The Choice of Techniques and the Optimality of Market Equilibrium with Rational Expectations

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This paper shows that, in the absence of a complete set of risk markets, prices provide incorrect signals for guiding production decisions. Even if all individuals have rational expectations concerning the distribution of prices which will prevail on the market next period, the market allocation is, in general, not a constrained Pareto optimum. Essentially the only conditions under which, for all technologies, the market equilibrium is a constrained Pareto optimum are those in which risk markets are redundant. We derive the necessary and sufficient conditions for redundancy of risk markets, which turn out to be extremely restrictive.

I. Introduction

This paper shows that, in the absence of a complete set of risk markets, prices provide incorrect signals for guiding production decisions. More precisely, we establish that, even if all individuals have rational expectations concerning the distribution of prices which will prevail on the market next period, the market allocation is, in general,

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not a constrained Pareto optimum. In other words, if we constrain the government to work within the same set of markets, not allowing it either directly or surreptitiously to alter the set of available markets, it would make different production decisions. As a consequence, there exists a set of taxes/subsidies which would generate a Pareto improvement. There are some very special cases where the market equilibrium is a constrained Pareto optimum; these, unfortunately, include some of the more commonly employed parameterizations (e.g., logarithmic utility functions and multiplicative risk). Writers who make these assumptions for analytic convenience may not fully appreciate what strong implications these assumptions have for market efficiency.

It is, of course, well known that if there were a complete set of risk markets the competitive market equilibrium would be Pareto optimal. When there does not exist a complete set of risk markets, a number of questions arise concerning the definition, existence, and optimality of market equilibrium (see, e.g., Diamond 1967; Radner 1968, 1972; Stiglitz 1972, 1975; Drèze 1974; Hart 1975).

This paper is concerned only with the optimality properties of competitive equilibria with rational expectations. We first establish a general characterization theorem providing a necessary condition for the market equilibrium to be Pareto optimal (Sec. III). We then look for restrictions on consumers' and producers' utility functions which will ensure that the economy is a constrained Pareto optimum for all specifications of the technology. We show (Sec. IV) that a necessary and sufficient condition is that the utility functions be such that risk markets are redundant; that is, even if they existed, there would be no trade on them. We provide, moreover, a set of necessary and sufficient conditions for redundancy of risk markets: If the output of all producers is perfectly correlated, we require that either (*a*) all consumers have a logarithmic utility function; or (*b*) all producers be risk neutral, and all consumers have utility functions for which the marginal utility of income is independent of price.

If the outputs of different producers are not perfectly correlated, only condition (*a*) obtains (Sec. X).

These conditions are, as we have said, extremely restrictive and, thus, there is a strong presumption that the market economy is not a constrained Pareto optimum (Sec. VII). On the other hand, using standard approximation techniques, we show that the welfare loss associated with this market imperfection may not be particularly serious (Sec. VIII).

The reason for the nonoptimality is simple: Relative price variability is a source of risk. Since each firm is competitive, it cannot benefit from the fact that its production decision changes the variability of prices. In a complete market, this would be a pecuniary externality, and the firm would be able to profit directly from reducing consumers' risk. In an incomplete market, this is impossible by assumption. In the concluding section of the paper, we provide some further interpretations of this class of market failures.

The question which we address here is, of course, not a new one: Diamond (1967) considered an economy in which there was a single output: All firms had multiplicative uncertainty (i.e., the level of investment did not affect the relative outputs in different states of nature), and no firm had any choice of technique. Under these restrictive assumptions, he established the constrained optimality of market equilibrium (where the notion of constrained optimality is precisely that employed here).

Several subsequent studies (Stiglitz 1972, 1975; Drèze 1974; Hart 1975) cast doubt on the generality of Diamond's results. Hart, in particular, while providing a set of (restrictive) sufficient conditions under which the market equilibrium has certain optimality properties, provides a number of interesting examples demonstrating that, when these conditions are not satisfied, the market equilibrium may not be a constrained Pareto optimum. Our paper differs from Hart's in two important ways: (*a*) Hart's analysis was limited to an exchange economy and, thus, the inefficiencies which he noted were exchange inefficiencies; we are concerned with productive efficiency. (*b*) While Hart provided sufficient conditions for optimality, we provide necessary and sufficient conditions; these conditions not only demonstrate that there is a strong presumption for the nonoptimality of the market equilibrium but provide considerable insight into the nature of the market failure. Moreover, they enable us to derive policies which lead to Pareto improvements in welfare and to estimate the magnitude of the welfare losses associated with nonintervention.

The other important work to which our results should be related is that of Grossman (1977) and Grossman and Hart (1979). They provide a characterization of the sense in which incomplete markets are optimal: "Let there be a different planner at each date and in each event. Assume that the planner at each date-event is permitted to make arbitrary transfers of goods using only the markets which are open in the competitive economy, but that there is no coordination of actions between the planners at different date-events—in other words, the planners play a Nash game with each other. Define an allocation to be a social Nash optimum (SNO) if, given the actions of other planners, each planner's transfers are Pareto optimal" (Grossman and Hart 1979, p. 316). The essential difference between our analysis and that of Grossman and Grossman and Hart is that, in our analysis, the government does not take the transfers of goods in each state as given; these transfers are determined endogenously, as a result of the working of the market. This implies that there may be Pareto improvements from the imposition of investment taxes and subsidies. In addition, we consider some taxes (like ad valorem output taxes) which can be viewed as mechanisms by which the government coordinates allocations across states of nature, a kind of coordination, though plausible in practice, that Grossman does not allow his planners to undertake.

In this paper, we do not discuss alternative explanations of the absence of a complete set of markets. Short of such an explanation, there is always the concern that the proposed market intervention is infeasible for the same reason that the markets are incomplete.[1] In this paper, we analyze a specific context in which equity markets are absent because output is not observable (other than to the farmer himself) but inputs are. Although in such an environment output taxes and subsidies would not be feasible, input taxes/subsidies would be, and, under certain circumstances, Pareto improvements can be effected even with these limited instruments.

II. A Simple Model with Identical Farmers and Consumers

We examine these questions within the context of the simplest possible model. There are two groups within the population: farmers and consumers. All farmers are identical, and all consumers are identical. We first describe the farmers' behavior, then consumers', and finally market equilibrium. In the next section, we define and analyze the constrained Pareto optimum and compare it with the market equilibrium.

Farmers

All farmers are identical and must choose the level of some decision variable, ξ, at the start of the season, before the state of nature, θ (e.g., the weather), is known. Output, q, is an increasing function of ξ and θ, and is concave in ξ:

$$q = f(\xi, \theta), \ f_\xi \geq 0, \ f_\theta > 0, \ f_{\xi\xi} \leq 0. \tag{1}$$

[1] For instance, if the proposed policy intervention involves output taxes, the natural question to ask is, given that it is assumed that the value of output can be observed, is it not reasonable to introduce securities the payments on which are contingent on the value of output (equities)? And if these securities are introduced, would not the efficiency of the market be restored? It is important to observe that the introduction of equity markets would not alter the basic nonoptimality result (see Stiglitz, in press).

If there are N farmers, aggregate output is

$$Q = Nq \equiv Q(\xi, \theta). \tag{2}$$

Since all farmers are identical, we can represent the action taken by a single number (although in principle we should write down the action taken by each farmer).

Each farmer takes the distribution of prices as given (this is the natural generalization of the price-taking assumption of the conventional nonstochastic model). Later, we shall discuss how this price distribution is determined. As we shall see, it will depend on the actions taken by all other farmers, the state of nature, and the income of the consumers I:[2]

$$p = p(\xi, \theta, I). \tag{3}$$

The income of a farmer in state θ when he takes action ξ is thus

$$y = pf(\xi, \theta). \tag{4}$$

We assume the farmer has a concave utility function which depends on both his income and the action he takes:

$$U = U(y, \xi), U_y > 0, U_{yy} < 0, U_{\xi\xi} \leqslant 0. \tag{5}$$

(The marginal utility of income is positive but diminishing, and U is concave in ξ.) He chooses ξ to maximize his expected utility

$$\max_{\{\xi\}} EU(y, \xi), \tag{6}$$

given expectations about prices, $p(\xi, \theta, I)$, so that he sets

$$E\{U_y pf_\xi + U_\xi\} = 0. \tag{7}$$

Several special interpretations of this general model should be noted. In one interpretation, ξ is a choice of technique. In that case, we postulate that ξ changes the probability distribution of outcomes but does not directly affect utility, that is, $U_\xi = 0$. A second interpretation has ξ as the level of investment or the cost of purchased inputs such as fertilizer. Then, net income of the farmer is $y - \xi$, and we write $U = u(y - \xi)$. In the third interpretation, ξ is the level of effort supplied by the individual. If the individual's utility function is separable between income and effort, $U = u(y) - z(\xi)$, where $z(\xi)$ is the disutility of effort.

The action taken by the individual farmer is a function of his

[2] If consumers do not have identical, homothetic indifference maps, it will also depend on the distribution of income as well; but we shall assume that the distribution of income remains invariant throughout the model.

expectations concerning the distribution of prices. If his expectations are rational, that is, the expected price distribution corresponds to the actual price distribution, then, since the latter will depend on the actions taken by all other farmers, his action will depend on the actions taken by all other farmers. The precise relationship depends, however, on the properties of the demand functions of consumers, to which we now turn.

Consumers

Consumers make their consumption decisions after the state of nature and, hence, market prices are known. Their choices can, therefore, be described by an indirect utility function, which we represent as a function of the price of this particular good, p, and money income, I, the prices of all other goods being assumed constant. We assume, again for simplicity, that (1) consumers' income does not depend at all on producers' income or prices or the state of the world, θ. (This makes sense if production and consumption occur in different locations, and consumers cannot or do not buy stock or speculate on the price of the agricultural commodity. The assumption is for simplicity and can be relaxed, as in Stiglitz [in press] without changing the presumption of market inefficiency.) (2) Producers do not consume the commodity which they produce at all (this again is a simplifying assumption, not crucial to the analysis). (3) The price of the given good does not have any significant effect on the price of other goods, an assumption which makes sense for a commodity which is a small part of consumers' budgets, or if other relative prices were determined by a technology satisfying the nonsubstitution theorem. The representative consumer thus has utility represented by the indirect utility function $V(p, I)$, and his demand q^c, derived from Roy's identity is

$$q^c = -\frac{\partial V}{\partial p} \Big/ \frac{\partial V}{\partial I}. \tag{8}$$

Aggregate demand, D, of the M identical consumers is just

$$D = Mq^c \equiv D(p, I), \tag{9}$$

a function of price and the income of the representative consumer.

Market Equilibrium

The market equilibrium price distribution is now easy to determine, given the demand function (9): For each ξ and θ, there is a particular value of aggregate supply, $Q(\xi, \theta)$, and the market-clearing price is then the price which equates aggregate demand, D, to this supply:

$$Q(\xi, \theta) = D[p(\xi, \theta, I), I]. \tag{10}$$

We described earlier the behavior of farmers. Recalling equation (7) and now letting $p(\xi, \theta, I)$ be the solution to equation (10), since all farmers are identical, a rational expectations market equilibrium is a value of ξ^* and a function $p(\xi^*, \theta, I)$ for which

$$E\frac{\partial U[p(\xi^*, \theta, I)f(\xi^*, \theta), \xi^*]}{\partial y}pf_{\xi}(\xi^*, \theta) + E\frac{\partial U[p(\xi^*, \theta, I)f(\xi^*, \theta), \xi^*]}{\partial \xi} = 0, \tag{11}$$

and equation (10) is satisfied for all values of θ.

III. The Nonoptimality of Market Equilibrium

Introduction

We now wish to evaluate the market equilibrium described in the previous section. To do this, we need to compare the welfare of consumers and producers in the market equilibrium with that in some other feasible allocation. In making the comparison, however, we need to take into account the constraints on the set of markets. It is obvious that, except under certain special cases (to be detailed below), the marginal rate of substitution between income in different states of nature will differ for different individuals, so long as there are not markets which enable them to trade income in one state for income in another. Thus, were it costless to establish new markets, clearly there exists a resource allocation which is Pareto superior to the market equilibrium. But this is an unfair (and probably irrelevant) comparison. We now wish to know, given the restrictions on the set of markets, whether there exists a Pareto-superior allocation. The answer is that there almost always does. We first analyze the optimal resource allocation assuming: (1) the government could directly control the choice of technique, ξ; (2) the government can engage in lump-sum redistributions which are not state dependent;[3] but (3) it cannot introduce any new markets, in particular, it cannot introduce insurance markets (on θ), futures markets (on p), or stock markets. Later we ask

[3] Obviously, if the government could make state-dependent lump-sum transfers, it could equate all individuals' marginal rates of substitution across the states of nature and achieve the same outcome as a complete set of markets.

whether this constrained Pareto optimum is decentralizable (i.e., by tax-subsidy policies).

Suppose the lump-sum subsidy to each of the N producers is s, financed by a lump-sum tax on each of the M consumers of amount Ns/M.

The set of (constrained) Pareto optima is described by the solution to

$$\max_{(s,\xi)} \mathscr{L} \equiv EV\left[p(\theta, \xi, s), I - \frac{sN}{M}\right] + \frac{\lambda N}{M} EU[p(\theta, \xi, s)f(\xi, \theta) + s, \xi] \tag{12}$$

for values of $\lambda \geqslant 0$. By changing λ we can trace all points on the utility-possibility frontier. This formulation assumes that the government has full power to redistribute income, so that the only remaining issue is the one under study of achieving an efficient allocation of resources. We are concerned with characterizing the Pareto-efficient allocations. Choosing s yields the first-order condition:

$$\frac{\partial \mathscr{L}}{\partial s} = \frac{N}{M}(-EV_I + \lambda EU_y) + E\left(V_p + \frac{\lambda N}{M} U_y f\right)\frac{\partial p}{\partial s} = 0. \tag{13}$$

Using Roy's identity (eq. 8), equation (10), and the fact that $Nf = Q$, total supply, and $Q = Mq^c$, total demand, we can rewrite (13):

$$E(\lambda U_y - V_I)\left(1 + \frac{Q}{N}\frac{\partial p}{\partial s}\right) = 0. \tag{14}$$

The term $\partial p/\partial s$ is found by implicit differentiation of demand, $D[p, I - (Ns/M)]$, which is fixed equal to the level of supply:

$$\frac{Q}{N}\frac{\partial p}{\partial s} = \frac{Q}{N}\frac{\partial D/\partial s}{\partial D/\partial p} = \frac{Q}{M}\frac{\partial D/\partial I}{\partial D/\partial p} = -\frac{\alpha\eta}{\epsilon}, \tag{15}$$

where α is the fraction of consumer income spent on the commodity, η is the income elasticity of demand, and ϵ is the (absolute value of the) elasticity of demand. Equation (14) can be rewritten as

$$E\{(\lambda U_y - V_I)[1 - (\alpha\eta/\epsilon)]\} = 0. \tag{16}$$

Now choose ξ so that

$$\frac{\partial \mathscr{L}}{\partial \xi} = E\left(V_p + \lambda\frac{N}{M} U_y f\right)\frac{\partial p}{\partial \xi} + \lambda\frac{N}{M}E\left(U_y p\frac{\partial f}{\partial \xi} + \frac{\partial U}{\partial \xi}\right) = 0. \tag{13'}$$

From equation (7), in market equilibrium, the second term is zero.

The first term can be simplified using Roy's identity (8) and noting that:

$$\frac{Q}{M}\frac{\partial p}{\partial \xi} = \frac{QN}{M}\left(\frac{\partial f}{\partial \xi} \Big/ \frac{\partial D}{\partial p}\right) = -\frac{N}{M}\frac{p}{\epsilon}f_{\xi}. \tag{17}$$

We therefore have the following fundamental result.

Theorem 1a.—A necessary condition for the rational expectations equilibrium to be a constrained Pareto optimum is that

$$B(\xi) \equiv E(\lambda U_y - V_I)\frac{p}{\epsilon}\frac{\partial f}{\partial \xi} = 0. \tag{18}$$

$B(\xi) = 0$ is almost a sufficient condition for the rational expectations equilibrium to be a constrained Pareto optimum. We have, however, not yet ruled out the possibility that the Lagrangian has several critical points; the market equilibrium may correspond to one of these (so $B = 0$), but this may not be a global maximum. It is easy to establish the following theorem, however.

Theorem 1b.—A sufficient condition for the market to be constrained Pareto optimal is that $\mathscr{L}$ be concave in s and ξ and, at the market allocation, ξ^m, $B(\xi^m) \equiv 0$.

We shall show below that only under unusual circumstances will $B = 0$ at the market equilibrium, and it follows that only under even more unusual circumstances will $B = 0$ at the market equilibrium and the market not be a constrained Pareto optimum.

We should point out that concavity of U in s and ξ, of V in s, and of f in ξ is not sufficient to ensure the concavity of $\mathscr{L}$, as can be seen by twice differentiating $\mathscr{L}$. However, for the logarithmic indirect utility function which plays a central role in the following analysis, concavity is ensured.

IV. Redundancy of Risk Markets and Constrained Pareto Optimality

In the previous subsection, we derived a simple condition which (together with the assumption of concavity) was both necessary and sufficient for the market equilibrium to be a constrained Pareto optimum. We need, however, to interpret this condition, to see under what circumstances it will be satisfied, in order to ascertain whether it is likely that the market equilibrium is a constrained Pareto optimum.

The condition (18) can be thought of as a generalization of the condition for full Pareto optimality, that the marginal rate of substitution between different states of nature be the same for all individuals. What equation (18) requires is that some kind of weighted-average marginal rate of substitution be the same. That is, we can rewrite equation (18) as

$$B \equiv E(1 - \rho)V_I \frac{Q}{M} \frac{\partial p}{\partial \xi} = 0, \tag{19}$$

where $\partial p/\partial \xi$ is given by (17), and where

$$\rho = \frac{U_y(\theta)/U_y(\hat{\theta})}{V_I(\theta)/V_I(\hat{\theta})} \tag{19'}$$

is the ratio of marginal rates of substitution between income in states θ and $\hat{\theta}$, and where $\hat{\theta}$ is that state where the ratio of marginal utilities equals λ.

A special case of this arises when the marginal rates of substitution are the same state by state, that is, $V_I = \lambda U_y$ for some value of λ. In that case, of course, if risk markets were opened up, there would be no trade on them. We say that in these cases risk markets are redundant. We thus have an immediate corollary of theorem 1.

Theorem 2.—A sufficient condition for the constrained optimality of the market equilibrium is the redundancy of risk markets.

If risk markets are redundant, the market equilibrium is a full Pareto optimum.

We next ask three questions.

i) Are there restrictions on the utility functions which, for all production functions, ensure the redundancy of risk markets?

ii) Are there weaker restrictions on the utility functions which, for all production functions, ensure the constrained optimality of market equilibrium? If there are not, then, in a sense, the conditions for risk market redundancy are both necessary and sufficient for the constrained optimality of the market.

iii) Are there reasonable restrictions on the technology which, together with some weak restrictions on the utility functions, ensure the constrained Pareto optimality of the market?

The first question is easy to answer: There are a set of (fairly restrictive) assumptions under which (in our simple model) risk markets are always redundant. These conditions are set out below in Section V.

The second question is more difficult to answer but provides one of our key results: In Section VI we are able to show that redundancy of risk markets is both necessary and sufficient for the market equilibrium to be a constrained Pareto optimum for all technologies. It turns out that constrained Pareto optimality is critically as strong a condition as full Pareto optimality.

The final question is the most difficult, and Section VII provides some insight into it.

V. Necessary and Sufficient Conditions for Risk Market Redundancy

The set of conditions under which risk markets are redundant is very restrictive. We first establish the following theorem.

Theorem 3a.—Sufficient conditions for the redundancy of risk markets are either that (1) there is no risk; or (2) producers are risk neutral, and $V_{Ip} = 0$; or (3) consumers have an indirect utility function of the form

$$V = -k \ln p + b\phi(I), \tag{20}$$

which corresponds to a direct utility function defined on consumption, q, of the risky commodity and c of "other goods": $\alpha \ln q + (1 - \alpha) \ln c$, in the special case where $\phi = \ln I$.

Proof.—Condition 1 is trivial. (2) If $V_{Ip} = 0$, then consumers' marginal utility of income, V_I, is constant in all states of nature; and if producers are risk neutral, their marginal utility is constant in all states of nature. Hence, the marginal rate of substitution between any two states of nature is unity for both producers and consumers, or ρ in equation (19) is unity, guaranteeing the redundancy of risk markets. (3) The logarithmic indirect utility function generates, by Roy's formula, demand curves which have unitary price elasticity. Hence, farmers' income is constant. Hence, the marginal utility of farmers' income is the same in all states. Moreover, $V_{Ip} = 0$, so consumers' marginal utility of income is the same in all states. Hence, the marginal rate of substitution between income in all states is unity, and risk markets are redundant.

These conditions are, in fact, necessary as well. If risk markets are to be redundant, we require the ratio of the marginal utilities of income, V_I/U_y, to be the same for all θ. As θ varies, so does Q, so this is equivalent to requiring

$$\frac{d \ln U_y}{d \ln Q} = \frac{d \ln V_I}{d \ln Q}. \tag{21}$$

But

$$\frac{d \ln U_y}{d \ln Q} = y \frac{U_{yy}}{U_y} \frac{d \ln y}{d \ln Q} = -R \frac{d \ln pQ}{d \ln Q} = -R\left(1 - \frac{1}{\epsilon}\right), \tag{22}$$

where R is the coefficient of relative risk aversion of producers. Similarly, the right-hand side of equation (21) gives

$$\frac{d \ln V_I}{d \ln Q} = \frac{d \ln V_I}{d \ln p} \frac{d \ln p}{d \ln Q} = -\frac{V_{Ip}p}{V_I} \frac{1}{\epsilon}. \tag{23}$$

Using (8), V_{Ip} can be evaluated as follows: $V_{Ip} = -(dq^c/dI)V_I - q^c V_{II} =$

$(V_I q^c/I)(-\eta + R^c)$; $R^c = -(V_{II}I/V_I)$, where R^c is consumers' relative (income) risk aversion. Substituting into (23), and substituting (23) and (22) into (21), we require for risk market redundancy that

$$R(1 - \epsilon) = -\frac{pV_{Ip}}{V_I} = \alpha(\eta - R^c). \tag{24}$$

Equation (24) can also be written (if $\epsilon \neq 1$) as a condition relating producers' attitudes to risk to consumers' behavioral characteristics:

$$R = \frac{\alpha(\eta - R^c)}{1 - \epsilon}. \tag{24'}$$

Equation (24) can be interpreted as a condition which must hold between producers' and consumers' attitudes, as measured by parameters R, R^c, η, α, and ϵ, if risk markets are to be redundant when there is risk. If producers are risk neutral, $R = 0$; so for (24) to be satisfied, V_{Ip} must be zero. If (24) is to hold for all values of R, ϵ must be unity, and $V_{Ip} = 0$. But if $V_{Ip} = 0$, the indirect utility function must have the special form $V = a(p) + b\phi(I)$, so $q^c = -(a'/b\phi')$. If the elasticity of demand is unity, $a' = -k/p$ for some (positive) constant k; hence, $a = -k \ln p$. We have thus established (if there is risk) the following theorem.

Theorem 3b.—A necessary condition for risk market redundancy with risk-neutral producers is that $V_{Ip} = 0$.

If risk markets are to be redundant regardless of the risk aversion of producers, consumers must have a utility function of the form

$$V = -k \ln p + b\phi(I). \tag{25}$$

These results are important in identifying the special set of circumstances in which the market attains not only a constrained Pareto optimum but a full Pareto optimum.

VI. Necessary Conditions for Constrained Pareto Optimality

The sufficient conditions for the full optimality of the market are, of course, very restrictive. We wish to know whether there are other conditions which will lead the market equilibrium to be a constrained Pareto optimum. For particular values of the parameters, the market might happen to be a constrained Pareto optimum. But a small perturbation of any of the functions involved in the analysis—the consumer's utility function, the producer's utility function, the probability distribution of states, or the production function—might destroy the constrained Pareto optimality of market equilibrium.

We establish here that the necessary conditions for the market equilibrium to be a constrained Pareto optimum for all technologies are exactly the same as the conditions for redundancy of risk markets. We establish this by looking at a special subset of technologies. There are only two states of nature, which occur with probability π and $1 - \pi$. There is a transformation curve facing each farmer,

$$q_2 = T(q_1), \tag{26}$$

where q_i = output in state i, $i = 1, 2$. The choice of technique has no direct effect on utility, $U_\xi = 0$. For notational simplicity, we let p_i, y_i, U'_i, and so on equal price, income, and marginal utility of income in state i, and we use dashes for derivatives. The farmer's first-order condition (7) becomes

$$U'_1 p_1 \pi + U'_2 p_2 (1 - \pi) T' = 0, \tag{27}$$

while the condition for the socially optimal choice of ξ (18) becomes

$$\lambda\left[U'_1 \frac{p_1}{\epsilon_1}\pi + U'_2 \frac{p_2}{\epsilon_2}(1 - \pi)T'\right] = V_I(p_1)\frac{p_1\pi}{\epsilon_1} + V_I(p_2)\frac{p_2}{\epsilon_2}(1 - \pi)T', \tag{28}$$

where $V_I(p_i) \equiv V_I(p_i, I)$.

Substituting (16) and (27) into (28), we obtain as a necessary condition for Pareto optimality that

$$U'_1\left(\frac{1}{\epsilon_1} - \frac{1}{\epsilon_2}\right) = \frac{EU'[1 - (\alpha\eta/\epsilon)]}{EV_I[1 - (\alpha\eta/\epsilon)]} \cdot V_I(p_1)\left[\frac{1}{\epsilon_1} - \frac{1}{\epsilon_2}\frac{U'_1/U'_2}{V_I(p_1)/V_I(p_2)}\right]. \tag{29}$$

If equation (29) is to be satisfied identically for all technologies, it must be satisfied identically for all values of q_1, q_2, and π. Define

$$\psi_i = U'_i[1 - (\alpha_i\eta_i/\epsilon_i)] \tag{30}$$

and

$$\chi_i = V_I(p_i, I)[1 - (\alpha_i\eta_i/\epsilon_i)]. \tag{31}$$

Equation (29) can be rewritten as

$$\left(\frac{1}{\epsilon_1} - \frac{1}{\epsilon_2}\right) = \frac{E\psi}{E\chi}\left(\frac{1}{\epsilon_1}\frac{\chi_1}{\psi_1} - \frac{1}{\epsilon_2}\frac{\chi_2}{\psi_2}\right).$$

Expand the expected values and rearrange to give

$$\left(\frac{\chi_2}{\chi_1} - \frac{\psi_2}{\psi_1}\right)\left(\frac{1 - \pi}{\pi} + \frac{\psi_1}{\psi_2}\frac{\epsilon_1}{\epsilon_2}\right) = 0. \tag{32}$$

If this is to hold for all values of π, then

$$\frac{\chi_2}{\chi_1} = \frac{\psi_2}{\psi_1}, \text{ or } \frac{U'_2}{V_I(p_2)} = \frac{U'_1}{V_I(p_1)}, \tag{33}$$

and the ratio of the marginal utilities is the same state by state. If this is to be true for all technologies, this must hold for all values of (Q_2, Q_1) or (p_2, p_1). But this is precisely the condition we identified before as the necessary condition for risk market redundancy (eq. 21).

We summarize our analysis in the following theorems.

Theorem 4.—A necessary condition for the constrained Pareto optimality of the market equilibrium for all technologies and for all attitudes toward risk by farmers is that risk markets be redundant.

Theorem 5.—Only for those particular combinations of utility functions of farmers and consumers which satisfy equation (24′) will the economy be a constrained Pareto optimum for all technologies.

VII. Restrictions on Technology Which Ensure Optimality

The previous section established that, without restrictions on the technology, the necessary and sufficient conditions for the optimality of the market equilibrium were precisely the conditions for the redundancy of risk markets. If we impose restrictions on the set of technologies, then we can obtain constrained Pareto optimality under conditions which are weaker, but only slightly so. Using the kinds of techniques used to prove theorems 2–5 we can establish the following theorem.[4]

Theorem 6.—If producers face multiplicative risk, so $f(\theta, \xi) = g(\theta)h(\xi)$, a sufficient condition for constrained Pareto optimality is that consumers' preferences can be represented by the indirect utility function

$$V = (a + bp)^{-1/b}I. \tag{34}$$

The proof consists in showing that the term $1 - (\alpha\eta/\epsilon)$ of equation (16) is constant for this function, which, together with multiplicative risk, ensures that $B(\xi^m) = 0$ in equation (18).

Theorem 7.—If individuals have homothetic indifference maps and firms have multiplicative risk, then if, for all specifications of the probability distribution of returns and producers' utility functions, the market equilibrium is to be a constrained Pareto optimum, the consumers' utility function must be of the form of equation (34).

Theorem 8.—If consumers' utility function is of the form of equation (34) (which includes the constant demand elasticity as a special case), then a necessary condition for constrained optimality is either that risk markets be (locally) redundant or that there be multiplicative risk.

[4] For a more extended discussion of these theorems and proofs, see Newbery and Stiglitz (1981).

VIII. The Magnitude of the Distortions

In previous sections we have established conditions required for the market equilibrium to be a constrained Pareto optimum. We would like to be able to assess the magnitude and direction by which the optimal value of ξ differs from the market equilibrium value. To do this we define $X(\xi) = U_y p f_\xi + U_\xi$. The optimal choice of ξ, ξ^o, must satisfy equation (13′), which we rewrite as

$$EX(\xi^o) = \frac{1}{\lambda} B(\xi^o). \tag{35}$$

In contrast, from (7) $EX(\xi^m) = 0$.

The left-hand side of equation (35) can be expanded about the market choice of technique, ξ^m, to find the direction and magnitude of the bias away from the constrained efficient allocation:

$$\xi^o - \xi^m \approx \frac{B(\xi^o)}{\lambda EX'(\xi^m)}. \tag{36}$$

In order to interpret this result, it is necessary to decide how best to parameterize the choice of technique, ξ. One natural method is to let ξ measure the standard deviation (or perhaps the coefficient of variation) of output, in which case equation (36) will measure the extent to which the farmers choose insufficiently risky production, and the right-hand side will typically depend on the degree of risk aversion and the extent to which mean output increases as more risky techniques are employed. Rather than derive various measures of the bias, it might be more useful to illustrate the method for the two-state example of Section VI. Moreover, the fundamental issue is how large is the loss of welfare that results from the market's failure to achieve a constrained Pareto optimum relative to the likely welfare gains to be derived from specific policy intervention (such as price stabilization), which we can calculate once the model has been fully specified.

Consider the special case in which there are equally probable states of the world, and the production trade-off between output in the two states of the world is linear:

$$q_2 = T(q_1) = a - bq_1, \quad b > 1. \tag{37}$$

Suppose also that the choice of technique does not affect farmers' welfare ($U_\xi = 0$) and that consumers have an indirect utility of the form

$$V(p, I) = \frac{(p^{-\alpha} I)^{1-R^c}}{1 - R^c}, \tag{38}$$

so that price and income elasticities are unity, and their coefficient of relative risk aversion is R^c. Suppose, finally, that the distribution of income is satisfactory at the competitive equilibrium (i.e., we are only interested in efficiency). In this simple model, farmers experience no risk, and their welfare is independent of the state of the world and the level of output, since (with equal numbers of consumers and farmers) $y_i = p_i q_i = \alpha I$. The competitive equilibrium choice of q_1, q_2 is given by equation (27), which can be solved to give

$$q_1^m = \frac{a}{2b}, q_2^m = \frac{a}{2}, \bar{q}^m = \frac{a(1 + b)}{4b}, \sigma^m = \frac{b - 1}{b + 1}, \tag{39}$$

where $\bar{q}^m$ and σ^m are, respectively, mean output and its coefficient of variation at the market equilibrium.

The constrained efficient solution is given by equation (28) (using [27] and the fact that $\epsilon_1 = \epsilon_2 = 1$):

$$-T' = \frac{V_I(p_1)p_1}{V_I(p_2)p_2} = \left(\frac{p_1}{p_2}\right)^{1-\alpha(1-R^c)} = \left(\frac{q_2}{q_1}\right)^{1-\beta}, \tag{40}$$

where $\beta = \alpha(1 - R^c)$. Hence, if $\gamma = 1/(1 - \beta)$, then

$$q_1^o = \frac{a}{b + b^\gamma}, q_2^o = \frac{ab^\gamma}{b + b^\gamma}, \bar{q}^o = \frac{a(1 + b^\gamma)}{2(b + b^\gamma)}, \sigma^o = \frac{b^\gamma - 1}{b^\gamma + 1},$$

where q_i^o is output in the optimal allocation in state i, $\bar{q}^o$ is mean output, and σ^o is the coefficient of variation of output. If $R^c > 1$, $\beta < 0$, and the optimal choice of technique involves less risk than the market choice, while, if consumers are not very risk averse ($R^c < 1$), then the market supplies too little risk. The optimum and competitive equilibrium are shown below in figure 1 for the case $R^c < 1$.

Since farmers enjoy the same income for any output (unit price elasticity), their welfare is constant along the transformation frontier AB. Consumers would, however, rather be at E than M, and the inefficiency of competitive equilibrium can be measured by the lump-sum tax on consumers' income which, if paid at E, would make them no better off than at M. The benefit of moving from M to E (equal to this lump sum) can be found by expanding consumers' welfare in a Taylor series, and, as a fraction of consumer expenditure on the commodity, is approximately

$$L \approx \frac{\Delta\bar{q}}{\bar{q}} - \frac{(1 - \beta)}{2}\Delta\sigma^2; \qquad \Delta\bar{q} \approx Eq^o - Eq^m$$
$$\Delta\sigma^2 \approx (\sigma^o)^2 - (\sigma^m)^2. \tag{41}$$

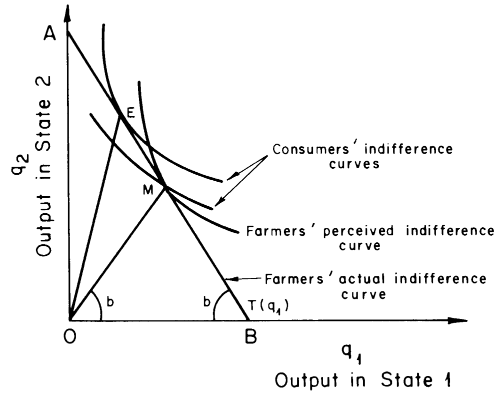

FIG. 1.—The difference between market and efficient choice of technique

These terms can also be evaluated by Taylor series expansions, assuming b is near 1, so σ^0 and σ^m are small:

$$\frac{\Delta\bar{q}}{\bar{q}} \simeq \frac{\beta}{1-\beta}(\sigma^m)^2; \qquad \Delta\sigma^2 \simeq \left[\left(\frac{1}{1-\beta}\right)^2 - 1\right](\sigma^m)^2. \tag{42}$$

Altogether, the proportional benefit from eliminating inefficiency is approximately

$$L \approx \frac{\beta^2}{2(1-\beta)}(\sigma^m)^2. \tag{43}$$

Although this expression is of the order $(\sigma^m)^2$, it should be remembered that if R^c is not too large, $\beta = \alpha(1 - R^c)$ is small, since the expenditure share, α, for most commodities is very small. Thus, for this particular parameterization, the welfare loss associated with the production inefficiencies from incomplete markets will be small if consumers' risk aversion is not too large. If it is, the loss may be significant. In the more general case, the welfare loss will depend not only on the magnitude of consumers' risk aversion but also on that of producers and the elasticity of demand (see Newbery and Stiglitz, in press).

IX. Optimal Corrective Tax Policy

The allocation described in Section III could be attained if the government could directly control ξ, the choice of technique. One interpretation of our finding is that the fundamental decentralization theorem does not hold in the absence of a complete set of risk markets, for it is not possible to achieve the constrained efficient allocation on competitive markets using only lump-sum taxes. Since direct control is evidently impractical, it is necessary to inquire whether there are tax policies which allow the constrained optimum to be decentralized. This question raises some subtle issues.

For example, if the government levies an ad valorem tax on producers, its tax revenue will depend on the state of the world, and we must ask whether its budget is to be balanced in each state of the world or only on the average. In the former case, the lump-sum transfer will vary with the state of the world, while in the latter case purchasing power will vary. It can, however, be shown that regardless of the restrictions on feasible tax policies it is, in general, possible to make Pareto improvements.

Let us consider the simplest case in which the government budget must balance state by state and taxes can be at either constant ad valorem rates or lump sum. We now establish the following theorem.

Theorem 9a.—A constant ad valorem tax rate (the proceeds of which are distributed as lump-sum payments to producers),

$$\tau^* = \frac{1}{\lambda}\,\frac{E(\lambda U_y - V_I)pf_\xi/\epsilon}{EU_y pf_\xi}, \tag{44}$$

supports the constrained Pareto optimum.

Proof.—Farmers will set $EU_y p(1 - \tau^*)f_\xi + EU_\xi = 0$. Substituting for the tax rate τ^*, this implies $\lambda E(U_y pf_\xi + U_\xi) - E(\lambda U_y - V_I)pf_\xi/\epsilon = 0$, which is the condition for constrained Pareto optimality of equation (18′).

Pareto improvements may even be attainable (under somewhat more restrictive conditions) if the government is further restricted in its instruments. Consider, for instance, the case where ξ has the interpretation as the level of investment, and where producers' utility function, accordingly, is written $U = U(pf + s - \xi)$. Now assume that ξ is observable, and the government imposes an investment tax at the rate τ with proceeds, $\tau\xi$, distributed to producers as lump-sum payments. Assume, moreover, that the government provides an additional lump-sum subsidy (tax) so that producers' expected utility is left unchanged. Producers will now set $EU'pf_\xi = EU'(1 + \tau)$, and the required subsidy $\hat{s}$ is such that (at $\tau = 0$)

$$EU'\left(f\frac{dp}{d\tau} + \frac{d\hat{s}}{d\tau}\right) = 0, \tag{45}$$

where $dp/d\tau$ is the total derivative of price with respect to the change in policy. The effect of this policy on the representative consumer is given by $E[V_p(dp/d\tau) - V_I(ds/d\tau)]$, where s is the per capita tax on consumers to finance the producer subsidy. Using Roy's identity, (8), and (45), we observe that

$$\frac{dV}{d\tau} \gtreqless 0 \text{ as } \frac{EV_I f(dp/d\tau)}{EV_I} \gtreqless \frac{EU' f(dp/d\tau)}{EU'}.$$

It is immediate from our earlier analysis that the only conditions under which equality will hold (for all technologies) will be those in which risk markets are redundant; otherwise, there always exists an investment tax or subsidy, accompanied by a lump-sum tax or subsidy, which leaves producers unaffected and improves consumers' welfare. Under more restrictive conditions, a lump-sum transfer from consumers to producers (or conversely), unaccompanied by a production tax or subsidy, may constitute a Pareto improvement.

X. Imperfectly Correlated Output Risk

We shall now show that if farmers do not have perfectly correlated outputs, then, even under the stringent conditions in which the market allocation is a constrained Pareto optimum with perfect correlation, the market allocation is unlikely to be a constrained Pareto optimum. We prove the following theorems.

Theorem 10a.—A sufficient condition for constrained Pareto optimality with imperfectly correlated returns is the redundancy of risk markets.

Theorem 10b.—Necessary and sufficient conditions for redundancy of risk markets for all technologies are that all farmers be risk neutral and $V_{Ip} = 0$.

Theorem 10c.—If the economy is to be a constrained Pareto optimum for all technologies, all farmers must be risk neutral and $V_{Ip} = 0$.

The first theorem is obvious: If risk markets are redundant, the economy in fact attains a first-best optimum. Sufficiency in the second theorem is also fairly trivial. If the marginal rates of substitution between any two states are the same for all individuals, clearly risk markets will be redundant; and they will be the same if the marginal utility of income of all individuals is constant. But if all farmers are risk neutral and $V_{Ip} = 0$, clearly, the marginal utility of all producers and all consumers is constant.

Necessity is only slightly more difficult to establish. If risk markets are to be redundant, the marginal rates of substitution between income in different states of nature must be the same for all farmers; that is, letting $U^j(y^j)$ represent the utility of the jth farmer as a function of his income, y^j, we require that U^j_y/U^k_y be constant. Differentiating logarithmically with respect to aggregate output, Q, we obtain

$$R^j\left(\frac{d\ln q^j}{d\ln Q}-\frac{1}{\epsilon}\right)=R^k\left(\frac{d\ln q^k}{d\ln Q}-\frac{1}{\epsilon}\right), \tag{46}$$

where q^j is the output of the jth farmer, and R^j is his relative risk aversion. The quantity $d\ln q^j/d\ln Q$ measures the correlation between the jth farmer's output and aggregate output. In the previous discussion, this was assumed to be unity. However, in the more general case with imperfect correlation this can take on any value; hence, if (46) is to hold for all technologies, clearly $R^j = R^k = 0$, all farmers must be risk neutral. Moreover, if their marginal rate of substitution between income in different states is unity, so must consumers', if risk markets are to be redundant. But this implies $V_{Ip} = 0$.

Theorem 10c is the most difficult to prove. To do this we first state a characterization theorem for the constrained Pareto optimality of markets with many producers which is the analogue to theorem 1. (The proof is exactly parallel to that of theorem 1.)

Theorem 11.—A necessary condition for the rational expectations equilibrium to be a constrained Pareto optimum is that

$$B^i(\xi^i)\equiv E\left(\sum_k\lambda^k\beta^kU_y^k-V_I\right)\frac{p}{\epsilon}Qf_\xi^i=0,\quad\text{all } i, \tag{47}$$

where $f^i(\theta,\xi^i)$ = the ith farmer's production function; λ^k = Lagrange multiplier associated with the kth farmer's utility; and $\beta^k = q^k/Q$, share of the kth farmer's output in aggregate output ($\Sigma_k\beta^k = 1$). Defining ρ^k as in (19′), we can rewrite (47) as

$$B^i(\xi^i)=E\left(1-\sum_k\rho^k\beta^k\right)\frac{V_{Ip}}{\epsilon}Qf_\xi^i=0. \tag{48}$$

This says that a necessary condition for the constrained Pareto optimality of the market is that a particular weighted average of marginal rates of substitution of producers and consumers be the same.

Since, from theorem 4, we already know that if the market is to be a constrained Pareto optimum for all perfectly correlated technologies, either farmers must be risk neutral and $V_{Ip} = 0$ or consumers must have logarithmic utility functions, in order to establish theorem 10c all we need to do is to show that, for the logarithmic utility function, if returns are not perfectly correlated, for some technologies (48) is not satisfied. Consider the case where there are two symmetric groups of farmers with N farmers of each type; the production functions of the two groups are identical except for the effect of risk, which we assume is multiplicative and identically distributed:

$$Q^i = Nf^i(\theta^i, \xi^i) = N\theta^i h(\xi^i), \quad i = j, k. \qquad (49)$$

Given this symmetry in production, it is natural to assume symmetry in social weight, $\lambda^j = \lambda^k = \lambda$. The optimal lump-sum subsidy to the ith producer is derived as in Section III. We obtain, as the counterpart to equation (16),

$$E(\lambda U^i_y - V_I) + \alpha E(V_I - \lambda\beta^j U^j_y - \lambda\beta^k U^k_y) = 0, \quad i = j, k, \qquad (50)$$

which, because of our symmetry assumptions, can be simplified to

$$V_I = \lambda E\left(\frac{1 - 2\alpha\beta^i}{1 - \alpha}\right)U^i_y, \quad i = j, k, \qquad (51)$$

since V_I is constant for the logarithmic utility function.

Under our special assumptions (47) may be simplified to

$$\tfrac{1}{2}V_I = \lambda E(\beta^j U^j_y + \beta^k U^k_y)\beta^i, \quad i = j, k \qquad (52)$$

(where we have made use of the fact that with multiplicative risk $f^i_\xi = Q^i[h'(\xi^i)/h(\xi^i)]2\beta^i h'(\xi^i)$ and $\bar{Q}^i = \tfrac{1}{2}\bar{Q}$). By symmetry, $E(\beta^j)^2U^j_y = E(\beta^k)^2U^k_y = E(1 - \beta^j)^2U^k_y$, so equation (47) can be written

$$\tfrac{1}{2}V_I = \lambda E[(\beta^j)^2U^j_y - (1 - \beta^j)^2U^k_y + \beta^k U^k_y] = \lambda E\beta^j U^j_y. \qquad (53)$$

If β^j is constant, then equation (51) implies (53) and optimality is ensured; but β^j will only be constant if the outputs of the two groups of farmers are perfectly positively correlated, in which case the example collapses into the earlier example of a single group of farmers. If β is not constant, then equations (51) and (53) together require $E(\beta^i - \tfrac{1}{2})U^i_y = 0$. But β^i and y^i are positively correlated (unless β^i is constant), so, unless $U^i_{yy} = 0$ (farmers are risk neutral), $E(\beta^i - \tfrac{1}{2})U^i_y < 0$. It is easily checked that, given the form of the indirect utility function, total welfare is concave in the control variable. This establishes theorem 10c.

XI. Conclusions

This paper has shown that even when individuals have rational expectations—they have fully absorbed all the information which is available on the market and they use it efficiently in making their production decisions—the market equilibrium is, in general, not even a constrained Pareto optimum. Specific biases have been identified, in the context of some simple models, but in more general situations, the exact nature of the inefficiency may be hard to ascertain. The force of our argument is that there is no presumption that market equilibria are efficient; indeed, there is a strong presumption that the market equilibrium is not a constrained Pareto optimum.

In a sense, these results should not be surprising: When there is not a complete set of markets, farmers will not have the right prices to use in making their production decisions. Farmers pay attention only to their own marginal rates of substitution across states of nature. In general, these will differ from those of consumers because there is no market to bring them into equality and, hence, the market allocation will not be Pareto optimal.

There is another way of looking at these results which may prove instructive. In a world of complete markets, insurance markets allocate risk, and goods markets allocate goods; but in the absence of insurance markets, the remaining goods markets have to serve both functions. For example, if the source of the variability lies on the supply side, and if demand is not too inelastic, the negative correlation between price and output means that the output market transfers some of the risk facing producers to consumers, and producers' income variability will be less than their output variability. In a rational expectations equilibrium, each farmer correctly forecasts the distribution of prices and chooses the level and riskiness of output to maximize his expected utility. Together, these output decisions generate a distribution of total supply which in turn generates the price distribution. No one farmer can influence the price distribution, but each one is affected by it, and, collectively, their actions reproduce it. The price distribution is, therefore, a public good, or collective consumption good, and its form affects the level and distribution of income risk. However, we already know that the competitive market will, in general, fail to induce the optimum level of supply of public goods, so it should come as no surprise that the output market does not, in general, induce the optimum level of income risk.

If an omniscient planner were to decide on the choice of technique, he would take account of the effect of supply on the price distribution and, hence, on the distribution of risk. Insurance markets in this context transform a public good (the whole price distribution) into a set of private goods (one price for output in each state of the world). Notice that the one-commodity world popular in early risk analysis is very special, because income and output risk are the same, and there is no public good element of a collectively produced price distribution.

There were basically two cases where the market allocation was optimal. In the first, consumers had unitary price elasticity and all farmers were identical. This meant that farmers faced no income risk. They thus maximized their expected income. This coincides with what consumers would like farmers to maximize, since price is proportional to the marginal utility of consumption of the given commodity.

In the second case, farmers are risk neutral and again maximize expected income. As before, this would coincide with consumers' objectives, if price were proportional to the marginal utility of consumption of the commodity. However, this time the marginal utility to consumers of increasing output and hence consumption, Q, in some state of nature is $U_Q = pV_I$, and this is proportional to price, p, if V_I does not vary with p, that is, $V_{Ip} = 0$, so that consumers are price risk neutral.

When there is more than one type of farmer, that is, when the output of different farms is not perfectly correlated, these simple relationships between output and income which we have assumed above will not prevail. Even with unitary price elasticity, farmers will still face income risk and, hence, will not maximize the value of their output, so that even if consumers' marginal utility of consumption were proportional to price, as with the logarithmic utility function, consumers' interests would not be maximized by farmers. The only general condition which ensures optimality is that consumers are price risk neutral and farmers are income risk neutral.

Some readers have found the following alternative interpretation of the nonoptimality of the market allocation instructive. Except under unusual conditions (described in the text), the absence of a full set of risk markets implies that the marginal rate of substitution between income in different states of nature differs between consumers and producers. Consider a production decision which increases output in one state and decreases it in another. The market allocation is made, as we have emphasized, with producers assuming the price distribution is given. Now, by increasing output in one state and decreasing it in another, the price will increase in one state and decrease in the other; if the elasticity of demand is less than unity, producers will be better off in the first and worse off in the second, while consumers will be better off in the first and worse off in the second. It is clear that such a marginal change can reduce the difference between consumers' and producers' marginal rates of substitution between the two states; thus, this production decision can serve as a partial substitute for the risk market which is absent.

The important point is that it is only under very special circumstances that the market allocation will attain even the weak sense of optimality implicit in our notion of constrained Pareto optimality. This, in turn, has some important implications; there is, for instance, a widespread belief that international buffer-stock schemes for the stabilization of prices of agricultural commodities are unnecessary and undesirable, since the market provides an "efficient" level of storage.[5] Our analysis shows that this particular argument against such schemes is not valid; indeed there is a presumption that the market does not provide an efficient level of storage when there is an incomplete set of risk markets.

More generally, we have shown that, in general, there exists some tax policy which would generate a Pareto-optimal improvement over existing market allocations. Our results suggest, moreover, that the tax would depend sensitively on the specific form of production and utility functions, while the calculations of Section VIII suggest that, if risk aversion is not too large, the quantitative gain from such policies may not be significant. Thus, while there is a strong presumption that the market is not a constrained Pareto optimum, the desirability of government intervention remains a moot question.

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[5] The detailed implications of our analysis for commodity price stabilization are presented in Newbery and Stiglitz (1981, in press). Implications of our analysis for trade policy are discussed in Newbery and Stiglitz (1979).