This section is devoted to a comparative static analysis that consequently points out the evolution of our economy at some parameter changes. To begin with, and to simplify the study, let assume the cost of picking up a coconut be described by an upward sloping distribution function, that is

[8]Fig. 2 is drawn by assuming the following reasonable parameter values: $\alpha = \beta = \theta = \frac{1}{2}$. In particular, we assume $\mu = \frac{3}{4}$, for we suppose a high probability to meet a trader with a clean good.

[9]Formally, N is a decreasing function of g. Thus, $\frac{dN}{dg} < 0$, for all $N \in [0, 1]$.

$F(c) = c$.

Proposition 1 *For any $N \in [0,1]$, a unique non-degenerate equilibrium for the economy exists.*

Proof. See the Appendix. ■

We can thus derive the equilibrium condition by means of a two-stage procedure. Firstly, by means of Eq. (1) and (2), we obtain

$$\varphi(k,g) \equiv k = \frac{\alpha\eta}{r+\alpha} + \frac{r+\alpha\theta\varepsilon}{r+\alpha}g + \frac{\alpha\theta}{2(r+\alpha)}g^2 \tag{6}$$

while from Eq. (1) and (3), it follows

$$\phi(k,g) \equiv k = \frac{\beta u - \beta\mu\delta + \alpha\eta}{r+\beta(1-\mu)+\alpha} - \frac{\beta\mu g}{r+\beta(1-\mu)+\alpha} \tag{7}$$

A steady state equilibrium point (k^{*}, g^{*}) can be then obtained by means of the previous $\varphi(k,g)$ and $\phi(k,g)$ equations, as graphically depicted in the following Fig. 3.

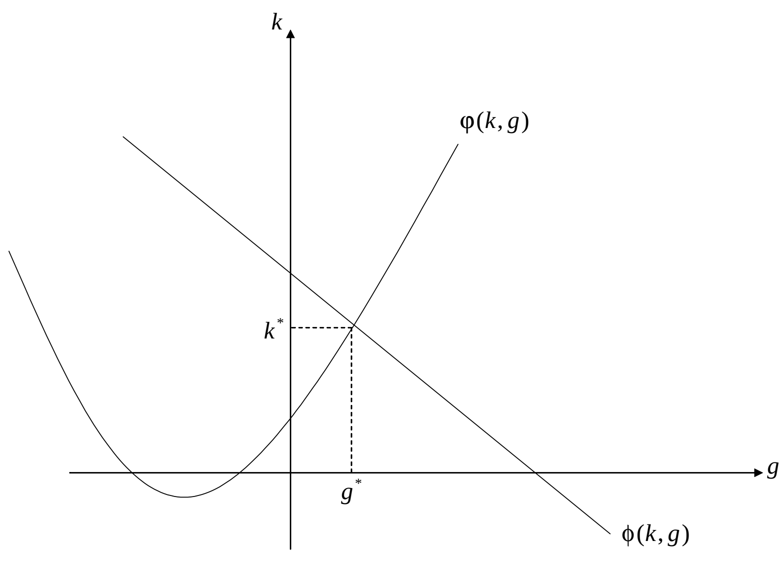

Fig. 3: Equilibrium point

It can be of interest to determine how might the system react at some changes occurring in the parameter space (δ, ε). therefore,we characterize our model, by defining δ as a cost measure of any recycling policy being adopted, and ε as the positive effect arising from any clean policy action (e.g., clean air, unpolluted fields).

First of all, let assume a society basically oriented towards clean productions. Mathematically, this would imply ε to be constantly rising. More extensively, we can imagine this positive outcome as due to a subsidy a public authority introduces to favour those producers that decide to engage in clean activities (i.e., to realize a *JI* project). Equilibrium outcome will then slightly modify, as shown in Fig. 4.

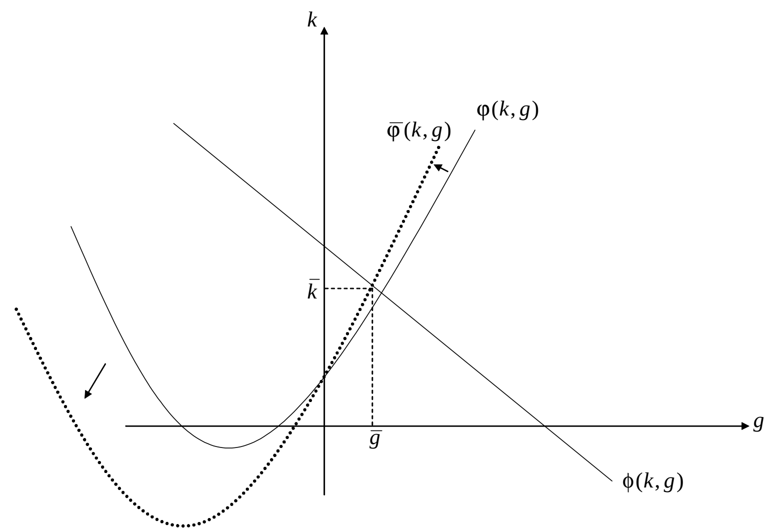

Fig. 4: Subsidising policy

As a consequence, the $\varphi(k, g)$ curve rotates to $\bar{\varphi}(k, g)$, and determines a new equilibrium point $(\bar{k}, \bar{g})$, with $\bar{k} > k^*$ and $\bar{g} < g^*$. Consequently, with a higher probability, a bigger number of clean producers will enter the trading sector, and put on the market an increasing variety of clean goods, thus raising the existing environmental quality too.

On the contrary, if it is δ to be increased, only the $\phi(k, g)$ curve will be affected, so moving downwards, both reducing k and g to the new equilibrium point $(\hat{k}, \hat{g})$, as shown in Fig. 5.

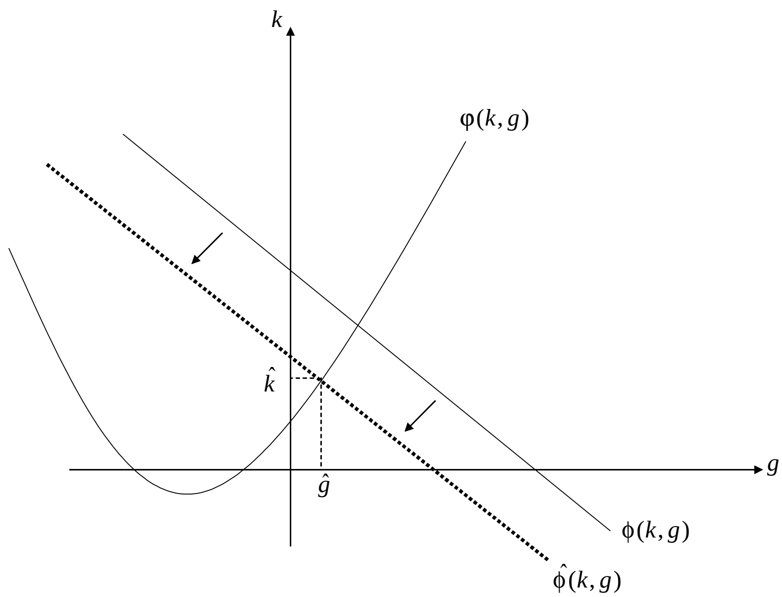

Fig. 5: Increase in the recycling policy

Interpretation of this result is direct and straightforward. If we increase the price (δ) of recycling our dirty produced good, we cannot be so sure about the effect arising therefrom. Indeed, either the value of being a clean producer, or the value of being a dirty producer do finally increase. Both cases can be justified. The former is probably due to a reduction in the number of clean producers, which increases their market value; the latter might be simply a consequence of unwelcome free-riding problems instead. Basically, in this situation, a dirty producer takes advantage of an increase in the value of being a clean one, that might solely pay the cost of cleaning up the environment for the sake of the entire society.

5 Concluding remarks

Emissions' reduction is a global problem in current economies. Trading mechanisms to comply with emission targets may occur when developed and developing countries trade over the same project to achieve the resulting optimal allocation. The aforementioned market may not be efficient in its own structure, but deviations form the perfect market solution are very likely to arise. The presence of market frictions and coordination failures particularly characterize the market of joint implementation projects, and thus leave the door open to a "search theory" framework.

The aim of this paper has been twofold. On the one hand, we presented a modified version of the famous Diamond (1982) *coconut* model in the light of environmental economics, suitable for describing the functioning of joint implementation programmes, where matching frictions arise, and might not be solved through the common Coase theorem. On the other hand, we characterized our model letting what we called as *clean* and *dirty* producers dwell the same market, and finally derive the associated outcome.

A comparative static approach has determined whether a policy intervention might be useful to drive our economy towards a sustainable path, where clean productions shall be hopefully achieved. Our analysis has consequently pointed out that only when public interventions start subsidizing clean productions (i.e., *JI* projects) our system will positively react to the adopted policy; being nonetheless free riding problems very likely to occur in any other case. In this light, any increase in the cost of recycling yields, in fact, only some undesired (i.e., distorsive) effects.

Basically, we sustained that whenever a rule to correct for the market failures could not be adopted, we had better intervene to subsidize our *clean* agents, awaiting for efficiency to be finally restored.

Appendix

The expected value of being a dirty producer V_d can be written as

$$V_d = \frac{1}{1+r}\left\{(1-\alpha)V_d + \alpha(V_t - \eta)\right\} \tag{A.1}$$

that is also

$$rV_d = \alpha(V_t - V_d - \eta) = \alpha(k - \eta) \tag{A.2}$$

where $k = V_t - V_d$.

On the other hand, the expected value of being a clean producer is given by

$$V_c = \frac{1}{1+r}\left\{(1-\alpha\theta)V_c + \alpha\theta E_{\max}[V_c, V_t - c + \varepsilon]\right\} \tag{A.3}$$

or else

$$rV_c = \alpha\theta \int_0^g (g - c + \varepsilon) dF(c) \tag{A.4}$$

with $g = V_t - V_c$. And by assuming $F(c) = c$, it simply turns to

$$rV_c = \alpha\theta \int_0^g (g - c + \varepsilon) dc \tag{A.4a}$$

that is

$$rV_c = \alpha\theta \left[(g + \varepsilon)c - \frac{c^2}{2} \right]_0^g = \alpha\theta \left[\frac{g^2}{2} + g\varepsilon \right] \tag{A.4b}$$

Finally, the expected value of being a trader is

$$V_t = \frac{1}{1+r} \left\{ (1-\beta)V_t + \beta \left[(1-\mu)(u + V_d) + \mu(u + V_c - \delta) \right] \right\} \tag{A.5}$$

and also

$$rV_t = \beta \left[(1-\mu)(u-k) + \mu(u - g - \delta) \right] \tag{A.6}$$

Subtracting Eq. (A.4b) from Eq. (A.2), we obtain

$$r(g-k) = \alpha(k - \eta) - \alpha\theta \left[\frac{g^2}{2} + g\varepsilon \right] \tag{A.7}$$

That is also, solving for k,

$$k = \frac{\alpha\eta}{r+\alpha} + \frac{r + \alpha\theta\varepsilon}{r+\alpha} g + \frac{\alpha\theta}{2(r+\alpha)} g^2 \tag{A.7a}$$

On the other hand, by means of Eq. (A.2) and (A.6), we may write

$$rV_t - rV_d = \beta \left[u - k - \mu\delta + \mu(k - g) \right] - \alpha(k - \eta) \tag{A.8}$$

which can be reorganized as follows

$$k = \frac{\beta u - \beta\mu\delta + \alpha\eta}{r + \beta(1-\mu) + \alpha} - \frac{\beta\mu g}{r + \beta(1-\mu) + \alpha} \tag{A.8a}$$

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