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Decentralization, Externalities, and Efficiency

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In the competitive model, externalities lead to inefficiencies, and inefficiencies increase with the size of externalities. However, as argued by Coase, these problems may be mitigated in a decentralized system through voluntary coordination. We show how coordination is limited by the combination of two factors: respect for individual autonomy and the existence of private information. Together they imply that efficient outcomes can only be achieved through coordination when external effects are *relatively large*. Moreover, there are instances in which coordination cannot yield any improvement at all, despite common knowledge that social gains from agreement exist. This occurs when external effects are *relatively small*, and this may help to explain why coordination is so seldom observed in practice. When improvements are possible, we describe how simple subsidies can be used to implement second-best solutions and explain why standard solutions, such as Pigovian taxes, cannot be used. Possible extensions to issues arising in the structure of research joint ventures, assumptions in the endogenous growth literature, and the location of environmental hazards are also described.

1. INTRODUCTION

Decentralization has many benefits; most importantly, it takes advantage of local information and gives individual firms, agents or localities control over their affairs.[1] However, decentralization also has costs; spillovers from one jurisdiction or firm to another can undermine efficiency in a decentralized system. For example, emissions from factories in the United States contribute to acid rain in Canada, and New Jersey's public school expenditures benefit employers in New York. In the absence of coordination, societies end up with too much smoke and too little education.[2]

As Coase (1960), has noted, however, voluntary coordination may reduce these inefficiencies. We show that, given the superiority of local information and respect for the autonomy of individual localities or firms, there is an important interaction between the

1. In fact, in this paper a decentralized environment will be defined by these two features: (i) power is decentralized such that each party has the right to take actions without coercion, and (ii) use is made of relevant decentralized (privately held) information.
2. See, for example, Laffont (1988) and the survey by Rubinfeld (1987).

size of the externality and the efficacy of coordination.[3] Specifically, coordination can raise social welfare only when external effects are *relatively large*. In contrast, when external effects are relatively small, coordination cannot yield improvements at all. As the externality becomes larger, the benefits to coordination increase, making it easier to reach an agreement which is acceptable to all parties and within budget. Since the gains from coordination can outweigh the inefficiencies caused by an increased externality, the classical argument that small externalities lead to small inefficiencies while large externalities give rise to large inefficiencies can be violated.

The paper builds on previous work that shows how asymmetric information increases the expected costs of coordination and thus makes it difficult to obtain efficient outcomes through bargaining (e.g., Laffont–Maskin (1979), Myerson–Satterthwaite (1983), Cramton–Gibbons–Klemperer (1987), Farrell (1987), Rob (1989), and Mailath–Postlewaite (1990)). While the results in the previous literature are suggestive, there has been little work on the particular problems associated with introducing externalities into such contexts.[4]

The following example illustrates our intuition. Imagine that the state of New York will benefit by $\$w$ from reduced acid rain if Ohio Electric builds a new, cleaner power plant to replace an existing facility. Since Ohio Electric has the right to decide whether to build the plant, New York's only way to affect the decision is to offer to compensate Ohio Electric in exchange for a promise that the new plant will be built. However, when the net benefits to Ohio Electric of building the plant are not publicly known, New York does not know how much it needs to pay in order to secure an agreement. For example, it might be in Ohio Electric's interest to build a new plant anyway, in which case New York need pay nothing.

This uncertainty interferes with the ability to reach a mutually acceptable agreement in two ways. First, it increases the expected costs of coordination and, second, it decreases the expected net benefits. In particular, suppose that New York offers $\$x$ in return for Ohio Electric building the new plant. New York knows that Ohio Electric will accept this offer if its net valuation of the plant is above $-\$x$. If Ohio Electric's net valuation is strictly larger than $-\$x$, New York will have "overpaid" and Ohio Electric will get an "informational rent" from its private information.

The second complication arises from uncertainty about Ohio Electric's actions under autonomy (i.e., without an agreement). In making its choices, New York considers two

3. Our framework takes as given that the autonomy of localities or firms is inviolable. Presumably, in framing a constitution, a degree of autonomy is guaranteed in order to protect localities against the possibility that future governments will abuse their power (Madison, Hamilton and Jay (1787) *Federalist X*). As a recent example, enhancing local autonomy has been a key point of the political changes in China; the political reforms have strengthened economic reforms by ceding authority to provincial and county governments and thus making future reversals more difficult (Weingast (1993)). An argument of the present paper is to show that these guarantees can have costs in terms of forsaken efficiency. Other papers which have used politically motivated participation constraints include Feenstra and Lewis (1991) and Lewis, Feenstra, and Ware (1989). They show how these constraints in combination with private information shape the optimal means of protection from import competition.

4. Farrell (1987) presents a simple example of bargaining in the presence of externalities, in which private information can lead to inefficiencies. The example highlights the role of the individual rationality constraint (i.e., autonomy) as in Myerson–Satterthwaite (1983), but he does not consider the range of issues taken up here. Greenwood–McAfee (1991) address externalities and asymmetric information in the context of education; their paper centres on a case in which monotonicity conditions are binding (e.g., the government wants to devote extra resources to slow and fast learners, but not to average learners). This yields the inefficiency in their model, rather than individual rationality—which they do not impose. Pratt and Zeckhauser (1987) also do not consider individual rationality constraints; as above, they show that efficiency can be obtained in a wide range of environments through taxes and subsidies based on "expected externalities". In the present context, it is natural to assume that monotonicity is not a binding constraint, and we highlight the ways in which autonomy and externalities interact with private information to limit efficient coordination.

scenarios. In the first scenario, an agreement is reached, payment is made, and Ohio Electric promises to build the plant. In the second scenario, there is no agreement, but Ohio Electric might choose to build the plant of its own accord. The expected net benefit of coordination for New York is thus the *difference* in expected outcomes with coordination and without. When there is a positive probability that Ohio Electric will take the desired action on its own, New York's expected net benefit from coordination will always be less than the full value of eliminating the externality.[5]

We can express these expected costs and net benefits in a straightforward and compact way. Assume that Ohio Electric's net valuation of building a new plant is in the interval $[\underline{v}, \bar{v}]$ where $\underline{v} < 0 < \bar{v}$, and that, from the point of view of an outsider, this valuation is distributed according to the cumulative distribution function $F(\cdot)$. The probability that Ohio Electric will build the plant if New York offers \$$x$ is $1-F(-x)$, and the probability without a transfer is $1-F(0)$. So, if New York offers to pay Ohio Electric \$$x$ if the plant is built, the expected cost of this offer is $x(1-F(-x))$. The corresponding expected net benefit to New York is \$$w$ times the *increase* in the probability that Ohio Electric will build the plant. Formally, this is

$$w[(1-F(-x))-(1-F(0))] = w(F(0)-F(-x)).$$

For an offer of \$$x$ to be beneficial to New York, these expected net benefits must outweigh the expected costs. This is true if and only if

$$w(F(0)-F(-x)) \geq x(1-F(-x)). \tag{1}$$

This cost/benefit inequality is central to understanding when coordination will occur and how much it can accomplish. For example, note that Pigovian subsidies equal to the size of the externality are ruled out by this inequality.

We show that the combination of asymmetric information, respect for autonomy, and externalities can increase expected costs and decrease expected benefits to such a degree that, for a wide range of cases, the outcome under a coordinated agreement cannot improve on the autonomous allocation—i.e., it is no better than doing nothing at all. For example, returning to equation (1), suppose that $F(\cdot)$ is the cdf for the uniform distribution on $[\underline{v}, \bar{v}]$ (i.e. $F(x) = (x-\underline{v})/(\bar{v}-\underline{v})$). Then the condition for expected benefits to exceed expected costs becomes $w \geq \bar{v} + x$. Thus if the externality, w, is smaller than the largest possible net benefit, $\bar{v}$, no positive offers will be made and no improvement over the autonomous allocation is possible. This finding may help to explain why coordination is so infrequently observed in practice.

This result implies that coordination may fail to yield improvements even if it is common knowledge that there are social gains to coordination. In the example above, if $\underline{v} = -1/2$, $\bar{v} = 1$, and $w = 1$ then there is simultaneously common knowledge that social gains from agreement exist for all possible net valuations and no mutually acceptable improvement over the no agreement (autonomous) outcome.

The next section describes and solves the problem of designing the optimal coordination policy. Section 3 interprets the results in terms of the intuition developed above, characterizes optimal transfers, and describes when improvements can be made over the autonomous allocation and when the first-best allocation can be achieved. Section 4 considers extensions of the basic model, and Section 5 describes potential applications to choices by firms about research and development, assumptions underlying the theory of

5. So, as is further described in Section 3, New York would refuse to make a Pigovian transfer to Ohio Electric—i.e. a subsidy equal to the full value of the externality (\$$w$).

endogenous growth, and the siting of environmental hazards like a waste dump or polluting factory.

2. THE MODEL

For ease of exposition, we describe the model in terms of two firms, $i=1, 2$, but the model itself is general enough to encompass several interpretations. We discuss some of these in Section 4.

We begin by assuming that each firm is concerned solely with its own welfare. Firm 1 has a project which it could undertake; this might be, for example, building a new plant or introducing a new worker training programme.

The benefits of undertaking the project do not accrue just to firm 1—there may also be spillovers to firm 2. The value of the spillovers is given by w^*. In the case of a worker training programme, for example, there may be positive externalities ($w^*>0$), since some of the trained workers may leave firm 1 to work for firm 2. The spillover parameter w^* is assumed to be public knowledge, whereas the private net benefit of the project is known within the firm that can undertake it only. This information structure arises because the firm has special knowledge about the cost or profitability of the project, while outsiders do not.

Formally, welfare is determined by the investment, X, in the project. This variable is binary (either 0 or 1).[6] Firm 1's objective function is given by:

$$u_1(X, v, t) = vX + t, \tag{2}$$

where $v \in [\underline{v}, \bar{v}]$ is a parameter which reflects the private net benefit of the project; it is drawn from distribution $F(\cdot)$ with strictly positive, continuous density $f(\cdot)$ on the domain $\underline{v}<0<\bar{v}$.[7] Net transfers from firm 2 to firm 1 are given by t.

Firm 2's objective function is given by:

$$u_2(X, w^*, t) = w^*X - t. \tag{3}$$

Given these objectives, we consider the ability to coordinate the activities of the firms. A government (or mediator) attempts to achieve efficient outcomes by offering an appropriately designed menu of options to the firms. A given option provides a transfer coupled with a production plan (specified as a probability of producing), based on the announced net benefits of production $\hat{v}$.

We model the problem as a three-stage game. In the first stage, the government proposes the menu of options to the firms. In the second stage, each firm accepts or rejects the menu. Then, in the third stage, if *both* accept, the programmes are implemented with enforcement by the government. Otherwise, there is no agreement, and firm 1 is free to pursue its production decision independently.

Note that this is not the most general proposal that we could allow. Consider the case of a positive externality. Suppose that the government could sign a side-contract with firm 1 (*without* the approval of firm 2) which required firm 1 not to undertake the project unless firm 2 agreed to pay a transfer of w^*. Firm 1 would agree to sign such a contract,

6. The assumption that the project is $\{0, 1\}$ is equivalent to assuming constant returns to scale in production and constant marginal benefits, along with an upper bound on project size—i.e., that there is a linear objective function with continuous project choice from an interval $[0, \bar{X}]$.

7. Note that we have no inefficiency if v is *always* less than zero or if v is *always* greater than zero, since there is then no ambiguity as to whether firm 1 will produce or not under autonomy. In this case, either autonomy is efficient or Pigovian taxes will work.

since, if firm 2 believes that there is no chance of production absent a payment of w^*, it would indeed be willing to pay w^* contingent on production. Thus, the socially efficient outcome would result.[8] The key assumption needed here is that the side-contract is a credible one.

However, the government and firm 1 have an incentive to renegotiate if firm 2 does not agree to pay w^*. More formally, suppose that the three-stage game above is modified in two ways. First, side-contracts are allowed: the menu of options in the first stage is expanded to include a separate menu which will be implemented if firm 1 accepts and firm 2 rejects (in addition to the programme that will be implemented if both firms accept).[9] This menu is, of course, restricted to options which do not require transfers from firm 2. Second, renegotiation is allowed: if firm 1 accepts in the second stage, the government has the opportunity to offer a new proposal which is subject to the approval of firm 1, and, if firm 2 accepted at stage two as well, firm 2. If this new proposal is approved it is implemented. If not, the initially agreed upon proposal takes effect.

This simple model, which includes renegotiation and side-contracting, yields the same outcome as our initial model without side-contracting. To see this, observe that the goal of the side-contract with firm 1 is to lower the payoff that firm 2 expects if it deviates and refuses the proposal. Thus, in the case of a positive externality, the government would like the side-contract to induce as little production (and thus benefit for firm 2) as possible. The only way to do this is to force firm 1 to pay if it produces. However, these payments do not generate any social utility, and they result in a socially costly distortion of production. Therefore, if firm 1 accepted and firm 2 rejected at the second stage, the government would optimally propose a new contract with firm 1 that eliminates the penalty on production. This is the best that the government can do with a balanced budget and no participation from firm 2.[10] Thus, under this model, renegotiation simply undoes the effect of any side-contract that might reduce production, and firm 2 faces the same behaviour after a refusal as it did in the model without the possibility of side-contracting.

For side-contracting to make any difference, therefore, one of the parties must be able to credibly commit not to renegotiate. Such a commitment might be plausible for a long-lived patient government which knows that it will be involved in many such mechanisms and can develop a reputation for not renegotiating. However, a reputation story could also go the other way and work for firm 2 if it was to be involved in many similar circumstances and found it desirable to build a reputation for not giving in to such contracts (i.e. rejecting even though it is not optimal in the short-run to do so).

In general, our inclination is that the level of commitment needed to make these contracts credible is very high. Consequently, we focus on the no side-contracts case as an upper bound on what is achievable in most situations.[11]

8. We thank Eric Maskin for suggesting this type of contract to us.

9. The role of this side-contract menu is to lower firm 2's expected payoff if it says "no" in the second stage. There is no loss of generality in ignoring side-contracts with firm 2 since it never provides benefits to firm 1 in the absence of an agreement.

10. We formally introduce the budget balance assumption below. A similar model without budget balance is analyzed in Appendix D. In that model side-contracts, even without renegotiation, do not change the optimal production plan.

11. The reader may be wondering why our setup requires any less commitment than the one we are ruling out. The mechanism design modelling makes it seem that, after firm 1 has revealed its private information, the two firms and the government might have an incentive to renegotiate the mechanism. In general, this is true; however, for our problem, we show in Section 3 that the optimal mechanism can be implemented by a subsidy contingent on production. Thus, the only time that any information gets revealed is when firm 1 actually decides to undertake the project or not. When that decision has been made, the subsidy is the only thing left to negotiate about, and, since it is simply a transfer between firms there is no scope for renegotiation. This is an example of the general point made by Beaudry and Poitevin (1993) that different organizational structures may be subject to different types of renegotiation.

Now we proceed to state and solve the problem. As in similar problems of mechanism design, the government's problem is simplified via the revelation principle, which states that, without loss of generality, the menu of programmes can be limited to direct revelation mechanisms which induce truth-telling.[12] We thus consider direct revelation mechanisms of the form:

$$\langle p(v), t(v) \rangle, \tag{4}$$

which gives the probability of producing the project and the net monetary transfer from firm 2 to firm 1 as a function of firm 1's type (the fact that p is a probability requires that $0 \leqq p(v) \leqq 1, \forall v$). By allowing only for a transfer between firms, we are imposing budget balance. Budget balance is natural in considering a decentralized setting since it restricts attention to programmes which do not require support from higher authorities.[13]

In evaluating a given menu, firms consider expectations of production plans and net transfers under an agreement. The expectations of firm 1 are conditional on the private net benefit v of producing, as this is known to it. Those of firm 2 however are not. Accordingly, define:

$$P \equiv E(p(v)),$$
$$T \equiv E(t(v)).$$

If there is an agreement, firm 1's expected probability that it will produce is given by $p(v)$; P gives firm 2's expectation that firm 1 will produce under an agreement; and $t(v)$ gives firm 1's expected net transfers, while $-T$ gives firm 2's expected net transfers. The firms' expected utility under an agreement as a function of type is then:

$$U_1(v) = vp(v) + t(v), \tag{5}$$

$$U_2 = w^* P - T. \tag{6}$$

The government maximizes the sum of expected utilities over all firms, weighting production according to the valuations of both firms affected:[14]

$$\max_{p(\cdot)} \int_{z=\underline{v}}^{\bar{v}} (U_1(z) + U_2) f(z) dz = \max_{p(\cdot)} \int_{z=\underline{v}}^{\bar{v}} (z + w^*) p(z) f(z) dz \tag{7}$$

subject to incentive compatibility (IC) and individual rationality (IR) constraints:

$$\text{(IC)} \qquad U_1(v) \geqq vp(\hat{v}) + t(\hat{v}), \qquad \forall v, \hat{v},$$

$$\text{(IR1)} \qquad U_1(v) \geqq \max(v, 0), \qquad \forall v,$$

$$\text{(IR2)} \qquad U_2 \geqq w^*(1 - F(0)).$$

12. Fudenberg and Tirole (1991), Chapter 7, e.g., provides a good overview of issues in mechanism design and the revelation principle.

13. Note that introducing other firms which are also autonomous—but not affected by these projects—does not relax budget balance in a way relevant to the present problem. In Section 4.3 and Appendix D we analyse a case in which budget balance is not required.

14. While we assume here that the government is utilitarian (in that it wishes to maximize the unweighted sum of utilities over firms), our model applies equally well to decentralized bargaining. For example, if the objective function puts zero weight on firm 1, this corresponds to a bargaining process in which firm 2 makes a take-it-or-leave-it offer to firm 1. The results in this case are the same as those presented in Appendix D except that the $\lambda/1+\lambda$ is replaced by 1. Thus the qualitative features all carry over from the analysis of the evenly-weighted case.

The incentive compatibility constraint ensures that firm 1 has no incentive to misrepresent its type, and the individual rationality constraints ensure that expected utility under an agreement for each firm is at least as great as that without.[15,16] Here, we see the role of respect for autonomy, which requires that participation must be strictly voluntary. Unlike common problems of bargaining over control of a single good without externalities (e.g., Myerson–Satterthwaite (1983)), the autonomous (i.e., "no trade") position can involve utility generated by the actions of the other party even if participation is rejected.[17,18]

The problem in equation (7) is not easy to solve since there is a continuum of constraints. The following theorem allows us to reduce the set of constraints to just two:

Theorem 1. *Suppose that* $p(v)$ *is non-decreasing in* v. *Then a direct revelation mechanism* $\langle p(\cdot), t(\cdot)\rangle$ *satisfies* (IC), (IR1), *and* (IR2) *if and only if*:

$$(\overline{A.1}) \quad \int_{z=\underline{v}}^{\bar{v}} p(z)\left(z+w^*+\frac{F(z)}{f(z)}\right)f(z)dz \geqq \bar{v}+w^*(1-F(0)),$$

and

$$(\underline{A.1}) \quad \int_{z=\underline{v}}^{\bar{v}} p(z)\left(z+w^*-\frac{1-F(z)}{f(z)}\right)f(z)dz \geqq w^*(1-F(0)).$$

Proof. We provide the basic intuition for why we can limit attention to just these two constraints (the first pertaining to the type with the greatest possible local net benefit from producing, $\bar{v}$, the second pertaining to the type with the lowest local net benefit, $\underline{v}$.)[19] The incentive constraint implies that the left-hand side of firm 1's individual rationality constraint (IR1) rises at a rate (weakly) between 0 and 1. The right-hand side rises at rate 0 until 0 and at rate 1 thereafter. Thus, if the constraint is satisfied for the lowest type, it is always satisfied for all higher types less than zero. Similarly, if the constraint is satisfied for the highest type, it is satisfied for all lower types greater than 0. Accordingly, it is only necessary to check that the constraint is satisfied for the highest and lowest types. The two constraints are then a combination of incentive compatibility, individual rationality

15. Under autonomy (i.e. in the absence of an agreement) firm 1 produces on its own if $v>0$. Since each firm knows this, from the point of view of firm 2, firm 1 will produce with probability $(1-F(0))$ under autonomy. Thus, without coordination, firm 1 will obtain max $(v, 0)$ from its own production and firm 2 expects to get $w^*(1-F(0))$ from firm 1's production.

16. Note that under autonomy each firm has a dominant strategy; thus, we do not need to consider the possibility that the information revealed in the mechanism approval/disapproval stage will affect the autonomous outcome. This consideration can become important with more general payoff structures as has been pointed out by Cramton and Palfrey (1989). In such a case, pinning down the individual rationality constraints may require some type of equilibrium selection argument. Thus an analysis along the lines of this paper would be more complicated and entail more stringent assumptions about equilibria, but it could nevertheless be undertaken. (See also Section 4.4.)

17. The framework can be naturally extended to coordination among a number of different firms, as long as the assumption is maintained that agreement must involve *all* firms or none. While we have not formally investigated the case where some firms coordinate their activities while others opt out, this can only make efficiency more difficult to achieve since the individual rationality constraint will be made more stringent if a firm expects others to agree even if it opts out. So, again, our results can be seen as placing an upper bound on what is achievable without extraordinary commitment. A more complete treatment of the multiple firm case would examine issues of coalition formation and how partial acceptance of mechanisms would affect the form of the second-best outcome.

18. The presence of this type-contingent outside option for firm 1 can create countervailing incentives in our problem (see. e.g., Lewis and Sappington (1989) and Maggi and Rodriguez (1993)). Whether the incentive to overstate v or understate v is dominant will determine where (IR1) binds.

19. A formal proof of the theorem is available from the authors.

for firm 2, and individual rationality for the highest $(\overline{A.1})$ and lowest type $(\underline{A.1})$ of firm 1. ||

Constraint $(\overline{A.1})$ says that total expected social surplus, adjusted for information costs which arise from the incentive compatibility constraint, must be as big as the sum of what both localities would expect to get in the absence of coordination if firm 1 was the high type (but firm 2, of course, does not know this valuation). Constraint $(\underline{A.1})$ gives the analogous condition for the lowest type.

Thus, we can write the central government's problem as

$$\max_{p(\cdot)} \int_{z=\underline{v}}^{\bar{v}} (z+w^*)p(z)f(z)dz.$$

subject to $(\overline{A.1})$, $(\underline{A.1})$, and $p(v)$ non-decreasing.

We make the additional assumptions that

$$\frac{d}{dv}\left(\frac{F(v)}{f(v)}\right) \geqq 0 \tag{8}$$

and

$$\frac{d}{dv}\left(\frac{1-F(v)}{f(v)}\right) \leqq 0. \tag{9}$$

These assumptions are satisfied for many common distributions and ensure that the monotonicity constraint is satisfied at the solution.[20] We can now solve using Kuhn–Tucker multipliers. Let $\bar{\lambda} \geqq 0$ be the multiplier on $(\overline{A.1})$ and $\underline{\lambda} \geqq 0$ be the multiplier on $(\underline{A.1})$. We can rewrite the maximization problem as:

$$\max_{p(\cdot)} \int_{z=\underline{v}}^{\bar{v}} \left((1+\bar{\lambda}+\underline{\lambda})(z+w^*)+\bar{\lambda}\frac{F(z)}{f(z)}+\underline{\lambda}\frac{(-1+F(z))}{f(z)}\right)p(z)f(z)dz$$
$$-\bar{\lambda}(\bar{v}+w^*(1-F(0)))-\underline{\lambda}(w^*(1-F(0))).$$

The first-order conditions yield that production by firm 1 is determined by a simple "cut-off" rule:

$$p(v)=\begin{cases} 1 & \text{if } v+w^*+\dfrac{\bar{\lambda}}{1+\bar{\lambda}+\underline{\lambda}}\dfrac{F(v)}{f(v)}+\dfrac{\underline{\lambda}}{1+\bar{\lambda}+\underline{\lambda}}\dfrac{(F(v)-1)}{f(v)} \geqq 0, \\ 0 & \text{otherwise.} \end{cases}$$

While the setup allowed that the optimal agreement could incorporate an element of randomization, the result above is in fact straightforward to implement: firm 1 produces with probability equal to 1 if its announced valuation is above a cut-off value and does not produce otherwise. We will show that in the case of positive externalities, firm 1 then receives a simple matching grant for producing, and in the case of negative externalities, it receives a matching grant for not producing.

The first two terms of the cut-off rule, $v+w^*$, give the social benefit of firm 1's production. If these were the only terms, we would have the rule: produce if and only if

20. Bagnoli and Bergstrom (1989). The distributions include the uniform, normal, exponential, logistic, chi-squared, Laplace, and, with parameter restrictions, the Weibull, gamma, and beta distributions.

social benefits of production are positive, which is the first-best outcome. However, the presence of asymmetric information leads to the addition of the final two terms (the first of these terms is positive and the second is negative, with weights given by which constraints are binding.) These two terms give deviations from first-best production levels, and in the next section we describe how they affect the limits to coordination.

First, note that the fact that the solution takes the form of a cut-off rule makes it easy to see which constraint, $(\overline{A.1})$ or $(\underline{A.1})$, will be binding. Let $\tilde{v}$ be the cut-off value defined by the first-order condition. Constraint $(\underline{A.1})$ requires that

$$\int_{\tilde{v}}^{\bar{v}} [-1+F(z)+(z+w^*)f(z)]dz \geqq w^*(1-F(0))$$

or, simplifying,

$$w^*(F(0)-F(\tilde{v})) \geqq -\tilde{v}(1-F(\tilde{v})). \tag{10}$$

This condition is the relevant one when externalities are positive—i.e., when more production is desirable ($\tilde{v}<0$). Notice that this is the same cost/benefit inequality as equation (1) of Section 1 except that x is chosen optimally to equal $-\tilde{v}$. Similarly, constraint $(\overline{A.1})$ requires that

$$w^*(F(0)-F(\tilde{v})) \geqq \tilde{v}(F(\tilde{v})). \tag{11}$$

This condition is relevant for negative externalities, when less production is desirable ($\tilde{v}>0$).[21] We provide intuition for these conditions below.

3. WHAT CAN COORDINATION ACHIEVE?

The conditions above have a simple interpretation in terms of the expected costs and benefits from coordination and lead to an easily implemented system of optimal transfers. Following this interpretation, we show when coordination can make any improvements at all over the autonomous allocation and when the first-best outcome can be achieved.

3.1. *Expected costs and benefits of coordination*

The constraints $(\underline{A.1})$ and $(\overline{A.1})$, simplified as equations (10) and (11), have a straightforward interpretation. Each says that the expected benefits to firm 2 of setting the cut-off at type $\tilde{v}$ must outweigh the expected costs associated with that cut-off.

Following the intuition in the introduction, in the case of positive externalities, the right-hand side of equation (10), $-\tilde{v}(1-F(\tilde{v}))$, gives exactly the expected cost of the subsidies necessary to implement a cut-off of $\tilde{v}<0$. This is because if the cut-off type is paid $-\tilde{v}$ all other types that produce must receive the same amount since net benefits are not observed.

Similarly, with negative externalities, the expected cost of paying the subsidy is $\tilde{v}F(\tilde{v})$, reflecting the fact that all types $v \geqq \tilde{v}$ must be paid *not* to produce. The cost is the right-hand side of equation (11).

21. Note that at the autonomous allocation ($\tilde{v}=0$), where production is neither encouraged nor discouraged by the programme, both $(\overline{A.1})$ and $(\underline{A.1})$ are binding.

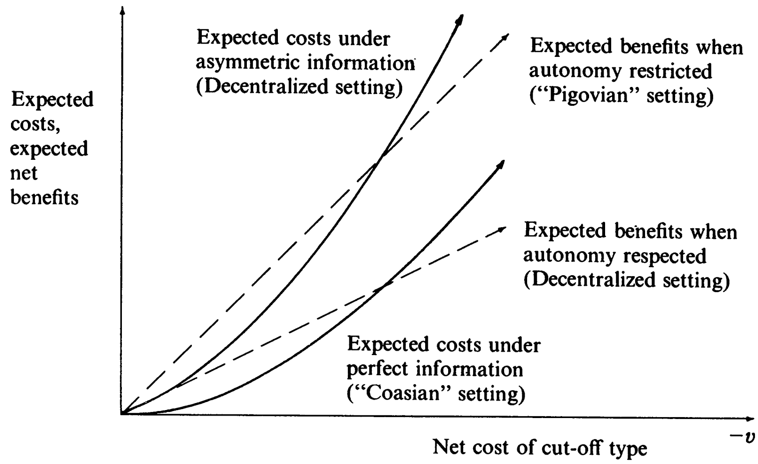

FIGURE 1

Expected costs and expected net benefits of coordination with positive externalities, $v \sim U[-k, k]$

Figure 1 illustrates these expected costs (solid lines) for the case of positive externalities. The horizontal axis gives net costs faced by the cut-off type. The upper cost curve reflects firm 2's expected costs under asymmetric information, $-\tilde{v}(1-F(\tilde{v}))$. In contrast, the lower cost curve shows expected costs in a world with perfect information. In this "Coasian" setting, expected costs are just $-\int_{\tilde{v}}^{0} zf(z)dz$ for any cut-off type; here, each type, marginal or infra-marginal, is paid exactly the smallest amount required to induce them to produce. The space between the two curves gives the "information costs" which arise from the informational asymmetry.

The expected benefits of coordination (over and above the autonomous outcome) are given by the left hand sides of the inequalities in (10) and (11), $w^*(F(0)-F(\tilde{v}))$. This is illustrated in Figure 1 as well, where benefit curves (dashed lines) are defined for a given positive externality, w^*. The upper benefit curve gives the expected benefits when firms are prohibited from producing outside of a coordinated agreement (the "Pigovian" world), and the lower benefit curve reflects expected benefits in the decentralized setting of our model. The difference in the curves is exactly $w^*(1-F(0))$ in that the lower one accounts for the probability that a firm may make the desired production choice in the absence of an agreement, while in the higher one this probability is zero.

3.2. *Characterization of optimal transfers*

Once the cut-off type, $\tilde{v}$, has been determined, implementing the optimal programme here is simple: when $w^*>0$ ($w^*<0$) we require firm 2 to pay $-\tilde{v}$ ($\tilde{v}$) to firm 1 if it produces (does not produce). This is a per unit subsidy on production in the case of a positive externality and on non-production in the case of a negative externality. We can calculate $\tilde{v}$, and thus the size of an optimal subsidy, by assuming the relevant inequality ((10) or (11)) holds with equality. Thus, for example, for a positive externality $\tilde{v}$ solves

$$w^*(F(0)-F(\hat{v}))+\hat{v}(1-F(\hat{v}))=0. \tag{12}$$

Observe that this equation always has a solution at $\hat{v}=0$ (i.e., the autonomous outcome) and may, under the hazard rate assumption (9), have at most one non-zero solution. The optimal, $\hat{v}$, i.e. $\tilde{v}$, will be the minimum of these solutions, since this will encourage the most production and will still be acceptable to firm 2. Notice that firm 1 receives all of the surplus from coordination under these transfers. This may not be true in related models. For example in Appendix D we discuss the case in which firm 2, rather than a government or mediator, proposes the transfers. In that case, firm 2 captures some of the surplus by trading off reduced efficiency (compared to the model here) in return for paying smaller subsidies. This is analogous to a monopolist restricting output to raise profits.

It is interesting to compare these transfers with standard Pigovian taxes. In our framework, Pigovian taxes correspond to the case where $-\hat{v}=w^*$. The needed assumption here is that, in the case of positive externalities, firm 2 is willing to pay in full for the external benefits, and thus firm 1 is subsidized in exactly the amount of the externality. Similarly, if the externality is negative, firm 1 is subsidized by the magnitude of the externality for refraining from production.[22] In these cases the socially optimal level of production is achieved.

In a truly decentralized setting, however, firms do not face involuntary restrictions on their actions. So, firm 2's expected benefit from participating in the scheme is reduced to the extent that these benefits would be forthcoming under autonomy as well. Firm 2 will thus not be willing to pay transfers as large as w^*, as required in the Pigovian case, and a form of second-best "Pigovian" subsidies instead involve transfers equal to $-\tilde{v}(\tilde{v})$ to address positive (negative) externalities. These second-best subsidies can be called "Pigovian" in the sense that they are paid uniformly to all firms that produce (do not produce), irrespective of actual benefits and costs. The fact that these transfers are strictly smaller than w^* is proved in Proposition 1.

Proposition 1. *If $\underline{v}<0<\tilde{v}$ and $w^*\neq 0$, transfers will be lower than the "Pigovian" level (i.e., $|\tilde{v}|<|w^*|$.)*

Proof. See Appendix A.

3.3. *Obtaining first-best outcomes*

When can the first-best, ex post efficient outcome be reached? Consider the case of positive externalities ($w^*>0$). Efficiency requires that firm 1 undertake the project if $v\geqq -w^*$. In light of Proposition 1, therefore, we know that efficiency will not be possible if $w^*<-\underline{v}$, since in this case firm 1 produces if and only if $v\geqq\tilde{v}$ which is greater than $-w^*$. This yields too little production. Thus if we are to achieve efficiency at all, it can only occur when the external effect is greater than the largest possible cost ($w^*>-\underline{v}$) so that in the first-best *all* possible types of firm 1 are required to produce. Equation (10) tells us when the expected cost of compensating all possible types of firm 1 to produce (by paying a transfer equal to the greatest possible cost of producing, $-\underline{v}$) is less than the expected benefits:

$$\underline{v}(1-F(\underline{v}))+w^*(F(0)-F(\underline{v}))=\underline{v}+w^*F(0)\geqq 0.$$

That is, the net benefit of guaranteeing that all types produce, $w^*F(0)$, must be greater than the expected cost incurred by paying $-\underline{v}$ to firm 1 with probability equal to 1.[23]

22. Usually, the Pigovian solution to a negative externality entails a tax on firm 1 by the magnitude of the externality. Here, the subsidy implements the same outcome, is still of "Pigovian" size (i.e., the size of w^*), and facilitates comparison with our model.

23. When implementing efficiency it is sufficient to have transfers of size $-\underline{v}<-\tilde{v}$ instead of requiring larger transfers equal to $-\tilde{v}$ as in Section 3.2.

So, when externalities are positive, coordination can lead to all localities producing only when

$$w^* \geqq \frac{-\underline{v}}{F(0)} \tag{13}$$

To obtain a sense of relative magnitudes, assume that private net benefits are distributed uniformly on the interval $[-k, k]$. Then, the condition implies that

$$w^* \geqq 2k$$

is necessary to obtain the first-best outcome.[24] That is, coordination will only achieve efficiency if external effects are at least *twice as large* as the *largest possible* private net benefit.

While the result suggests that external effects must be large relative to private net benefits for the first-best to be achieved, there may be common situations in which "large enough" externalities exist. For example, if a public service is not very "local", such as a waste disposal site which can serve many localities in a region, then the externalities, taken together, are likely to be very large relative to private net benefits. Similarly, even with two firms or localities, if production costs are a large fraction of benefits, then the externality could be large compared to private *net* benefits.

3.4. *Improvements on the autonomous allocation*

How large must the externality be in order to obtain an improvement over the autonomous allocation? Again, take the case of positive externalities ($w^* > 0$). Improving on the autonomous outcome is only possible when the externality, w^*, is large enough so that the weight on the marginal type induced to produce, $f(0)$, multiplied by the gain from production, w^*, is larger than the weight on transfer payments to all types at least as large, $(1 - F(0))$. These latter types would have produced anyway without compensation and thus enter only in the cost calculation and not in the benefits.[25]

Thus, when externalities are positive, the external effect must be at least as big as

$$w^* \geqq \frac{1 - F(0)}{f(0)} \tag{14}$$

to improve on the autonomous allocation.[26] Again, to obtain a sense of relative magnitudes, consider the case in which private net benefits are distributed uniformly on the interval $[-k, k]$. Then, equation (14) implies that

$$w^* \geqq k$$

24. Appendix B formally derives this result and the symmetric result for negative externalities.

25. The sharpness of this result arises from considering whether or not firms undertake investments of a fixed size $\{0, 1\}$, as in Myerson–Satterthwaite (1983), Cramton–Gibbons–Klemperer (1987), and much of the bargaining literature. The assumption is equivalent to assuming constant marginal net benefits of production up to a finite limit. If, instead, firms make continuous, unbounded choices about levels of production, increasing subsidies induces a firm to raise levels of production and this has social benefits. Here, however, increasing subsidies to a firm which would have made the investment anyway does not affect their actions.

26. Appendix C formally derives the result, as well as the symmetric result for negative externalities.

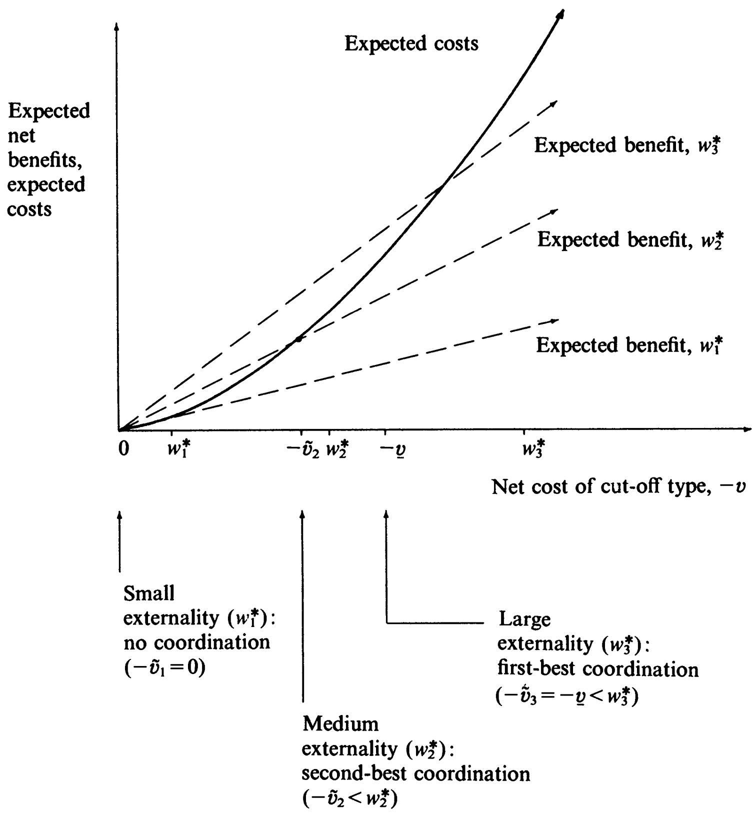

FIGURE 2

Expected costs and net benefits of coordination under decentralization: increasing positive externalities ($w_1^* < w_2^* < w_3^*$)

must hold for any improvements to be implementable. That is, coordination will be worthwhile only if external effects are *at least as large* as the *largest possible* private net benefit.

Figure 2 illustrates the three regimes (no improvement, some improvement, and efficiency) in terms of the expected costs and net benefits shown in Figure 1. In order to achieve a gain over autonomy, the expected benefit curve must be above the expected cost curve at some $-\tilde{v} > 0$. In other words, there must be a beneficial subsidy which is acceptable to firm 2. For this to occur, the slope of the expected benefit curve must exceed the slope of the expected cost curve at the origin. This is precisely what equation (14) captures. The three net benefit curves in Figure 2 reflect different-sized externalities corresponding to each of the three regimes.

The lowest expected benefit curve (for w_1^*) is always below the expected cost curve, so that no agreement satisfying the constraints will improve on the autonomous allocation. The middle expected benefit curve (for w_2^*) lies partially above the expected cost curve but intersects it at a point below that where first-best efficiency (i.e., $-\tilde{v}_2 = w^*$) is obtained. The intersection point identifies the optimal cut-off type (and thus the optimal subsidy), since there are always gains from increasing the $-\tilde{v}$ as long as $-\tilde{v} \leqq w^*$, and only cut-off types for which benefits exceed costs satisfy the constraint. The highest expected benefit curve (for w_3^*) reflects a level of externalities sufficient to achieve first-best efficiency. Here, although the point of intersection is below w_3^*, it is greater than $-\underline{v}$ and thus efficiency is obtained in that all types are induced to produce.

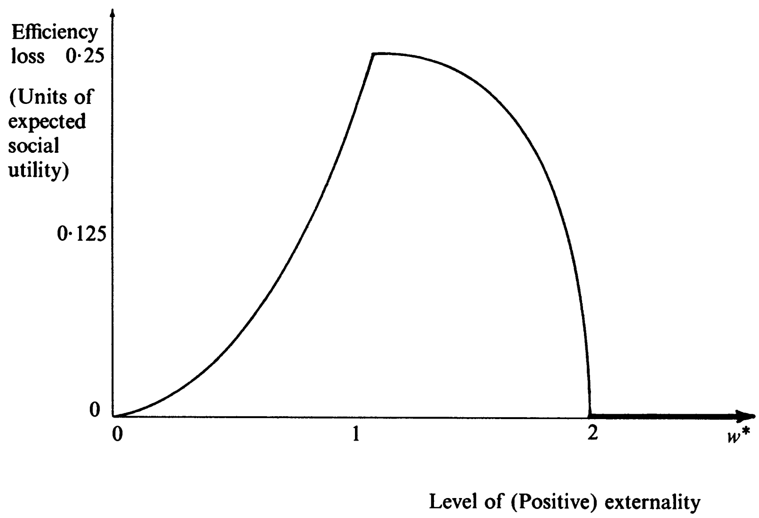

FIGURE 3
Deviations from efficiency with coordination, private net benefit $v \sim U[-1, 1]$

3.5. *Externalities and efficiency loss*

Figure 3 summarizes the analysis in terms of efficiency losses (relative to the first-best) associated with externalities. Here, we have assumed that externalities are positive and that private net benefits, v, are distributed uniformly on the interval $[-1, 1]$. Note that when w^* is between 0 and 1, coordination does not improve on autonomy, so initially larger externalities are associated with larger inefficiencies. But, beyond this range, coordination does improve on the autonomous allocation. When w^* is between 1 and 2, co-ordination serves to reduce inefficiencies so that beyond $w^* = 2$, the first-best outcome can be achieved and no efficiency is lost. Thus, only when external effects are relatively small does inefficiency rise with externalities. At its height ($w^* = 1$), the efficiency loss equals one quarter of social welfare under the first-best allocation. As the size of externalities increases, inefficiency falls until it is eventually eliminated.

If the private net benefit were instead distributed with an unbounded distribution, a similar graph would emerge. However, efficiency would only be reached at the limit as the size of the externality approaches ∞. In the case in which $v \sim N(0, 1)$, the peak efficiency loss would correspond to an externality of size $\frac{1}{2}\sqrt{2\pi} \approx 1{\cdot}25$.

4. INTERPRETATIONS AND EXTENSIONS

4.1. *Public expenditures and public goods*

There is nothing about our model which is specific to firms. As in our introductory example, one of the parties might be a government, or, indeed, both parties might be. For example, consider two localities, one of which can invest in improvements in its public education system, generating a positive externality. We model each locality as maximizing the welfare of a representative resident. Our results then characterize optimal coordination between benevolent governments.

Alternatively, our model can be used to analyze certain public goods problems where unanimous approval is required to implement a mechanism which would determine a provision and funding scheme. A simple example is as follows. Suppose there are two consumers who may differ in their valuation of the public good. Normalize production costs to zero, and suppose that the valuations are independently distributed on $[\underline{v}, \bar{v}]$ according to $F(\cdot)$, where $\underline{v}<0<\bar{v}$. Unanimous approval is required for the public good to be provided. In this situation, if one consumer has a positive valuation v, they are only willing to subsidize the other consumer for voting "yes" if v is large enough. This is precisely because the other consumer might vote "yes" even without a subsidy. Thus the size of the valuations here play the role of the size of externalities in our model. It should be noted, however, that as the number of consumers gets large in this set-up, the probability of approval goes to zero (as shown by Mailath and Postlewaite (1990) and Rob (1989)). This occurs because each consumer knows that the chance that her contribution will be essential to gain approval is very small, while the loss to giving this contribution is not small.

4.2. *Information Structure*

We have assumed that the net benefits of investing in projects are only known privately. The critical aspect of this assumption is that other firms or localities and any higher level of government or mediator are uncertain about whether investment will take place under autonomy (i.e., if no agreement is reached).[27] To see this, observe that if externalities are positive and it is publicly known whether v is larger or smaller than zero, a policy of offering a transfer of w^* to any locality which has $v<0$, in return for an agreement to produce, will yield the first-best outcome. This policy satisfies the incentive, individual rationality and budget constraints.

Similarly, if v is publicly known, but the size of the externality w^* is private information of the firm or locality affected, then the first-best outcome can always be obtained. For example, if an external benefit $w^*=\frac{1}{2}$ is received by firm 2, it will be willing to offer firm 1 exactly the smallest subsidy required to guarantee production, as long as firm 1's net costs are no greater than the external benefit, $-v\leqq\frac{1}{2}$. This means that all types such that $v+w^*\geqq 0$ will produce. Thus, we see that asymmetric information concerning the externalities is not sufficient to create inefficiencies in our problem.

If asymmetric information about both direct and indirect effects (i.e., both v and w^*) were considered, the formal analysis becomes more difficult and lies beyond the scope of this paper. However, we conjecture that the presence of this extra asymmetry, beyond the one necessary for our results, can only make it more difficult to improve on the decentralized outcome.

4.3. *Budget balance*

A possible argument against imposing budget balance in the model (interpreted as one of government coordination rather than bargaining) might be that "actual governments do not balance their budgets." There are several responses to this. First, at the level of state and local governments, budget balance is often mandated through legislation or constitutional provision. Second, in the long run, all governments must balance their budgets; i.e., current deficits necessitate future surpluses. Since our model is purely static,

27. The side-contracts we discussed earlier were precisely attempts to remove the uncertainty about what would happen under autonomy by committing to a particular action.

this sort of intertemporal shifting of resources cannot occur. Presumably, in a more complex model, there would be a trade-off between running a deficit today and alleviating a current incentive problem versus running a surplus tomorrow and exacerbating (or mitigating to a smaller degree) another incentive problem them. However, the fundamental point remains unchanged: a lack of outside subsidies limits the ability to reach socially desirable outcomes.

A related criticism of the budget balance assumption is that, although governments may balance budgets overall, they often have discretionary revenues which can be shifted among different items in the budget. Thus, in a more complex model where the government is concerned with many projects beyond the one at hand, it might subsidize one project by taking funds from another, rendering the assumption of budget balance too stringent for our framework.

We show in Appendix D, however, that the qualitative conclusions of our model are robust to this type of story as long as diverting funds to the project has some positive social opportunity cost. Such a social opportunity cost may arise naturally from distortions introduced by taxation, for example.

4.4. *Multiple projects*

Rather than just considering a single producer, we can consider cases in which both firms have an investment opportunity which generates an externality on the other. If the effect of each investment is independent, and the private information about the net benefits of each investment is independent, the problems are completely separable and our analysis holds for each individually.[28] However, if there are complementarities or substitution effects across projects, the analysis becomes more complex.

One example where such effects might be present is the case of two neighbouring states, each considering whether or not to build a road in the direction of the other. A state will benefit more from the other state's road if it has built its own connecting road. Thus the size of the externality is affected by the state's own production decision. This complementarity lends an aspect of coordination to the problem that is absent in our setting. Now, the distortion that externalities generate in a state's investment decision will vary with the actions of the other state. Therefore the actual autonomous outcome will depend very much on the beliefs that the states hold about each other. Thus, the relevant individual rationality constraints will also depend on these beliefs, and the problem becomes difficult to set up since beliefs can change with actions taken within the mechanism.

4.5. *Multiple spillovers*

In some situations more than one firm is affected by the spillovers; several difficulties may then need to be considered. For example, the assumption that all firms participate or not is a much stronger one when there are more than two firms. If we allow for participation by subsets of the firms while others opt out, the effect will be to increase the welfare of

28. Recent work by McAfee and Reny (1992) and Crémer and McLean (1985, 1988), among others, has shown that when private information is correlated in mechanism design problems, typically the first-best can be achieved, even with ε correlations. These results are striking, but the types of mechanisms which they require are unrealistic, necessitating very large bets. Auriol and Laffont (1991) have shown that the results of the independent case go through while allowing for some correlation if preferences are additive in a common component and an idiosyncratic component and both components are known by the firm. It is then only the idiosyncratic component which matters in the mechanism design problem.

firms when they refuse an agreement. Since this makes the individual rationality constraint harder to satisfy, this will make efficiency harder to achieve than in the model in Section 2. This is closely related to the way that we think about free-rider problems in that assuming that the other firms will form an agreement if one firm opts out is like assuming that it is possible for a firm to free-ride.[29]

It is interesting to compare the effect of renegotiation in this model with its role in the version of our model that was discussed in Section 2. As there, allowing side-contracts and renegotiation cannot lead to improvements. Here, it will in general yield outcomes which are strictly inferior to those when participation is by all firms or none (and thus no side-contracting is allowed and commitment not to renegotiate is assumed). Consider the case where there are two firms (firms 2 and 3) affected by a positive externality. Suppose that firm 1 and firm 3 write a contract that says that firm 1 will not produce without a transfer from firm 2. Firms 1 and 3 will be open to renegotiation if firm 2 refuses to pay the transfer. In particular, they will be willing to accept a subsidy scheme like the optimal one described in Section 3. From our previous results, we know that strictly more production will take place for a sufficiently large per-firm externality. Since firm 2 anticipates that such a renegotiation will take place if it refuses, its individual rationality constraint is at least as hard to satisfy as the one relevant in the no side-contract/no renegotiation world. Thus the model with renegotiation and side-contracting will yield (weakly) less efficiency than in the all-or-nothing case since firm 2's individual rationality constraint is (weakly) harder to satisfy here. For the remainder of this section, we assume that all firms or no firms participate and rule out renegotiation.

One issue that arises in a multiple firm setting which can be easily dealt with in our framework is the interpretation of externalities. There are two polar cases to consider. First, externalities can, themselves, have the quality of a public good in that the total external effect increases proportionally with the number of firms affected. Second, gross external effects may be fixed. Then considering more firms reduces the per firm externality.

In the model above, we have defined the external effect w^* in per firm terms. Because the external effect is non-rival in the first case, adding firms does not affect externalities elsewhere, so, here, the government would want to consider the sum of external effects across the n firms. If, for example, all firms are equally affected and equal-sized, a per firm externality equal to $(1/(n-1))w^*$ is required to obtain efficient outcomes, where w^* is the level required for efficiency in the case with two firms. Thus, when the external effect has the non-rival attributes of a pure public good, the more firms that are affected, the more likely it will be that an efficient outcome can be obtained.

In the second case, in which adding firms reduces the per firm externality proportionally, the basic results carry over unchanged from Section 3. Doubling the number of firms affected reduces per firm external effects by half. Thus, the sum of external effects is invariant to the number of firms involved. Here adding firms does not change the likelihood of reaching the first-best outcome.

29. This is different and less severe than the free-rider problem in Mailath–Postlewaite (1990) and Rob (1989). There, a large number of agents have private information and are taking part in a decision in which unanimity (i.e., all or none participate) is required. The fact that there are a large number of agents implies that misreporting one's valuation is unlikely to change the provision decision concerning a public good, but it is very likely to change what one pays (is paid) if the good is provided. Thus, as the number of agents grows, the probability of provision goes to zero as long as there is any type that is not willing to pay the per capita cost of the good. In our model, only the producer has private information and the other firms know exactly what each is willing to pay. Furthermore, under unanimity with no renegotiation, adding more firms affected by the externality can never hurt. Even allowing for renegotiation, the expected amount of production is bounded below by the amount which takes place in the two-firm model, and it can be higher depending on values of w^* and $f(\cdot)$.

5. APPLICATIONS

5.1. *Research and development*

The creation of new products often arises through cross-fertilization of different endeavours. Firms often have a range of research and development projects under way, each overlapping and depending in some way on the other, often through the accumulation of skills or new insights. Without coordination, however, firms will under-invest in projects with positive spillovers. Our framework extends naturally to help explain the optimal behaviour of firms in this situation.

In particular, the sort of coordination we describe with respect to local governments has a natural analogue in research joint ventures like Sematech, where micro-chip manufacturers joined forces to create a new generation of semi-conductors. The problem of designing the initial agreement involves the sort of individual rationality and budget constraints considered here, although budget balance is often violated due to heavy government subsidization. Our analysis in Appendix D, where budget balance is not required, suggests that externalities must be relatively large to make joint ventures efficient in the presence of private information (about, say, the net costs of R&D).

One aspect of the joint venture problem which is not present in our model is that the externalities are often partly endogenous as a result of output or profit-sharing agreements. A fully worked-out application would need to incorporate this feature.

5.2. *Models of long-run growth*

The renewed interest in models of long-run economic growth has been spurred by the explanatory power of new models which feature positive spillovers in production (e.g., Lucas (1988)). The spillovers provide a justification for the assumption that firms face decreasing returns individually while there are constant or increasing returns to aggregate production. Thus, equilibria are competitive, keeping the models simple, but, unlike the standard neo-classical model, growth rates need not converge across economies and capital will not necessarily flow from rich to poor economies.

The fundamental assumption of these models is that there is no coordination. If it were possible to fully internalize externalities, individual firms would face increasing returns, and the non-convexity in the production function would diminish the likelihood of reaching a competitive equilibrium (Laffont (1988)).[30]

The lack of coordination in these models is invoked, rather than explained. If there are an infinite number of producers and no central authority, then presumably coordination would be difficult indeed. Still, even with many producers, there is no reason that governments cannot create tax and subsidy schemes to address externalities; see, for example, Barro (1991).

The present paper suggests that if there is asymmetric information about the direct costs and benefits of production, then even a central authority may not be able to fully internalize externalities through voluntary programmes. While our model is static, the intuition carries over to a dynamic framework. However, we have shown that if the gains from coordination, reflected by w^*, are large enough, then we would expect efficient coordination, counter to the assumptions of the new growth literature. In considering

30. Strictly speaking, a competitive equilibrium could be maintained as long as coordination is not so effective that it introduces non-convexities into firms' problems.

deviations from efficient growth paths, we expect that those gains *would* be large, since the benefits to coordination accrue for all time.

5.3. *Siting a toxic waste dump*

Where should toxic waste dumps be situated? Can they be situated efficiently? While localities understand the need for waste dumps, no one wants one in their own "back yard". Clearly, if no one had to have a dump, under autonomy no one would. But, given that a site must be chosen, the problem involves determining which locality can bear the burden at least cost. This choice framework can be captured by adding to our model the constraint that the sum of probabilities of building a dump must equal one: the dump must go somewhere, but only one is needed.

Consider the case in which the gross external effect is constant no matter where the dump is sited. If no single locality accepts the communal dump, then all localities build private dumps which yield a level of utility equal to zero.[31] A simple auction can be created (e.g., sealed bid, second price) to allocate the dump, such that the n localities bid to receive a given transfer conditional on building the dump.

If the transfer is at least as large as $-\underline{v}$, the largest possible cost of building the dump, localities will always participate in the auction. Thus the central government taxes each locality $-\underline{v}/(n-1)$; localities will voluntarily pay these taxes as long as $w^* \geqq -\underline{v}/(n-1)$. Thus, the auction is consistent with individual rationality, and it does not require running a budget deficit—indeed, the programme runs at a surplus, with the central government keeping the money paid by the highest bidder. But, while the auction will lead to the efficient location of the dump, it will not lead to the first-best social outcome. This is because the programme runs at a surplus, and there is no return to money in the hands of the government in the present model.

The proportional welfare loss falls as the external effect w^* increases beyond $-\underline{v}/(n-1)$, since the gains from having the dump increase with w^* while the surplus from the auction stays constant. Although this is not a formal analysis, it gives some intuition as to how large externalities can help improve this type of allocation problem.

6. CONCLUSION

The fact that information is known only locally or by individual firms provides a strong reason for favouring decentralized arrangements. Decentralization is also appealing for both political and philosophical reasons, in that it limits the coercive powers of central authorities. However, we have shown that autonomy and private information together can make it very difficult to internalize externalities. This can lead to substantial losses in social efficiency.

Respect for autonomy (the essence of decentralization in this paper) is critical for this result, since even with private information and externalities, a central government with coercive powers can implement efficient outcomes. In this case, a system of Pigovian taxes and subsidies can be used to achieve efficiency.[32]

When autonomy is respected, and when firms or localities decide whether to make investments of a given size, voluntary agreements may not improve the outcome in a large range of cases. This occurs when the size of the external effect is relatively small compared

31. More realistically, the level of utility flowing from a private dump would equal v. We do not address this scenario here.

32. That is, a system of taxes/subsidies based on w^* and contingent on production.

with net benefits to producers (where "relatively small" may nevertheless be large in an absolute sense.) This may help to explain why coordination is so rarely observed relative to the number of activities associated with externalities.

While these principles are derived in a fairly general framework, the optimal plan is easily implementable. When improvements are possible, they can be achieved through simple subsidies. The results suggest that asymmetric information can lead to large costs in terms of efficiency. However, we have also shown that when externalities are relatively large, the first-best outcome can always be obtained.

APPENDIX A

Proof of Proposition 1

In Section 2, we showed that the inequalities in (10) and (11) give the constraints on our problem. We will proceed by examining three cases, corresponding to possible values of $\bar{v}$.

Case 1: Suppose that $\bar{v}>0$. Then rearranging (11) yields

$$w^*\left[\frac{F(0)-F(\bar{v})}{F(\bar{v})}\right]\geqq \bar{v}.$$

As $\underline{v}<0<\bar{v}$, the term in brackets is less than one in magnitude. Therefore, $\bar{v}=|\bar{v}|<|w^*|$.

Case 2: Suppose that $\bar{v}<0$. Rearranging (10) yields

$$w^*\left[\frac{F(0)-F(\bar{v})}{1-F(\bar{v})}\right]\geqq -\bar{v}.$$

Again our assumptions imply that the term in brackets is less than one in magnitude. Thus, $-\bar{v}=|\bar{v}|<|w^*|$.

Case 3: Suppose $\bar{v}=0$. Since $w^*\neq 0$, $|\bar{v}|<|w^*|$. ||

APPENDIX B

Obtaining ex post efficient outcomes

When can we reach the first-best outcome? If $w^*>0$, we can get the first-best outcome (produce if $v+w^*\geqq 0$) if and only if:

$$\max(\underline{v}, -w^*)(1-F(\max(\underline{v}, -w^*)))+w^*(F(0)-F(\max(\underline{v}, -w^*)))\geqq 0. \tag{15}$$

We look at the two relevant cases. First, we consider the case where $\max(\underline{v}, -w^*)=-w^*$. Here,

$$-w^*(1-F(-w^*))+w^*(F(0)-F(-w^*))=w^*(F(0)-1).$$

Thus we cannot achieve the first-best outcome unless $F(0)=1$ – i.e., unless no firm will ever produce on their own.

In the second case, $\max(\underline{v}, -w^*)=\underline{v}$. Here,

$$\underline{v}(1-F(\underline{v}))+w^*(F(0)-F(\underline{v}))=\underline{v}+w^*F(0).$$

Thus, we require

$$w^*\geqq\frac{-\underline{v}}{F(0)} \tag{16}$$

in order to achieve the first-best. If externalities are negative ($w^*<0$), we can get the first best if and only if

$$-\min(-w^*, \bar{v})F(\min(-w^*, \bar{v}))+w^*(F(0)-F(\min(-w^*, \bar{v})))\geqq 0.$$

By analogous reasoning, this happens if and only if

$$w^*\leqq\frac{-\bar{v}}{1-F(0)} \tag{17}$$

and/or $F(0)=0$.

APPENDIX C

Obtaining the second-best outcome

We are interested in the circumstances under which the second-best outcome improves on the autonomous allocation (i.e., when does the second-best mechanism involve a cut-off type $\tilde{v} \neq 0$?).

We consider first the case of a positive externality ($w^* > 0$; constraint ($\underline{A.1}$) will bind here.) Thus we want to know if there exists a $\tilde{v} < 0$ such that:

$$K(\tilde{v}) \equiv \tilde{v}(1 - F(\tilde{v})) + w^*(F(0) - F(\tilde{v})) \geqq 0.$$

We observe that $K(0) = 0$ and

$$\frac{dK(\tilde{v})}{d\tilde{v}} = 1 - F(\tilde{v}) - \tilde{v}f(\tilde{v}) - w^* f(\tilde{v}).$$

Since

$$\text{sign}\left(\frac{dK(\tilde{v})}{d\tilde{v}}\right) = \text{sign}\left(\frac{1 - F(\tilde{v})}{f(\tilde{v})} - \tilde{v} - w^*\right)$$

and $(1 - F(\tilde{v})/f(\tilde{v})) - \tilde{v} - w^*$ is non-increasing in $\tilde{v}$ by our hazard-rate assumption (9), such a $\tilde{v} < 0$ exists if and only if:

$$\left.\frac{dK(\tilde{v})}{d\tilde{v}}\right|_{\tilde{v}=0} \leqq 0.$$

This is equivalent to

$$w^* \geqq \frac{1 - F(0)}{f(0)}. \tag{18}$$

We now take up the case of a negative externality ($w^* < 0$; constraint ($\overline{A.1}$) will bind here.) Here, we want to know if there exists a $\tilde{v} > 0$ such that:

$$J(\tilde{v}) \equiv -\tilde{v}F(\tilde{v}) + w^*(F(0) - F(\tilde{v})) \geqq 0.$$

Analogous to the case above, this happens when

$$\left.\frac{dJ(\tilde{v})}{d\tilde{v}}\right|_{\tilde{v}=0} \geqq 0$$

since our hazard rate assumption (8) implies that $J(\cdot)$ is single-peaked. This is equivalent to

$$w^* \leqq \frac{-F(0)}{f(0)}. \tag{19}$$

APPENDIX D

Relaxing budget balance

In keeping with our focus on decentralization, we have assumed that budgets must be balanced. However, if there is cross-subsidization of the various activities of governments, budget balance may be too restrictive. Here we show that the qualitative results go through in the more general case in which there is a social cost λ to raising revenues (but no restriction on budget deficits). This section closely follows the general approach of Laffont and Tirole (1993).

We also note that the problem solved in this section is very similar to the problem faced in decentralized bargaining where firm 2 can make a take-it-or-leave-it offer to firm 1. The objective function for that problem is the same as the one here with $\lambda = 0$ and an extra $-U_1$ term subtracted off (since firm 2 dislikes paying transfers to firm 1). The solution to the bargaining problem is the same as the solution to the problem solved in this section with $\lambda/1 + \lambda = 1$.

The central government's problem is

$$\max \int_{\underline{v}}^{\bar{v}} [(1+\lambda)(z+w^*)p(z)-\lambda U_1(z)-\lambda U_2)]f(z)dz$$

subject to

$$\text{(IC)} \quad \frac{dU_1(v)}{dv}=p(v),$$

$$\text{(IR1)} \quad U_1(v)\geqq \max(v, 0), \forall v,$$

$$\text{(IR2)} \quad U_2 \geqq w^*(1-F(0)),$$

$$\text{(Monotonicity)} \quad p(v) \text{ non-decreasing.}$$

The first thing to observe is that U_2 is not a function of v and enters the objective function with a negative sign. Therefore, (IR2) will always bind at the optimum and U_2 is just a constant which can be ignored. This fact implies that side-contracts between the government and firm 1 can never play a role other than to adjust the level of transfer to/from firm 2, even without assuming renegotiation. The reason is that the cost of funds for inducing production depends only on λ in this model; unlike the model with budget balance, it does not depend on the cost of getting these funds from firm 2. Therefore we can again ignore side-contracting with the understanding that our results are modulo a lump-sum transfer to/from firm 2.

We ignore the monotonicity constraint for now, and solve using optimal control. Letting $\mu(v)$ be the Pontryagin multiplier on the (IC) constraint we can write the Hamiltonian as,

$$H=[(1+\lambda)(v+w^*)p(v)-\lambda U_1(v)]f(v)+\mu(v)p(v). \tag{20}$$

Applying the Maximum Principle we have

$$\dot{\mu}(v)=-\frac{\partial H}{\partial U_1}=\lambda f(v)$$

and

$$\frac{\partial H}{\partial p}=(1+\lambda)(v+w^*)f(v)+\mu(v).$$

Assume for the moment that the (IR) constraint binds only at $\underline{v}$. Transversality then requires that $\mu(\bar{v})=0$. This gives

$$\mu(v)=\lambda(F(v)-1).$$

So the conditions on production become

$$p(v)=\begin{cases} 1 & \text{if } v+w^*+\dfrac{\lambda}{1+\lambda}\dfrac{(F(v)-1)}{f(v)}\geqq 0 \\ 0 & \text{otherwise.} \end{cases}$$

Similarly, if the (IR) constraint binds only at $\bar{v}$, transversality requires that $\mu(\underline{v})=0$. This gives

$$\mu(v)=\lambda F(v)$$

and the conditions on production are

$$P(v)=\begin{cases} 1 & \text{if } v+w^*+\dfrac{\lambda}{1+\lambda}\dfrac{F(v)}{f(v)}\geqq 0 \\ 0 & \text{otherwise.} \end{cases}$$

Note that these are the same formulas obtained in the corresponding cases in our model with budget balance, except for the fact that λ is now exogenous rather than endogenous.

We can now investigate the potential for coordination. To ensure that monotonicity is satisfied, assume as before that

$$\frac{d}{dv}\left(\frac{F(v)}{f(v)}\right) \geqq 0$$

and

$$\frac{d}{dv}\left(\frac{1-F(v)}{f(v)}\right) \leqq 0.$$

Define $\tilde{v}(w^*)$ as $\tilde{v}$ such that $v+w^*+(\lambda/1+\lambda)(F(\tilde{v})/f(\tilde{v}))=0$ (i.e., the cut-off type if (IR1) binds only at $\bar{v}$). Then, the cut-off type if $\underline{v}$ only binds is greater than $\tilde{v}(w^*)$; denote it $\hat{v}(w^*)$.

So suppose that $\underline{v}$ binds. This implies

$$U_1(\underline{v})=0$$

$$U_1(\bar{v})=\int_{\hat{v}(w^*)}^{\bar{v}} 1 dv$$

$$=\bar{v}-\hat{v}(w^*).$$

The (IR1) constraint will not bind at $\bar{v}$ if and only if $\hat{v}(w^*)<0$). That is, if and only if

$$w^* > \frac{\lambda}{1+\lambda}\frac{1-F(0)}{f(0)}.$$

Now suppose that $\bar{v}$ binds. This implies

$$U_1(\bar{v})=\bar{v}$$

$$U_1(\underline{v})=\bar{v}-\int_{\tilde{v}(w^*)}^{\bar{v}} 1 dv$$

$$=\tilde{v}(w^*).$$

The (IR1) constraint will not bind at $\underline{v}$ if and only if $\tilde{v}(w^*)>0$. That is, if and only if

$$w^* < -\frac{\lambda}{1+\lambda}\frac{F(0)}{f(0)}.$$

Thus, the constraint binds at both points if

$$-\frac{\lambda}{1+\lambda}\frac{F(0)}{f(0)} \leqq w^* \leqq \frac{\lambda}{1+\lambda}\frac{1-F(0)}{f(0)},$$

and coordination cannot improve on the autonomous allocation.

Note that, other than the $\lambda/1+\lambda$ terms, this is the same condition that we derived in the model with budget balance. As λ approaches $+\infty$, this range approaches the range that we derived earlier. Intuitively, with budget balance there is an infinite cost to subsidizing the project when the constraint binds at both points. Here, however, there is some fixed cost λ.

The first-best outcome can be obtained if

$$w^* \leqq -\bar{v}-\frac{\lambda}{1+\lambda}\frac{1}{f(\bar{v})}$$

or

$$w^* \geqq -\underline{v}+\frac{\lambda}{1+\lambda}\frac{1}{f(\underline{v})}.$$

Notice that here, for the uniform case, if we let λ approach $+\infty$, we get stronger conditions than under budget balance. The intuition is that as the (IR1) constraint binds at only one end as the second-best approaches the first-best, the cost of subsidizing the project is no longer infinite. This reinforces the point that $\underline{\lambda}$ and $\bar{\lambda}$ in the budget balance model are endogenous and depend on the parameters of the model such as w^*, whereas λ here is exogenous.

Finally, for values of w^* which do not fall into either the autonomous or the first-best ranges, we have a second-best outcome which improves on the autonomous allocation. As before, the second-best outcome can be described by a cut-off type $\tilde{v}$ and can be implemented using second-best Pigovian subsidies.

A key here is that reducing the amount of money required for the project at hand frees money for other (valued) projects elsewhere. So, having negative net subsidies (i.e., net taxes) is viable in the model here. It is more difficult to obtain efficient outcomes because when the gains from leaving the money in the projects here are small (since we are very close to the first-best), they are outweighed (socially) by diverting the funds to other projects. In other words, in this setting, a marginal as well as a total cost/benefit evaluation is required. This is important in understanding why, for example, it is harder to obtain first-best investment when firm 2 makes a take-it-or-leave-it offer as compared to a mediator or government proposing a balanced budget scheme.

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