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*Sequencing and the Success of Gradualism:  
Empirical Evidence from China's Agricultural Reform*

## INTRODUCTION

At its most basic level the Big Bang versus gradualism debate can be characterized by two questions. Should reforming nations lead with radical market liberalization policies? Or should institutions that offer strong incentives to those involved with economic activity be fostered and be allowed to evolve before central planning is dismantled and markets are unleashed?

While the debate has raged for more than ten years, there has been little progress in understanding exactly what has accounted for the success of countries adopting gradualism and why most countries beginning their reforms with market liberalization have not enjoyed rapid growth. Most explanations of the success of gradualism relative to rapid reform have considered the comparative growth record of countries in East Asia which were normally gradual reformers, or those in Europe which began with radical liberalization policies (Roland and Verdier, 1999). According to almost any performance criteria, East Asian gradualism is the clear winner (see Macours and Swinnen in the present volume). In response, researchers who still believe in the necessity of Big Bang reforms argue that the comparison of East Asia and Europe is not valid because of structural differences in the economies (Sachs and Woo, 1994).

Despite great interest among academics and policy makers, progress in settling the debate has stalled, almost certainly because few researchers have been able to isolate the factors contributing to the performance of the different transition economies. So, in a sense, the aim is to respond to this lack of evidence; our paper seeks to show empirically that the sequencing of policies in transitional economies matters. Though our study is limited to the case of China's agricultural sector and its reforms, we argue that our findings help to explain why gradualism works. To meet our goal, we pursue three objectives. First, we briefly delineate the various gains that countries can expect from incentive changes (that is, decollectivization), on one hand, and market liberalization, on the other. Second, we lay out a framework for measuring the

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source of, and returns to, incentive reforms (studied in the past by, for example, McMillan *et al.*, 1989; Lin, 1992) and market liberalization initiatives (our main methodological contribution). Finally, we offer initial estimates of the timing and magnitudes of returns to incentive and market reforms.

## INCENTIVES, MARKETS AND BEHAVIOUR

The literature has carefully documented the returns to increased incentives in China's early stages of reform. Decollectivization, commonly called the Household Responsibility System (HRS), made the household the residual claimant and left production decisions to those with the best information (Putterman, 1992). Although McMillan *et al.* (1989), Fan (1991), Lin (1992) and Huang and Rozelle (1996) used different data sets, examined different subsectors of the economy and applied different methods, they all concluded that HRS led to sharp increases in output and greater efficiency. The HRS variable is assumed to proxy for the added incentives that decollectivization provided for producers in the early 1980s. In the rest of this study, we assume that the incentive effects are synonymous with the reforms embodied in HRS.<sup>1</sup>

Unlike what happened in the transition economies in Europe, leaders in China did not move to dismantle the planned economy in the initial stages of reform in favour of liberalized markets. Policy makers only began to shift their focus to market liberalization in 1985, after decollectivization was complete. Even then, liberalization was 'stop and start' (Sicular, 1995). For example, in the case of fertilizer, Ye and Rozelle (1994) show that, after an early attempt at market liberalization in 1986 and 1987, perceived instability in the rural economy in 1988 led to sharp retrenchments. Agricultural officials only took controls back off fertilizer marketing and began encouraging private trade in the early 1990s. Lin *et al.* (1996) offer a detailed analysis of reform policy. They argue that leaders were mainly afraid of the disruption that would occur if the institutions through which leaders controlled the main goods in the food economy (such as grain, fertilizer and meat products) were eliminated without first having the institutions in place which work to support more efficient market exchange.

Rozelle (1996) shows that the sequencing of agricultural reform policies followed the gradualism strategy of China's more general, economy-wide reforms described by McMillan and Naughton (1991). In the initial stages of reform, leaders consciously restricted the promotion of market-based economic activity, allowing exchanges only of less important products (for example, minor fruits and vegetables) in sharply circumscribed regions. Not until 1985, after the completion of HRS, did policy makers begin to encourage market activity for more important commodities (such as grain), although initially market activity only occurred within the framework of China's renowned two-tier price system (Sicular, 1988). There was no commitment to more complete market liberalization until the early 1990s, more than a decade after the initiation of HRS. From this description, it is clear that China's reforms fall into two distinct stages: the incentive reforms that dominate the period from 1978 to

1984, and a period of gradual market liberalization that begins in 1985 and extends through the 1990s.

### *The record of market liberalization*

Attempts to quantify the gains from market liberalization, unfortunately, have been largely unsuccessful. Part of the problem may be the period of analysis and the inability of the various research approaches to separate efficiency gains of market reform from overall gains in the reforming economy. For example, Wen (1993) found total factor productivity (TFP) growth had stopped in the post-1985 period, a trend he blames on the failure of the second stage of reform. Holding constant the effect of technology, Huang and Rozelle (1996) find that TFP growth restarts in the 1990s and is in at least a small way linked to increased liberalization of the economy. Fan (1999) uses frontier methods to decompose the efficiency gains of Jiangsu provincial farm producers in the late reform era. He concludes that there have been only limited gains from market liberalization. If one were to take the findings of this admittedly scant literature seriously, it would appear as if there is at most only a relatively small measured gain from market reforms in China. We believe there are three possible explanations for the findings, though only one is plausible. First, if market liberalization actually contributes little or nothing to growth, output or incomes, this would, of course, in part explain why economies that lead reform with market liberalization do not experience significant gains. Theory and the experiences of other economies in other settings, however, would argue against such an interpretation. Second, it could be that China's agricultural market liberalization has just proceeded so slowly that it is still too early for output to have been positively affected. But, as seen above, the record on market expansion and the observations of many researchers would not support this view.

If the first two arguments are faulty, we are left with just one explanation. It may be that the methods previously used to measure the return to markets have not fully captured the effect of market liberalization. In fact, almost all of the previous literature on this subject (with the exception of Fan, 1999) has tried to capture the liberalization effect by examining the residual growth of output after other sources of growth have been accounted for. It may be that the part of the efficiency gains coming from markets is missed because of the presence of measurement error or other factors.

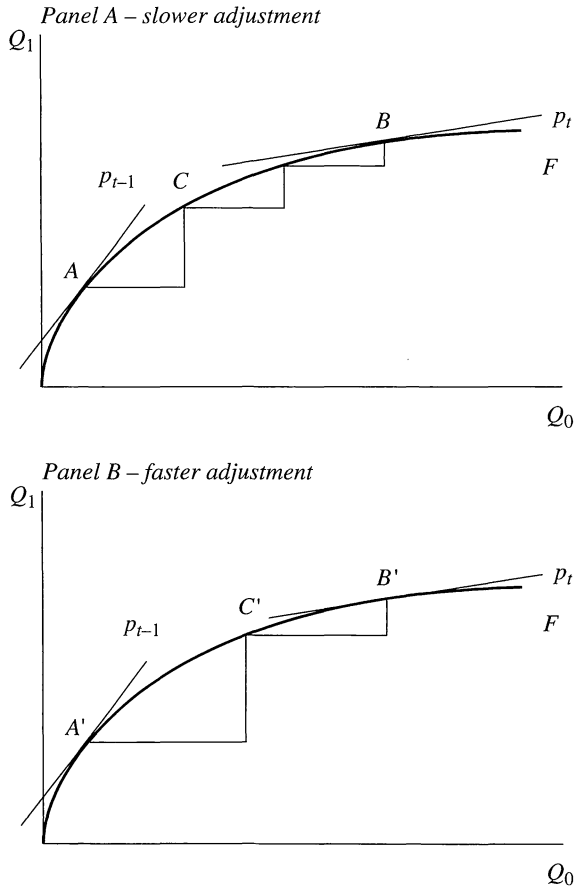
## RETURNS TO MARKETS

Absent or poorly functioning markets impose two constraints on producers. First, when markets are not well developed, or when policies or institutional constraints raise transaction costs and limit market-based exchange, producers lack the *flexibility* to change the allocation of their productive assets and choice of enterprises. Second, as prices and other factors in the economy change, producers are less *responsive* when shifting their variable inputs. This

section will explain the effects of market liberalization on flexibility and responsiveness in more detail.

### *Flexibility*

To understand more precisely what is meant by flexibility, we refer to Figure 1. Suppose a country's aggregate agricultural production function is  $F_A$  in a pre-liberalization period in panel A and  $F_B$  in a post-liberalization period in panel B. A profit-maximizing farmer who in year  $t-1$  faces an output price  $p_{t-1}$ , chooses to produce at point A, and uses a quantity of the quasi-fixed input,  $X_{AA}$ . The first subscript refers to the point on the figure, and the second refers to the panel. In year  $t$ , the price changes to  $p_t$ . A farmer who is unconstrained would



**FIGURE 1** *Flexibility in adjustment*

move to the point of optimal production by increasing the use of the input to  $X_{BA}$  (by moving from point  $A$  to point  $B$ ).

However, if there are frictions in the economy, the producer will not be able to perfectly adjust the quantity of the quasi-fixed input,  $X$ , in response to the price change within one year. Instead, the producer is only able to increase the quasi-fixed input to  $X_{CA}$ , and can only produce at point  $C$  in year  $t$ . While profits increase, they do not rise as much as they would have had the producer increased inputs to  $X_{BA}$ . The lost profit from producing at  $C$  rather than  $B$  is a measure of the inefficiency due to inflexibility.

Market liberalization can reduce the amount of inefficiency as follows. In panel B, although the producer is not able to adjust perfectly, market liberalization policies have facilitated exchange. In response to the price change, from  $p_{t-1}$  to  $p_t$ , the producer can increase the use of the quasi-fixed input to  $X_{C'B}$  and move further, to point  $C'$ . The more rapid adjustment can be most easily seen by comparing the number of years that it takes to make the full adjustment from the original point ( $A$ ) to the point of long-run optimality. In Figure 1, it is three years before the producer reaches point  $B$  before market liberalization, and only two years after.

Certainly, there is reason to believe that China's producers have begun operating in more flexible environments in the late reform period, especially with regard to their choices of sown area and labour. In the late reform period, as quotas have fallen (Wang, 2000) and labour markets developed (Parish *et al.*, 1995), the scope for farmer decision making has expanded greatly. In particular, the rise of rural industry and increased opportunities to work off the farm in areas near the farmer's home village conceivably have had a large effect on the flexibility of labour use.

### *Responsiveness*

The lack of well-functioning markets may also limit the *responsiveness* of farmer supply and associated derived demand decisions. According to one of Marshall's fundamental principles, the more variable factors of production there are, the more responsive producer choices are to changes in price and other fixed factors. If newly emerging markets allow farmers to choose more of their inputs, the increased scope for substitution among inputs will make farmers at least as responsive, *ceteris paribus*.

To examine responsiveness in terms of Figure 1, suppose the production function,  $F_A$ , illustrates the relationship between  $X$  and  $Y$ , holding  $Z$  constant.  $Z$  is a set of other production factors needed to produce  $Y$  (panel A), and is composed of two subsets:  $Z_1$ , a set of  $n$  variable factors of production that can be bought and sold in a market, and  $Z_2$ , a set of  $m$  fixed factors. The rate at which  $Y$  increases in response to an increase in the price,  $p$ , is, among other things, a function of the curvature of the production surface. If in time period 2, where the relationship between  $X$  and  $Y$  is shown in panel B as  $F_B$ , the rate at which  $Y$  increases for the same increase in price,  $p$ , could change if  $Y$  were more responsive. Market liberalization could cause  $Y$  to become more responsive, because in essence the technology could change. The relationship between

$X$  and  $Y$  after market liberalization might, for example, be conditioned on  $n+1$  variable factors of production ( $Z'_1$ ) and  $m-1$  fixed factors ( $Z'_2$ ). If so, for a given increase in  $Y$ , profits realized from moving from  $A'$  to  $B'$  in panel B would be greater than the profits from moving from  $A$  to  $B$  in panel A, since the producer is able to produce more of  $Y$  as its price rises. The difference in profits would measure the magnitude of the gain to efficiency caused by greater responsiveness due to market liberalization.

### *Incentive reforms and market liberalization*

While we are trying to isolate the behavioural effects of the incentive reforms from those of market liberalization, in reality it is likely the two are interrelated. For example, Lin (1991) and Huang and Rozelle (1996) have shown that China's agricultural sector has experienced both positive and negative interactions between market improvements and increased incentives.<sup>2</sup> Since we are trying to identify the impact of market liberalization in the late reform period, quantitative measures of the liberalization effects should not be affected if the incentive reforms were already implemented (and fully effective) by the mid-1980s. When considering issues of policy sequencing, however, to the extent that increased responsiveness is conditional on having good incentives, the true returns to liberalization policies will be overstated if all of the efficiency gains in the late reform period are attributed to them.

## MEASURING BEHAVIOURAL EFFECTS OF LIBERALIZATION

### *Flexibility*

As discussed above, the increase in the speed by which quasi-fixed factors adjust corresponds to increased *flexibility*. To estimate the adjustment speed of quasi-fixed factors while considering the main sources of production growth, a theoretical/empirical framework is needed. It must explicitly account for the elements that facilitate or constrain producers from adjusting inputs and outputs to their optimal levels in response to exogenous shocks. Such approaches exist. They include the agricultural treadmill approach (Cochrane, 1965), fixed asset theory (Johnson, 1956; Hathaway, 1963) and adjustment cost models (Lucas, 1967; Johnson and Quance, 1972).

The adjustment cost approach is particularly appropriate for modelling the production behaviour of China's farmers in a reform economy because it allows us to measure the rate of adjustment of resources in response to exogenous changes. Factors that are slow to adjust are called quasi-fixed inputs, and are endogenous variables; their levels and rates of change are in part chosen by the producer in response to changes in exogenous factors. Quasi-fixed inputs affect production in both the short and long run. A theoretical framework is described in Appendix A as well as in Warjiyo (1991) and de Brauw *et al.* (2000).

*Empirical model for measuring flexibility*

To estimate the dynamic supply response system that is defined by equations (A3)–(A5) in Appendix A, and measure quasi-fixed factor flexibility, we use a normalized quadratic value function, developed by Epstein (1981), which is a specification that has been used frequently in empirical work and is expressed as follows:

$$V(p, w, q, K, Z) = a_0 + [a_1 a_2 a_3 a_4][pwqK]' + \frac{1}{2}[pwqK] \begin{bmatrix} AF'G'H' \\ FBL'N' \\ GLC(R^{-1})' \\ HNR^{-1}D \end{bmatrix} [pwqK]' + [a_5 pwqK][T_0 T_1 T_2 T_3 T_4]' Z \quad (1)$$

where  $V, p, w, q, K$  and  $Z$  are as defined in Appendix A and  $a_0, \dots, a_5, A, F, G, H, B, L, N, C, R, D, T_0, \dots, T_4$  are parameter matrices with the appropriate dimensions. Following the steps outlined in Appendix A, the empirical formulation of the complete system of input demand and output supply equations has the following form:

$$\Delta K_{(t)} = B_{12} + (rU + R)K_{(t-1)} + rRGp_{(t-1)} + rRLw_{(t)} + rRCq_{(t)} + T_{12}Z_{(t)} + e_{12(t)} \quad (2)$$

$$L_{(t)} = B_{03} - rFp_{(t-1)} - rBw_{(t)} - rL'q_{(t)} - N'K_{(t)}^* - T_3Z_{(t)} + e_{3(t)} \quad (3)$$

$$Y_{12(t)} = B_{45} + rAp_{(t-1)} + rF'w_{(t)} + rG'q_{(t)} + H'K_{(t)}^* + T_{45}Z_{(t)} + e_{45(t)} \quad (4)$$

$$Y_{3(t)} = B_{06} + ra_4K_{(t)}^* - 0.5rp'_{(t-1)}Ap_{(t-1)} - 0.5rw'_{(t)}Bw_{(t)} - 0.5rq'_{(t)}Cq_{(t)} \quad (5)$$

$$- rp'_{(t-1)}F'w_{(t)} - rp'_{(t-1)}G'q_{(t)} - rw'_{(t)}L'q_{(t)} + 0.5rK'_{(t-1)}DK_{(t-1)}$$

$$- K_{(t)}DK_{(t-1)} + ra_5T_{60}Z_{(t)} + Z'_{(t)}T_{61}K_{(t)}^* + e_{6(t)}$$

where  $B_{12} = rRa_3$ ,  $B_{03} = -ra_2$ ,  $B_{45} = ra_1$ ,  $B_{06} = ra_0$ ,  $K^* = rK_{(t-1)} - \Delta K_{(t)}$ ,  $T_{12} = rR^{-1}T_3$ ,  $T_3 = -rT_2$ ,  $T_{45} = rT_1$ , and  $U$  is an identity matrix. Conditions for consistent aggregation requires  $V_{KK} = D = 0$  (Epstein and Denny, 1983), which is imposed in estimation.

The adjustment cost model generates two useful sets of relationships between the choice variables (that is, variable and quasi-fixed inputs and outputs) and exogenous factors. The first, defined as short run elasticities, measure the one-period response of choice variables to shifts in prices and policy variables, including *direct and indirect changes* of variable inputs and outputs. *Indirect changes* occur through the *partial* quasi-fixed factor response of the producer.



As quasi-fixed factors do not fully adjust in one time period, the indirect change in the variable input or output amount reflects the speed of adjustment of quasi-fixed inputs. Therefore, the slower the adjustment process, the smaller the elasticities are, in an absolute value sense. Long-run elasticities, on the other hand, account for the full adjustment of quasi-fixed inputs, and measure the optimal *direct and indirect* response of producers to price changes. The indirect portion of the elasticity accounts for the *full* shift in quasi-fixed inputs to their optimal amounts after the price change occurs. Warjiyo (1991, p. 78) includes detailed calculations for deriving the short- and long-run elasticities from the estimated parameter matrices in equations (2) to (5). We will take advantage of the differences between these two relationships, since one measure, the long-run elasticity, lets us measure the full response to a change in price. The other measure, the short-run elasticity, captures the extent of the inefficiency since, *ceteris paribus*, the smaller the response, the greater the inefficiency.

Our empirical model includes three crops;  $Y_{12}$  is a two-element output vector for wheat and maize, and  $Y_3$  is cash crop output. Prices for wheat and maize, the variable input (fertilizer), and the two quasi-fixed inputs (labour and sown area) are normalized by the cash crop price to satisfy homogeneity. The  $Z$  vector is made up of three shifter variables:<sup>3</sup> national research stock, irrigation capacity and a variable reflecting the effect of institutional incentive reform.<sup>4</sup> Provincial dummy variables account for fixed, province-specific effects.

We consider sown area and labour to be quasi-fixed inputs. The  $R$  matrix in equations (1) and (2) is the adjustment matrix, and the coefficients on the diagonals of  $R$  are called ‘adjustment cost parameters’. The parameters are estimates of the average, one-period proportional adjustment of a quasi-fixed factor to its long-run optimal level that is made in response to a change in an exogenous variable. The adjustment cost model, then, gives us explicit measures of the flexibility of quasi-fixed factors. The diagonals of the  $R$  matrix, in some sense, are exactly what we are interested in: a measure of how well markets allow factors to adjust. Appropriately, some researchers call these estimated parameters ‘flexible acceleration coefficients’.

To measure the *change of flexibility*, we interact a dummy variable (that is, zero for the early reform period, 1975–84, and one for the late reform period, 1985–95) with all of the variables in equation (1) and (2) associated with the adjustment parameters (called  $R_{11}$  and  $R_{22}$ ). The parameters associated with the interaction term (denoted  $R_{11D}$  and  $R_{22D}$ ) measure how much more or less flexible quasi-fixed factors become in the market liberalization period.

### *Responsiveness*

Since our model includes quasi-fixed factors and variable inputs, we can estimate responsiveness by using the parameters of the model to calculate measures such as input price elasticities. Ideally, we should measure the *change* in responsiveness between the early and late periods by separately estimating equations (2) to (5) for the early and for the late periods and comparing the results. In the period after market liberalization has begun, we

would expect to find higher absolute values of the elasticities. Such a finding would intuitively show that producers were becoming more responsive as markets emerged. And a more responsive producer will see higher profits than a less responsive one.

Unfortunately, the lack of data makes the estimation of two separate models impossible.<sup>5</sup> As a compromise, we re-estimate our original model for the full period with a more ‘flexible specification’ by interacting the parameters associated with the own-price responses with the subperiod dummy variable.<sup>6</sup> We use the parameters from this estimation to generate short-run elasticities for early and late periods to examine how the responsiveness of China’s producers changes as markets emerge.

## EFFICIENCY GAINS, RESPONSIVENESS AND FLEXIBILITY

### *Creating the measure of increased efficiency due to market liberalization*

The first step in arriving at an estimate of the gains to market liberalization is to calculate the inefficiency *in any given economy* (or any given period,  $P$ ) that arises from imperfect adjustment. The difference in lost profits between the full adjustment and the partial adjustment is a measure of the inefficiency due to partial adjustment, and is defined as:

$$\Omega_t = \Delta\Pi_{t, \text{full}} - \Delta\Pi_{t, \text{partial}} \quad (6)$$

where  $\Delta\Pi_{t, \text{full}}$  is the amount of additional profits that the farmer will earn from a price increase (from  $p_{t-1}$  to  $p_t$ ) if there are no adjustment costs from year  $t-1$  to  $t$  (or if full adjustment occurs in one year); and  $\Delta\Pi_{\text{partial}}$  is the additional profits realized if the farmer only partially adjusts.

To create a measure of the change in inefficiency between two periods, we first label the early reform period when producers are less responsive as ‘slow’, and the late reform period when partial adjustment is faster as ‘fast’. Then we can simply calculate equation (6) for the late reform period as:

$$\Omega_{t, \text{fast}} = \Delta\Pi_{t, \text{full, fast}} - \Delta\Pi_{t, \text{partial, fast}} \quad (7)$$

We do the same calculation using the parameters from the slower adjusting, pre-liberalization period:

$$\Omega_{t, \text{slow}} = \Delta\Pi_{t, \text{full, slow}} - \Delta\Pi_{t, \text{partial, slow}} \quad (8)$$

The overall gain in year  $t$ ,  $G_t$ , to increased flexibility and responsiveness from a one year change in an exogenous variable can be calculated by subtracting equation (7) from equation (8):

$$G_t = \Omega_{t, \text{slow}} - \Omega_{t, \text{fast}} \quad (9)$$

To compute measures of efficiency,  $\Omega$  and  $G$ , we need to start with a measure of profits. Since almost no land is rented in China and almost no labour is hired for farming, we define profits as returns to land and labour, and can write this as:

$$\Pi_t = \sum_i p_{it} q_{it} \quad (10)$$

where  $p$  represents all output and variable input prices,  $q$  represents output and variable input quantities, and  $i$  indexes them ( $i$  = wheat, maize, cash crop and fertilizer). Variable inputs (in our case, fertilizer) are taken to be negative quantities. Following this notation, the change in profits,  $\Delta\Pi_t$ , from year  $t-1$ ,  $\Pi_{t-1}$ , to year  $t$ ,  $\Pi_t$ , can be expressed as:

$$\Delta\Pi_t = \Pi_t - \Pi_{t-1} = \sum_i (p_{it} \Delta q_{it} + q_{it-1} \Delta p_{it}) \quad (11)$$

where  $\Delta q_{it}$  is the change in output or input quantities between  $t-1$  and  $t$ , and  $\Delta p_{it}$  is the corresponding price change. The term  $\Delta q_{it}$  is estimated by equation (12):

$$\Delta q_{it} = q_{it} \sum_j (\Delta p_{jt} / p_{jt}) \varepsilon_{jt} \quad (12)$$

where  $p$  represents all prices and government policy variables,  $j$  indexes them ( $j$  = wheat, maize, cash crop, fertilizer, research and irrigation), and  $\varepsilon$  represents all elasticities.

Equation (12) can be calculated using either the long- or short-run elasticities. When it is calculated with long-run elasticities, the quantity responses reflect the fact that quasi-fixed factors *fully* adjust and the producer is at a point of optimal profits. When it is calculated with short-run elasticities, quasi-fixed factors only *partially* adjust, the indirect responses are ignored and profits have not been maximized.

After plugging long-run elasticities into equation (12) and getting the profit-maximizing output responses to a given change in an exogenous variable, we can then find the predicted change in profits by plugging the predicted  $\Delta q_{jt}$  into equation (11). In fact, if our change in an exogenous variable is a change in price from year  $t-1$  to  $t$  (which we can call  $\Delta p_{jt}$ ), then our resulting change of profits,  $\Delta\Pi_{\text{full}}$ , is exactly what we need to calculate inefficiency. If we are using long-run elasticities from the pre-liberalization era and changes in the exogenous variables from the second period, then the change in profits is  $\Delta\Pi_{\text{full, slow}}$ . The short-run quantity response to a change in exogenous variables is called  $\Delta\Pi_{\text{partial, slow}}$ , is different, as quasi-fixed factors do not fully adjust, and reflects the fact that short-run elasticities from the early reform period are used. The difference between early reform profits, calculated with long-run and short-run elasticities in year  $t$  given the change in the exogenous variables in year  $t-1$  (from the second reform period), is our measure of the inefficiency ( $\Omega_{\text{slow}}$ ) due to market imperfections. In essence,  $\Omega_{\text{slow}}$  is derived from a conceptual experiment; if flexibility and responsiveness remained the same during the incentive reform period and during the market liberalization period, the level of inefficiency would be  $\Omega_{\text{slow}}$ .

To compute our measure of the change in efficiency due to market liberalization, we need to measure the actual inefficiencies in the post-liberalization period,  $\Omega_{\text{fast}}$ . These calculations are exactly the same as for  $\Omega_{\text{slow}}$ , except that the long- and short-run elasticities from the second period are used. Once calculated, the estimates of  $\Omega_{\text{fast}}$  and  $\Omega_{\text{slow}}$  can be substituted into equation (9) to get a measure of the overall gain in efficiency in year  $t$  from market liberalization,  $G_t$ .

#### *Decomposing the measure of the gain to efficiency from market liberalization*

We actually break down the total efficiency gains,  $G_t$  even further, into one part that comes from increased flexibility and one that is due to increased responsiveness. By substituting equations (7) and (8) into (9) and rearranging, we find that we can write  $G_t$  as

$$G_t = -((\Delta\Pi_{\text{partial,fast}} - \Delta\Pi_{\text{partial,slow}}) + (\Delta\Pi_{\text{full,fast}} - \Delta\Pi_{\text{full,slow}})) \quad (13)$$

Written this way, the two terms in equation (13) have intuitive interpretations that correspond to the two components of market liberalization. The first term is just the loss of profits that would have resulted had the speed of adjustment been the same in the second period as in the first. This is just a measure of the change in efficiency due to flexibility ( $F_t$ ). The second term is just the profit lost if market liberalization had not led to larger long-run elasticities, which is just responsiveness ( $R_t$ ). Hence we can write  $G_t$  as  $G_t = F_t + R_{gt}$ .

#### *Measuring the gain to better incentives*

To meet our ultimate goal of comparing the gains from market liberalization with the gains from the incentive reforms, we will use our estimated empirical model to simulate profits in the early reform period (1978–84), both including and excluding the effect of the incentive reform. The difference between the simulated profits with ( $\Pi_t^*$ ) and without ( $\Pi_t^{*'}\prime$ ) the incentive reform measures the gains in efficiency. Normalizing by  $\Pi_t^*$ , we have a measure of the gain to incentive reforms,  $I_t$ , which is the proportion of increased profits due to those reforms:

$$I_t = (\Pi_t^* - \Pi_t^{*'}\prime) / \Pi_t^* \quad (14)$$

## DATA

Provincial-level cross-section, time-series data for 1975–95 are used in the analysis.<sup>7</sup> Output for wheat, maize and other grains, and cash crops (cotton, sugar cane, peanuts and rapeseed) are measured in kilograms and after 1980 are from published statistical compendia (ZGTJNJ, 1980, 1986–93; ZGNYNJ, 1981–93). Prior to 1980, data for these variables come from provincial year-books. Data on total sown area in each province are from the same source.

Cash crop output is an aggregated variable; output values for each individual crop are summed, then divided by a Stone price index.

Prices for grain, cash crops and fertilizer are obtained from China's national 'Cost of Production Survey'.<sup>8</sup> This information comes from a data-collection programme run by the State Price Bureau since the mid-1970s (SPB, 1988–95). Based on annual household surveys conducted by county level Price Bureau personnel, detailed information is available by crop and by variety for over 50 variables, including both revenue and expenditure (in value terms) and quantity data.<sup>9</sup> Prices are generated by dividing total revenues or expenditures by the quantity.<sup>10</sup> The price for land is calculated as net return to cultivated land (total revenue per unit of cultivated land for each commodity less per land unit expenditures on labour, fertilizer and other variable inputs). The wage is derived from per capita labour income in rural areas. The data are from each province before 1984 and ZGTJNJ thereafter.

The irrigation stock, research stock and incentive reform variables were created using data from the following sources. Irrigation expenditures are from each province, and are documented in a statistical compendium published by the Ministry of Water Resources and Electrical Power (MWREP, 1988–96). They include all sources of investment in water control that pass through the financial system to regional water conservancy bureaus. National grain research expenditures are assumed to have the same effect on production in each province, implicitly implying that breakthroughs spill over into all provinces. Because irrigation and research stocks, rather than expenditures, affect input demands and output supply, irrigation and research expenditures are transformed into stock variables (see de Brauw *et al.*, 2000). The incentive reform variable measures the cumulative proportion of households in China each year implementing decollectivization policies.

## ECONOMETRIC RESULTS

### *Grain and cash crop production in North China's reforming economy*

To estimate the relationship among the two quasi-fixed inputs (equation 2), three outputs (equations 4 and 5) and one variable input (equation 3), a non-linear, three stage least squares estimator is used (Gallant, 1977). The estimator accounts for contemporaneously correlated error terms. The equation system for North China contains 46 exogenous variables and 135 parameters.

The entire set of estimated coefficients for equations (2) to (5) is reported in Appendix B. Many of the coefficients have relatively high *t*-ratios and the signs and magnitudes of most of them are as expected. The important results also appear to be robust to the choice of estimator. In particular, the flexible accelerator parameters, R11 and R22, are negative and significant (Table 1). Because the model is written in terms of first differences, the eigenvalues of the adjustment matrix R provide a check on the stability of the adjustment process of land and labour. Since the absolute values of the estimated eigenvalues for R are less than unity, the quasi-fixed demand system is stable.

**TABLE 1** *Adjustment parameter estimates from non-linear, three-stage least squares estimators for Northern China*

Parameter	Estimate
R11	-0.16 (3.65)
R22	-0.35 (8.38)
R11D	-0.04 (2.98)
R22D	-0.25 (5.49)

*Notes:* t-ratios in parentheses; the full set of parameter estimates is reported in Appendix B.

The properties of the value functions also are mostly satisfied. The estimated value function is non-declining in  $p$  (wheat and maize),  $K_1$  (sown area) and  $Z$  (agricultural research and irrigation investment) and is non-increasing in  $w$  (wage) and  $q$  (the price of labour and value of land). The only violation of monotonicity is found in  $K_2$  (labour), a result commonly found in other studies (see the survey by Warjiyo, 1991). When considering parameters significant at the 10 per cent level, convexity is satisfied for the sets of equations; the own-price response matrices (A, B and C) are all positive semi-definite.

Estimates of government policy variables also have the expected impacts on agricultural production. For example, positive signs on the IRR4 and IRR6 parameters (Appendix B) indicate that irrigation investment boosts wheat and cash crop production. The estimated coefficient for maize, IRR5, is negative and insignificant, which reflects the fact that Chinese farmers tend to grow maize on more marginal, hilly land. Irrigation also seems to save labour (IRR2). Agricultural research boosts both wheat and maize output (RES4 and RES5), but has an insignificant effect on cash crop production (RES6). This result reflects the observation of Fan and Pardey (1992) that the agricultural research system has been focused on grain. The positive and significant coefficients on the variable associated with the effect of research on labour (RES2) indicates that agricultural research has intensified labour use.

The signs of the coefficients associated with the variables measuring incentive reform (HRS), imply that it had a positive impact on the production of all crops except for maize in North China, which coincides with the result found by other studies (Lin, 1992; McMillan *et al.*, 1989; Fan, 1991; Huang and Rozelle, 1996). This decollectivization-led increase in output, however, did not come about by increased labour use. Consistent with the labour use pattern since the late 1970s, incentive reforms led to substantially lower labour use.<sup>11</sup> Farmers in the post-reform period use chemical fertilizers to substitute for

labour, an insight described by Ye and Rozelle (1994) in their study of Jiangsu rice farmers in the late 1980s.

## INCREASING FLEXIBILITY DURING CHINA'S REFORMS

### *Adjustment in the early reform period*

The model allows us to test a series of hypotheses relating to the initial assumption that changes in the use of labour and land require significant adjustment costs, and the hypothesis that the speed of adjustment increases after the HRS reform is complete. The results of two sets of hypothesis tests are reported in Table 2. Since we have interacted the variables associated with the speed of adjustment parameters with a period dummy variable, the interpretations of R11 and R22 relate to the early reform period.

**TABLE 2** *Hypotheses testing for the presence of adjustment costs, quasi-fixity of inputs and increase in speed of adjustment*

Hypotheses	Lagrange multiplier statistic
No adjustment cost or no quasi-fixity	
(1) Crop area ( $R_{11} = -1$ & $R_{12} = 0$ )	383.82*
(2) Agricultural labour ( $R_{22} = -1$ & $R_{21} = 0$ )	271.69*
(3) Both crop area and agricultural labour ( $R_{11} = R_{22} = -1$ & $R_{12} = R_{21} = 0$ )	663.31*
Independent adjustment	
(4) Crop area v. agricultural labour ( $R_{12} = R_{21} = 0$ )	9.97*
No adjustment cost during market liberalization	
(5) Crop area ( $R_{11} + R_{11d} = -1$ )	519.32*
(6) Agricultural labour ( $R_{22} + R_{22d} = -1$ )	28.71*
No increase in speed of adjustment post-HRS reform	
(7) Both crop area and agricultural labour ( $R_{11d} = R_{22d} = 0$ )	25.50*

*Notes:* The \* indicates statistical significance at the 1% level. All test statistics are calculated from the non-linear three-stage least squares estimates of the entire system of equations. The null hypotheses for the tests are in parentheses.

The high test statistics in the analysis of quasi-fixity of sown area by itself (row 1) and labour by itself (row 2), and the joint test of the two quasi-fixed inputs (row 3), highlight the importance of accounting for dynamic adjustment costs in the analysis of China's agricultural crop area and farm labour decisions during the incentive reform period. Tests of quasi-fixity for adjustment coefficients in the market liberalization period also indicate that sown area and labour do not fully adjust (rows 4 and 5). Given that there are adjustment costs, the next test in this set (row 6) indicates that the adjustment paths are not independent. In other words, if an exogenous shock occurs, making the previous allocations of sown area and labour less than optimal, the movement of sown area towards its new, long-run equilibrium point (that is, the profit-maximization point) is affected by the adjustment process of labour (and vice versa).

To estimate the time of adjustment in the early reform period, we invert the R matrix and find that, in the early reform period, land adjusts in about six years and labour in three years. These figures are consistent with the findings of Huang *et al.* (1995), who found adjustment times of five years for land and four years for labour for the agricultural economy as a whole during the entire post-1978 era. Hence our results can be interpreted as indicating that frictions in the economy kept producers from fully adjusting their labour or sown area during the incentive reform period.

Interestingly, even though adjustment is not instantaneous, China's rural economy is not particularly rigid in a comparative sense. Natural, behavioural and policy-created barriers exist everywhere. In fact, when the results are compared with those of similar adjustment cost analyses, it could be argued that China's crop sector adjusted rather quickly. With the exception of Vasavada and Chambers, who found land in the USA being adjusted to a new optimum after two years, land adjustment in Canada can take up to 15 years to equilibrate after exogenous shocks, whereas labour adjustment requires six to 19 years (Warjiyo, 1991; Luh and Stefanou, 1991; Vasavada and Chambers, 1986). Despite the existence of policy-created barriers in China, adjustment may occur faster than in North America because the relatively labour-intensive farming systems and more responsive, small-scale rural-based industrial sector ultimately make resource reallocation among sectors less costly. Apparently, even though formal markets are not complete, informal institutional arrangements may have allowed China's farmers to engage in exchange even in the early reform period.

#### *Changes in flexibility in the late reform period*

So have the market liberalization reforms increased the flexibility of China's agriculture? The negative and statistically significant coefficients on the interaction terms in Table 1 (R11D and R22D) demonstrate that quasi-fixed factors have begun to adjust even faster in the late reform period. The negative coefficients are to be interpreted as the degree by which flexibility increases in the market liberalization period.

The results demonstrate that flexibility increased significantly in the second period. The flexible acceleration parameters for labour and sown area are



-0.60 (-0.35-0.25) and -0.20 (-0.16-0.04). In terms of the time to fully adjust, the speed becomes faster at five years for land and one year eight months for labour after market reform begins. If faster adjustments by producers are made possible by better markets and fewer restrictions on producers, the liberalization reforms have increased efficiency in China's late reform economy. In the last section of the paper, we examine the magnitude of these efficiency gains.

### *Changes in responsiveness*

We have also produced evidence that responsiveness increased in the market liberalization period. To show this, we estimate elasticities that are based on the parameters from the more flexible model (that is, the additive parameters from the 'period dummy - own-price variable' interaction terms). The interaction terms are all significant at the 10 per cent level, which indicates that own-price responses change after market liberalization begins (see de Brauw *et al.*, 2000, for parameter estimates). Table 3 summarizes the changes in responsiveness of quasi-fixed and variable inputs to own prices (own-price elasticity changes based on estimating changes in parameters across periods). Among all inputs, responsiveness of labour appears to rise most significantly (row 2). The elasticity of sown area does not change (row 1). Somewhat unexpectedly, the own-price elasticity for fertilizer seems to show less price responsiveness in the second period (row 3).

To explain the somewhat counter-intuitive results for fertilizer, we return to our earlier discussion of the 'start and stop' nature of the fertilizer market liberalization. Since that did not become permanent until the 1990s, it is possible that we should not expect to see producers change their behaviour during the entire post-1985 period; increased responsiveness should not be expected to begin until 1990. To test whether the fertilizer own-price elasticity becomes more responsive for the second half of the late reform period, we re-

**TABLE 3** *Changes in responsiveness of quasi-fixed and variable inputs: own-price elasticity changes based on estimating changes in parameters across periods*

Own price elasticity of:	1975-84	1985-95
Sown area	-0.001	-0.001
Labour	-0.013	-0.082
Fertilizer	-0.867	-0.467
Own price elasticity of:	1975-89	1990-95
Fertilizer	-0.229	-0.446

*Notes:* Elasticities are calculated using a modification of the model that allows for the own-price response of each output or input to change for the later period (1985-95 or 1990-95). See de Brauw *et al.* (2000) for the parameter estimates that were used to calculate these elasticities.

estimate the model with own-price responses again, this time interacting them with a dummy variable that is 0 for all years before 1990 and 1 thereafter. Our new results show increased responsiveness in the use of fertilizer in the second reform period. The own-price fertilizer elasticities calculated with these parameters are in Table 3, row 5. Our findings suggest that, after 1990, fertilizer becomes more own-price responsive ( $-0.229$  before,  $-0.446$  after). With the exception of sown area, the results are consistent with the interpretation that the late-period liberalization policies have made producers more sensitive to input price changes.

### EFFICIENCY, RESPONSIVENESS AND FLEXIBILITY

Efficiency measurements for comparing returns to the incentive reforms in the early reform period with the returns to market liberalization in the late reform period are presented in Table 4. Gains to incentive reform are only calculated for the years 1978 to 1984 in order to highlight the fact the HRS significantly boosted farm incomes in the early reform era. In fact, the gains in profits from HRS continue indefinitely, since there would likely be a fall in income after 1985 if the HRS policy were reversed and the incentives that HRS brought to farmers were weakened. By contrast, the gains to market liberalization are only calculated over the late reform period (1985–95) on the assumption that policy officials implemented few policies beyond HRS prior to 1985 that led to a richer environment for exchange.

Our results clearly show the large contribution of HRS to farm incomes during the early reform period. The gains from the incentive reform increased throughout the period, rising as HRS spread through the economy. In 1984, the peak year, farm profits rose by more than 7 per cent. While this percentage is less than the additions to production output and production growth measured by McMillan *et al.* (1989) and Lin (1992), they are not inconsistent. To obtain the large increases in output, many of the factors that we deduct from our measure are included. Moreover, since farm income during the reform period was such a large part of total rural household income, this does represent a significant increase in the wealth of rural areas. Moreover, this is an average figure; some regions gained more and others gained less. Aggregating the total increase in profits from just farm production across more than 200 million rural households still represents an immense gain of wealth.

The results of this exercise show that, on a year-to-year basis, the overall gains from market liberalization have increased efficiency overall, between 0.12 and 1.73 per cent (Table 4, column 2).  $G_t$  was lower when prices declined, and higher in years when the price level increased sharply. At the extremes, in 1990, when the real price of wheat declined by 4 per cent and that for maize fell by 8 per cent,  $G_t$  was the smallest. On the other hand, as real prices rose steadily through the mid-1990s,  $G_t$  reached its highest annual growth in 1994/5.

Relative to the gains in the incentive reforms, those from market liberalization not only start later (by policy choice), they are much smaller (Table 4,

**TABLE 4** *Estimated efficiency gains to HRS, increased responsiveness and faster adjustment in the reform and post-reform periods*

Year	Incentive Reform Period	Market Liberalization Reform Period		
	Cumulative percentage return to incentive reform ( $I_t$ )	Total percentage change in returns due to market reforms ( $G_t$ )	Percentage change in returns due to increased flexibility ( $F_t$ )	Percentage change in returns due to increased responsiveness ( $R_t$ )
1978	0.00	–	–	–
1979	0.07	–	–	–
1980	1.16	–	–	–
1981	3.25	–	–	–
1982	5.24	–	–	–
1983	6.51	–	–	–
1984	7.55	–	–	–
1985	–	0.38	–0.01	0.39
1986	–	0.63	0.21	0.43
1987	–	0.21	–0.20	0.41
1988	–	0.79	0.14	0.66
1989	–	1.01	0.30	0.70
1990	–	0.12	–0.42	0.54
1991	–	0.69	–0.25	0.94
1992	–	0.79	0.23	0.56
1993	–	0.58	0.05	0.53
1994	–	1.73	0.86	0.87
1995	–	1.11	0.48	0.63

*Note:* Percentages are calculated by taking estimated total year-to-year gains and dividing by total estimated returns to land and labour.

column 2). The average annual gain to liberalization over the entire period is 0.73 per cent, which means it is roughly 10 times smaller than the annual rise in profits from the gains to incentive reforms at the end of that period (7.55 per cent). Even at the peak, in 1994, aggregate gains to market liberalization are less than four times the size of the gains to incentive reform. These findings suggest that reforming incentives have much higher returns than reforming markets. This conclusion is reinforced when we consider the fact that our returns to market liberalization may be overstated since, in some sense, the returns are conditioned on the earlier reform of incentives.

Decomposing the returns to market liberalization, we see that most of the change has come from increased responsiveness (Table 4, column 4). On a

year-to-year basis, the returns to producers being more responsive to exogenous changes to prices and other factors average more than 0.50 per cent per year. The responsiveness gains have also been fairly constant over time, ranging from 0.39 to 0.94 per cent. Moreover, since producers became more responsive between the periods and the level of most of the exogenous variables, such as prices and the research and capital stock, rose, the returns to responsiveness were never negative.

In contrast to the returns from increased responsiveness, the benefits of increased flexibility are smaller, more variable, and are even negative in some years (Table 4, column 3). In part, the cause of the small gain is simply that the increase in speed of adjustment, especially for sown area, is relatively small. The variability of the returns and the appearance of negative values demonstrate that increased adjustment speed is not always a virtue, especially in an economy like China's that is experiencing year-to-year fluctuations in important factors that affect production, such as the output price. If prices soar in one period and then fall in the next, it is easy to see why slower adjustment could be beneficial. While there are lost profits in the first year when adjustment is slower, the second-period adjustment made in an attempt to catch up to the rising price in the first year might be exactly the right allocation (by accident) when prices in the second year fall. The more flexible producer is able to catch up more quickly, but the new flexibility could make him chase the prices back down in the second year (as opposed to being correct, as in the case of the producer who adjusts more slowly).

## CONCLUSIONS

In this paper we have tried to develop a framework to estimate the return to incentive and market liberalization reforms. Building on the adjustment cost literature, which provides us with ways to assess whether or not producers have become more flexible or responsive over time, we have developed a measure of the changes in efficiency that arise during periods of market liberalization. The measure can be broken down into two components, the returns to responsiveness and to flexibility.

We find that the behaviour of producers in China has been affected by the liberalization reforms, but that the gains have been relatively small. Farmers have increased their speed of adjustment between the early and late reform period for both labour and sown area. According to our estimates of own-price elasticities for labour and fertilizer, producers are also becoming more responsive. The magnitude of the gains in efficiency from increased responsiveness and flexibility in the late reform period, however, is substantially less in percentage terms (less than 1 per cent per year) than that from the incentive reforms in the early reform period (up to 7 per cent). Given these results, we argue that gradualism has succeeded where Big Bang has not.

In its most simple version, our story is as follows. Although we find that market liberalization policies in China's agriculture have increased producer responsiveness and flexibility, the returns to the incentive reforms were much

larger in terms of their impacts on farm profits, and household income, than market liberalization. Since the incentive reforms came first, and occurred without the disruption that almost invariably accompanies market transition in a reform setting, the large rise in wealth that was generated by the incentive reforms almost certainly gave the economy its initial positive boost. This may also have helped to trigger a series of positive downstream actions. While this is speculative, we believe that the initial surge of productivity helped raise the ability of households to make further investment, increase the demand for goods and services across the economy, and provide regional and national governments with a larger pool of resources from which they were able to draw taxes needed to finance transition. According to our estimates, at most only a fraction of these resources would have been generated if leaders started reforms by liberalizing markets. In fact, it is possible that liberalizing markets before agents face the right incentives and have the support of certain institutions and infrastructure leads to greater disruption and even smaller (or negative) returns that would have limited, not triggered, subsequent economic activity.

On the basis of our findings, we believe that leaders in transitional countries should first work hard to increase incentives and build the institutions that agents need to operate efficiently before moving to 'free up' markets radically. Our results need to be interpreted carefully, however. The study was limited to agriculture. In more complex sectors, reforming incentives may not lead to greater efficiency if markets are not already in place, given the need for greater coordination. We are also estimating the changes in parameters between periods with relatively few observations. It would be worth trying to replicate these results on other sectors with larger time series.

## NOTES

<sup>1</sup>Other institutional changes have had a number of important incentive effects associated with them, such as land tenure. We are ignoring them here, or claiming that the incentives for investing in land were sufficiently strong in the HRS reforms for the residual rights to farm output and the claim to the increase in land value to be indistinguishable. As argued below, we believe the rise of markets, although affecting incentives, should not be confused with incentives (see Lin, 1991; Huang and Rozelle, 1996). Rather, markets allow participants more scope for efficiently using resources. In this respect, we interpret market liberalization narrowly.

<sup>2</sup>In both Lin (1991) and Huang and Rozelle (1996), own-price output elasticities of farm producers rise after HRS, but the total output shows a secular drop due to the demise of some centrally planned functions that free market agents do not take over.

<sup>3</sup>The two quasi-input equations only contain a three-element vector as the three environmental variables are hypothesized to affect only the three output commodities.

<sup>4</sup>When explaining aggregate grain yields in China's provinces, Huang and Rozelle (1993) found four factors to have an important and robust effect: erosion, damage due to the deterioration of the local environment, salinization and soil fertility exhaustion from over-intense land use. The first two of these variables are included in the three output equations in this analysis.

<sup>5</sup>We currently have only 260 observations for the whole study period and there are 135 parameters to be estimated. If we were to divide the sample into two subperiods, we would have negative degrees of freedom for estimating the model for the first period and only 24 for the second period.

<sup>6</sup>We interact a dummy with all own-price responses except for wheat. The parameter for wheat is not precisely estimated in the original specification; it has a *t*-ratio of 0.26, and varies

widely when the model is specified differently. Other own-price response parameters are well-behaved when interacted with a dummy and are robust to different econometric specifications.

<sup>7</sup>Data were available for 13 provinces in North China (all provinces except for Inner Mongolia and Qinghai).

<sup>8</sup>The prices for creating the cash crop output variable come from the Cost of Production Data. The price used as an explanatory variable for equations 2–5 is from a national cash crop price index.

<sup>9</sup>Some people have questioned the reliability of the data since they are based on a relatively small sample size. A closer examination would indicate otherwise. In the 1990 enumeration, over 15 000 households living in 2245 counties were questioned about their costs of production for the six major grain crops. Price Bureau officials claim that they have maintained a random selection process. Consistency in the data is maintained by carrying over respondents for an average period of three to four years. Data are recorded by the households.

<sup>10</sup>Lin (1992) shows theoretically that, if the producer's marketing quota is output-dependent, production decisions depend on both the quota and market price. The best specification would include both prices. Unfortunately, these data are unavailable and the 'mixed' price is used as a proxy. The construction of these average prices implicitly assumes that producers are responding to an average price, constructed of quantity-weighted state and market (or 'negotiated') prices.

<sup>11</sup>The signs of the environmental variables are consistent with those found by Huang and Rozelle (1995). The erosion and deterioration of the local environment effects are particularly harmful to other grains, the crop grown in the most environmentally fragile regions. Salinity has the most significant impact on cash crops, especially in the North China Plain, China's cotton and peanut belt.

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## APPENDIX A: THEORETICAL MODEL

Facing adjustment problems with a set of their quasi-fixed inputs ( $K$ ), farmers are assumed to select optimal levels of variable inputs ( $L$ ), investment rate ( $I$ ), and  $K$ , given the prices of output ( $p$ ), variable input ( $w$ ) and quasi-fixed inputs ( $q$ ), and the level of external constraints. This maximization problem can be written as

$$V(p, w, q, K, Z) = \text{Max}_{Y, L, I} \int_0^{\infty} e^{-rt} (pY - wL - qK) dt \quad (\text{A1})$$

subject to:  $\dot{K} = I - \delta K$ ,  $K(0) = K_0 > 0$ , and  $Y = f(K, L, I, Z)$ , where  $r$  is the discount rate,  $K$  is the net investment in quasi-fixed inputs,  $K(0) = K_0$  is the stock of investment at the base year, and  $\delta$  is a diagonal matrix with positive depreciation rates on the diagonal. The function,  $f(\cdot)$ , is a multi-product production function. Given the regularity conditions on  $f(\cdot)$  and static price expectations, the value function in equation A1 satisfies the following Hamilton–Jacobi equation:

$$\begin{aligned} rV(p, w, q, K, I, Z) = \text{Max} I [\pi^*(p, w, q, K, I, Z) - q'K \\ + V'_K(p, w, q, K, Z)(I - \delta K)] \end{aligned} \quad (\text{A2})$$

where  $\pi^*$  is variable profit,  $V_K$  is derivative of  $V$  with respect to  $K$ . Epstein (1981) has shown that by applying duality and the envelope theorem to (A2), the following investment ( $K^*$ ), variable input derived demand ( $L^*$ ) and output supply ( $Y^*$ ) equations can be obtained:

$$\Delta K^* = V_{Kq}^{-1}(rVq + K) \quad (\text{A3})$$

$$L^* = -rV_w + V'_{Kw}K \quad (\text{A4})$$

$$Y^* = rV_p - V'_{Kp}K \quad (\text{A5})$$

where the lower-case subscripts are used to designate derivatives.



## APPENDIX B: PARAMETER ESTIMATES

**TABLE B1** *Parameter estimates of dynamic supply response system using non-linear three stage least squares estimator, Northern China*

Parameter	Estimate	T-ratio	Parameter	Estimate	T-ratio
B01	-45.25	0.73	H22	-0.37	0.57
B02	-148.27	2.54	IRR1	0.0024	0.69
B03	-494.11	1.41	IRR2	-0.0069	2.16
B04	-1799.31	2.16	IRR3	-0.038	2.23
B05	-2412.72	3.29	IRR4	0.054	1.64
B06	9.98	0.05	IRR5	-0.0033	0.12
A11	11574.59	0.26	IRR60	0.81	3.87
A12	71334.97	1.79	IRR61	5.70e-06	0.36
A22	73741.03	1.33	IRR62	1.64e-05	0.48
A41	-2.87	1.64	RES1	0.36	1.78
A42	-0.92	0.36	RES2	0.95	5.00
R11	-0.16	3.65	RES3	0.40	0.33
R12	-0.21	4.22	RES4	6.76	3.10
R21	0.12	1.64	RES5	17.30	8.93
R22	-0.35	8.38	RES60	-21.69	1.25
R11D	-0.04	2.98	RES61	0.0059	1.74
R22D	-0.25	5.49	RES62	0.00095	0.22
G11	0.14	0.03	HRS 1	-31.59	0.80
G12	6.41	1.37	HRS2	-140.71	3.84
G21	-3257.79	1.30	HRS3	564.06	2.50
G22	-12412.82	4.69	HRS4	927.59	2.31
L1	-8.60	3.14	HRS5	-684.74	1.92
L2	2575.69	1.80	HRS6	145.73	1.42
C11	-0.0010	0.73	DIS1	-2470.11	2.38
C12	0.54	0.93	DIS2	-3141.24	3.51
C22	879.83	2.32	DIS3	-225.27	0.94
F1	-31364.86	2.27	EROI	-660.72	1.71
F2	-39668.19	2.52	ER02	-1247.29	3.74
B	52181.49	4.79	ER03	-74.67	0.81
N1	-0.033	0.09			
N2	-0.067	0.16			
H11	4.02	5.97	Objective function *N = 757.3		
H12	0.68	1.18	Provincial dummies: not reported		
H21	-2.19	2.89	Number of parameters: 135		
			Number of equations: 6		