# REDISTRIBUTION AND FREE TRADE IN AGRICULTURE: ARE THEY COMPLEMENTARY?

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ABSTRACT

The purpose of the paper is to look at the welfare effects of trade in agricultural goods in a less developed country where the agricultural market is controlled by a handful of large farmers. It is shown that the success of trade reform depends on the distribution of output between large and small farmers and the success of land reform leading to redistribution from the large to the small farmers depends on trade reform. In other words, if undertaken in isolation, each reform might lead to a fall in welfare, but if jointly undertaken, they will lead to an increase in welfare. Thus the two reforms are complementary.

## 1. INTRODUCTION

The paper is concerned with the welfare effects of two types of agricultural reforms. The first type of reform relates to opening up the agricultural sector to free international trade. The second is related to pure redistribution of output within the agricultural sector from large to small farmers, say, through land reforms. While apparently the two reforms seem unrelated and independent, the purpose of the paper is to argue that, in the context of a large class of backward agricultural sectors, they are, to a great extent, *complementary*. More specifically, the paper shows that for the type of agricultural sectors under consideration, each of these reforms, if undertaken in isolation, might lead to a fall in welfare. But if both reforms are undertaken *simultaneously*, welfare must go up.

What kind of agricultural sectors are we talking about? We focus our attention to a class of backward agricultural sectors where the domestic

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market is characterized by a handful of large sellers with market power coexisting with a large number of price-taking small sellers. Apart from lacking market power, the small sellers are handicapped, in comparison with the large sellers, in several other respects. First, due to credit constraints and the urgent necessity to pay back their previous loans the small sellers are compelled to sell a large part of their output just after the harvest. Second, due to a lack of information about the overall market situation, especially about the total harvest that would arrive at the market in the course of the year, the small sellers are unable to predict future prices perfectly. The intertemporal spread of their sales is often based on partial information, rumours and the like. The credit constraint severely restricts the participation of the small sellers in markets away from the harvest in terms of time. Even when they can store a small part of their product for sales in the pre-harvest lean season, due to informational deficiency, they do not know exactly when to sell. So rather than smoothing out intertemporal supply through arbitrage, they often end up increasing the variance of market arrival over time.

Neither do the small sellers have smooth access to markets far away in *space*. They do not have the marketing infrastructure as well as the right information to take part in spatially distant markets.[1] In the context of the present paper, this means that the small sellers *cannot directly* sell to the international market when trade opens up. They can, of course, sell through the large sellers.

Clearly, the inability of the small sellers to participate in markets distant in *space* as well as to arbitrage efficiently and freely across markets spread in *time* creates distortions. But they create different types of distortions with different economic implications. The compulsion of the small sellers to sell early or their lack of knowledge regarding when to sell leads to an increase in the variance of market arrival and of the price. Indeed, the higher is the share of the small sellers in total output, the higher is the variance in prices from the busy to the lean season. Welfare, on the other hand, is maximized when prices are completely smoothed out. It, therefore, follows that, other things remaining the same, a redistribution of output from the large to the small sellers leads to an increase in the variance of prices and a loss of welfare. Thus, a reform leading to redistribution within the agricultural sector, if undertaken in isolation, leads to a welfare loss.

On the other hand, the inability of the small sellers to sell directly to the international market allows the large sellers to price discriminate between the

[1] There is a substantial literature emphasizing the limits on marketing channels of small farmers in less developed countries (see, for example, Lele, 1971; Rudra, 1982, 1992; Bardhan and Rudra, 1984; Mitra and Sarkar, 2003; Sarkar and Mitra, 2005).

domestic and the international markets. As a result, a wedge is created between the international and the domestic price and there is a tendency for welfare to go down as trade opens up. As long as this wedge exists, the cost of withdrawing one unit of output from the domestic market, as represented by the domestic price, is different from the benefit of selling this unit stock in the foreign market. This leads to a distortion the magnitude of which varies directly with the share of the large sellers in total output. Indeed, the welfare loss due to this distortion may outweigh the direct welfare gain due to the opening up of trade if the share of the large sellers in total output is sufficiently high. In other words, trade, if introduced in isolation, may lead to a loss in welfare if distribution is sufficiently skewed in favour of the large sellers.[2]

It is now easy to see why the two reforms are complementary. Suppose, initially the distribution land and hence of output is sufficiently skewed in favour of the large sellers. As argued above, under autarky, redistribution to the small sellers will increase price seasonality and hence reduce welfare. Again, without redistribution, if trade opens up, welfare might go down if the share of large sellers in total output is sufficiently high. But if simultaneously trade opens up and there is a sufficient redistribution to the small sellers, the gain from opening up to trade will outweigh the loss due to market distortion and welfare will certainly go up.

It may be pointed out that here we are assuming away one important effect of redistribution. Normally, if the share of price-taking sellers goes up in a market and that of large sellers with market power goes down, there is a positive effect on welfare due to a rise in output. In the paper, total output is assumed to be constant even after land reforms and the consequent distribution of output. Hence no such positive effect of redistribution on welfare is present. The assumption of constant output can be justified at different levels. First, let us confine our focus to the short run. In the backward agricultural sectors under consideration, output, in the short run, is to a large extent dependent on weather conditions and the supply of land and not a choice variable for the producers. Once uncertainty about the weather is resolved and output is obtained, in no way can it be changed. In this paper, we are looking at the market *after* the harvest and therefore it is natural to assume that the total output is exogenously given. In the long run, however, redistribution of land can have significant effects on the level of output. But here one can think of two opposite effects of redistribution.

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[2] It is well known that under imperfect competition, countries may or may not gain from trade (see, for example, Markusen, 1981; Markusen *et al*., 1995).

First, redistribution of land may lead to too much fragmentation and lower output. The factors contributing to this could be losses due to extra travel time (if the same farmer has land scattered over a large area), wasted space along borders, inadequate monitoring and the inability to use certain types of machinery such as harvesters. In a recent paper, Jha *et al*. (2005) have shown that there is a clear empirical evidence of land fragmentation having significant adverse effects on land productivity in the Southern states of India. This points to the possibility of land redistribution having an adverse effect on total output.

Second, ownership or well-defined tenancy rights given to small sellers, who are often the real cultivators of land, might increase the level of output through incentive effects. A recent paper by Banerjee *et al.* (2002) has reported to have found empirical evidence of land reforms giving tenancy rights to the farmers having a positive effect on the level of output in the East Indian state of West Bengal. There is yet another and much older body of literature that looks at the relationship between land size and land productivity (see Binswanger *et al*. (1995) for a survey). There are conflicting views found in this literature and the question as to whether the relationship between the two is positive or negative still remains undecided. In short, one may think of different effects of land redistribution and tenancy reforms working in opposite directions on the level of output. As we do not know which effects are likely to dominate, for the purpose of model building and in order to focus on other factors, we simply assume that these effects cancel each other keeping output constant.

The importance of our result can be hardly overemphasized. It is well known that in recent years a number of less developed countries are going through a process of economic reforms. Again, many of these countries are predominantly agricultural. For these countries, economic reforms cannot be complete without agricultural reforms. Question is: what kind of agricultural reforms are to be undertaken by these countries? The 'rightist' and the 'leftist' answers to this question, however, differ significantly. The 'rightists' always insist that the most important reform for the agricultural sector is to open up the sector to free international trade. This view has been expressed earlier by the World Bank and more recently by the World Trade Organization. Studies conducted by the World Bank and its sympathizers have repeatedly pointed out that the agricultural sectors in less developed countries are heavily taxed. They are taxed mainly because they are denied the opportunity to sell the output to the international market at a price that is higher than the price prevailing in the domestic market (see, for example, Kreuger *et al*., 1991; Cassen and Gulati, 1995; Cassen and Joshi, 1995; Joshi and Little, 1999). Therefore, according to this view, it is necessary above all to remove all barriers to international trade in agricultural goods. The 'leftists', on the other hand, always insist on land reforms as the most important agrarian reform. They cite the history of Europe, Japan and that of the newly industrialized countries of South-East Asia where social reforms including redistribution of land have preceded economic growth and hence played an important role in the process of development (see, for example, Lipton, 1995). Our result synthesizes the two views by demonstrating that the policy prescription suggested by the two rival schools are actually complementary.

## 2. THE BASIC MODEL UNDER AUTARKY

### *2.1 The environment*

We consider the market for a single agricultural good. Output is seasonal and is obtained at discrete points in time. These discrete points are identified with the harvest. The time interval, which lies between two consecutive harvests, is denoted by $[0, T]$. We focus our attention on this time interval. Although production is discrete, consumption is continuous. To meet continuous consumption, output has to be stored from one harvest to another. Thus, storage is a very important activity in the present model.

There are three types of agents operating in the market: large sellers, small sellers and consumers. Both large and small sellers own some stocks at the initial time point 0. They sell these stocks throughout the time horizon. Each seller may also buy stocks from the market at some point in time if he/she so desires. However, it is assumed that by the end of the time horizon he/she exhausts his/her entire stocks so that his/her terminal stocks are zero. A large seller is able to affect the market price through his/her sales decision. Thus each large seller enjoys oligopolistic market power. Each small seller, on the other hand, is a price taker. As compared with the sellers, the consumers are passive in this model. They do not, by assumption, hold any stock for future consumption. They buy and consume at the same instant. At any point in time they have a demand curve that is assumed to be linear and uniform across time. The inverse demand function takes the form

$$p(t) = a - q(t) \tag{1}$$

where $p(t)$ is the price of the good and $q(t)$ is the quantity demanded at time $t$. Let $y(t)$ be market sales (market purchase, if $y(t)$ is negative) by the large sellers and $z(t)$ be market sales by the small sellers at time $t$. Then demand–supply equality at time point $t$ implies that $q(t) = y(t) + z(t)$. Consequently, equation (1) may be written as

$$p(t) = a - \{y(t) + z(t)\} \tag{1A}$$

The sellers take (1A) as given while planning their sales.

### 2.2 The large sellers' problem

A large seller maximizes his/her intertemporal profits by choosing his/her sequence of sales (and purchases) *given* the sequence of sales of the small sellers, the sequence of sales of the other large sellers and the demand equation (1A). Formally, a large seller's problem is

$$\max \int_0^T p(t)\, y_i(t)\, \mathrm{d}t - k_i X_i \tag{2}$$

subject to $X_i(0) = X_i$, $X_i(T) = 0$, where $y_i(t) = -\dot{X}_i(t)$.

In the above maximization problem, $X_i(t)$ denotes stocks held by the $i$th large seller at time $t$. His/her initial stocks are $X_i$ and his/her terminal stocks are zero. Sales at any $t$ are denoted by $y_i(t)$, which is equal to the fall in stocks at $t$. If $y_i(t)$ is negative, then it is interpreted as purchase. $k_i X_i$ denotes the fixed cost of storage of the $i$th large seller. It is assumed that storage costs depend only on *total stocks* and not on the length of time for which these stocks are held. The assumption may be justified in the following way. When some stocks are withdrawn for sales from the storehouse where they were stored, some empty space is created. However, there will be no demand for this empty space of storage till time $T$ because no new stocks would be forthcoming till the next harvest. Therefore, the storehouse owner cannot rent the empty space for the remaining part of the time horizon when some stocks are withdrawn for sales. Hence he/she will charge the same price for a unit stock irrespective of how long it is kept in the storehouse. Thus storage costs would be proportional to the total amount of initial stocks kept in the storehouse. As these fixed storage costs are not going to play any role in the maximization exercise and in the subsequent analysis, we assume that $k_i = 0 \forall_i$. For simplicity, we also assume that the initial stock $X_i$ is the same for all $i$. Each large trader chooses his/her sequence of sales (or purchases) $\{y_i(t)\}$ to maximize profits. The first-order conditions, given by the Euler equations, are (Kamien and Schwartz, 1981)

$$\dot{m}_i(t) = 0 \quad \text{for} \quad i = 1, 2, \ldots, n \tag{3}$$

Here $m_i(t)$ denotes marginal revenue of the $i$th large seller at time $t$. Using the demand equation (1A) we can solve (3) simultaneously for all $i$ to obtain

$$\dot{y}_i(t) = -\frac{\dot{z}(t)}{n+1} \tag{4}$$

$$\dot{y}(t) = -\dot{z}(t)\frac{n}{n+1} \tag{5}$$

$$\dot{p}(t) = -\frac{\dot{z}(t)}{n+1} \tag{6}$$

A few comments on the maximization and the consequent solutions are now in order. First, a large seller chooses his/her sequence of sales and purchases $\{y_i(t)\}$ to maximize (2). We confine our attention to the case where the path of purchase and sales is *pre-committed*. In other words, the $i$th large seller chooses his/her optimal path at time 0 and sticks to this path for the entire interval of time. We could alternatively assume that the seller is able to revise his/her optimal path at any point in time in future. This, however, would not change the solutions (see Sarkar (1993) for a formal argument).

Second, as is clear from equations (4) and (5), the rate of change in optimal sales and purchases of the $i$th large seller is independent of the sales or purchases of the other large sellers. The rate of change depends only on the rate of change in the market arrival of stocks from the small sellers and the *number* of large sellers in the market. The latter variable $n$ is inversely related to the degree of monopoly in the market.

Third, from equation (6) it follows that the extent of price fluctuations (as represented by the rate of change in price at any $t$) depends only on the extent of fluctuation in market arrival from the small sellers and the degree of monopoly. In particular, for any given fluctuation in market arrival, the higher the value of $n$, i.e. the lower the degree of monopoly in the market, the lower is the extent of price fluctuations. We shall have more to say on this point after we compute the equilibrium paths.

### 2.3 The small sellers' problem

We take the sequence of market arrivals from the small sellers as *exogenously* given. This may be justified on a couple of grounds. First, we assume that small sellers are faced with credit constraints in varying degrees, which compel them to sell their stocks at an early date. This assumption is clearly consistent with existing empirical and theoretical literature (see, for example, Bhaduri, 1983; Bardhan and Rudra, 1984). As the credit constraints are arbitrarily distributed across small sellers, their early sales are also exogenously distributed, which in turn makes the sequence $\{z(t)\}$ exogenous.

Second, Even if a small seller has some stocks left, after meeting his/her borrowing commitments, to sell freely across the lean season, often he/she does not know exactly when it is optimal to sell the stocks. As he/she is a price taker, theoretically he/she would like to sell his/her stocks at a time point when he/she *expects* that the price will not be higher at some future date than the present price. But due to lack of complete information about the market, his/her expectations are often based on rumours, local and partial knowledge and gut feeling. Because the bases on which expectations are formed significantly vary across small sellers, the selling behaviour also has significant variations. This introduces a lot of arbitrariness in the sequence of market arrival from small sellers and so it makes sense to treat $\{z(t)\}$ as exogenously given.

In spite of all these reasons, if there existed a large number of *small but perfectly informed* pure traders whose objective is to buy cheap and sell dear, intertemporal price differences would have been arbitraged away. But we assume that while small price-taking pure traders may exist in plenty, these agents are as badly informed about the market as small sellers. As a result, instead of smoothing out intertemporal price differences, these small traders tend to add to the price variance by creating noise in the sequence of market arrival. For all these reasons, we assume that $\{z(t)\}$ is an exogenously given sequence, but we *do not* impose any further restriction on the nature of this sequence.

## *2.4 Equilibrium under autarky*

An *equilibrium* is defined as a collection $[\{y_i(t)\}, \{p(t)\}]$ such that the following conditions hold:

(i) $\{y_i(t)\}$ maximizes (2) given $\{y_j(t)\}_{i\neq j}$ and $\{z(t)\}$ $\forall i,j$.
(ii) $p(t) = a - y(t) - z(t)$ $\forall_t$.

Given $\{z(t)\}$, the time paths of $y_i(t)$, $y(t)$, $p(t)$ may be derived from equations (4), (5) and (6) along with the initial conditions. These time paths are

$$y_i(t) = \frac{1}{n+1}[\bar{z} - z(t)] + \bar{y}_i \tag{7}$$

$$y(t) = \frac{n}{n+1}[\bar{z} - z(t)] + \bar{y} \tag{8}$$

$$p(t) = a - \frac{n}{n+1}\bar{z} - \frac{1}{n+1}z(t) - \bar{y} \tag{9}$$

where

$$\bar{y}_i = \frac{1}{T}\int_0^T y_i(t)\,\mathrm{d}t, \quad \bar{y} = \frac{1}{T}\int_0^T y(t)\,\mathrm{d}t, \quad \bar{z} = \frac{1}{T}\int_0^T z(t)\,\mathrm{d}t$$

Clearly, $\bar{y}_i$, $\bar{y}$, $\bar{z}$ are *average* sales. The detailed derivation of equations (7)–(9) is given in Appendix A. It is clear that once the time path of $z(t)$ is given exogenously, the other time paths are known from (7)–(9). A few comments on the equilibrium time paths are now in order.

First, consider the optimal strategy of a large seller as given by equation (7). A large seller sells the average amount $\bar{y}_i$ from his/her own stocks at each time $t$; in addition, he/she sells an extra amount if at any $t$ the market arrival $z(t)$ falls short of the average market arrival $\bar{z}$. This is captured by the first term in the right-hand side of equation (7). If, on the other hand, the actual market arrival at $t$ is greater than the average, he/she withholds some stocks and sells less than $\bar{y}_i$. In the extreme case, when the actual market arrival exceeds the average market arrival by a very large amount, $y_i(t)$ becomes *negative* and in this case the large seller *buys* from the market. Clearly, through his/her purchase and sales over time, a large seller tends to smooth out intertemporal prices.

Second, to follow their optimal sequence of sales and purchases, the large sellers have to know only the average market arrival $\bar{z}$ or equivalently, the total market arrival $H$ from the small sellers. The market arrival at any time $t$ can, of course, be observed by a large trader at time $t$. In particular, a large seller has to know neither the future sequence $\{z(t)\}$ of market arrival coming from the small sellers nor the sequence of sales of other large sellers in order to follow his/her optimal path of sales and purchases.

Third, the degree of withholding or over-releasing of stocks by the large sellers in response to the difference between actual and average market arrival depends on the degree of monopoly that is inversely related to $n$. The higher the value of $n$, i.e. the lower the degree of monopoly, the higher is the total response of the large sellers. This is clear from (8) where, in the right-hand side, $n/(n + 1)$ is increasing in $n$. In the extreme case, when $n \to \infty$, this total response is the highest and is equal to unity. In this case, whatever be the fluctuations in $\{z(t)\}$, $\{y(t)\}$ adjusts in such a way that at each point in time the average amount, i.e. $\bar{z} + \bar{y}$, is sold in the market and $p(t) = \bar{p}$, $\forall t$. Here we define $\bar{p} = a - \bar{z} - \bar{y}$. Thus, as the number of large sellers become very large, there is *perfect arbitrage* leading to perfect smoothing of intertemporal prices. The extent of arbitrage goes down and the price path exhibits fluctuations as the degree of monopoly increases.

## 2.5 Welfare under autarky

Welfare, in this model, is taken to be equal to the sum of consumers' surplus and producers' surplus. Formally, we write welfare under autarky, $W$, as

$$W = \int_0^T \frac{1}{2}[z(t) + y(t)]^2 \mathrm{d}t + \int_0^T p(t)[z(t) + y(t)]\mathrm{d}t \tag{10}$$

In the right-hand side of equation (10), the first term represents consumers' surplus and the second term represents producers' surplus over the time horizon [0, $T$]. As shown in Appendix B, the above expression may be reduced to

$$W = T\left[as - \frac{1}{2}s^2 - \frac{1}{2}\frac{\sigma_z^2}{(n+1)^2}\right] \tag{11}$$

where $s = \bar{z} + \bar{y}$, i.e. the average stocks available in the economy, and

$$\sigma_z^2 = \frac{1}{T}\int_0^T [z(t) - \bar{z}]^2 \mathrm{d}t$$

is the variance of $\{z(t)\}$. It may be verified that welfare is increasing in the average stock $s$ and falling in the variance of market arrival $\sigma_z^2$. Let $H$ be the total stocks of the small sellers and let $u(t)$ be the time path of sales by the small sellers when their total stock $H = 1$. We assume that an increase in $H$ increases $\{z(t)\}$ proportionately[3] for all $t$ from which it follows that $u(t) = z(t)/H$. Let the variance of $u(t)$ be denoted by $\sigma_u^2$ where

$$\sigma_u^2 = \frac{1}{T}\int_0^T \left[u(t) - \frac{1}{T}\right]^2 \mathrm{d}t \tag{12}$$

It immediately follows that $\sigma_z^2 = H^2\sigma_u^2$. Then the expression for welfare may be further simplified as

$$w = \left(as - \frac{1}{2}s^2\right) - \frac{1}{2}H^2\Omega \tag{13}$$

where $w \equiv W/T$ and $\Omega \equiv \sigma_u^2/(n+1)^2$.

[3] An increase in $H$ does not relax the credit constraints of the small sellers. The credit requirement for production should go up in proportion to the rise in $H$ leading to a proportionate rise in distress sales after the harvest. As a result $z(t)$ will increase proportionately for all $t$.

In equation (13) $w$ is welfare per unit of time and $\Omega$ is a constant as far as the present analysis is concerned. Moreover, $s$, the total stock available in the economy per unit of time, is also treated as given.

Let us now talk about land reforms. In this paper we talk about land reforms in a very simple manner. By land reforms we mean two things: first, a redistribution of land from the large oligopolistic producers to the small price-taking ones and second, strengthening of agricultural tenural laws guaranteeing a larger share of the produce to the sharecroppers. This redistribution and tenancy reform, in turn, leads to a redistribution of initial stocks from the large sellers to the small sellers. The important assumption is that these reforms and the consequent redistribution of output keep total output unchanged. We have explained in section 1 why such an assumption might be justified. In other words, agrarian reforms lead to an increase in $H$ and a fall in $X$, keeping $H + X$ and hence $s$, which is equal to $(1/T)(H + X)$, unchanged. It immediately follows from (13) that a measure of land reforms, leading to an increase in $H$, reduces welfare. Thus we have the following proposition.

*Proposition 1:* A redistribution of output from the large to the small sellers unambiguously reduces welfare under autarky.

It must be pointed out that our welfare function does not incorporate any objective of redistribution from the rich to the poor. It only gives an overall measure of efficiency.

Thus redistribution can certainly come as a separate objective. Indeed, one of the main purposes of the paper is to see whether such redistribution can be implemented without significant efficiency loss. Our analysis suggests that under autarky there are indeed efficiency costs to be incurred if redistribution is to be implemented.

Why does welfare go down if there is a redistribution of output from the large to the small sellers? We have already noted that welfare is increasing in mean output, i.e. $s$, and falling in the variance of market arrival $\sigma_z^2$. This variance increases as the amount of stocks owned by the small sellers goes up. Hence, as $H$ goes up keeping the mean output constant, there is a fall in welfare. Actually, the large sellers' intertemporal buying and selling tend to smooth out prices. On the other hand, the small sellers contribute to price fluctuations. Therefore, redistribution in favour of the small sellers increases price variance, which, in turn, reduces welfare and efficiency requires that all stocks be held and marketed by the large sellers. Hence redistribution from the large to the small sellers reduces welfare. The negative effect on welfare is captured by a rise in the negative term in the expression for welfare in equation (13). However, equity requires redistribution of stocks from the large sellers to the small sellers. Our analysis suggests that under autarky there is a trade-off between efficiency and equity.

## 3. INTERNATIONAL TRADE

### *3.1 Equilibrium under free trade*

We now introduce international trade into our model. We assume that the country is small with respect to the rest of the world and faces a given price $p^*$ in the world market as trade opens up. It is also assumed that while the large sellers have free access to the international market, the small sellers do not. In other words, the large sellers can buy and sell freely in the international market, but the small sellers are constrained to buy or sell only in the domestic market. First we consider the case where the *average* market price under autarky is less than the international price, i.e. $\bar{p} < p^*$. Not surprisingly, in this case the country will emerge as an exporter of the agricultural commodity. We shall also consider below the other case where $\bar{p} \geq p^*$.

Now, under autarky, marginal revenue of a large seller is the same for all time points. Using the demand function it may be easily verified that this common marginal revenue is less than the average market price under autarky. As $\bar{p} < p^*$ by assumption, the marginal revenue of a large seller under autarky is less than the international price. Therefore, as trade opens up, the large sellers find it profitable, on the margin, to withdraw stocks from the domestic market and sell them to the international market. In other words, the country will be a net exporter of the agricultural good.

We now proceed to determine the trade equilibrium. Suppose, for simplicity, that the large sellers make all their sales to the international market at the terminal date $T$. This is a harmless supposition because, for the large sellers, the variable cost of holding stocks is zero and the international price remains unchanged throughout. Thus even if stocks were sold at intermediate dates, the profits would be the same, provided the same amount of total stocks are sold. The problem of a large seller is to

$$\max \int_0^T \tilde{p}(t)\,\tilde{y}_i(t)\,\mathrm{d}t + p^* X_i(T) \tag{14}$$

subject to $X_i(0) = X_i$, $X_i(T)$ is free.

In equation (14), $\tilde{p}(t)$, $\tilde{y}_i(t)$ represent domestic price and domestic sales (or purchase) by the $i$th large seller at time $t$; $X_i(T)$, the terminal stock of the $i$th large seller, represents the amount sold by him/her to the international market. Clearly, this amount has to be *determined* in equilibrium. The first-order conditions, given by the Euler equations, are, as before, $\dot{m}_i(t) = 0$, $\forall i, t$ and the transversality condition is given by

$$m_i(T) = p^* \forall i \tag{15}$$

The Euler equations yield equations (4)–(6) as before. These, given $\{z(t)\}$, determines the time paths of prices and sales as obtained earlier.

Trade equilibrium is determined once we know how much, of the total stock available in the economy, is sold in the domestic market and how much is sold in the international market. The division of stocks between the domestic and the international markets is determined by equation (15). Using the demand equation, equation (15) may be rewritten as

$$a - \tilde{y}_i(t) - \tilde{y}(t) - z(t) = p^* \forall t \tag{16}$$

where $\tilde{y}(t) = \sum_{i=1}^{n} \tilde{y}_i(t)$. Summing over $t$ and dividing by $T$ we get

$$a - \tilde{y} - \bar{z} - p^* = \tilde{p} - p^* = \tilde{y}_i \tag{17}$$

where $\tilde{p}$ (which is equal to $\frac{1}{T}\int_0^T \tilde{p}(t)\,\mathrm{d}t$) is the average price in the domestic market in trade equilibrium, $\tilde{y}_i$ (which is equal to $\frac{1}{T}\int_0^T \tilde{y}_i(t)\,\mathrm{d}t$) is the *average net sales* of the *i*th large seller from his/her own stocks to the domestic market in trade equilibrium and $\tilde{y} = \Sigma \tilde{y}_i$. Note that $\tilde{y}_i(t)$ could be positive, negative or zero. A large seller starts with his/her initial stocks and throughout the time horizon $[0, T]$ depletes this stocks by selling to the domestic market or adds to his/her stocks by purchasing from the domestic market. At the terminal period he/she is left with a stock that he/she sells to the international market. It is possible that the terminal stock is greater than his/her initial stocks. This would be the case when his/her initial stocks are low. In this case a large seller will be selling his/her *own stocks* entirely to the international market and moreover he/she will buy additional stocks in the domestic market and sell them in the international market. Consequently, $\tilde{y}_i$ will be negative and the large seller will be a *net buyer* in the domestic market. If, on the other hand, his/her own stocks are large enough, he/she will sell part of it to the domestic market and the remaining to the international market. In this case, $\tilde{y}_i$ will be positive and the large seller will emerge as a *net seller* in the domestic market.

In the borderline case where he/she is neither a net buyer nor a net seller in the domestic market, and sells his/her entire stocks in the international market, $\tilde{y}_i = 0$. It should be pointed out that if a large seller is a net buyer from the domestic market, it *does not* mean that he/she never sells anything in the home market. The fact that he/she is a net buyer simply means that the *total* amount he/she sells to the home market is *less than* the *total* amount he/she buys from the home market. Similarly, if he/she is a net seller, then his/her total sales to the home market exceeds his/her total purchase from the home market.

To see these things more clearly, note that from (16) we get

$$\tilde{y} = \frac{n}{n+1}(a - \bar{z} - p^*) \tag{18}$$

In the extreme case, if $\bar{z} = s$, i.e. all stocks are initially held by small sellers, then the expression within square brackets is negative (since in this case, $a - \bar{z} = \bar{p} < p^*$ by assumption) and consequently each large seller is a net buyer from the domestic market. At the other extreme, if $\bar{z} = 0$, i.e. all stocks are held by the large traders, then $\tilde{y} > 0$, assuming, of course, $a > p^*$. In general, given a constant $s$, as the share of large sellers in total stocks goes down, they tend to become net buyers from the home market.

As the right-hand side of (17) is given, equation (17) determines $\tilde{y}$. Then the time paths of domestic prices and sales (or purchases) of the large sellers in trade equilibrium may be determined as before using the fact that $\int_0^T \tilde{y}(t)\,\mathrm{d}t = T\tilde{y}$. The solutions are given by

$$\tilde{y}_i(t) = \frac{n}{n+1}[\bar{z} - z(t)] + \tilde{y}_i \tag{19}$$

$$\tilde{y}(t) = \frac{n}{n+1}[\bar{z} - z(t)] + \tilde{y} \tag{20}$$

$$\tilde{p}(t) = a - \frac{n}{n+1}\tilde{z} - \frac{1}{n+1}z(t) - \tilde{y} \tag{21}$$

The solutions imply that the time paths under autarky and trade differ only with respect to their *levels*. In particular, it may be easily verified that the autarky domestic price lies below the domestic price level under free trade *for all t*. However, in view of equation (17) and (18), the average domestic price in trade equilibrium may lie above or below the international price depending on whether the large sellers are net sellers or net buyers in the domestic market. This leads to the following proposition.

*Proposition 2:* If the international price is greater than the average domestic price under autarky, then as trade opens up, domestic price increases. However, the average domestic price in trade equilibrium lies above or below the international price according as the large sellers are net sellers or net buyers in the domestic market.

The intuition behind the second part of the proposition is that if large sellers are net buyers, to earn monopsony profits, they keep the domestic price below the international price. Similarly, if they are net sellers, to earn monopoly profits, they keep the domestic price above the international price.

We end this section by considering the case where $\bar{p} \geq p^*$. First consider the case where the average domestic price under autarky is exactly equal to the international price. To determine the pattern of trade, note that the marginal revenue of a large seller under autarky is given by

$$m_i(t) = \bar{p} - \bar{y}_i \tag{22}$$

As $\bar{p} = p^*$, it follows that on the margin a large seller will gain by withdrawing stocks from the domestic market and selling them in the international market. In other words, barring the extreme case where the large sellers do not possess any stocks initially, i.e. $\bar{y}_i = 0$, the country will be an exporter of the agricultural good even if the autarky price and the international prices are the same. Clearly, this happens due to imperfect competition in the domestic market. Next consider the case where $\bar{p} > p^*$. Even in this case, if the two prices are sufficiently close and/or $\bar{y}_i$ is sufficiently high, the marginal revenue under autarky may be less than the international price and the country will emerge as an exporter. Only when $\bar{p}$ is sufficiently higher than $p^*$, the country will start importing the agricultural good. The basic point to note is that even for $\bar{p} \geq p^*$, if the difference between the two prices is small, the country might emerge as an exporter though comparative advantage dictates otherwise. The determination of time paths of domestic prices and sales (or purchases) may be derived in the same way as done above and will not be repeated here. Our results regarding the pattern of trade is summarized in the following proposition.

*Proposition 3:* If the average autarky price lies below the international price, the country exports the agricultural good in trade equilibrium. If the average autarky price is equal to the international price, the country still exports the agricultural good. If the average autarky price is greater, the country will import the good provided the difference between the two prices is sufficiently large. If the difference is small, the country may export the good.

*3.2 Welfare comparisons of free trade and autarky*

As under autarky, welfare in free trade equilibrium is given by the sum of consumers' surplus and producers' surplus. The only difference is that in trade equilibrium the producers' surplus consists of profit from domestic sales as well as sales to the international market. Let us first assume that $\bar{p} < p^*$ so that the country is a net exporter of the agricultural good. Consequently, welfare, in trade equilibrium, is given by

$$\tilde{W} = \int_0^T \frac{1}{2}[\tilde{y}(t) + z(t)]^2 \mathrm{d}t + \int \tilde{p}(t)[\tilde{y}(t) + z(t)]\mathrm{d}t + p^*(S - \tilde{S})\mathrm{d}t \tag{23}$$

where $S$, $\tilde{S}$ denote total stocks and stocks sold to the domestic consumers, respectively. Clearly, $(S - \tilde{S})$ represents total exports. Analogous to equation (13), the above expression may be written as

$$\tilde{w} = \left(a\tilde{s} - \frac{1}{2}\tilde{s}^2\right) - \frac{1}{2}H^2\Omega + p^*(s - \tilde{s}) \tag{24}$$

where $\tilde{w} = (1/T)\tilde{W}$, $s = (1/T)S$, $\tilde{s} = (1/T)\tilde{S}$ and $\Omega$ is defined as before. To analyse gains from trade, we have to compare (24) with (13). First note that from (13) $\mathrm{d}w/\mathrm{d}H = -H\Omega$ so that autarkic welfare as a function of the stocks held by the small sellers may be represented as a downward sloping straight line as shown in figure 1. Next note that from (24),

$$\frac{\mathrm{d}\tilde{w}}{\mathrm{d}H} = \frac{\tilde{p} - p^*}{T(n+1)} - H\Omega \tag{25}$$

Clearly, at $H = 0$, the right-hand side of (25) is positive. On the other hand, at $H = S$, the large sellers are net buyers in the home market and hence by Proposition 2, $\tilde{p} < p^*$ so that the right-hand side of (25) is negative. Thus, there is an $H^*$ such that at $H = H^*$, the right-hand side of (25) is zero. Next, subtracting (24) from (13) we get

$$w - \tilde{w} = (s - \tilde{s})\left[(\tilde{p} - p^*) - \frac{1}{2}(s - \tilde{s})\right] \tag{26}$$

Now suppose that $\bar{z}$ is close to $s$, i.e. almost all the stocks are initially owned by the small sellers. In this case the large sellers will be net buyers in the home market and by proposition 2, $\tilde{p} < p^*$. From (26) it then follows that $w < \tilde{w}$. In other words, when the small sellers initially own most of the stocks, autarky welfare will be less than welfare under trade. Thus, around $H = S$, the $\tilde{w}(H)$ curve will lie above the $w(H)$ curve as shown in figure 1. This leads to the following proposition.

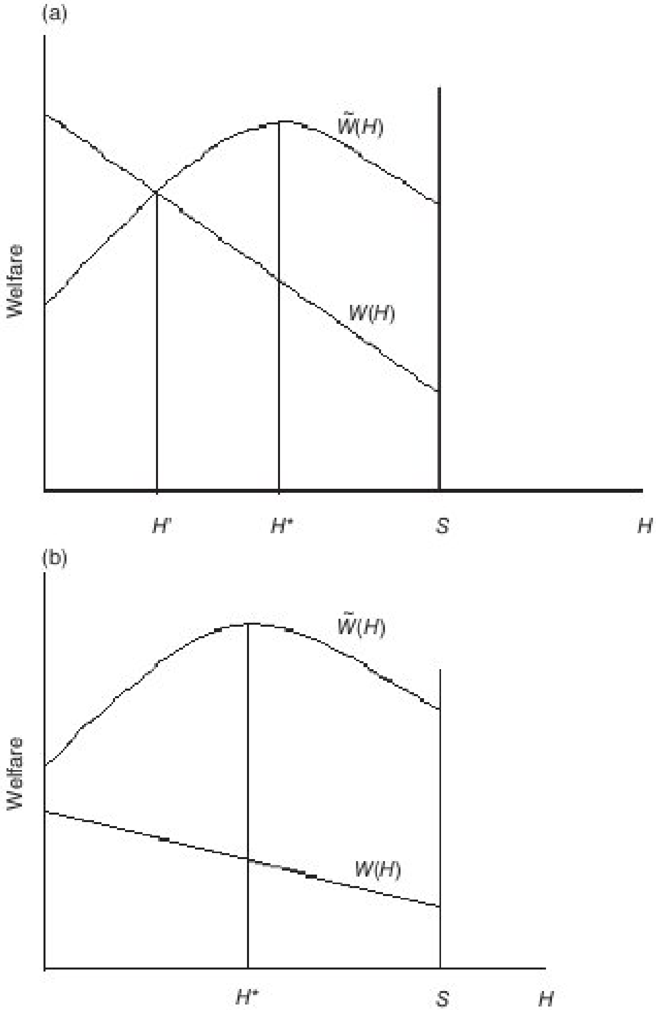


*Figure 1. Welfare curves under autarky and free trade.*

*Proposition 4:* If output is sufficiently redistributed, i.e. the small sellers hold a sufficiently high proportion of the total stocks, then free international trade is better than autarky.

Next, note that around $H = S$, $|\mathrm{d}\tilde{w}/\mathrm{d}H| > |\mathrm{d}w/\mathrm{d}H|$ so that if the $w(H)$ line intersects the $\tilde{w}(H)$ curve at all, the point of intersection lies to the left of $H^*$ (figure 1a). Or else the two curves do not intersect at all $\forall H \varepsilon [0, S]$ (figure 1b).

Presently we will show that either the trade curve lies above the autarky curve for all $H$ or they intersect only once. We will also derive the condition under which the two cases occur.

The sign of the right-hand side of (26) depends on the sign of the term within square brackets as long as the country is an exporter, i.e. $(s - \tilde{s}) > 0$. In Appendix C we show that the sign of the term within square brackets on the right-hand side of (26) depends on the sign of $[\bar{y} - (n + 2)\delta]$ where $\delta = p^* - \bar{p}$. In other words

$$w \leq \tilde{w} \Leftrightarrow [\bar{y} - (n+2)\delta] \leq 0 \tag{27}$$

where the equality sign prevailing in one expression implies that equality prevails in the other. Clearly, if the two welfare curves intersect, as in figure 1a, they intersect at $\bar{y} = (n + 2)\delta$, which gives a specific value of $H$ denoted by $H'$ in figure 1a. This means that the point of intersection, provided there is one, is unique. It is also clear that if $\delta$, the difference between the international price and the domestic price under autarky, is large, then the welfare curve in trade equilibrium lies above the welfare curve under autarky for all values of $H$. This case is depicted in figure 1b. Thus, to conclude, for small values of $\delta$ the two curves intersect and for sufficiently large values the trade welfare curve lies above throughout. It may also be verified that as long as $\delta > 0$, it is not possible for the trade welfare curve to lie below the autarky welfare curve for all $H$. It follows from our analysis that the trade welfare curve lies above the autarky welfare curve for all $H$ (figure 1b) if $\delta > s/(n + 2)$ and the two curves intersect at some $H \geq 0$ if $\delta \leq s/(n + 2)$ (figure 1a).

We are now in a position to talk about gains from trade. First consider figure 1a. Suppose land distribution is such that $H < H'$. Then, opening up of trade reduces welfare. On the other hand, if trade is not opened up, but there are land reforms leading to an increase in $H$, welfare unambiguously goes down (i.e. the country moves along the $w(H)$ curve). In other words, when implemented *in isolation*, either trade reform or land reform reduces welfare. However, if the two reforms are implemented simultaneously, the country moves along the $\tilde{w}(H)$ curve to $H^*$ where welfare is maximized. Welfare at this maximizing point may very well be greater than that under autarky. Indeed, if the difference between the autarky and the international price is not very small, welfare under trade at $H^*$ will be greater than welfare under autarky for any $H$. We say that the two reforms are *strictly complementary* if the two welfare curves intersect and initially $H < H'$. If $H' < H < H^*$, then free trade increases welfare independent of any land reforms. But if the aim is to implement land reforms, then this aim can be implemented without any welfare cost if the country opens up to trade. Thus, in this case, successful

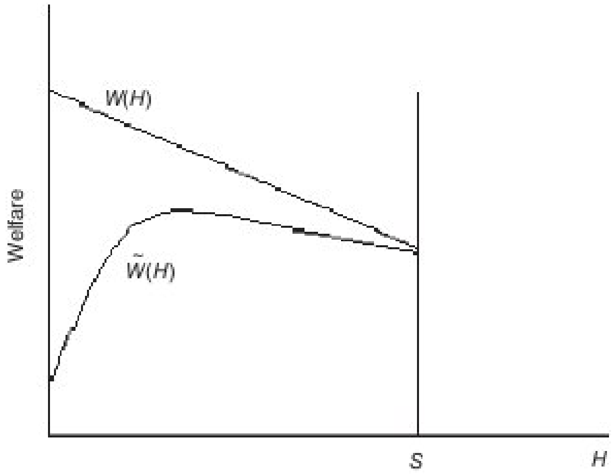


*Figure 2. Loss from trade with identical autarky and trade prices.*

implementation of land reforms would depend on trade reforms, i.e. the opening up of trade. The same comments apply to the situation in figure 1b where the trade welfare curve lies above the autarky welfare curve for all $H$. In either case, we ignore the situation where $H > H^*$ because our concern is restricted to less developed countries with sufficiently skewed distribution of income in the agricultural sector. We summarize our findings in the following proposition.

*Proposition 5:* Suppose the difference between the autarky and the international price is not very large, i.e. $\delta < s/(n+2)$. Then if the initial share of output of the small sellers is not very large, i.e. less than $H'$, then the two reforms are strictly complementary. If $\delta \geq s/(n+2)$, land reforms lead to welfare gains if trade reforms are simultaneously implemented, provided the initial share of output of the small sellers does not exceed the optimum $H^*$.

We may now consider the case where $p^* \leq \bar{p}$. First consider the case where the two prices are equal. We have already seen that in this case the country will be an exporter of the agricultural good provided $H < S$. Consequently, from (27), $w > \tilde{w}$ (since $\delta = 0$) for $\bar{y} > 0$. Only at $\bar{y} = 0$, or alternatively, $H = S$, the two welfare levels are equal. Hence, if the international price is equal to the autarky price, the trade welfare curve lies below the autarky welfare curve for all $H < S$ and only at $H = S$ the two curves intersect. This is shown in figure 2.

Finally consider the case where $p^* < \bar{p}$. If the difference between the two prices is sufficiently large, the country will be an importer at all $H$ and in (26) $(s - \tilde{s})$ would be negative. This, along with the fact that $\delta < 0,\ \bar{y} > 0$, implies that the trade welfare curve lies above the autarky welfare curve for all $H$. So we are in a situation similar to figure 1b. If, on the other hand, the difference between $\bar{p}$ and $p^*$ is small, then for low $H$, the country will be an exporter and $\tilde{w} < w$. So, in this case, we are in a situation similar to figure 1a. In other words, in the case where $p^* < \bar{p}$, the welfare curves intersect if the difference between the two prices is not very large; the trade welfare dominates autarky welfare for all $H$ if the difference is large. Hence our earlier comments regarding the complementarity of the two types of reforms apply in this case as well.

We may now discuss the intuition behind our results. First note that under autarky, redistribution from the large to the small always reduces welfare in our model. In a standard model, as a market gets more oligopolistic, there is a loss in welfare. But this loss in welfare is due to the *fall in output* resulting from the shrinkage of the competitive fringe and an expansion of the monopolistic fringe. In the present model, as total output is given, such effects are absent. On the other hand, in the present context, the large sellers smooth out the price through intertemporal trade and this increases welfare. Thus the net effect of redistribution from the large to the small increases the variability of the price path, which is welfare reducing. As trade opens up, the standard monopoly effect comes into play. The oligopolistic large sellers act as discriminating monopolists selling at a higher price in the domestic market, which is achieved by restricting domestic sales below the optimum level. So, on one count, welfare falls as the share of output of the large sellers increases. On the other hand, the large sellers still smooth out intertemporal prices and on this count a redistribution from the large to the small reduces welfare as under autarky. The two opposing effects lead to an *optimum distribution* denoted by $H^*$ in figure 1.

## 4. GOVERNMENT INTERVENTION

We had so far been talking about free trade and autarky. We shall now talk about optimal interventions by the government. In particular, we shall discuss the desirability of the kind of interventions, e.g. export quotas or international trade through government agencies, that have been criticized by the proponents of free trade. Not surprisingly, it turns out that some government intervention is optimal, given the distortion created by the existence of oligopolistic traders.

Let us consider equation (24) that represents welfare after international trade opens up. For any given $H$, suppose the government chooses the optimal $\tilde{s}$, i.e. domestic sales, to maximize welfare. The actual choice of

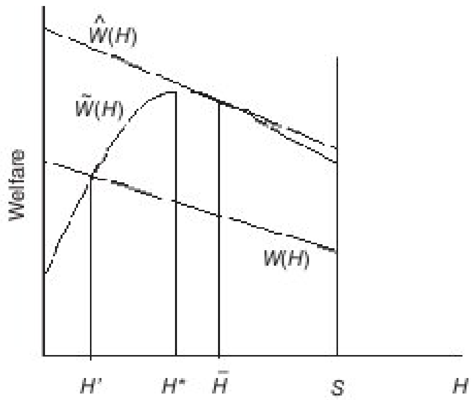


*Figure 3. Optimal government intervention.*

domestic sales may be implemented through appropriate policies, which we shall discuss later. The first-order condition, implied by this maximization, yields

$$\frac{\mathrm{d}\tilde{w}}{\mathrm{d}\tilde{s}} = \tilde{p} - p^* = 0 \tag{28}$$

This is what we should expect. Welfare is maximized at the point where the domestic price is equated to the international price. The government, through an appropriate policy, has to fix $\tilde{s}$ in such a way that the corresponding $\tilde{p}$ is equal to the international price. Suppose the government makes the optimal choice at all levels of $H$. We know from equation (25) that at $\tilde{p} = p^*$, $d\tilde{w}/\mathrm{d}H < 0$. Thus, if the government makes the optimal choice of $\tilde{s}$ for all $H$, the function $\hat{w}(H)$, which represents welfare for different levels of $H$ *with optimal government intervention*, will lie above the free trade welfare curve whenever under free trade $\tilde{p} \neq p^*$. Now, noting that $\tilde{p} = a - \bar{z} - \bar{y}$ and using (18), it is straightforward to verify that $\tilde{p} = p^* \Leftrightarrow \bar{z} = a - p^*$. In other words, under free trade, the domestic and the international prices are equal only at a unique value of $H$, say $\bar{H}$. At this level of $H$, welfare under free trade and welfare under trade with optimal government intervention will be the same. At all other points, the $\hat{w}(H)$ curve will lie above the $\tilde{w}(H)$ curve. This is shown in figure 3. The $\bar{H}$ point will lie to the right of $H^*$ because at the later point $\tilde{p} > p^*$ and the domestic price falls as $H$ increases. Also the slope of the $\hat{w}(H)$ curve is $-\Omega$ and so the $\hat{w}(H)$ curve and the $\tilde{w}(H)$ curve will be parallel.

Now suppose that we start with a skewed distribution of agricultural output so that $H < \bar{H}$. Clearly, free trade will not be optimal in this case and optimal government intervention will be desirable. In other words, free trade without any government intervention can be advocated only if we have sufficient land reforms to start with, i.e. only if we have $H = \bar{H}$. It should also be pointed out that the welfare loss due to free trade, as measured by the vertical gap between $\hat{w}(H)$ and $\tilde{w}(H)$, goes down as output is redistributed from the large to the small sellers. Proposition 6 is immediate.

*Proposition 6:* If distribution is not at the optimum, government intervention is superior to free trade.

Given that it is optimal for the government to choose domestic sales, the question arises as to what specific policies should be adopted to fix $\tilde{s}$. We concentrate only on the case where distribution is sufficiently skewed, i.e. $H < \bar{H}$. First, consider the case where the country is a net exporter and the large sellers sell positive amounts to the domestic market from their *own stocks*. Of course, this will be the case when $H$ is low. In this case, under free trade, $\tilde{p} > p^*$ and to achieve the optimal domestic sales have to be increased. Clearly, this can be achieved through an appropriate *export quota*. The size of the required export quota will go down as there is land reform leading to an increase in $H$. Also, if the country is a net importer and $\tilde{p} > p^*$, once more a higher output has to be sold in the domestic market than under free trade. As the large sellers will not be willing to undertake this additional import, the government would have to undertake this import through its *own agencies*. In other words, as long as there are distortions in the trade of agricultural goods, we need to have precisely those government interventions that have been criticized by the proponents of free trade.

Before ending this section, let us point out that, as under free trade, it is easier to pursue land reforms under restricted trade than under autarky. Suppose the initial distribution is denoted by $H'$ as shown in figure 3, and the government wants to improve it to $H^*$. Under autarky, this measure leads to a welfare loss. But with optimally restricted trade, the welfare level actually goes up if land reform and restricted trade are implemented simultaneously.

## 5. CONCLUDING REMARKS

In this paper we looked at the effects of two types of economic reforms on the level of welfare of a less developed agricultural economy that is characterized by an oligopolistic product market. The first is land reform redistributing output from the large to the small farmers; the second is trade reform leading to the opening up of the domestic agricultural market to the rest of the world. The main conclusions we drew from our analysis were as follows.

First, we showed that if initial distribution of output is sufficiently skewed and the difference between the average autarky price and the international price is not very large, then there is a strict complementarity between the opening up of free trade and redistribution of output. Undertaken in isolation, each leads to a loss in welfare, but if undertaken jointly, welfare unambiguously increases.

Second, if the difference between the autarky and international prices is large, then free trade welfare is always greater than welfare under autarky. Indeed, the higher is the difference between international and autarky prices, the higher is the gain from free trade for any given distribution of output. Moreover, the trade-off between redistribution and welfare loss disappears once free trade is opened up. Thus if the economy is open, it becomes easier to pursue land reforms.

Third, restricted trade with optimal government intervention in general dominates free trade; government intervention can be totally removed only if distribution attains a certain optimum level. On this count, too, proper land reform is a prerequisite for the optimality of free trade.

Fourth, as compared with autarky, restricted trade also makes land reforms easier, for the latter increases the welfare level and hence reduces the welfare cost of land reforms. To draw these conclusions, we have made the simplifying assumption that redistribution of land, which is behind the redistribution of initial stocks from the large to the small sellers, has no output effect, i.e. redistribution of land neither reduces nor increases total output. If this assumption is relaxed and we allow an output effect of land reforms, say a positive output effect, we basically introduce another term in our welfare function. If this effect is not very strong, the negative effect of land reforms under autarky would still be valid and the rest of the conclusions would also follow. If, on the other hand, the positive output effect of land reform is very strong, our conclusion about the effect of land reform under autarky would be reversed. But we have serious doubts as to how strong the positive effects of land reforms could possibly be. On the other hand, our field studies (see Mitra and Sarkar, 2003; Sarkar and Mitra, 2005) indicate that the problems of credit and information, especially the latter, could be very acute among small sellers. The paper argues that given these problems, simple redistribution of land might not work under autarky, but if trade is simultaneously opened up both types of reforms would be beneficial.

## APPENDIX A

*Derivation of equations (7)–(9)*

We have, by definition,

$$z(t) = z(0) + \int_0^t \dot{z}(\tau)\,\mathrm{d}\tau \tag{A1}$$

$$y_i(t) = y_i(0) + \int_0^t \dot{y}_i(\tau)\,\mathrm{d}\tau \tag{A2}$$

Hence $y_i(t) = y_i(0) - \frac{1}{n+1}\int_0^t \dot{z}(\tau)\,\mathrm{d}\tau$ (using equation (4))

$$= y_i(0) - \frac{1}{n+1}[z(t) - z(0)] \quad \text{(from (A1))} \tag{A3}$$

Hence, integrating over $T$, and dividing both sides by $T$, we get

$$\frac{1}{T}\int_0^T y_i(t)\,\mathrm{d}t = y_i(0) - \frac{1}{n+1}\frac{1}{T}\int_0^T z(t)\,\mathrm{d}t + \frac{1}{n+1}z(0)$$

Substituting the value of $y_i(0)$ from (A3) and using the definitions of $\bar{y}_i$, $\bar{z}$ the above expression becomes

$$\bar{y}_i = y_i(t) + \frac{1}{n+1}[z(t) - \bar{z}] \tag{A4}$$

which is nothing but equation (7). Summing (A4) over $n$ we get equation (8). Finally, from (8) and the demand equation we get (9).

## APPENDIX B

*Derivation of equation (13)*

From equation (8) we have

$$y(t) + z(t) = \frac{n}{n+1}\bar{z} + \frac{1}{n+1}z(t) + \bar{y} \tag{B1}$$

Now, consumers' surplus $= \frac{1}{2}\int_0^T [y(t)+z(t)]^2 \mathrm{d}t.$

Similarly, producers' surplus $= \int_0^T [a-\{y(t)+z(t)\}][y(t)+z(t)]\,\mathrm{d}t$

$$= a\int_0^T [y(t)+z(t)]\mathrm{d}t - \int_0^T [y(t)+z(t)]^2 \mathrm{d}t$$

Hence consumers' surplus + producers' surplus

$$= aS - \frac{1}{2}\int_0^T [y(t)+z(t)]^2 \mathrm{d}t \tag{B2}$$

where $S = X + H$, the total stocks available in the economy. Using (B1), we may write, after some straightforward algebraic manipulations,

$$\int_0^T [y(t)+z(t)]^2 \mathrm{d}t = T\frac{\sigma_z^2}{(n+1)^2} + Ts^2 \tag{B3}$$

where $s = S/T$ and

$$\sigma_z^2 = \frac{1}{T}\int_0^T [z(t)-\bar{z}]^2 \mathrm{d}t$$

Equation (13) follows directly from (B2) and (B3).

## APPENDIX C

*Derivation of equation (27)*

The sign of $w - \tilde{w}$ depends on the sign of $(\tilde{p} - p^*) - (s - \tilde{s})$. Now from equation (17), $\tilde{p} - p^* = \tilde{y}_i$ and by definition, $s - \tilde{s} = \bar{y} - \tilde{y}$. Hence it is sufficient to look at the sign of $\{\tilde{y}_i - \frac{1}{2}(\bar{y} - \tilde{y})\}$. Using equation (18) and the fact that $\bar{y} = a - \bar{z} - \bar{p}$, it is straightforward to show that the required sign depends on the sign of $[\bar{y} - (n+2)\delta]$, where $\delta = p^* - \bar{p}$.

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