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Cost-effective provision of environmental services: the role of relaxing market constraints*

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ABSTRACT. Ferraro and Simpson (2002) argue that when markets are competitive, payments for environmental services (PES) are more cost-effective in achieving environmental goals than more indirect approaches such as subsidies to capital. However, when eco-entrepreneurs face non-price rationing in input or output markets, as is typical for credit in developing countries for example, we show that interventions which relax constraints can be more cost-effective than PES. One corollary of this is that such indirect approaches are preferred to PES by interveners (e.g., donors) and eco-entrepreneurs alike. Both of these outcomes are more likely when constraints are severe. This has implications for schemes with dual environment and poverty alleviation objectives.

1. Introduction

The term 'Payments for Environmental Services' (PES) defines a wide range of incentive mechanisms to address the underlying causes of environmental degradation by inducing behavioural changes among local actors (Bulte *et al*., 2008). There are numerous examples of how payments from beneficiaries within a locality, river-basin, region or even globally have been implemented in attempts to overcome environmental externalities of one kind or another. There are global and multilateral mechanisms such as the Clean Development Mechanism of the Kyoto Protocol and the Global Environment Facility, as well as more localised PES schemes such as the Primampiro municipal watershed-protection scheme in Ecuador (Wunder and Albán, 2008). In addition to varying in their geographical scope, PES schemes also vary in the nature of the incentive provided and hence in

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their effectiveness in any given circumstance. The purpose of this paper is to shed further light on the relative cost-effectiveness of PES with respect to other, more indirect policy instruments, also commonly used to supply environmental services around the world.

In PES schemes, such as the Costa Rican *pagos por servicios ambientales* (PSA) scheme and the Sloping Lands Conversion Programme in China, compensation is offered to farmers directly for each unit of land reforested or conserved (e.g., Xu and Cao, 2002; Pagiola, 2008). More indirect policy approaches can be conceptualised to provide incentives via some associated input to production. These so-called 'joint-production' activities include selective logging, eco-certification and eco-tourism (see Kotchen, 2005; Donovan *et al.*, 2006; Macqueen *et al.*, 2008).[1] Recent theoretical and empirical work has naturally shaped the views of the institutions involved in implementing policy to supply environmental services, as well as the design of schemes on the ground. For obvious reasons, perhaps the most influential contributions in this respect have been those which address the question of the relative cost-effectiveness of different policy approaches to supply environmental services.[2]

One virtually unequivocal answer to this question can be found in an oft-cited and influential paper by Ferraro and Simpson, who, using a broad definition of PES to include both PES as defined in this paper ('direct payments') and indirect policy approaches ('indirect payments'), conclude, 'Conservation practitioners should be wary of adopting indirect payments' (Ferraro and Simpson, 2002: 345, henceforth F&S). F&S reach this conclusion by employing duality theory to analyse the mechanics of different policy approaches to an 'ecological entrepreneur', for whom conserved land is an input to an eco-friendly production process, e.g., ecotourism. Although their approach presupposes perfectly elastic supply in input and output markets and profit-maximising behaviour by a price-taking entrepreneur, their conclusion appears to be remarkably robust, even when some of these assumptions are relaxed.[3] One corollary of this result is that, in the absence of side payments, the preferences of the NGO or donor and

[1] Non-timber forest products (NTFP), on the other hand, are not necessarily produced jointly with environmental services. Indeed, some NTFP collection may actually be unsustainable (we thank the referee for highlighting this point).

[2] For empirical work see e.g., Xu and Cao (2002); Wätzold and Schwerdtner (2005); Drechsler *et al*. (2007). For theoretical work see e.g., Ferraro and Simpson (2002, 2005) and Muller and Albers (2004).

[3] Ferraro and Simpson (2005) acknowledge that their original analysis neglects some important features that characterise activities in developing countries, in particular missing and imperfect markets for inputs and outputs. Typically, self-sufficiency/autarkic production arises where markets are missing for inputs or outputs, or where significant transactions costs exist (Key *et al*., 2000). In the context of 'non-separable' households producing environmental services, Muller and Albers (2004) find that, with the exception of the trivial case, where there are no markets for households' output (consumption goods), 'direct payments' generally outperform 'indirect payments' adding further weight to F&S's (2002) result.

eco-entrepreneur are generally opposed. The donor will prefer the cost-effective PES, while the eco-entrepreneur will prefer the more indirect approach, since it profits from the additional payments required. An alternative interpretation of this result is that, in a developing country context there is tension between environmental and poverty alleviation objectives.

It is well documented, however, that among the many market imperfections found in developing countries, quantity constraints and non-price rationing are among the most common, particularly in the agricultural sector (see e.g., Azam *et al.*, 2001; Colman *et al.*, 2005; Petrick, 2005). Input and output quotas are obvious examples and, at the extreme, markets may be missing completely. Beyond this, perhaps the most frequent example of non-price rationing in developing countries is credit rationing (e.g., Hoff and Stiglitz, 1993). While there are several definitions of credit rationing, it is usually thought of as a situation in which the borrower's private demand is higher at the current rate of interest than the loan offered by the lender (Petrick, 2005).[4] This description of developing countries has led to frequent calls in development policy circles for the relaxation of constraints, particularly in relation to credit (e.g., Azam *et al.*, 2001; Vakis *et al.*, 2004). While such issues are frequently discussed in the context of agricultural production, similar problems undoubtedly beset the 'eco-entrepreneurs' that are the focus of policy implementation, and were the subject of analysis by F&S. For example, there are often missing markets for the necessary inputs, such as the skills required to develop business plans, viable market contacts and quality products (RCW, 2007). Credit rationing is also likely due to the risks inherent in joint production, insecure tenure and asymmetric information between lenders and borrowers (Ascher, 1994; RCW, 2007).[5]

In the context of joint-production enterprises, the implications for policy are obvious: Indirect approaches which relax quantity constraints offer an important opportunity to expand ecological entrepreneurship and generate environmental services. Indeed, there are already numerous examples of this kind of intervention in which NGOs or governments provide assistance to relax certain constraints, rather than direct incentive payments. One example, in the context of credit, is the Brazilian government's programme,

[4] Ghosh *et al.* (2000) make the distinction between macro- and micro-credit rationing. Regarding the former, sections of the economy are rationed or excluded from credit, this being the lenders' response to adverse selection. The definition in the text is classic micro-credit rationing. The causes and implications of each are generally different. For instance, asymmetric information (resulting in adverse selection and/or moral hazard), pervasive risk, limited collateral and enforcement costs conspire to ensure that lenders ration credit in both formal and, albeit to a lesser extent, informal markets (Azam *et al.*, 2001). For recent empirical examples of credit rationing in developing countries, see Mohieldin and Wright's (2000) study of Egypt, and Barslund and Tarp's (2007) study of Vietnam.

[5] Of course, property rights to ecosystems, such as forests, are typically insecure and hence cannot generally be used as collateral (e.g., Ascher, 1994).

FNO-Especial, which provides credit to small forest enterprises based in the Amazon that have environmental and social goals (Campos *et al.*, 2005).[6] In other cases contributions come in the form of complementary inputs, such as tourism infrastructure, product marketing and processing facilities (see e.g., Wunder, 2000; MacQueen *et al.*, 2008), all of which give rise to another important question: In the presence of quantity constraints, which policy is more cost effective, PES or more indirect approaches that relax constraints? This paper goes part way to answering this question.

In order to make direct comparisons with F&S we return to the parsimony of their benchmark model of a donor and an eco-entrepreneur each with perfect information. Our sole addition to the model is a quantity constraint on an input to the production process, the relaxation of which is the objective of the donor's indirect scheme. This quantity constraint is open to a rather general interpretation: a credit constraint, an input quota and analogous arguments can be made for constraints on output.[7] We apply the work of Fulginiti and Perrin (1993) who extended duality theory to the constrained profit function. For relative cost-effectiveness, we compare the cost to the donor of subsidising inputs directly versus the indirect policy of relaxing capital constraints, which can be thought of as the purchase of inputs or provision of capital by the donor. Thus, the deadweight welfare losses of each approach are compared alongside the creation of positive quota rents from the implementation of an indirect policy. The results of the analysis are revealing and run counter to F&S in two senses. Firstly, PES are shown to have no systematic cost advantage over a more indirect approach which relaxes constraints. Secondly, there are instances when both the donor and the eco-entrepreneur prefer the indirect approach. In these instances, it is possible that indirect schemes are more likely to achieve dual environment and poverty objectives. Within the confines of the model these outcomes are more likely when constraints are, or rationing is, severe.

The paper is organised as follows. Section 2 describes the model, while section 3 analyses the overall cost-effectiveness of each intervention. Sections 4 and 5 analyse the preferences of the donor and eco-entrepreneur respectively. Section 6 offers a discussion of the results, while 7 concludes.

2. Policies to supply environmental services: a model with constraints

In order to assess the relative cost-effectiveness of PES and a policy to relax constraints, we follow closely the model of F&S. We have a profit-maximising eco-entrepreneur (henceforth, firm) that operates an 'ecologically benign' production process with two variable inputs to

[6] There are many other examples. For instance, in the Lacandon forest of Mexico, eco-entrepreneurs receive credit from the Fondo Nacional de Empresas en Solidaridad (National Fund of Enterprises in Solidarity) to buy new boats, outboard motors and equipment for an eco-tourism venture (Hernandez-Cruz *et al.*, 2005). Around the world, other programmes are run by organisations such as the Global Environment Facility and the Asian Development Bank (RCW, 2007).

[7] We posit that where inputs are constrained or markets for inputs are missing, entrepreneurs may fail to reach their potential. Similarly, where credit is rationed, under-investment and an inability to smooth production over time are common consequences (Petrick, 2005).

production, forest and capital. 'Forest', F, represents any ecological attribute useful in the generation of an eco-friendly output. 'Capital', K, represents some arbitrary input. Thus, a quantity, Q, of an eco-friendly product is produced using a production technology, $f(K, F)$. This technology represents an economic activity such as eco-tourism that allows environmental services, for instance, biodiversity, to flow from the forest used in eco-production activities. The market prices of output, capital and forest are P_Q, P_K, and P_F, respectively, where P_F is the opportunity cost of using forest in eco-production and could represent the returns to converting the forest to agricultural production. Following F&S, we assume that K is a technical complement to forest in eco-production, i.e., $\frac{\partial F}{\partial P_K} < 0$.[8] Moreover, as in F&S, we also assume that a unit of forest in eco-production provides the same quantity and quality of environmental services as a unit of conserved forest. In the absence of outside intervention, the firm uses and thus conserves forest for eco-production. The decision of the firm, therefore, concerns the quantity of forest to allocate to eco-production given that its cost as an input to production is P_F.

We depart from the benchmark of F&S by assuming that capital, K, is subject to non-price rationing and limited to $\bar{K}$. As well as reflecting credit-rationing or input quotas, this constraint could also approximate missing markets ($\bar{K} = 0$). This approach is perhaps closest to the analysis of non-separability by Muller and Albers (2004) in which market constraints are addressed in the context of a utility-maximising household. However, while Muller and Albers focused on the response of constrained households to conventional PES schemes and 'agricultural development programmes', our focus is on the cost-effectiveness of relaxing quantity constraints.[9] Henceforth, we refer to the latter policy as an 'indirect approach', since it is an alternative means of supplying environmental services.

The return to the model of F&S, and the focus on profit rather than utility maximisation, allows us to obtain general results concerning the cost-effectiveness of these interventions in a reasonably tractable manner. For simplicity, we assess cost-effectiveness in the context of a constraint on inputs, although parallel arguments apply to output constraints. Fortunately, the theory of firm behaviour under quantity constraints is already well developed and we apply the work of Fulginiti and Perrin (1993) to analyse constrained profit functions.

Define the constrained profit function as

$$\Pi^C(P_Q, P_F, P_K; \bar{K}, z) = \max_F P_Q f(F, \bar{K}) - P_F F - P_K \bar{K}, \tag{1}$$

where z represents other fixed factors. This can be contrasted to the unconstrained profit function $\Pi^U(P_Q, P_F, P_K; z)$, which describes the solution to the unconstrained problem. It is straightforward to show that the constrained profit function is related to the unconstrained profit function

[8] Without this assumption, a constraint on capital promotes forest cover compared to the unconstrained outcome.

[9] Muller and Albers (2004) model agricultural development programmes as increasing productivity of agricultural production (e.g., $f\ (F, K)$) through a multiplicative parameter α, such that production is measured as $\alpha f\,(F, K)$.

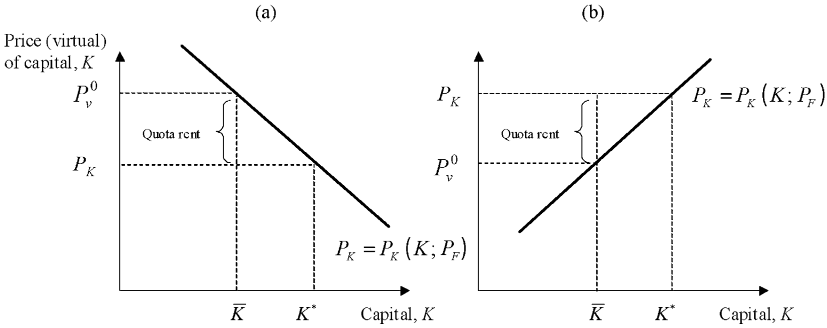

Figure 1. *Virtual prices and quota rent for (a) rationed input and (b) rationed output*

in the following way (see Appendix A for details):

$$\Pi^C(P_Q, P_F, P_K; \bar{K}, z) = \Pi^U(P_Q, P_F, P_v; z) + (P_v - P_K)\bar{K}, \tag{2}$$

where P_v is the 'virtual' or shadow price of capital, i.e., the price which would induce an unrestricted firm to choose the quantity $\bar{K}$. Each value of $\bar{K}$ has a unique virtual price. Figure 1 shows the virtual prices for input and output quotas respectively. Also shown in figure 1 is the quantity $(P_v - P_K)$, which is often called the 'quota rent'. This is an important determinant of the results that follow.

Following F&S we assume that a donor wants to induce greater forest conservation than the firm would find privately beneficial under prevailing market conditions. In F&S, the donor has two options for inducing greater conservation: subsidies to 'Forest' or 'Capital' inputs. That is, PES or the indirect approach, respectively. In the case presented here, the donor also has two options: (1) payments in the form of a subsidy to forest land, or (2) indirect provision of forest land via relaxation of the constraint on capital, $\bar{K}$. The latter could involve the provision of inputs as opposed to cash subsidies to capital (or output).

We follow F&S and compare the relative cost-effectiveness of policies in achieving a unit change on forest land. Hotelling's Lemma applied to the constrained profit function, together with the derivative of the constrained profit function with respect to the constrained input, $\bar{K}$, yield respectively (see Appendix A)

$$-\Pi_F^C = F,$$

$$\Pi_{\bar{K}}^C = (P_v - P_K).$$

Choosing dP_F and dK so as to induce a unit change in forested land, F, gives the following relationship:[10]

$$dF = 1 = -\Pi_{FF}^C dP_F = \frac{\partial F^C}{\partial P_F} dP_F = -\Pi_{F\bar{K}}^C dK = \frac{\partial F^C}{\partial \bar{K}} dK \tag{3}$$

[10] Note that throughout, $\Pi_F^C = \frac{\partial \Pi^C}{\partial P_F}$, $\Pi_{\bar{K}}^C = \frac{\partial \Pi^C}{\partial \bar{K}}$, $\Pi_{FF}^C = \frac{\partial^2 \Pi^C}{\partial P_F^2}$ and $\Pi_{\bar{K}\bar{K}}^C = \frac{\partial^2 \Pi^C}{\partial \bar{K}^2}$.

Following Fulginiti and Perrin (1993), who describe the Hessian of the constrained profit function in terms of the derivatives of the unconstrained function, the impact of the indirect policy can be expressed as

$$1 = -\Pi^C_{F\bar{K}}\, dK = \frac{\Pi^U_{Fv}}{\Pi^U_{vv}}\, dK, \tag{4}$$

where the subscript v refers to the derivative with respect to the 'virtual' price of capital, P_v.

The construct of virtual prices and the representation in equation (4) are convenient since they allow the analysis to be undertaken using the unconstrained profit function, making the results more directly comparable to F&S. Equations (3) and (4) exploit the duality between the derivative of the constrained profit function with respect to K and the unconstrained profit function with respect to P_v. To be clear, the derivative of the constrained profit function with respect to the virtual P_v yields the unconstrained demand for capital K, while the derivative of the constrained profit function with respect to $\bar{K}$ yields the virtual/shadow price.

We now proceed by determining the cost-effective intervention, and then analyse the donor's and firm's preferred interventions.

3. Cost-effective policy to supply environmental services

For PES, the cost to the donor and the impact on firm profits can be described in a manner similar to that of F&S. The indirect policy of relaxing capital constraints requires the purchase of inputs by the donor. We undertake the analysis assuming that the unit resource cost of capital is the underlying market price P_K. Questions remain concerning the share of the costs and benefits of this policy between the firm and the donor, but this only becomes important when discussing the intervention preferred by each party. It is also likely that the cost of transacting in each market differs. For ease of presentation, we assume for the moment that transactions costs, be they fixed or variable, are the same for each intervention.[11]

Using the relations between the constrained and unconstrained profit functions allows the cost-effective analysis to be undertaken in *virtual* price-space. Appendix B shows that the incremental cost (dC) of using an indirect approach rather than PES is given by[12]

$$dC = \frac{dK}{2}\left[-dP^I_v - dP^D_v\right] - \left(P^0_v - P_K\right) dK. \tag{5}$$

[11] As discussed by Key *et al.* (2000), transactions costs have fixed and proportional dimensions. In this sense we could define the price paid by the donor as $P^* = P_K\ (1 + \delta)$, where δ represents the proportional transaction cost. The overall cost of the intervention could also include a fixed element, R, reflecting search costs relative to the direct intervention. We also ignore costs associated with the implementation of the contract in each case. The model could be extended to include such costs, but this is left for future work.

[12] Throughout the superscript 0 refers to the pre-intervention level of a variable and superscript 1 refers to the post-intervention level. Similarly, I refers to indirect intervention and D refers to PES.

This expression has clear parallels with F&S.[13] Whereas F&S compare the cost-effectiveness of each policy approach by comparing the quantities of capital needed in each case, here the comparison is made in terms of changes in *virtual* prices. The term dP_v^I is the change in the virtual price as a consequence of relaxing the constraint on capital, $\bar{K}$. The term dP_v^D is the change in the virtual price of capital as a consequence of the direct subsidy to forest land. Given the assumptions, the former is negative and the latter is positive.

As shown in Appendix B, the first term in equation (5) is positive, since it has the same sign as the determinant of the Hessian of the constrained profit function. The second term is the quota rent associated with the intervention and is positive as explained above.[14] Hence, the sign of dC is indeterminate. If equation (5) is positive, then PES outperform the indirect approach in terms of cost-effectiveness. Further manipulations yield the following approximation for the marginal cost:

$$\frac{dC}{dK} = P_K - \frac{1}{2}\left(P_v^{1I} + P_v^{1D}\right). \tag{6}$$

This leads to proposition 1:

Proposition 1. *When the unit resource cost of capital is P, the relaxation of input constraints will be more cost-effective than PES to forest land when P is less than the average of the terminal virtual price under PES and an indirect approach,* P_v^{1D} and P_v^{1I}, *respectively. That is*

$$P < \frac{1}{2}\left(P_v^{1I} + P_v^{1D}\right).$$

Proof. This follows from equation (6). □

Figures 2 and 3 provide a graphical comparison of policy interventions under the assumption that the donor can choose either one or the other. Figure 2 illustrates the analysis for the case of a severe input constraint. In this case $P_K \ll P_v^{1D}, P_v^{1I}$, and it is obvious that the indirect approach would be preferred to PES.[15] Graphically, the second term on the right-hand side of equation (5), the *total* quota rent, is given by c in figure 2.[16] The term $\frac{1}{2}dP_v^I dK$ is given by (negative) area b and $\frac{1}{2}dP_v^D dK$ is given by (negative)

[13] F&S show that PES are always more cost-effective than an indirect approach and that the cost saving is proportional to

$$\frac{dP_K}{2}[dK^I - dK^D],$$

where dK^I is the change in capital under an indirect approach, dK^D is the change in capital under PES and dP_K is the subsidy to capital.

[14] This term would be negative in the case of an output constraint. This is shown in figure 1(b).

[15] Figure 2 also shows that if the resource cost of the intervention rises to P^*, the cost advantage for an indirect approach declines.

[16] This is the total quota rent over the interval dK, not the marginal quota rent as defined in figure 2.

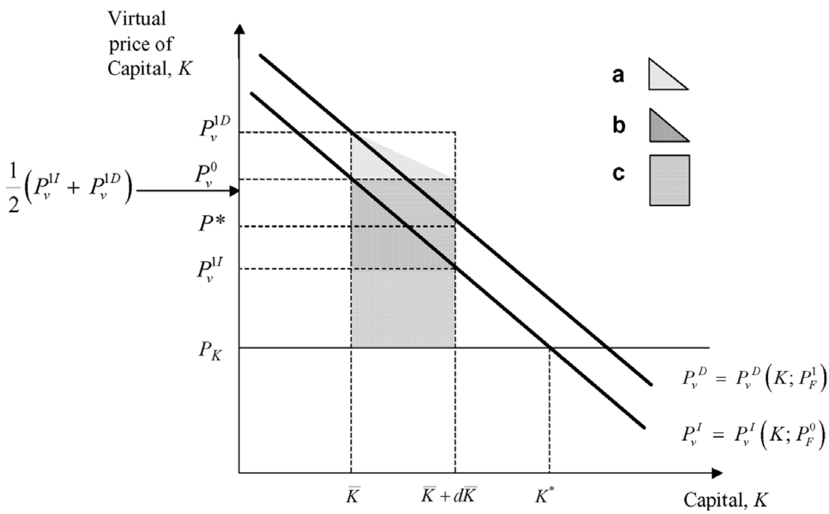

Figure 2. *PES vs the indirect approach (for Capital, K) – a severe constraint*

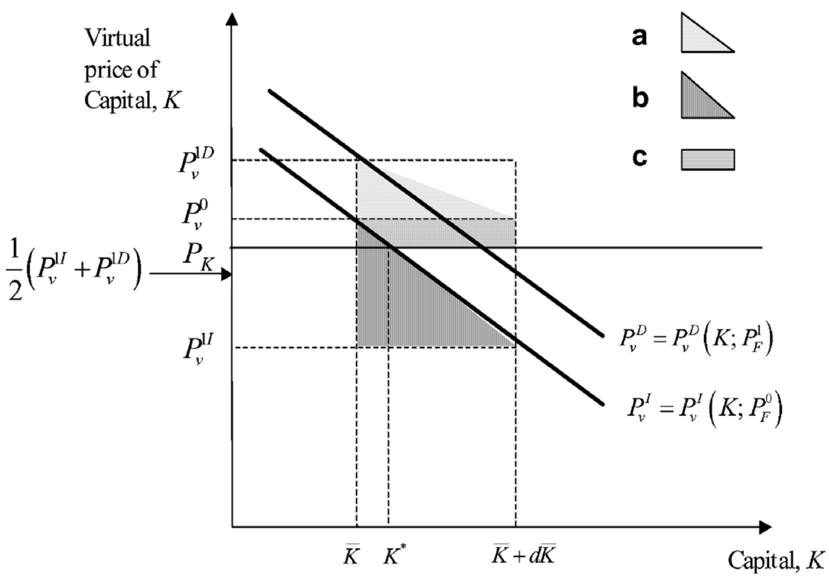

Figure 3. *PES vs the indirect approach (for Capital, K) – a minor constraint*

area *a*. Relative cost-effectiveness is given by a comparison of areas *a* and (*b* + *c*). In this case, the area (*b* + *c*) represents the additional profits to the firm and is clearly large and positive.

Figure 3 shows a case at the other extreme in which the donor would effectively 'over-egg the pudding' in order to achieve its environmental services target. Although the quota rent exists, area *c*, it is much smaller than the large and negative deadweight loss, area b. This loss outweighs the deadweight loss under PES, given by area a. In addition to this, capital is increased beyond what would be efficient in the absence of constraints (K^*), thereby causing a social loss. Here, PES are more cost-effective.

F&S compared the deadweight loss associated with different policy approaches when markets function perfectly. Loosely speaking, in the context of figures 2 and 3, F&S compared areas a and b and showed that the former is almost always smaller than the latter. Where markets are constrained, however, the total quota rent, area c, must also be considered.

What proposition 1 and figures 2 and 3 show is that when constraints are severe, other things being equal, the relaxation of constraints can be more cost-effective than PES. This finding differs from F&S and illustrates an important example in which PES are not preferred to more indirect alternatives to supply environmental services. Effectively, the quota rent represents a reduction in the funds required to achieve the targeted change in forest land under an indirect approach, compared to PES, where no such rents are released.

The preceding analysis also presents the possibility that a fully informed donor could obtain a kind of *optimum optimorum* by employing a combined policy strategy. That is, by first removing the constraint via the provision of capital at the world price in the quantities desired by the firm, and then subsidising forest land directly. The theory as it stands suggests that the firm would purchase K^* of capital, at which point it would be cost-effective to subsidise forest land directly à la F&S. Once again, the cost-effective-combined strategy will depend on the severity of the constraint.

Of course, there are many possible behavioural and informational assumptions that could be explored. The presence of rents suggests the possibility of arbitrage between each party and that the analysis of bargaining power could be apposite. The presence of credit rationing points to an analysis of informational asymmetries, and a discussion of the ability of the donor to overcome these asymmetries and relax the constraint. We return to this in section 6, but for now we remain with the simple framework and analyse the conditions under which the donor and firm prefer PES or the indirect approach.

4. The donor's preferred policy

The donor must pay either $-dP_F F$ with PES, or $P_K dK$ under the policy of relaxing the constraint. The donor will prefer PES if

$$-d P_F F < P_K d K. \tag{7}$$

Appendix C shows that this condition becomes

$$\frac{\eta^U_{KF}}{\eta^C_{FF}} < \eta^U_{KK} + \frac{1}{K}\frac{\partial K^U}{\partial P_v}\left(P^0_v - P_K\right), \tag{8}$$

where η^C_{ij} is the constrained elasticity of demand for input i with respect to price of input j, and η^U_{ij} is the unconstrained equivalent.[17] This is a

[17] Elasticities are defined as follows: $\eta_{ij} = -\frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i}$. Note that η^C_{FF}, η^U_{KK} and $\eta^U_{KF} > 0$.

convenient form for the result since it reveals the dependence on the *virtual* price elasticity of demand for capital: η^U_{KK}, and the quota rent associated with the constraint $(P_v - P_K)$. The result is analogous to that of F&S, but introduces some important differences. F&S show that in the case of perfect markets, the donor will prefer PES ('direct payments') if the following inequality holds:

$$\frac{\eta^u_{KF}}{\eta^u_{FF}} < 1, \tag{9}$$

which F&S show is always the case for homothetic technologies and some non-homothetic ones. This leads to proposition 2:

Proposition 2. *If the eco-entrepreneur is a profit maximiser and subject to a quantity constraint in an input market, a policy that relaxes the constraint in the input market will be the donor's preferred policy to increase forest cover if*

1. *the quota rent associated with the constraint is large:* $(P^0_v - P_K)$*;*
2. *the resource cost of the constrained input is low:* P_K *is low;*
3. *the demand for capital is highly inelastic with respect to its own (virtual) price:* η^U_{KK} *is small.*

Proof. This follows from the inspection of equation (8), noting that $\frac{\partial K^U}{\partial P_v} < 0$ and $(P^0_v - P_K) > 0$ for an input constraint. (See also Appendix C). □

In a world of perfect markets, the donor will almost always prefer PES to the indirect approach, as shown by F&S. When constraints exist in input markets, this conclusion is no longer robust. When a severe constraint exists and the quota rent is large, the donor will prefer to relax input constraints rather than subsidise forest. This preference is also enhanced by the fact that the constrained own-price elasticity of demand for forest land is smaller than the unconstrained: $\eta^C_{FF} < \eta^U_{FF}$. This means that a larger subsidy is required for a given response. Both of these features can conspire to make the indirect approach more preferable.

5. The eco-entrepreneur's preferred policy

When the firm is constrained in an input market, for small changes in P_F or K, the firm's profits will change respectively as follows:

$$d\Pi^C_F = \frac{\partial \Pi^C}{\partial P_F} dP_F = -dP_F F,$$

$$d\Pi^C_K = \frac{\partial \Pi^C}{\partial K} dK = P^0_v dK,$$

where the latter comes from equation (18) in Appendix A, and assumes that the firm receives the additional inputs for free (does not pay P_K). Hence the firm prefers PES if

$$-dP_F F > P^0_v dK. \tag{10}$$

This leads to proposition 3:

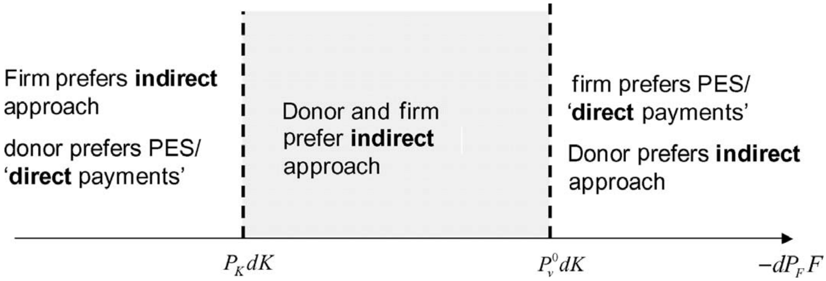

Figure 4. *Donor vs eco-entrepreneur's preferences over PES and indirect approaches*

Proposition 3. *Three outcomes are possible for an input constraint: (i) the donor prefers PES and the firm prefers the indirect approach; (ii) vice versa and (iii) both donor and firm prefer the indirect approach.*

Proof. Inspection of equations (10) and (7), noting $P_v^0 > P_K$ reveals that (i) if $-dP_F F < P_K dK$, the donor prefers PES and the firm prefers the indirect approach; (ii) the reverse is true if $-dP_F F > P_v^0 dK$ and (iii) if $P_v^0 dK > -dP_F F > P_K dK$, then both the donor and the firm prefer the indirect approach. □

Figure 4 elaborates on proposition 3 and shows the intermediate values of the cost of PES ($-dP_F F$) at which the donor and firm will both desire the indirect approach. The area of agreement is large when the quota rent is large, i.e., when the input constraint is severe. One interpretation of this result is that environmental and poverty alleviation objectives need not be in tension. Where constraints are severe, the indirect policy approach not only provides cost-effective provision of forest land in this case but also provides the largest transfer to eco-entrepreneurs. We now discuss these implications in further detail.[18]

6. Discussion

In this paper, we compared the cost-effectiveness of payments for environmental services with an indirect approach that relaxes market constraints, where constraints can be understood to represent any type of non-price rationing of inputs and outputs. With this minor adaptation, which better reflects the situation in many developing countries, cost-effectiveness is investigated following Ferraro and Simpson (2002) using the duality between the constrained and unconstrained profit function shown by Fulginiti and Perrin (1993).

[18] The mechanics of relaxing the output constraint are slightly different. If the constraint can be relaxed at a unit cost P to the donor, then equations (7) and (10) become $-F dP_F < P dK$ and $-F dP_F > (P_K - P_v^0) dK$, respectively, if the NGO receives the market price for output. Similar areas of agreement occur when $P > (P_K - P_v^0)$.

The underlying premise of F&S is that donor funds are directed towards the eco-output price or to facilitate the acquisition of complementary inputs such as tourism infrastructure, product marketing and processing facilities. Local agents such as communities faced with cheaper inputs or higher output prices will therefore increase production, hence increasing the demand for intact ecosystems as an input to production. The key assumption is that, prior to the intervention, agents face perfectly elastic supply or demand and can buy profit-maximising quantities of the inputs they need at prevailing market prices. The addition of a quantity constraint is a simple way to analyse the cost-effectiveness of differing policy approaches in the presence of market constraints.

The theoretical results differ from F&S on two counts. First, PES are not systematically more cost-effective than an indirect approach which relaxes the market constraint. Second, there are instances when both donor and recipient prefer the indirect approach. Within the limited context of our model, both outcomes are more likely when market constraints are severe. In order for these results to be useful to the practitioner, it is important to give them a practical interpretation.[19]

Quantity restrictions and other forms of non-price rationing appear to be very common among small-scale entrepreneurs in developing countries, with perhaps credit rationing as the most obvious example. While credit rationing may be as pertinent an issue in eco-production as in agriculture, where constraints on credit for eco-entrepreneurs are relaxed, there may still be problems in accessing other inputs necessary for production. In fact attracting credit may be contingent on having access to other inputs in the first place (RCW, 2007). This suggests that modelling behaviour under quantity constraints of one sort or another is extremely apposite. Indeed, there are numerous empirical examples of interventions that have attempted to boost eco-production activities and increase the area of forest being preserved via policy to relax underlying constraints.

So, what types of inputs are likely to be constrained? The answer to this may depend on the eco-production process under consideration, although some generalisations can be made. In Suriname, for example, a bio-prospecting agreement between local tribes and the International Cooperative Biodiversity Group (ICBG), a US government-funded programme, led to the provision of inputs to local communities in the form of training, information and technology transfer (Guérin-McManus *et al.*, 1996). These inputs were an integral part of the drug development process,

[19] One interpretation of these results is that care should be taken in interpreting axiomatic models of production. Firstly, it seems clear that minor changes in the assumptions can change the results dramatically. Secondly, since it is always possible to generate a result from such models, due consideration of the 'applicability' of the model should be an important part of its interpretation. In this respect, a model in which markets are not perfect and are constrained appears to be more applicable to the developing-country context. Nevertheless, the continued representation of technology as a 'black box' masks many issues pertinent to production processes, such as the social relationship between inputs. We thank Dan Bromley for reminding us of these issues.

for example, in the extraction of plant chemicals from organic matter. In this and other cases, such as those involving selective logging, there exists a need to support first-stage processing on a small scale, for example, by facilitating the acquisition of simple grading, processing or packaging techniques.

As a result of small-scale production of natural products, and regional and seasonal variability in supply quality and quantity, it is often difficult to reach a scale of production that is of commercial interest to buyers in domestic or international markets. Here coordination problems among entrepreneurs, for example, can exacerbate capital constraints and limit the scale of production. One way of dealing with and overcoming both the quality and scale problem has been for firms to group together as cooperatives or associations. These are often initiated or at least enabled by third parties, such as donors and NGOs, who effectively resolve this constraint (MacQueen *et al.*, 2008). Moreover, eco-products generally cater to niche markets and despite rapid growth in recent years are still typically found in developed rather than developing or emerging markets. This suggests that at least some inputs to joint production may not be easily available via the market, particularly more intangible ones such as skills development and technology transfer, and may partially explain why they tend to be supplied by third parties. The same could be said of interventions to relax constraints on output.

In addition, the United Nations Conference on Trade and Development's (UNCTAD) BioTrade Initiative[20] recorded that eco-entrepreneurs often lack clear business plans with well-elaborated product and market-chain analyses. They also lack links with existing enterprises that create backward linkages and involve business managers in programme design and training. Obtaining market information, establishing transport links and promoting trade effectively is often difficult and costly. For example, in the Cuyabeno Wildlife Reserve in Ecuador, the Cofans of Zabalo independently operate all eco-tourism services, with complementary marketing and transport logistic inputs from a larger tourism services firm (Wunder, 2000). In Indonesian Borneo, marketing and transport networks were established by the local NGO, SHK-Kaltim, so that high-quality, sustainably-produced rattan could be transported and sold in national and international markets as a certified eco-product. A number of rattan-producing villages share the same networks.[21] All these are effective examples of input constraints, which can be understood in light of the model presented above. Naturally, the exact nature of these constraints is likely to vary from case to case and hence, requires more refined analysis than is presented here.

This is certainly true in relation to credit rationing. Nevertheless, one interpretation of the above results is that donors or NGOs should

[20] Since its launch in 1996, the UNCTAD BioTrade Initiative has been promoting sustainable biotrade in support of the objectives of the Convention on Biological Diversity (CBD). The Initiative also hosts the BioTrade Facilitation Programme (BTFP), which focuses on enhancing sustainable bio-resources management, product development and assisting in processing and marketing. See: http://www.biotrade.org

[21] See: http://www.worldwildlife.org/bsp/kemala/kpshk.htm

involve themselves in providing more credit to eco-entrepreneurs. Indeed, historically this has been a common policy prescription in development circles and there are numerous examples of subsidised credit schemes, even in the realm of PES (e.g., Campos *et al*., 2005; Petrick, 2005). However, by and large, the history of such schemes is littered with defaults, losses and eventual failure (Petrick, 2005). In part, this is a consequence of failure to understand the complex causes of credit rationing and the fact that credit rationing often represents a constrained Pareto optimum. For instance, Ghosh *et al*. (2000) show that where moral hazard is the cause, additional credit need not lead to Pareto improvements and suggest that such strategies may be resisted by existing lenders. Rather, interventions should target the root cause of market constraints by reducing asset inequality, increasing bargaining power for borrowers and improving credit information networks. While these are not simple recommendations to act upon, successful micro-finance projects do exist.

There are a host of issues that we have not yet considered that may be important for forest protection interventions in developing countries. Similar to those highlighted by F&S, there are issues relating to, for example, transaction costs, designing and targeting effective contracts and property rights enforcement. For the most part, these issues are relevant for the cost-effectiveness of any policy approach despite not being explicit features of our modelling framework. A critical assumption of our model is the supply of environmental services in an eco-production process that utilises a unit of forest being identical to those from a unit of directly conserved forest. In the real world, eco-production processes vary widely in terms of the process under consideration in addition to the context in which they are being implemented. It is likely, however, that the environmental services provided from eco-production will be inferior to those from pure conserved forest in many cases. In such cases, the relaxation of this assumption weakens our result. Nevertheless, much still depends on the characteristics of the constraint, e.g., its severity, the eco-production process as well as the context under study.

It is also important to point out that, despite being couched in terms of activities such as eco-tourism and eco-certification, our results have wider applicability. Firstly, the model is relevant for the provision of environmental services via certain agricultural activities, which can be seen as joint production processes, such as the planting of hedgerows by farmers. But the idea of relaxing constraints is more general still. For instance, in the case of the Sloping Lands Conversion Programme, a large reforestation PES scheme in China, *ex post* analysis of farmers' responses to direct payments to retire cultivated land revealed the role of relaxing market constraints in achieving dual environmental and poverty objectives. Crucially, it was found that indirect strategies, targeting important binding constraints such as weak land tenure or local public goods, might be more cost-effective means to reduce cultivation at the extensive margin, and increase incomes, than direct payments (Gauvin *et al*., 2009; Groom *et al*., 2009).[22]

[22] Interestingly, both types of approaches relaxed constraints on off-farm labour to some extent (see Groom *et al*., 2009).

This, in turn, highlights the potential for indirect policy approaches both to maximise cost-effectiveness and alleviate poverty at the same time. In reality, many policy programmes in developing countries have been designed with dual goals. Conceptually and empirically, the performance of policy to achieve dual policy goals has been studied, for example, by Feng (2007) and Gauvin *et al.* (2009). They show that while trade-offs exist, better targeting of environmental providers could improve performance. This, of course, requires information that may be privately held, thus raising the problem of strategic behaviour. For cost-effectiveness in our case, we would need information on constraints that may also be very costly to obtain. Further complicating the issue is the fact that finding information on the severity of constraints may be a matter of trial and error given that providers might not hold this information either.

7. Conclusion

In conclusion, our model results show that, in contrast to F&S, payments for environmental services are not always more cost-effective than an indirect approach that relaxes market constraints. Moreover, there are instances when both parties prefer the indirect approach. Both outcomes are more likely when rationing is severe. But how relevant is this stylised model with respect to eco-production processes in the real world? First, model results hinge on the assumption of equality in supply of environmental services from eco-production and pure conservation, which may not hold for many eco-production processes. Moreover, from the discussion of some empirical examples in the previous section, we observe that many donors and NGOs transfer capital and other inputs rather than cash for the purchase of inputs. It is clear that in the absence of heavy outside support many of these eco-production processes would not be economically viable. Our model shows that such interventions can be cost-effective where constraints are severe. Nevertheless, careful empirical research is needed to compare these outcomes to various counter-factuals.

A final question relates to asking how far such constraints can be used to explain the supposed dearth of successful eco-entrepreneurs in Africa, Asia and Latin America in a rapidly expanding global market for eco-products (as indicated by, for example, the RCW, 2007). In this paper we have focused only on the possible role of market constraints. Nevertheless, there may be numerous reasons for the failure for eco-production processes in the developing world. Therefore, donors would be well advised to identify the cause of limited eco-production before intervening. In a world of more-or-less perfect markets, this points to PES for land as suggested by F&S. Where they can be identified and measured, relaxing constraints could well be cost-effective in a constrained world.

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Appendix A: Constrained and unconstrained profit function

Fulginiti and Perrin (1993) analyse the profit function when one of the inputs is constrained. Their analysis completely characterises the Hessian of the constrained profit function in terms of derivatives of the unconstrained profit function with respect to prices of unconstrained inputs and 'virtual' prices of constrained inputs.

We explore their approach using our simple model.

$$\Pi^{U}(P_Q, P_F, P_K; z) = \max_{K,F} P_Q f(F, K) - P_F F - P_K K. \qquad (11)$$

This defines the unconstrained profit functions in which the firm is free to choose the variable inputs, F and K, subject to the fixed inputs, z. Now, suppose that one of the inputs, K, is constrained such that $K = \bar{K}$, the constrained profit function can be written as

$$\Pi^C(P_Q, P_F, P_K; \bar{K}, z) = \max_F P_Q f(F, \bar{K}) - P_F F - P_K \bar{K}$$
$$= \Pi^P(P_Q, P_F; \bar{K}, z) - P_K \bar{K}, \tag{12}$$

where $\Pi^P(.)$ is the partial profit function. To define the relationship between constrained and unconstrained profit functions it is useful to define 'virtual' price, P_v, of K as the price that would induce the firm to choose $\bar{K}$:

$$P_v = P_v(P_Q, P_F; \bar{K}, z). \tag{13}$$

This yields

$$\Pi^U(P_Q, P_F, P_v; z) = \max_{K,F} P_Q f(F, K) - P_F F - P_K K$$
$$= \Pi^P(P_Q, P_F; \bar{K}, z) - P_v \bar{K}, \tag{14}$$

which gives a formal definition of $P_v : \Pi_v^U = -\bar{K}$.[23] This gives the following relationship between Π^U and Π^C at P_v:

$$\Pi^U(P_Q, P_F, P_v; z) = \Pi^C(P_Q, P_F, P_v; \bar{K}, z), \tag{15}$$

and from equations (12) and (14) we get

$$\Pi^C(P_Q, P_F, P_K; \bar{K}, z) = \Pi^U(P_Q, P_F, P_v; z) + (P_v - P_K)\bar{K}. \tag{16}$$

Using this relation it is possible to derive the following relationships, which are used in the derivations in the text (Fulginiti and Perrin, 1993: 99):

$$\Pi_F^C = \Pi_F^U + \left(\Pi_v^U + \bar{K}\right) \frac{\partial P_v}{\partial P_F} = \Pi_F^U, \tag{17}$$

$$\Pi_{\bar{K}}^C = (P_v - P_K) + \left(\Pi_v^U + \bar{K}\right) \frac{\partial P_v}{\partial \bar{K}} = (P_v - P_K). \tag{18}$$

More importantly, the Hessian of the constrained profit function can be defined in terms of the second own- and cross-price derivatives of the unconstrained profit function. The results for inputs F and $\bar{K}$ are

$$\Pi_{\bar{K}\bar{K}}^C = -\left(\Pi_{vv}^U\right)^{-1}, \tag{19}$$

$$\Pi_{F\bar{K}}^C = -\Pi_{Fv}^U \left(\Pi_{vv}^U\right)^{-1}, \tag{20}$$

$$\Pi_{FF}^C = \Pi_{FF}^U + \Pi_{Fv}^U \left(\Pi_{vv}^U\right)^{-1} \Pi_{vF}^U. \tag{21}$$

Were we to present the results for the output Q, the signs in equation (20) and the second term on the right-hand side of equation (21) would change.

[23] Where $\Pi_v^U = \frac{\partial \Pi^u}{\partial P_v}$.

Appendix B: Cost-effectiveness of policy approaches to supply environmental services – proof of proposition 1

Following F&S we can make a second-order approximation for the change in profits when additional forest is provided via PES. Dropping z for brevity we get

$$\Pi^C(P_Q, P_F + dP_F, P_K; \bar{K}) \approx \Pi^C(P_Q, P_F, P_K; \bar{K}) + \Pi_F^C dP_F + \frac{1}{2}\Pi_{FF}^C (dP_F)^2.$$

The total cost of the intervention can be calculated by subtracting from this expression the overall cost of the PES intervention to the donor. The cost of PES is given by the right-hand side of the following expression, where F_0 is the initial level of forest cover, and the right-hand side is the deadweight loss:[24]

$$\Pi^C(P_Q, P_F + dP_F, P_K; \bar{K}) - \Pi^C(P_Q, P_F, P_K; \bar{K}) + \left(F_0 + \frac{\partial F}{\partial P_F} dP_F\right) dP_F$$
$$\approx \frac{1}{2}\frac{\partial F}{\partial P_F}(dP_F)^2. \tag{22}$$

Following the same procedure yields an expression for the change in profits following the relaxation of capital constraints:

$$\begin{aligned}\Pi^C(P_Q, P_F, P_K; \bar{K} + d\bar{K}) &\approx \Pi^C(P_Q, P_F, P_K; \bar{K}) + \Pi_{\bar{K}}^C d\bar{K} + \frac{1}{2}\Pi_{\bar{K}\bar{K}}^C (dK)^2 \\ &\approx \Pi^C(P_Q, P_F, P_K; \bar{K}) + \left(P_v^0 - P_K\right) dK \\ &\quad + \frac{1}{2}\Pi_{\bar{K}\bar{K}}^C (dK)^2.\end{aligned}$$

Subtracting the resource cost of the policy, which in section 3 is assumed to be $P_K dK$, yields the net profits:[25]

$$\Pi^C(P_Q, P_F, P_K; \bar{K} + dK) - \Pi^C(P_Q, P_F, P_K; \bar{K}) - P_K dK$$
$$\approx \frac{1}{2}\frac{\partial P_v}{\partial \bar{K}}(dK)^2 + \left(P_v^0 - P_K\right) dK, \tag{23}$$

where P_v^0 is the initial virtual price of capital at $K = \bar{K}$. The right-hand side of equation (22) is a welfare triangle. The right-hand side of equation (23) contains the welfare triangle and an expression representing the quota rent, $(P_v^0 - P_K)$, the latter being the marginal value of relaxing the constraint. These terms are explained graphically in figures 2 and 3 in the text.

[24] This is equivalent to expression A4 in F&S, corrected only by the absence of the minus sign on the RHS.

[25] Note that $\Pi_{\bar{K}}^C = (P_v - P_K)$ and $\Pi_{\bar{K}\bar{K}}^C = \frac{\partial P_v}{\partial \bar{K}}$ in the case of a constrained input (Fulginiti and Perrin, 1993).

The proof of equation (5) is as follows. Taking the right-hand side of equation (23) from the right-hand side of equation (22) gives the following expression:

$$\frac{1}{2}\left[\frac{\partial F}{\partial P_F}(dP_F)^2 - \frac{\partial P_v}{\partial K}(dK)^2\right] - \left(P_v^0 - P_K\right)dK. \tag{24}$$

Note that the change in the virtual price of capital as a result of the indirect approach, dP_v^I, is given by

$$dP_v^I = \frac{\partial P_v}{\partial K}dK. \tag{25}$$

Similarly, the change in the virtual price as a result of PES is given by[26]

$$dP_v^D = -\frac{dP_F}{dK}. \tag{26}$$

Using relation (3) the first term in square brackets of equation (24) reduces to dP_F. It is then easy to see via substitution of equations (25) and (26) that equation (24) becomes

$$\frac{1}{2}\left[-dP_v^D dK - dP_v^I dK\right] - \left(P_v^0 - P_K\right)dK,$$

which is one step from equation (5).

The proof of equation (6) comes from noting that $dP_v^I = P_v^{1I} - P_v^0$ and $dP_v^D = P_v^{1D} - P_v^0$.

Appendix C: The donor's preferences – proof of proposition 2

The donor prefers PES if $-dP_F F < P_K dK$. Noting from equations (3) and (4) that $dP_F = -\frac{1}{\Pi_{FF}^C}$ and $dK = \frac{\Pi_{vv}^U}{\Pi_{Fv}^U}$, this becomes

$$\frac{F}{\Pi_{FF}^C} = \frac{-F}{\partial F^C/\partial P_F} < P_K\frac{\Pi_{vv}^U}{\Pi_{Fv}^U} = P_K\frac{-\partial K^U/\partial P_v}{-\partial F^U/\partial P_v}.$$

Taking the reciprocal and multiplying both sides by P_F gives

$$-\frac{\partial F^C}{\partial P_F}\frac{P_F}{F} > \frac{-\partial F^U/\partial P_v}{-\partial K^U/\partial P_v}\frac{P_F}{P_K}.$$

[26] The laborious algebra is as follows: $dP_v^D = \frac{\partial P_v}{\partial P_F}dP_F$, which noting equation (18) and using symmetry can be written as $dP_v^D = \Pi_{F\bar{K}}^C dP_F = -\frac{\Pi_{Fv}^U}{\Pi_{vv}^U}dP_F$. Given equation (4), this can be written as $dP_v^D = -\frac{dP_F}{dK}$. Details can be found in Fulginiti and Perrin (1993: 99).

Given the symmetry of the unconstrained profit function we have $\partial F^U/\partial P_v = \partial K^U/\partial P_F$. Inserting this, multiplying top and bottom by K and rearranging yields in equation (8)[27]

$$\frac{\eta^U_{KF}}{\eta^C_{FF}} < \eta^U_{KK} + \frac{1}{K}\frac{\partial K^U}{\partial P_v}\left(P^0_v - P_K\right).$$

[27] Note that the numerator of the RHS of equation (8) is equal to $-\frac{\partial K^U}{\partial P_v}\frac{P_K}{K}$, which would be the point elasticity at P_v but for the fact that it is evaluated at P_K. Noting that $P_K = (P_v + P_K - P_v)$, the numerator becomes

$$\eta^U_{KK} + \frac{1}{K}\frac{\partial K^U}{\partial P_v}(P_v - P_K).$$

From this point it is easy to get equation (8).

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