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ARTICLE *in* ECONOMICS OF TRANSITION · FEBRUARY 2004

Impact Factor: 0.68 · DOI: 10.1111/j.0967-0750.2004.00188.x · Source: RePEc

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Economics of Transition
Volume 12 (3) 2004, 427–465

The sequencing of reform policies in China's agricultural transition*

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Abstract

This paper provides evidence regarding gains due to agricultural market liberalization in China. We empirically identify the different effects that incentive and farm restructuring reforms and gradual market liberalization have on China's agricultural economy during its transition period. We find that average gains within the agricultural sector due to reforms that improved incentives and increased decision-making authority of producers exceed gains due to market liberalization by a large margin. Our method of analyzing the effects of transition policies on economic performance can be generalized to other reform paths in other transition economies.

JEL classifications: O4, P2, Q1.
Keywords: China, agriculture, adjustment costs.

* While writing portions of this paper, de Brauw was supported by a SSRC Program in Applied Economics fellowship funded by the John D. and Catherine T. MacArthur Foundation. The financial support from the Ford Foundation, Rockefeller Foundation, and China National Outstanding Youth Science Foundation (79725001) is gratefully acknowledged. Authors are in alphabetical order and the senior authorship is shared. Rozelle is a member of the Giannini Foundation of Agricultural Economics. The authors thank Julian Alston, Gershon Feder, John Mullen, Cathy Morrison-Paul, Johan Swinnen, and two anonymous reviewers for insightful comments that have improved this paper, as well as participants of the AAEA and IAAE meetings in Tampa and Berlin, respectively.

Published by Blackwell Publishing, 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA.

1. Introduction

At its most basic level, the debate over the optimal sequencing of economic transition policies can be characterized by two questions. Should reforming nations lead with radical market liberalization policies? Or should policy-makers provide individuals with incentives to increase productivity and increased decision-making authority before they dismantle central procurement planning and liberalize markets?

While the debate has raged since the fall of the Berlin Wall, there has been little progress in understanding exactly how better incentives, increased decision-making authority and liberalized markets have contributed to the success or failure of countries in transition. Most explanations of the success of a particular reform strategy have centred on comparing growth among different reforming economies. These studies ask whether countries in East Asia have grown faster than those in Europe because they sequenced their reform policies in a certain way rather than liberalizing quickly and radically (for example Roland and Verdier, 1999). However, comparative studies are typically unable to empirically isolate the factors that have positively and negatively contributed to the performance of different transitional economies. In evaluating the performance of specific aspects of transition, one particular difficulty appears to be in the measurement of the gains or losses due to market liberalization. While a number of studies have convincingly documented returns due to reforms that have provided producers with better incentives and increased decision-making authority (for example, Lardy, 1983; McMillan, Whalley and Zhu, 1989; Lin, 1992; Pingali and Xuan, 1992; Macours and Swinnon, 2000), only a few authors have attempted to empirically isolate the effects of market liberalization on behaviour and performance throughout the reform period (for example Wen, 1993; Fan, 2000; Huang *et al.*, 2000).

This paper is an attempt to fill this gap in the evidence. In it, we examine China's agriculture and seek to empirically differentiate the effects of the first-stage incentive reforms, which decentralized planning and provided incentives to producers who were operating restructured farms and farm restructuring and which gave increased decision-making authority to farmers, from the effects of market liberalization policies. We do this in three stages. First, we delineate the gains that countries can expect from changes to producer incentives operating in a more decentralized environment with increased decision-making authority on one hand and market liberalization on the other. Second, we set out a framework for measuring the sources of and returns to incentive reforms and farm restructuring as well as the sources of and returns to market liberalization policies. Third, we offer estimates of the timing and magnitudes of returns to both sets of reforms. Although our findings cannot unequivocally prove that Gradualism is superior to Big Bang reforms, they contribute to the debate on effective transition strategy and help to explain why China's choice of policies and their order of implementation has been successful. The paper also provides a methodology for analyzing the impact of specific transition policies on economic performance.

The study makes two main contributions to the literature. First, it provides estimates of gains to market liberalization in North China. And, second, it proposes a method for estimating the magnitude of returns to market reforms. We extend the empirical adjustment cost literature by developing a method of quantifying the effect of market liberalization policy shifts on economic efficiency. Our method can be generalized to other transition or developing economies which experience large scale market liberalization as part of either a transition or a structural adjustment process. To measure economic efficiency changes using an adjustment cost model, we find separate adjustment parameters for the early and late reform periods in China, which, we argue, coincide with pre- and post-market liberalization policy. We then exploit the difference between the two parameters to measure efficiency gains from faster adjustment, which we divide into what we call gains to flexibility and gains to responsiveness.

The study has some limitations. Because we limit our study to the cropping sector, our estimates for the gains to market reform do not account for some efficiency gains which may have occurred in other sectors of the rural economy. For example, we do not account for gains which may have occurred because labour is more free to move off-farm. We recognize that these gains may be significant and should be studied in the future. Furthermore, we only examine the case of producers in northern China so that crop and technology choices do not affect our analysis. The choice of North China is arbitrary but we have done an analysis of South China which reaches similar conclusions regarding increased flexibility and responsiveness for its different crop mix.

2. Incentives, markets and behaviour

The literature has carefully documented China's Household Responsibility System (HRS) reforms in the early 1980s and their impacts. Decollectivization provided producers with incentives by making them the residual claimants to the returns from cropping activities (henceforth, the *incentive reforms*). The reforms also restructured China's farms, shifting most decision-making authority from the commune to the household (henceforth *farm restructuring* or *increased decision-making authority*, terms that we use interchangeably in the rest of the paper). Specifically, households were given more authority – although it was still limited – over crop choices and production decisions (Lin, 1992; Sicular, 1988a; Fan, 1991). For example, Wiens (1982) reports that after decollectivization farmers were able to shift from three to two seasons in southern Jiangsu because mandatory production targets and planting plans were eliminated.

While the definition of the scope of these reforms varies from author to author, all measurements of the effect of HRS reforms on economic performance coincide. McMillan, Whalley and Zhu (1989), Fan (1991), Lin (1992) and Huang and Rozelle (1996) use different datasets, examine different sub-sectors of the rural economy, apply different methods but all conclude that the HRS reforms led to greater efficiency. The HRS variable which these authors use is assumed to proxy for the incentive reforms and farm restructuring provided to producers during the first-stage reforms. Their TFP decomposition and econometric analyses measure the gains from the reforms as upward shifts of the profit or production function. Implicitly, the authors assume that the first-stage reforms were completed by 1984. In the rest of this study, we make a similar assumption: that the efficiency gains in the early 1980s were caused by the incentive reforms and farm restructuring that are associated with HRS.[1]

Beyond decollectivization and farm restructuring, in the late 1970s, central planners also began to allow localities to make more production decisions themselves (Lardy, 1983; Sicular, 1988a). Production plans downplayed the importance of sown area targets and local producers had more latitude to make their own production and marketing plans. Instead of specifying the type of crops in terms of sown area and even the technology to be used, leaders in the late 1970s began to let regional authorities exert more control. In addition, the level of the mandatory delivery quotas fell, although almost all sales – both those that were mandatory and those that were more voluntary – still had to be made to the state. In our paper, we now call these complementary policy changes the *planning decentralization reforms*. In the rest of the paper, we refer to the incentive (or HRS) policies and planning decentralization as the *first-stage reforms*.

In contrast, less research has focused on the nature and timing of the market liberalization reforms (henceforth, the *market liberalization reforms* or the *second-stage reforms*). We subscribe to the argument put forth by Rozelle (1996) that China's reformers made only limited progress towards dismantling the planning system for the allocation of goods and services for *most* of the cropping sector before 1985. This position is consistent with the papers of Sicular (1988a; 1988b; 1995), which discuss the agricultural commercial reforms, and the works of Perkins (1988), Lin (1992) and Putterman (1993), which document the nature of China's early rural reforms. In the early 1980s China's leadership had little intention of letting the

[1] Other institutional changes are associated with important incentive effects, such as improved land tenure. We claim that during the HRS reforms incentives for investing in land were strong enough that the claim to profits from farm output and the claim to the increase in land value are indistinguishable. As will be argued below, we believe the rise of markets, although affecting incentives, should not be confused with reforms that created the efficiency-increasing incentives and better decision-making authority (Lin, 1991; Huang and Rozelle, 1996). Rather, markets allow actors with good incentives and decision-making authority more scope for efficiently using resources. In this respect, we interpret market liberalization more narrowly than McMillan (1997). It should also be recognized that the increased decision-making authority that the reforms provided to farmers would both raise technical efficiency and improve allocative efficiency in the same manner as better markets. While we discuss how improving the ability to respond would affect performance in subsequent sections, our assumption, as in the case of incentives, is that farm restructuring and planning decentralization were mostly completed by 1984 and if there was an impact on farmer performance, it primarily occurred during the first-stage reforms.

market play anything but a minor supplemental guidance role (Sicular, 1988b). In fact, the major changes to agricultural commerce in the early 1980s almost exclusively centred on increasing the purchase prices of crops (Sicular, 1988a; Watson, 1988). The decision to raise prices should *not* be considered as a move to liberalize markets since planners in the Ministry of Commerce made the changes administratively. Price increases themselves are not considered part of the incentive or restructuring reforms, although higher output prices (combined with better incentives) would certainly lead to increased farmer effort and higher production.[2]

An examination of policies and the extent of marketing activity in the early 1980s illustrates the limited extent market liberalization of China's food economy before 1985. Reformers allowed farmers increased discretion to produce and market crops in 10 planning categories, such as vegetables, fruits and coarse grains. By 1984, the state only claimed control over 12 commodities, including rice, wheat, maize, soybeans, peanuts, rapeseed and several other cash crops (Sicular, 1985). This may seem to represent a significant move towards liberalization; but, in fact, grain, oilseeds, cotton, tobacco and sugar – crops almost entirely under the planning authority of the government – still accounted for more than 95 percent of the sown area in 1984. Hence, the output and marketing of crops accounting for almost all of the sown area were still directly influenced by China's planners.

The lifting of restrictions on free market trade was equally limited. The initial decision to allow free markets in 1979 allowed farmers only to trade vegetables and a limited number of other crops and livestock products within their own county. From 1980 to 1984 reformers gradually reduced restrictions on the distance over which trade could occur, but as Sicular (1988a) points out, this was a time when local rural periodic markets were beginning to re-emerge. Farmers also began to sell their produce in urban settings, but free markets in the cities only started to appear in 1982 and 1983. In any case, traders could not engage in the marketing of China's monopolized commodities. Lin (1992) shows that only 3.69 percent of the gain in production in the 1978–84 period can be attributed to crop diversification, which he uses to proxy for market reforms.

The record of the expansion of rural and urban markets confirms the hypothesis that market liberalization had not yet begun by the early 1980s. Although agricultural commodity markets were allowed to emerge during the 1980s, their number and size meant that they had little significance in China's food economy. In 1984, the state procurement network still purchased more than 95 percent of marketed grain and more than 99 percent of marketed cotton (Sicular, 1995). In all of China's urban areas there were only 2000 markets in 1980, and only 6000 by 1984

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[2] Although we do not consider price changes, which could be created either by the planning system or by the market, as part of the first- or second-stage reforms, in our model we control for the effects of price changes on agricultural output. Therefore when we measure the effects of reforms on output, our measures do not include the effects of price changes.

(ZGSYNJ, 1992). In Beijing in the early 1980s there were only about 50 markets transacting around 1 million yuan of commerce per market per year. Each market site would have had to serve, on average, about 200,000 Beijing residents, each transacting only 5 yuan of business for the entire year. It would have been impossible for such a weak marketing infrastructure even to approach meeting the food needs of urban consumers.

After 1985, however, market liberalization began in earnest. Changes to the procurement system, further lifting of restrictions on trading of commodities, moves to commercialize the state grain trading system and calls for the expansion of market construction in rural and urban areas, all led to a surge in market-oriented activity (Sicular, 1995). For example, in 1980 there were only 241,000 private and semi-private trading enterprises registered with the State Markets Bureau; by 1990, there were more than 5.2 million (ZGSYNJ, 1992).

Even after the start of market liberalization in 1985, however, the process was still erratic (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. Only in the early 1990s did agricultural officials once again remove the controls on fertilizer marketing and begin to encourage private trade. Lin, Cai and Li (1996) argue that leaders feared the disruption which would result from eliminating those institutions which controlled the food economy before others were in place which could promote efficient market exchange.

Hence, in this paper, we make the assumption that there have been two distinct policy phases in China's agricultural reforms. The first-stage reform period (1978–84) was dominated by decollectivization and planning decentralization, which increased incentives for farmers and encouraged farm restructuring, allowing for more efficient decision making. The second-stage reform period (1985–95), in contrast, concentrated on a gradual liberalization of the economy by developing market institutions. The move to liberalize markets only came after the most important incentive, or first-stage, reforms had been completed.[3]

2.1 The record of market liberalization

Marketing and pricing reforms led to measurable improvements in markets during the late reform era. By the mid-1990s, most food commodities were marketed by farmers at market-determined prices (Sicular, 1995). Statistical analysis indicates that domestic grain markets became more integrated and that competition and

[3] Of course, we recognize that in reality the division was not so precise. Certainly there was some, albeit minor, relaxation of marketing restrictions prior to 1985. Furthermore, neither incentives nor the ability of regional authorities and producers to make their own decisions were perfect by 1985, and they both improved after 1985. To the extent that our assumptions are not perfectly valid, caution must be exercised regarding our interpretation of the results.

efficiency in markets rose (Park *et al.*, 2002). The rise of a private trading class resulted in an increase in China's grain procurement through non-official channels. The literature does not claim that markets were perfect by 1995. However, none who visited rural China in the mid-1980s and then returned in the mid-1990s could have missed the increase in market activity.

Although a few authors have attempted to quantify the gains from market liberalization, their studies have several shortcomings. Wen (1993) found that total factor productivity (TFP) growth stopped in the post-1985 period, the blame for which he lays on the failure of the second-stage reforms. However, Wen's analysis ends in 1990, which might be too early for market liberalization to have had effects on TFP. Second, he examines only the net change in TFP and does not account for other factors that could be affecting productivity. Huang *et al.* (2000), using data through 1995 and holding the effect of technology constant, find that TFP growth restarts in the 1990s, which they argue could be linked to increased liberalization of the economy. Like Wen, however, they do not explicitly examine the improvements in efficiency that are associated with market development. Fan (2000) decomposes the efficiency gains of Jiangsu provincial rice producers in the late reform era and finds that there were only limited gains in allocative efficiency after 1984. Unfortunately, Fan's study is limited to only one crop in one province, which limits its generalization.

From this small literature, it would appear that there is at most only a relatively small measured gain from market reforms in China. There are three possible explanations for this result: the first is that market liberalization in fact has little to contribute to income and output growth; second, the positive effects appear with a delay because the market liberalization was implemented slowly; or, third, the methods used are inadequate to capture the effects (possibly because most studies treat market liberalization as responsible for the residual growth after accounting for other sources).

3. Returns to market liberalization: Increased flexibility and responsiveness

The absence or poor functioning of markets imposes two constraints on economic 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 the choice of enterprises. Second, when markets function poorly, 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.

To understand more precisely what is meant by flexibility, we suppose there are two aggregate agricultural production functions, one in a pre-liberalization period (F_A) and one in a post-liberalization period (F_B).[4] A profit-maximizing farmer who in year $t-1$ faces an output price p_{t-1} chooses to produce an amount Q_A which is at a certain point on F_A, using a quantity of some quasi-fixed input X_{A1}. In year t, the price increases to p_t. A farmer who is unconstrained would move to the point of optimal production by increasing the use of the input to X_{A2}.

However, if there are frictions in the economy, the producer will not be able to completely adjust the quantity of the quasi-fixed input, X, in response to the price change within one year. For example, if the price of a commodity rises, profit-maximizing farmers would like to increase the application of fertilizer and raise the production of the commodity. If markets do not function well, because trade is not allowed across provincial boundaries or because the farmers are unable to purchase more fertilizer, the farmer would only shift part of his area into the commodity. Therefore, the producer is only able to increase the quasi-fixed input to X_{AP} in year t, which is between X_{A1} and X_{A2}. The lost profit from production at X_{AP} rather than X_{A2} is a measure of the inefficiency due to inflexibility. Other policy measures, such as the nation's mandatory procurement quota system which requires farmers to sell a certain commodity to the state for a state-set, below-market price (at least during the entire study period), could also prevent farmers from shifting their resources completely to the profit-maximizing point in the first year.

Market liberalization can reduce the amount of inefficiency as follows. Although the producer, producing on an alternative production frontier, F_B, is not able to adjust perfectly, market liberalization policies facilitate exchange. For example, it could be that the market liberalization reforms reduce the mandatory procurement quota. This time, the producer, since his actions are less constrained, in response to the price change from p_{t-1} to p_t, can increase the use of the quasi-fixed input from X_{B1} to X_{BP}, which is further than the shift the producer made on F_A from X_{A1} to X_{AP}. The more rapid adjustment in the post-liberalization era can most easily be illustrated by comparing the number of years that it takes to fully adjust from the original amount produced to the point of long-run optimality. For example, if in a pre-liberalization era it took four years, in the post-liberalization era, if the expansion of markets made producers more flexible, it would take two years.[5]

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

[4] The assumption of two production functions, one prior to market liberalization and one after market liberalization, is made to illustrate the change in the speed of adjustment that arises from differences in the level of market development during the two periods, not because technology necessarily changes. In our analysis, when we measure the speed of adjustment, we attempt to hold all other important factors constant.

[5] In the adjustment cost model we will use in estimation, farmers are assumed to respond to the previous year's price. While this assumption is extensively used in the literature, it could be that the method farmers use to generate price expectations may also make them adjust factors imperfectly when prices or other exogenous factors change. However, as long as the process of forming price expectations does not change, market liberalization should speed up adjustment. It could, of course, be that the emergence of markets themselves affects the adjustment process, which would also affect the speed of adjustment.

choices of sown area and labour. In the late reform period, as quotas have fallen (Wang, 2000) and labour markets developed (Parish, Zhe and Li, 1995; de Brauw *et al.*, 2002), the scope for rural household decision-making has expanded greatly. In particular, the rise of rural industry and increased off-farm work opportunities in areas near the farmer's home village have possible had an effect on the flexibility of labour use.

The lack of well-functioning markets may also limit the *responsiveness* of farmer supply and derived demand decisions. According to one of Marshall's fundamental principles of demand, the greater are the number of variable factors of production, the more responsive are producer choices to changes in price and other fixed factors (Marshall, 1890). 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*. We would expect that if new markets emerged and facilitated exchange, producers could respond more rapidly. Empirically, this change would show up as more elastic response parameters. For example, own price elasticities would become larger in absolute value terms.

Although we are trying to isolate the behavioural effects of the first-stage reforms from the effects of market liberalization, in reality it is likely the two are related. 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 improved incentives.[6] Since we are trying to identify the effect of increased market liberalization, quantitative measures of the liberalization should not be affected if the first-stage reforms were already implemented and fully effective by the mid-1980s. However, increased responsiveness is conditional on having good incentives and relatively full decision-making authority, so when one considers how policies should be sequenced in this case, the true returns to liberalization policies will be overstated if all of the efficiency gains in the late reform period are attributed to them.

4. Measuring behavioural effects of market liberalization

As discussed in the previous section, the increase in the speed with which quasi-fixed factors adjust relates to increased *flexibility*. To estimate the adjustment speed of quasi-fixed factors while considering the main sources of production growth, a theoretical and empirical framework is needed which explicitly accounts 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, including the agricultural treadmill (Cochrane, 1965), fixed asset theory (Johnson,

[6] 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 policy functions that free market agents do not take over.

1956; Hathaway, 1963) and adjustment cost models (Lucas, 1967; Johnson and Quance, 1972).

The adjustment cost approach is particularly appropriate for modeling 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. In this section, we will first briefly present the theory behind the adjustment cost model and an empirical model that follows it. Next, we will describe the empirical model, and finally we will describe our method for using the adjustment cost model to measure changes in flexibility and responsiveness.

4.1 The adjustment cost model

Facing adjustment problems with a set of their quasi-fixed inputs (k), farmers are assumed to select optimal levels of variable inputs (l), their investment rate (i), given prices of outputs (p), variable inputs (w), and quasi-fixed inputs (q), and the level of external constraints (z) (for example, the availability of technology; irrigation and agronomic factors) in order to produce output (y).[7] Their maximization problem can be written as:

$$V(p, w, q, k, z) = \max_{y,l,i} \int_0^\infty e^{-rt}(p \cdot y - w \cdot l - q \cdot k)\mathrm{d}t \tag{1}$$

subject to $\dot{k} = i - \delta \cdot k$, all elements of k at time $t = 0$ are positive, 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 vector of initial stocks of investment in each quasi-fixed input, and δ 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 (1) satisfies the following Hamilton–Jacobi equation:

$$rV(p, w, q, k, z) = \max_i [\pi^*(p, w, q, k, i, z) - q'k + V_k'(p, w, q, k, z)(i - \delta k)] \tag{2}$$

where π^* is variable profit, and V_k is the derivative of V with respect to k. Epstein (1981) has shown that by applying the envelope theorem to (2), the following equations for investment ($\dot{k}^*$), variable input derived demand (l^*) and output supply (y^*) can be obtained:

$$\dot{k}^* = V_{kq}^{-1}(rV_q + k) \tag{3}$$

[7] In this section, a variable show in bold type is a vector or matrix; one that is not is a scalar.

$$l^* = -rV_w + V'_{kw}\dot{k} \tag{4}$$

$$y^* = rV_p + V'_{kp}\dot{k} \tag{5}$$

where the lower case subscripts are used to designate derivatives.

Therefore, the adjustment cost model suggests that we should estimate a system of equations that represent quasi-fixed factors, variable factors and outputs in order to measure quasi-fixed factor flexibility consistently. We choose to follow Epstein (1981), who specifies the dynamic value function in equation (1) as a normalized quadratic, $V(\cdot)$:

$$\begin{aligned} V(p, w, q, k, z) &= a_0 + [a_1\ a_2\ a_3\ a_4]\,[p\ w\ q\ k]' \\ &+ \frac{1}{2}[p\ w\ q\ k]\begin{bmatrix} A & F' & G' & H' \\ F & B & L' & N' \\ G & L & C & (R^{-1})' \\ H & N & R^{-1} & D \end{bmatrix}[p\ w\ q\ k]' \\ &+ [a_5\ p\ w\ q\ k]\,[X_0\ X_1\ X_2\, X_3\ X_4]\,\mathrm{z} \end{aligned} \tag{6}$$

where $a_0, \ldots, a_5$, A, F, G, H, B, C, R, L, D and $X_0, \ldots, X_4$ are parameter matrices with appropriate dimensions and z is a vector of exogenously determined control variables.[8] The empirical formulation of the complete system of input demand and output supply equations, corresponding to equations (3) to (5), has the form:

$$\Delta k_t = \Theta^{12} + (rU + R)k_{t-1} + rRGp_{t-1} + rRLw_t + rRCq_t + T_{12}z_t + \epsilon_t^{12} \tag{7}$$

$$l_t = \Theta^3 - rFp_{t-1} - rBw_t - rL'q_t - N'k_t^* - T_3 z_t + \epsilon_t^3 \tag{8}$$

$$y_t^{12} = \Theta^{45} + rAp_{t-1} + rF'w_t + rG'q_t + H'k_t^* + T_{45}z_t + \epsilon_t^{45} \tag{9}$$

$$\begin{aligned} y_t^3 &= \Theta^6 + ra_4k_t^* - \frac{1}{2}rp'_{t-1}Ap_{t-1} - \frac{1}{2}rw'_tBw_t - \frac{1}{2}rq'_tCq_t \\ &- rp'_{t-1}F'w_t - rp'_{t-1}G'q_t - rw'_tL'q_t + \frac{1}{2}rk'_{t-1}Dk_{t-1} \\ &- \Delta k_tDk_{t-1} + rT_{60}z_t + z_tT_{61}k_t^* + \epsilon_t^6 \end{aligned} \tag{10}$$

where $\Theta^{12} = rRa_3$, $\Theta^3 = -ra_2$, $\Theta^{45} = ra_1$, $\Theta^6 = ra_0$, $k^* = rk_{t-1} - \Delta k_t$, $T_{12} = rR^{-1}X_3$, $T_3 = -rX_2$, $T_{45} = rX_1$, $T_{60} = a_5X_4$, and U is a 2×2 identity matrix. Our empirical model actually consists of two quasi-fixed inputs (represented by equation (7)), one variable input (equation (8)) and three outputs (equations (9)–(10)).[9] We consider

[8] The dimensions of each submatrix are determined by the number of prices and quasi-fixed inputs included in the system. As there are five prices and two quasi-fixed inputs, the entire large matrix is 7×7. Each submatrix has dimensions determined by the relationship it represents; for example, the A matrix represents the effects of output prices on output response, and therefore it is 2×2.

sown area and labour to be quasi-fixed inputs, so k in equation (7) represents an equation that explains the change in sown area and an equation that explains the change in labour. Δk represents the change in quasi-fixed factor level between period t and period $t - 1$. Fertilizer is the variable input, represented by l in equation (8).[10] The three output equations explain production of wheat, maize and cash crops; y_{12} is a two-element output vector for wheat and maize, and y_3 represents 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 shift variables: national research stock, irrigation capacity and a variable reflecting the effect of institutional incentive reform.[11] Provincial dummy variables account for fixed, province-specific effects. Conditions for consistent aggregation requires $V_{KK} = D = 0$ (Epstein and Denny, 1983), which is imposed in estimation.

The R matrix has special meaning in the adjustment cost model, since it measures the response of quasi-fixed input demand to changes in relative prices. Since we consider sown area and labour to be quasi-fixed inputs, we assume that it is costly to adjust them to their optimal levels. If adjustment of these inputs is costly, then the quasi-fixed input stocks affect demand for these inputs, as in equation (7). Alternatively, if these inputs can be adjusted costlessly to their optimal levels, then the diagonals of the R matrix, R_{11} and R_{22}, will both be −1, and the off-diagonal elements, R_{12} and R_{21} will both be 0. The former restriction implies that no disequilibrium exists in the use of the input, and the latter requires that the lagged stock of one input does not enter the investment demand equation for the other input (Warjiyo, 1991). These hypotheses can both be tested empirically. If the diagonals are not negative unity, then the coefficients can be interpreted as the percentage of the optimal adjustment that occurs in one period. For example, if we estimate $R_{11} = -0.25$, the model implies that sown area adjusts 25 percent of the way to its optimal level (Vasavada and Chambers, 1986; Warjiyo, 1991).

4.2 Measuring flexibility and responsiveness

To measure the *change of flexibility*, we interact a dummy variable (which is zero for the early reform period, 1975–84, and one for the late reform period, 1985−95)

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[9] We write out the six equations with matrix elements, as estimated, in Appendix A.

[10] We also test whether fertilizer is a quasi-fixed input by specifying the model with three quasi-fixed input equations and three output equations. We found that after 1985 we could not statistically reject the hypothesis that fertilizer is a variable input, indicating that at least over some portion of the study period, fertilizer acts as a variable input.

[11] The two quasi-input equations only contain the three element vector of shift variables explained in the text. The three crop output equations also include variables that measure erosion and local environmental degradation. When explaining aggregate grain yields in China's provinces, Huang and Rozelle (1995) 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.

with all of the variables in equations (6) and (7) associated with the adjustment parameters 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.

The adjustment cost model generated two types of elasticities which describe the relationship between the choice variables (in our model, fertilizer and the *changes* in sown area and labour) and exogenous factors (for example, prices and fixed factors). Short-run elasticities only consider the producer's partial, one period response in the choice variable to a change in an exogenous factor. Long-run elasticities describe the full, multi-period response to the change, a shift which accounts fully for the complete shifts of the quasi-fixed factors. In order to better understand why two types of elasticities exist in adjustment cost models (that is models with quasi-fixed factors), each elasticity can be thought of as having a *direct* and *indirect* component. The direct component is the part of the elasticity that is purely the response in the choice variable to the change in the exogenous factor and can be thought of as being an estimate of the *partial* derivative of the choice variable with respect to the exogenous factor. For example, we expect that fertilizer demand will increase if the fertilizer price falls, holding all other factors constant. The direct component of the elasticity is the same in the short run and the long run.

The indirect component of short- and long-run elasticities, however, differs. The indirect component of the elasticity measures the response in a choice variable to a change in an exogenous factor because of the changes in *other* choice variables. The indirect component of the elasticity is similar to the remainder of the *total* derivative of the change in a choice variable with respect to a change in an exogenous factor, after the direct component is removed. The indirect component of the elasticity differs in the short- and long-run, because the producer cannot completely adjust the quasi-fixed factors to their optimal levels in one period. In our example, fertilizer price changes induce producers to begin to shift their levels of the quasi-fixed factors, sown area and labour, and these changes will also affect fertilizer demand. This additional change in fertilizer demand is the indirect component in the short-run. Since the complete shift of the quasi-fixed factors to their long-run optimal levels take several periods, the long-run indirect component of the elasticity measures the shift in fertilizer to the final point of long-run optimality. The slower the adjustment process, the smaller the indirect component of the short-run elasticity.

Warjiyo (1991, p. 65) includes detailed calculations for deriving the short- and long-run elasticities from the estimated parameter matrices in equations (7) to (10). We will use the differences between the short- and long-run elasticities as a measure of inefficiency. Since the long-run elasticity allows us to measure the full response to a change in price, the fewer the years that it takes for the complete change in behaviour to occur in response to a change in the exogenous factor, the less inefficiency there is and the less difference there will be in the short- and long-run elasticities. If market liberalization leads to more rapid adjustment, we should see the differences between the short- and long-run elasticities decrease.

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 (7) to (10) for the early and for 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 limited size of our dataset makes the estimation of two separate models impossible.[12] 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 sub-period dummy variable.[13] 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.

5. Efficiency gains from increased responsiveness and flexibility

5.1 Creating the measure of increased efficiency due to market liberalization

In this section, we will use the adjustment cost model to develop a method to calculate the inefficiency that arises from imperfect adjustment. We begin with a measure of profits that is specific to China. Since in China almost no land is rented and almost no hired labour is used for farming, we define profits as the returns to the household's endowment of land and labour. Using our model's results to predict variable inputs and outputs, we can write the profits in year t as:

$$\Pi_t = \sum_i P_{it}\hat{Q}_{it} \tag{11}$$

[12] We have 260 observations for the whole study period, and there are 135 parameters to be estimated. If we were to divide the sample into two sub-periods, we would have negative degrees of freedom for estimating the model for the first period and only 24 for the second period.

[13] We interact a dummy with all own-price responses except for wheat. The own-price response 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. The estimates for this specification can be found in de Brauw, Huang and Rozelle (2000).

where P represents all output and variable input prices, $\hat{Q}$ represents predicted 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. In our attempt to measure the change in profit from market liberalization, however, we are not interested in profit *levels*. Rather, we are interested in the amount that profits *change* due to changes in prices and other exogenous factors. To capture the change in profits, we define:

$$\Delta\Pi_t = \Pi_t - \Pi_{t-1} \equiv \sum_i (P_{it}\Delta Q_{it}(\hat{R}_j, \hat{C}_j, \hat{\beta}) + Q_{it-1}\Delta P_{it}). \tag{12}$$

As discussed in the previous section, output and variable input responses are dependent on the speed of adjustment of quasi-fixed factors ($\hat{R}_j$), own-price responses ($\hat{C}_j$), and all other parameters that affect output and variable inputs ($\hat{\beta}$). The subscript j indexes the speed of adjustment (i.e., j = 1, 2, for adjustment in the first- and second-stage reforms, respectively). The term $\Delta Q_{it}(\hat{R}_j, \hat{C}_j, \hat{\beta})$ is calculated by:

$$\Delta Q_{it} = Q_{it}(\hat{R}_j, \hat{C}_j, \hat{\beta}) \sum_k \frac{\Delta\rho_{kt}}{\rho_{kt}} \varepsilon_{kt}(\hat{R}_j, \hat{C}_j, \hat{\beta}) \tag{13}$$

where ρ represents all prices and government policy variables, k indexes them (k = wheat, maize, cash crop, and fertilizer prices; research and irrigation stocks), and ε represents all elasticities.

We can calculate equation (13) using either the long- or short-run elasticities. When it is calculated with long-run elasticities, the quantity responses reflect that quasi-fixed factors *fully* adjust and the producer has shifted his output to the point at which he is earning optimal profits. Therefore, we will label calculations made with long-run elasticities as R_f, where f denotes full adjustment. When it is calculated with short-run elasticities, quasi-fixed factors only *partially* adjust, the full indirect responses are ignored, and the producer is *not* at a point that maximizes profits. Furthermore, we will measure the change in Q and profits when the speed of adjustment shifts at a pace that is characterized by the degree of market liberalization in both the first and second stages of reform. To do so we use two different sets of short-run elasticities. We will label the adjustment coefficients as R_1 when we use parameters from the first stage reform and R_2 when we use parameters from the second stage reform.

The first step in arriving at an estimate of the gains to market liberalization is to calculate the inefficiency that arises from imperfect adjustment. We define the inefficiency, Ω_t, as the difference between the *hypothetical* change in profits that would have occurred had the farmer fully adjusted (that is if the adjustment had been made with parameters from R_f) less the *actual* change based on partial adjustment ($\hat{R}_j$, j = 1, 2), given the change in prices and other exogenous factors that occurred during the period:

$$\Omega_{tj} = \Delta\Pi_t(R_f, \hat{C}_j, \hat{\beta}) - \Delta\Pi_t(\hat{R}_j, \hat{C}_j, \hat{\beta}). \tag{14}$$

The inefficiency measure can be measured in either period k = 1 or k = 2.

To measure of the *change* in inefficiency between two periods, we can measure the economic inefficiency using the parameters estimated for the first-stage reforms, Ω_{t1}, and compare them with the measure of inefficiency for the second period, Ω_{t2}. If we use measures of R_f from the second period in the calculations of both Ω_{t1} and Ω_{t2} and subtract one from the other, we get a measure of the *overall* gain to the economy due to market liberalization between the early and late reform. We call the gain G_t:

$$G_t = \Omega_{t1} - \Omega_{t2}. \tag{15}$$

In essence, our measure G_t is a measure of the gain from market liberalization to the overall economy in year t. It measures the amount of additional profits that are gained in a year during the market liberalization period because the speed of adjustment has increased from the first-stage adjustment rates to the second-stage reform rates.

To illustrate the concept behind our measure, consider an economy in which prices rise such that a full, optimal response would lead to $100 additional profits in year t (e.g., $\Delta\Pi(R_f) = 100$). If producers were only able to adjust at the slow rate during the time when markets were poorly developed as they were during the first stage of the reforms, their additional profits would have been $70. Therefore, the inefficiency due to slow adjustment would be $30, or $\Omega_{t1} = 100 - 70 = 30$. However, if after market liberalization the economy was able to adjust faster (during the second stage of the reforms), and the additional profits were $80, then the inefficiency drops to only $20, or $\Omega_{t2} = 100 - 80 = 20$. In our notation, the gain to faster adjustment, G_t, is 30 – 20 = $10.

5.2 Decomposing the measure of the gain due to efficiency from market liberalization

We actually break down the total efficiency gains, G_t, even further, into one part that arises from increased flexibility and one that is due to increased responsiveness. To do so, we rewrite G_t as a function of profit changes (from equation (14)), and rearrange:

$$G_t = -((\Delta\Pi_t(\hat{R}_2, \hat{C}_2) - (\Delta\Pi_t(\hat{R}_1, \hat{C}_1)) + (\Delta\Pi_t(R_f, \hat{C}_2) - \Delta\Pi_t(R_f, \hat{C}_1))) \tag{16}$$

As written, the two bracketed terms in equation (16) have intuitive interpretations that correspond to the two changes to efficiency caused by market liberalization. The first term is the loss of profits that would have resulted had the speed of adjustment been the same in the second period as 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 $G_t = F_t + R_t$. In order to make our measures of G_t, F_t, and R_t comparable across years as profit levels change, we normalize all three by dividing each measure by present year profits.

5.3 Measuring the gain due to better incentives and planning decentralization

To meet our goal of assessing the relative effects of market liberalization, we also need measures of the gains due to the first-stage reforms. We create such a measure by using our estimated empirical model to simulate profits in the early reform period (1978–84), with and without the shift attributable to the incentive reforms and planning decentralization. Since the decollectivization variable enters equations (6) to (10) linearly, the coefficients on the HRS variables can be interpreted as the shifts in production behaviour that can be attributed to HRS as the first-stage reforms are implemented. Suppressing all other arguments, the difference between the simulated profits with ($\Pi_t(HRS_t)$) and without ($\Pi_t(0)$) the shift due to the first-stage reforms measures the gains in economic efficiency.[14] The difference is a measure of the gain to the first-stage reforms, I_t, which is the increased profits due to the reforms:

$$I_t = \Pi_t(HRS_t) - \Pi_t(0). \tag{17}$$

As with the gains to market liberalization, we normalize by profits in year t ($\Pi_t(HRS_t)$) to make I_t comparable across years.

Both of our measures of gains due to reforms, G_t and I_t, measure the amount that profits would increase if the policies had not been implemented, while holding other factors constant. G_t measures the level by which profits increase due to decreased inefficiency that results from market liberalization reforms. I_t measures increase in profit levels that can be attributed to the first-stage reforms.

6. Data

Provincial-level cross-section, time-series data for 1975 to 1995 are used in the analysis.[15] Output for wheat, maize, other grains, and cash crops (cotton, sugar cane, peanuts, and rapeseed) are measured in kilograms and after 1980 are from published statistical compendia (ZGTJNJ, 1980–1993; ZGNYNJ, 1980–96).[16] Although these crops do not account for all of the sown area in North China,

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[14] As we explain below, we use data for 1975–95. However, we consider that the early reform period only occurred between 1978–84, when HRS and planning decentralization were being implemented.

[15] Data were available for 13 provinces in North China (all provinces except Inner Mongolia and Qinghai).

[16] Means for selected variables, tabulated by year, can be found in Appendix B.

wheat, maize, other grains, and the four cash crops account for over 80 percent of sown area (ZGTJNJ, 1980–96). Prior to 1980, data for these variables come from provincial yearbooks.[17] Data on total sown area in each province are from the same sources. 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 (CCPS). This information comes from a data-collection program run by the State Price Bureau since the mid-1970s (SPB, 1988–96). 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 revenue, expenditure (in value terms) and quantity data.[18] Prices are generated by dividing total revenues or expenditures by the quantity. This procedure gives us an average price or a unit value. While we usually assume that producers respond only to the marginal price, Lin (1991) shows theoretically that if the producer's marketing quota is output-dependent, the producer's production decisions depend on both the quota and market price. The best specification would include both prices, but unfortunately these data are unavailable. By constructing and using average prices, we implicitly assume that producers are responding to an average price, constructed of quantity-weighted state and market (or 'negotiated') prices.[19] While it is conceivable that this assumption could affect the results, in practice it is unlikely that there is a problem. Using a similar dataset, Wang (2000) shows that there is little econometric difference between the unit value and

[17] Provincial data before the early 1980s are not available from the State Statistical Bureau, so data before the early 1980s are from provincial yearbooks. We obtained a complete set of provincial statistical yearbooks from the library of the Agricultural Economics Institute of the Chinese Academy of Agricultural Sciences. These yearbooks have data back to the 1970s. One shortcoming of the provincial yearbooks that were released in the early 1980s was that its data series sometimes differed from those published in State Statistical Bureau publications. These discrepancies, however, were corrected in provincial publications that were published in the late 1980s. In this paper, we use the most recent yearbooks with corrected series, making our data the most consistent available.

[18] Some people have questioned the reliability of the data, and criticized it because it is based on a relative small sample size. A closer examination would indicate otherwise. In the 1990 enumeration, over 15,000 households living in 2,245 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 self-recorded by the households.

[19] In papers that examine pricing policy changes, three prices are often studied: the quota price, the market price, and a negotiated price. Formally, the negotiated price is the price paid by the state-run grain bureau for above quota grain purchases. While there are some subtle differences across provinces and over time, the negotiated price is actually very similar to the market price.

In an unpublished paper, Lohmar and Rozelle (2000) show that the only difference between the negotiated price and market price in 1995 is due to the timing of the purchase. On the basis of these observations, we assume throughout this paper that the negotiated price is close to the market price.

the marginal price.[20] The correlation coefficient between the marginal price and the unit value exceeds 0.95.[21]

Labour use per hectare and other price variables also are computed using data from the CCPS. In the CCPS, enumerators have farmers record the number of mandays that they used in each cropping activity. Huang and Rozelle (1996) find this measure far superior than information from the annual survey of villages that produce the number of agricultural labourers. Rawski and Mead (1998) also find the CCPS measure of labour input for agriculture to be the best measure of on-farm labour use.

Our wage variable is calculated as annual rural per capita income times the rural population divided by the rural workforce (ZGTJNJ, 1980–95), and then divided by the number of days per year worked by the average rural labourer (from the State Statistics Bureau Household Income and Expenditure Survey dataset). The measure captures the average labourer's earnings per day, which is somewhat different than the wage rate. However, it is well known that the increase in rural per capita income is largely due to expanding off-farm employment, self employment and other own-household activities (Rozelle, 1996). We assume that the year-to-year variability that is captured by this variable is highly correlated with the daily wage, which we would ideally use. Unfortunately, we do not have a series on daily wages for all years of our analysis and for all provinces. Although the Research Center for Rural Economy (RCRE) has put together such a series since 1986, it is not drawn from a truly random sample. However, it does report a daily wage that varies by province and over time, and efforts to check its representativeness have shown that it reflects the economic situation in each province reasonably well. We took this series and ran a correlation coefficient with the corresponding part of our series, finding that the two have a correlation coefficient greater than 0.90.

We use a proxy to measure rental rates of cultivated land. While a number of different factors can affect land prices, the major value of land in a year is the flow of income it provides through crop production. Using information from the Ministry of Agricultures Cost of Production annual survey (which generates observations on each province for each crop), we create a variable that measures the net returns to cultivated land, which is measured as total revenue per unit of

[20] Wang (2000) uses a similar set of variables to that used in this paper, but he uses county-level data, rather than provincial-level data. The *source* of the data is actually the same, but his dataset is more disaggregated. For example, the sown area variable in both studies is derived from the agricultural bureau's annual survey of townships and villages, which is the basis for figures that appear in provincial and annual yearbooks. The labour data and one set of price data came from county cost of production surveys. The only major difference between his data and our provincial data is that he found a series of market prices for major commodities in the archives of each county's price bureau. Access to two measures of market prices over time allows him to compare the effect of using alternative price series.

[21] While such high correlation may be surprising, Wang (2000) shows that one of the main determinants of the government's quota price is the market price. According to Wang's findings, officials in part rely on shifts in the market price to establish a quota price. Given concerns of simultaneity, Wang arrives at this conclusion after controlling for the endogeneity of market prices.

land less expenditures per unit of land on major inputs. The inputs include fertilizer, pesticides, plastics, custom use fees and hired labour. The value of family labour is not deducted. Therefore, our measure should be interpreted as the value of land and family labour in production. While there are no time series against which we can test our series for how well it is correlated with actual rental rates, we check our proxy variable against a dataset collected by the authors that includes observations on rental rates in six North China provinces for 1988 and 1995. The correlation coefficient between our proxy variable and the rental rates is 0.88. Furthermore, as we also include the wage measure in the model, to the extent that there is correlation between our returns to land variable and the wage variable (since our variable is also partly capturing the returns to family labour), in the regression analysis our measure will capture the net effect, which is primarily the returns to sown area.

The information for a number of other variables comes from a variety of alternative data sources. The irrigation and research stock variables were created from public expenditure data using formulae detailed in Appendix C. The formulae account for depreciation and lagged effects. 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 fiscal system to regional water conservancy bureau. 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. Cash crop research expenditure data come from the State Science and Technology Commission.

The first-stage reform variable measures the cumulative proportion of households in China each year that had implemented decollectivization policies (HRS). Data for the variable come from Lin (1992). While this variable is perhaps more suited to measuring the effects of incentives, it is plausible the reforms in planning decentralization also took a similar form, since the reforms often went hand in hand. In an alternative version of the model (reported in the results section), we include a period dummy in lieu of the HRS variable.

7. Econometric results

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

We use a non-linear, three stage least squares estimator (Gallant, 1992) to estimate the relationship among the two quasi-fixed inputs (equation 7), three outputs (equations 9 and 10), and one variable input (equation 8). The estimator accounts for contemporaneously correlated error terms. The 6 equation system for North China contains 46 exogenous variables and 135 parameters.

Table 1. Adjustment parameter estimates from non-linear, three-stage least squares estimator for Northern China

Parameter	Estimate
R_{11}	–0.16 (3.65)
R_{22}	–0.35 (8.38)
R_{11D}	–0.04 (2.98)
R_{22D}	–0.25 (5.49)

Notes**:** t-ratios in parentheses. The full set of parameter estimates are reported in Appendix B.

The entire set of estimated coefficients for equations (7) to (10) are reported in Appendix Table C1. Many of the coefficients have high t-ratios; the signs and magnitudes of most coefficients are as expected. Our important results also appear to be robust to the choice of estimator. In particular, the flexible accelerator parameters, R_{11} and R_{22} 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.

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 survey by Warjiyo, 1991). When considering parameters significant at the 10 percent 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 IRR_4 and IRR_{60} parameters (Appendix C) indicate that irrigation investment boosts wheat and cash crop production. The estimated coefficient for maize, IRR_5, 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 (IRR_2). Agricultural research boosts both wheat and maize output (RES_4 and RES_5), but has an insignificant effect on cash crop production (RES_{60}). 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 (RES_2) indicates that agricultural research has intensified labour use. The

Table 2. Hypothesis testing for the presence of adjustment costs, quasi-fixity of inputs, and increase in the speed of adjustment

Hypotheses	Lagrange Multiplier Statistic
No adjustment cost or no quasi-fixity:	
(1) Crop area ($R_{11} = -1$ and $R_{12} = 0$)	383.82**
(2) Agricultural labour ($R_{22} = -1$ and $R_{21} = 0$)	271.69**
(3) Both crop area and agricultural labour ($R_{11} = R_{22} = -1$ and $R_{12} = R_{21} = 0$)	663.31**
Independent adjustment:	
(4) Crop area vs. 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 percent level. All test statistics are calculated from the non-linear three stage least squares estimates of the entire system of equations. The null hypothesis for the tests are in parentheses.

signs of the coefficients associated with the variables measuring the first-stage reforms (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 (for example McMillan, Whalley and Zhu, 1989).[22]

7.2 Increasing flexibility during China's reforms

7.2.1 Adjustment in the early reform period

The model allows us to test a series of hypotheses related 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 first stage of the reforms were complete.[23] The results of two sets of hypothesis tests are reported in

[22] 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, crops grown in the most environmentally fragile regions.

[23] In our model, we are assuming that fertilizer is a variable input. Statistical tests show that by the mid-1980s, nearly 80 percent of adjustment was occurring in one year and by 1990 full adjustment was occurring. To the extent that fertilizer markets improved, our returns to market liberalization are understated, but because the improvements were only minor, these changes are negligible.

Table 2. Since we have interacted the variables associated with the speed of adjustment parameters with a period dummy variable, the interpretations of R_{11} and R_{22} pertain to the early reform period.

The high test statistics in the tests 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 first-stage reform period. Tests of quasi-fixity for adjustment coefficients in the market liberalization period indicate that sown area and labour do not fully adjust in one year (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 (i.e., 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 during the first-stage reforms land adjusts in about six years, and labour in three years. These figures are consistent with the findings of Huang, Rosegrant and Rozelle (1995), who estimate adjustment times of five years for land and four years for labour for China's agricultural economy as a whole during the post-1978 era. Our results can be interpreted as showing that frictions in the economy kept producers from fully adjusting their labour or sown area during the early reform period.

Even though sown area and labour do not adjust instantaneously, according to this metric, in a comparative sense China's rural economy was not particularly rigid during the first-stage reforms. Natural-, behavioural- and policy-created barriers exist in every agricultural economy. When these results are compared with results of similar adjustment cost analyses in other countries, one might conclude that China's crop sector was adjusting rather quickly. With the exception of Vasavada and Chambers (1986) – who found sown area for certain crops in the United States adjusts to a new optimum after two years – analysts estimate that sown area in Canada can take up to 15 years to equilibrate after exogenous shocks (Warjiyo, 1991), whereas labour requires 6 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 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.

7.2.2 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 (R_{11D} and R_{22D}) demonstrate that quasi-fixed factors have begun to adjust even faster in the late reform period. The negative coefficients can be interpreted as the amount that flexibility increases in the market liberalization period.

The results demonstrate that flexibility increased significantly in the second period, although the pace of improvements increased rapidly for labour and more modestly for sown area.[24] The flexible acceleration parameter for labour is −0.60 (−0.35−0.25). Regarding the time taken to fully adjust, the speed of adjustment increases to 1 2/3 years after market reform began. If better markets and declining restrictions on producers have made faster adjustment of labour by producers possible, the liberalization reforms have increased efficiency in China's late reform economy. This finding is consistent with the results and discussion of Knight and Song (1999).

The speed of adjustment of sown area, however, rises only marginally; it adjusts in five years rather than in six during the late reform period.[25] The flexible adjustment parameter was −0.20 (−0.16−0.04).[26] This result is consistent with the observation that prior to 1995, deregulation and liberalization of land policy has occurred more slowly than the relaxation of labour restrictions. Given the leadership commitment to gradualism, the result is not surprising. Regarding the time taken to fully adjust, the speed of adjustment becomes faster for both quasi-fixed factors. During the late reform period, labour adjusts in 1 2/3 years, while land

[24] Interestingly, the rates of adjustment in the early reform period are not zero (–0.16 for sown area; –0.35 for labour), which might be the case if there had been a pure planning regime during the first-stage reforms and planning officials did not pay any attention to relative price shifts or fixed factor changes. Although far from one, the estimated flexible adjustment parameters show that during the first-stage reforms, producers, *on average* were able to react to price changes, albeit imperfectly. While it is impossible to know how much flexibility increased during the first stages of reform (since we do not have data for the pre-reform period), it is likely that farm restructuring and the increased decision-making authority of farmers with incentives to earn a profit, even in the absence of well-functioning markets, did increase flexibility. The flexibility parameters may also have been increasing over the years of the first-stage reforms, but since we only estimated the average coefficient, we do not know the rate of change within the period.

[25] The slower rate of adjustment for land when compared to labour may not be surprising given the nature of the two inputs. Since land is more heterogeneous than labour, it could be that there is less scope for shifting land between crops and it is easier to shift labour. It could also be that to shift land among cropping alternatives, greater fixed investment is needed (for example, to tear down bunds between rice paddies if producers wanted to move to horticulture crops).

[26] We also tested the sensitivity of the dummy parameters to our assumption that the late reform period begins in 1985, by specifying the dummy variable interacted with the additive parameter as 0 for a longer time period and 1 for a shorter time period. We tested cutoffs for years 1986–92, and found that the additive parameters were relatively smaller for other years and even statistically insignificant for some years. For example, the additive parameters were $R_{11D} = -0.01$ and $R_{22D} = -0.07$ if market liberalization is taken to begin in 1986 instead of 1985, and are statistically insignificant. If we calculated efficiency gains using these parameters, the gains to market liberalization would be markedly smaller.

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). The parameter estimates used to generate the elasticities in rows 1–3 are in Appendix Table B2.

adjusts in five years. In the last section of the paper, we examine the magnitude of these efficiency gains.[27]

7.2.3 Changes in responsiveness in the late reform period

We have also produced evidence that responsiveness increased during the market liberalization period. To show the increase, we calculate short-run elasticities using parameter estimates from a model that allows own-price responses to change across periods. We do so by adding an interaction term created by multiplying the period dummy by each price. The interaction terms are all significant at the 10 percent level, which indicates that own-price responses change after market liberalization begins.[28] 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, the responsiveness

[27] It should be noted that our results in this section are limited to the sample areas in north China. If data were available for south China, we would probably have found that the magnitude of the change was quite different. According to most writings on China, market liberalization reforms in the south proceeded faster and were more pervasive than in the north. To know if the measured increase in flexibility were greater in the south, one would have to know if, as in the north, most market liberalization occurred after 1985. If so, we would expect to see the adjustment parameters show that the increase in flexibility in the south was greater than the north. If market liberalization started prior to 1985, it is possible that the speed of adjustment was faster during the early reform period, but the increase in flexibility was smaller, since there was less improvement in the second reform period.

[28] The full set of parameter estimates for Table 3 appear in Appendix Table C2.

of labour appears to rise most significantly (row 2). The elasticity of sown area does not change (row 1). In this sense, the responsiveness of labour relative to that of sown area mirrors the results for flexibility.[29]

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 reforms. Fertilizer markets were not permanently liberalized until the 1990s, so it is possible that we should not expect to see producers change their behaviour with respect to fertilizer during the mid-1980s; following this logic, increased responsiveness should not begin until the early 1990s. To test whether the fertilizer own-price elasticity becomes more responsive for the second half of the second-stage reform period, we re-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. With this model, we find increased responsiveness in the use of fertilizer in the second half of the late reform period (row 5). This set of own-price fertilizer elasticities indicates that fertilizer does eventually become more own-price responsive (−0.229 before 1990, −0.446 thereafter).

7.3 Efficiency gains from increased responsiveness and flexibility

Our efficiency measurements for comparing returns to the first-stage reforms in the early reform period with the returns to market liberalization in the late reform period are presented in Table 4. Gains due to the first-stage reforms are only

[29] It could be that the nature of our price data is in part responsible for this finding. The argument is as follows. We are using a price variable that is generated as a mix of quota and market prices. Moreover, the proportion of the marketed quantity shifted from relatively quota-intensive to relatively market-intensive between the first and second stages of reforms. If farmers react to quota price changes in one way (that is, if officials announced the quota price before the crop year and so farmers more immediately and more fully adjust) and react to market price changes in another (that is, they are unsure what market forces will turn out to be until the end of the crop year and so they adjust more cautiously), then the changing mix of quota and market procurement could negatively affect the measured increase in responsiveness between the first- and second-stages of the reforms. As a result, we may be underestimating the effect of market liberalization on price responsiveness. Although it is plausible, this argument has several shortcomings. For instance, observations in the field clearly have shown that in most years the procurement price was not announced until well into the cropping season. Moreover, there was usually a great deal of uncertainty about the actual price the farmer received, even in the case of the procurement quota, since agricultural bureau officials can use quality differentials to change the real price actually received by the farmer.

We believe that, although we are using proxies, they are constructed in such a way that they are good measures of the underlying shadow wages and price of land. It still may be that the measures improve over time. If so, one way to think about the econometric problem that would result from a measure that is initially weak, but then improving, is that during the first period the measurement error is greater than in the later period. If true, this would mean that our estimates in the earlier period would be biased towards zero (since the main effect of measurement error is attenuation bias). If so, this would mean our estimates for the change in responsiveness could be overstated.

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

Year	(1) First-stage reforms	(2)	(3) Second stage reforms	(4)
	Cumulative percentage return to incentive reform (I_t)	Total percentage change in returns due to to market reforms (G_t)	Percentage change in returns due to increased responsiveness (R_t)	Percentage change in returns due to increased flexibility (F_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

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

calculated for the years 1978 to 1984 in order to highlight the fact that HRS and planning decentralization, which was completed in 1984, significantly boosted farm incomes in the early reform era. In fact, the gains in profits from the first stage reforms continue indefinitely, since there would almost certainly have been a fall in income after 1985 if the first-stage reforms had been reversed and the incentives that HRS provided to farmers and greater decision-making authority that planning decentralization gave to regional authorities and producers had been weakened.

Our results clearly show the large contribution of the first-stage reforms to farm incomes during the early reform period. The gains from the first-stage reforms increase throughout the period, rising as HRS and planning decentralization spread through the economy. In 1984, the peak year, farm profits rise by more than 7 percent, holding other factors constant. While this percentage is less than the additions to production output and production growth measured by McMillan, Whalley and Zhu (1989) and Lin (1992), the two results are not inconsistent. The increases found in this paper are net of increases in prices and other shifts due to technology and infrastructure improvements. Moreover, since farm income during the reform period was such a large part of total rural household income, this increase represents a significant rise in the wealth of rural areas. Additionally, this is an average figure; some regions gained more and others gained less. Aggregating the total increase in profits from farm production alone across more than 200 million rural households represents an immense gain of wealth.

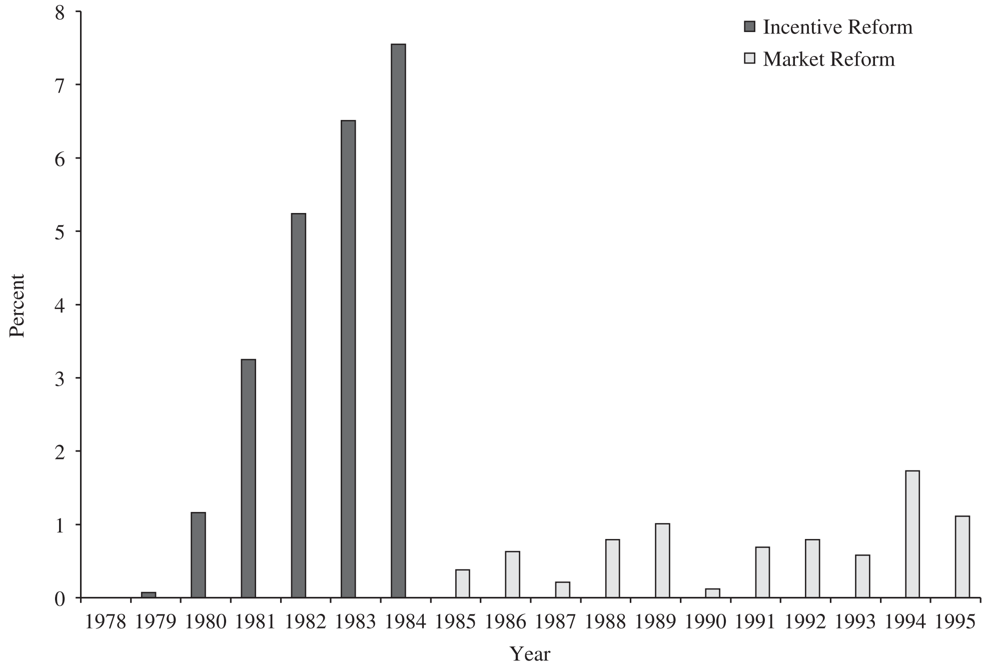
When we calculate G_t for the years 1985 to 1995, we find that the overall gains from market liberalization have increased efficiency (Table 4, column 2). G_t is lower when prices declined, and higher in years when the price level increased sharply. At the extremes, in 1990, when the real price of wheat declined by 4 percent and the real maize price declined by 8 percent, G_t is the smallest. On the other hand, as real prices rose steadily through the mid-1990s, G_t reached its highest annual growth in 1994.

Relative to the gains in the first-stage reforms, the gains from market liberalization not only start later, by policy choice, but they are also smaller (Table 4, column 2). The average annual gain due to market liberalization from 1985 to 1995 is 0.73 percent, which implies it is roughly 10 times smaller than the annual rise in profits due to first-stage reforms at the end of that period (7.55 percent). Even at their peak, in 1994, aggregate gains due to market liberalization are less than 4 times the size of the rise due to the first-stage reforms. Figure 1 illustrates the size of the gains due to the first-stage reforms versus the size of those due to market liberalization. The large returns to better incentives and decentralized planning, on the left side of the illustration, overwhelm the gains in the later reform period, on the right hand side of the graph.

The findings suggest that reforming incentives and decentralizing planning had much higher returns than reforming markets in rural China. This conclusion is reinforced when considering the fact that our returns to market liberalization may be overstated since the returns are, in some sense, conditioned on the earlier reform of incentives. Although small, the gains to market liberalization may be increasing in the latter half of the liberalization period (see upward trend between 1990 and 1995 in Figure 1), which may indicate that large returns to market liberalization could still be realized.

Decomposing the returns to market liberalization, we see that most of the change has come from increased flexibility (Table 4, column 4). On a year-to-year basis, the returns resulting from producers becoming more flexible to exogenous

Figure 1. Gains due to reform in China's agriculture



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

In contrast to the returns from increased flexibility, the returns to increased responsiveness are smaller and more variable (Table 4, column 3). In part the gain from increased responsiveness is small simply because the increase in elasticities, especially for sown area, is relatively small. The variability of the returns is just a function of the fact that economies experience year-to-year fluctuations in important variables, such as prices.

7.4 Comparing market liberalization with the first-stage reforms

Before drawing conclusions from our findings, it is important to note that the comparison of the returns to the first-stage reforms and the returns to the market liberalization reforms is complicated by several factors. First, we have a continuous measure of the first-stage reforms, and know that by 1984 the policies were nearly completely implemented. Second, it is reasonable to assume that the policy was relatively quick to meet its goals of increasing incentives for producers to exert more effort (as well as to increase their decision-making authority). In other words, we interpret our measure of a 7.55 percent gain in economic efficiency by 1984 to be the result of a policy which was completely implemented and which had realized most of its immediate goals.

In contrast, we do not have a continuous measure of the market liberalization reforms. Instead, we estimate parameters that only allow us to compute the average returns to the market liberalization reforms. However, we know from our discussion of the implementation of the market liberalization reforms that even by 1995, the last year of our sample, the reforms were not completed. Moreover, there is reason to assume that the liberalization policies will be relatively slow to realize their goals. As pointed out by McMillan (1997) and others, the operation of markets depend on the emergence of and coordination among many institutions, all of which take time to develop.

The differences in the nature of the reforms and methods for measuring the reforms make it important to exercise caution when interpreting our comparisons. First, our measures of the first-stage reforms and the market liberalization reforms may differ in part because the incentive reforms and planning decentralization are complete and the effects immediately realized, whereas the market liberalization reforms are incomplete and the effects are only gradually being realized. Second, there is a potential difference that arises because we have a continuous measure of the first-stage reforms but not of the market liberalization reforms. As a result, we can compute a return to the first-stage reforms in one year, 1984, and measure the *total* gain to economic efficiency from the policy in the year of its completion. Although we can compute annual increases in profits due to the market liberalization reforms, they are created using coefficients that are based on the average gain in flexibility and responsiveness of the policies that were implemented between 1985 and 1995.

One way to control for the second source of difference between the two measures would be to ignore our information about the gradual implementation of the first-stage reforms and include an early reform period dummy variable instead of the cumulative proportion of households that had adopted HRS. The estimated coefficient of this more blunt measure of the first-stage reforms would only allow us to compute a measure of the average economic efficiency gains from improved incentives and planning decentralization. When we do this (coefficients not reported), we find that the average gain is somewhat smaller than our estimate of the cumulative gain (5 percent instead of 7.55 percent). However, it is still much larger than the average gain for the market liberalization reforms, 0.73 percent. The difference between the 5 percent average gain from the first-stage reforms and the 0.73 percent average gains from the market liberalization reforms is due to the inherent difference in returns and to the extent and realization of the implementation of the market liberalization reforms.

8. Conclusions

In this paper we have developed a framework to estimate how market reforms affected producer behaviour in China, and to measure the effects of market liberalization on farm returns. Building on the adjustment cost literature, 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, the returns to responsiveness and the returns to flexibility. The reader, of course, needs to be warned that we have only presented the results for Northern China, although there is no reason to believe that they would differ significantly had we performed the study for Southern China.

Our results that the behaviour of producers in China has been affected significantly by indicate the liberalization reforms, but the effects have been relatively modest. Although these findings are consistent with attempts by others to measure the effects of market liberalization reforms, our results cover a larger area of China, cover a longer time period and decompose the sources of the efficiency gains. Farmers increased their speed of adjustment between the early and late reform period for labour and to a lesser extent for sown area. Our estimates of own-price elasticities for labour and fertilizer indicate that producers are also becoming more responsive. These changes in behaviour have also produced moderate gains in the late reform period. The magnitude of the gains in efficiency from increased responsiveness and flexibility in the late reform period, however, appear to be substantially lower in percentage terms (less than 1 percent per year) than that from the incentive reforms and planning decentralization in the early reform period (up to 7 percent). However, the effect of market liberalization may be increasing slightly over time.

Based on this record, what can be said about the success or failure of China's reforms? First and unambiguously, our work is consistent with a story that gradual transition has worked – at least in the case of China's agricultural sector and at least through the second decade of reform. The first-stage reforms generated large increases in output and productivity and the market liberalization reforms have not led to a decrease in either. Furthermore, the gains due to market liberalization occurred given that incentive reform had already occurred. Had China begun reforms with market liberalization rather than incentive reform, it is unlikely that market liberalization would have led to the same gains in agriculture. The returns to market liberalization might also be different had the second stage reforms been initiated during the first stage reforms (for example in 1982 or 1983 rather than 1985).

Judgement about the effectiveness of the market liberalization reforms, however, may be premature. It is tempting to say, on the basis of our results, that the gains from market liberalization have been disappointingly small and that the emergence of markets has only marginally increased flexibility and responsiveness and has not led to large increases in growth of the agricultural sector. A more careful interpretation of our results may lead to other conclusions. Our paper does not attempt to measure the gains from increased resource mobility between the agricultural sector and the rest of the economy. These effects could be quite large. Moreover, even within agriculture we do not know if we are seeing changes in efficiency due to relatively incomplete changes in markets or if the market reforms have largely been completed, most of the growth potential having been captured. If the former interpretation is correct, the outlook for future agricultural growth may be quite optimistic. It may be that continued market liberalization will eventually lead to large increases in the performance of the agricultural economy; but to date China's gradual shift to the market is just that – gradual. If continued market liberalization promises steady or increasing profit growth, our paper is consistent with calls for China's leadership to strengthen its resolve to carry through its market reforms.

References

Cochrane, W. W. (1965). *The City Man's Guide to the Farm Problem*, Minneapolis: University of Minnesota Press.

de Brauw, A., Huang, J. K. and Rozelle, S. (2000). 'Increased flexibility, responsiveness and efficiency from market liberalization reforms in China's agricultural sector', *Working Paper*, Department of Agricultural and Resource Economics, University of California, Davis.

de Brauw, A., Huang, J. K., Rozelle, S. D., Zhang, L. X. and Zhang, Y. G. (2002). 'The evolution of China's rural labor markets during the reforms', *Journal of Comparative Economics*, 30, pp. 329–53.

Epstein, L. (1981). 'Duality theory and functional forms for dynamic factor demand', *Review of Economic Studies*, 48, pp. 81–95.

Epstein, L. and Denny, M. (1983). 'The multivariate flexible accelerator model: Its empirical restrictions and application to US manufacturing', *Econometrica*, 51, pp. 647–74.

Fan, S. (1991). 'Effects of technological change and institutional reform on production growth in Chinese agriculture', *American Journal of Agricultural Economics*, 73, pp. 266–75.

Fan, S. (2000). 'Technological change, technical and allocative efficiency in Chinese agriculture: The case of rice production in Jiangsu', *Journal of International Development*, 12(1), pp. 1–12.

Fan, S. and Pardey, P. G. (1992). *Agricultural Research in China: Its Institutional Development and Impact*, International Service for National Agricultural Research: The Hague, Netherlands.

Gallant, A. (1992). 'Three-stage least squares estimation for a system of simultaneous, nonlinear, implicit equations', *Journal of Econometrics*, 5, pp. 71–88.

Hathaway, D. E. (1963). *Government and Agriculture: Public Policy in a Democratic Society*, New York: Macmillan Company.

Huang, J. K., Rosegrant, M. and Rozelle, S. (1995). 'Public investment, technological change, and reform: a comprehensive accounting of Chinese agricultural growth', *Working paper*, Food Research Institute, Stanford University.

Huang, J. K. and Rozelle, S. (1995). 'Environmental stress and grain yields in China', *American Journal of Agricultural Economics*, 77, pp. 853–64.

Huang, J. K. and Rozelle, S. (1996). 'Technological change: Rediscovering the engine of productivity growth in China's rural economy', *Journal of Development Economics*, 49, pp. 337–69.

Huang, J. K., Rozelle, S., Hu, R. F. and Jin, S. Q. (2000). 'The creation and spread of technology and total factor productivity in China: An analysis of the contribution of China's research system and CG-supplied genetic material', *Working paper*, Department of Agricultural and Resource Economics, University of California at Davis.

Johnson, G. L. (1956). 'Supply functions: Some facts and notions', in Heady, E. O. *et al*. *Agricultural Adjustment Problems in a Growing Economy*, Ames: Iowa State University Press.

Johnson, G. L. and Quance, L. (1972). *The Overproduction Trap in U.S. Agriculture*, Baltimore MD: Johns Hopkins University Press.

Knight, J. and Song, L. (1999). 'Employment constraints and sub-optimality in Chinese enterprises', *Oxford Economic Papers*, 51, pp. 284–99.

Lardy, N. R. (1983). *Agriculture in China's Modern Economic Development*, Cambridge: Cambridge University Press.

Lin, J. Y. (1991). 'Prohibitions of factor market exchanges and technological choice in Chinese agriculture', *Journal of Development Studies*, 27(4), pp. 1–15.

Lin, J. Y. (1992). 'Rural reforms and agricultural growth in China', *American Economic Review*, 82(1), pp. 34–51.

Lin, J. Y., Cai, F. and Li, Z. (1996). *The China Miracle: Development Strategy and Economic Reform*, Hong Kong: Chinese University Press.

Lohmar, B. and Rozelle, S. (2000). 'Price relations and marketing policy in China's agriculture', *Working Paper*, Department of Agricultural and Resource Economics, University of California at Davis.

Lucas, R. E., Jr. (1967). 'Adjustment costs and theory of supply', *Journal of Political Economy*, 75, pp. 321–34.

Luh, Y. H. and Stefanou, S. E. (1991). 'Productivity growth in US agriculture under dynamic adjustment', *American Journal of Agricultural Economics*, 73, pp. 1116–1125.

Macours, K. and Swinnen, J. F. M. (2000). 'Causes of output decline in economic transition: The case of central and eastern European agriculture', *Journal of Comparative Economics*, 28(1), pp. 172–206.

Marshall, A. (1890). *Principles of Economics*, London: Macmillan.

McMillan, J., Whalley, J. and Zhu, L. (1989). 'The impact of China's economic reforms on agricultural productivity growth', *Journal of Political Economy*, 97, pp. 781–807.

McMillan, J. and Naughton, B. (1991). 'How to reform a planned economy: Lessons from China', *Oxford Review of Economic Policy*, 8(1), pp. 130–44.

McMillan, J. (1997). 'Markets in transition', in Kreps, D. M. and Wallis, K. F. *Advances in Economics and Econometrics: Theory and Application: Seventh World Congress*, Vol. 2, Cambridge: Cambridge University Press.

MWREP (Ministry of Water Resources and Electric Power). (1988–96). *Compiled Statistics on the Development of China's Water Conservancy System*, Ministry of Water Resources and Electric Power: Beijing, China.

Parish, W., Zhe, X. Y. and Li, F. (1995). 'Nonfarm work and marketization of the Chinese countryside', *China Quarterly*, 143, pp. 697–730.

Park, A., Jin, H. H., Rozelle, S. and Huang, J. K. (2002). 'Market emergence and transition: Arbitrage, transaction costs and autarky in China's grain markets', *American Journal of Agricultural Economics*, 84(1), pp. 67–82.

Perkins, D. (1988). 'Reforming China's economic system', *Journal of Economic Literature*, 26(2), pp. 601–45.

Pingali, P. L. and Xuan, V. T. (1992). 'Vietnam: Decollectivization and rice productivity growth', *Economic Development and Cultural Change*, 40(4), pp. 697–718.

Putterman, L. (1993). *Continuity and Change in China's Rural Development*, New York, NY: Oxford University Press.

Rawski, T. G. and Mead, R. (1998). 'On the trail of China's phantom farmers', *World Development*, 26(5), pp. 767–81.

Roland, G. and Verdier, T. (1999). 'Transition and output fall', *Economics of Transition*, 7(1), pp. 1–28.

Rosegrant, M. and Kasryno, F. (1994). 'Dynamic supply response for Indonesian food crops', *Working Paper*, Washington D.C.: International Food Policy Research Institute.

Rozelle, S. (1996). 'Gradual reform and institutional development: The keys to success of China's rural reforms', in Naughton, B. *Economic Reform in China: Lessons for Economics in Transition*, University of Michigan Press: Ann Arbor.

Rozelle, S., Park, A., Huang, J. K. and Jin, H. H. (2000). 'Bureaucrat to entrepreneur: The changing role of the state in China's grain economy', *Economic Development and Cultural Change*, 48(2), pp. 227–52.

Sicular, T. (1985). 'Rural marketing and exchange in the wake of recent reforms', in Perry, E. J. and Wong, C. *The Political Economy of Reform in Post-Mao China*, Cambridge, MA: Harvard University Press.

Sicular, T. (1988a). 'Plan and market in China's agricultural commerce', *Journal of Political Economy*, 96(2), pp. 283–307.

Sicular, T. (1988b). 'Agricultural planning and pricing in the post-Mao period', *China Quarterly*, 116, pp. 670–705.

Sicular, T. (1995). 'Redefining state, plan, and market: China's reforms in agricultural commerce', *China Quarterly*, 144, pp. 1020–1046.

SPB (State Price Bureau) (1988–95). *Quanguo Nongchanpin Chengben Shouyi Ziliao Huibian (National Agricultural Production Cost and Revenue Information Summary)*, Beijing, China: China Price Bureau Press.

SSB (State Statistical Bureau) (1993). *Nongye Kexue Jishu Tongji Huibian (A Compendium of Statistical Material on Agricultural Science and Technology)*, Beijing, China: State Statistical Bureau.

Vasavada, U. and Chambers, R. G. (1986). 'Investment in US agriculture', *American Journal of Agricultural Economics*, 68, pp. 950–60.

Wang, D. W. (2000). 'The determinants of quotas and impact on grain supply and sown area', unpublished Ph.D. dissertation, Nanjing Agricultural University, Department of Agricultural Economics, Nanjing, China.

Warjiyo, P. (1991). 'Resource adjustment, dynamic price responses, and research impacts in the United States agriculture, 1950–82', unpublished Ph.D. Dissertation, Department of Agricultural Economics, Iowa State University, Ames, Iowa.

Watson, A. (1988). 'The reform of agricultural marketing in China since 1978', *China Quarterly*, 113, pp. 1–28.

Wen, J. G. (1993). 'Total factor productivity change in China's farming sector: 1952–89', *Economic Development and Cultural Change*, 42, pp. 1–42.

Wiens, T. (1982). 'The limits to agricultural intensification: The Suzhou experience', in *China Under the Four Modernizations*, Washington, D.C.: US Government Printing Office.

Ye, Q. and Rozelle, S. (1994). 'Fertilizer policy in China's reforming economy', *Canadian Journal of Agricultural Economics*, 42, pp. 191–208.

ZGSYNJ (Zhongguo Shangye Nianjian – China Commercial Yearbook) (1992). Beijing, China: Ministry of Domestic Trade Press.

ZGNYNJ (Zhongguo Nongye Nianjian – China Agricultural Yearbook) (1981–93). Beijing, China: China Agricultural Press.

ZGTJNJ (Zhongguo Tongji Nianjian – China Statistical Year Book) (1980; 1986–93). Beijing, China: China Statistical Press.

Appendix A

System of equations

The following system of equations was estimated using the SYSNLIN procedure in SAS, and corresponds to equations (7) to (10). All subscripts denote the parameter location in the named matrix. For the estimation reported in the paper, we used $r = 0.04$; the results were not sensitive to this choice.

$$\begin{aligned}\Delta K_t^a = {} & \Theta_1 + (R_{11} + r)K_{t-1}^a + R_{11D}K_{t-1}^a D_{8595} + R_{12}K_{t-1}^l + r(R_{11}G_{11} + R_{12}G_{21})P_{t-1}^w \\ & + rR_{11D}G_{11}P_{t-1}^w D_{8595} + r(R_{11}G_{12} + R_{12}G_{22})P_{t-1}^m + rR_{11D}G_{12}P_{t-1}^m D_{8595} \\ & + r(R_{11}L_1 + R_{12}L_2)P_t^f + rR_{11D}L_1 P_t^f D_{8595} + r(R_{11}C_{11} + R_{12}C_{12})q_t^a \\ & + rR_{11D}C_{11}q_t^a D_{8595} + r(R_{11}C_{12} + R_{12}C_{22})q_t^l + rR_{11D}C_{12}q_t^l D_{8595} \\ & + IR_1 \times IRR_t + S_1 \times RES_t + DH_1 \times HRS_t + \in_t^1\end{aligned} \tag{A1}$$

$$\begin{aligned}\Delta K_t^l = {} & \Theta_2 + R_{21}K_{t-1}^a + (R_{22} + r)K_{t-1}^l + R_{22D}K_{t-1}^l D_{8595} + r(R_{21}G_{11} + R_{22}G_{21})P_{t-1}^w \\ & + rR_{22D}G_{21}P_{t-1}^w D_{8595} + r(R_{21}G_{12} + R_{22}G_{22})P_{t-1}^m + rR_{22D}G_{22}P_{t-1}^m D_{8595} \\ & + r(R_{21}L_1 + R_{22}L_2)P_{t-1}^f + rR_{22D}L_2 P_{t-1}^f D_{8595} + r(R_{21}C_{11} + R_{22}C_{12})q_t^a \\ & + rR_{22D}C_{12}q_t^a D_{8595} + r(R_{21}C_{12} + R_{22}C_{22})q_t^l + rR_{22D}C_{22}q_t^l D_{8595} \\ & + IR_2 \times IRR_t + S_2 \times RES_t + DH_2 \times HRS_t + \in_t^2\end{aligned} \tag{A2}$$

$$\begin{aligned}F_t = {} & \Theta_3 - rF_1P_{t-1}^w - rF_2P_{t-1}^m - rBP_{t-1}^f - rL_1q_t^a - rL_2q_t^l - N_1(rK_{t-1}^a - \Delta K_t^a) \\ & - N_2(rK_{t-1}^l - \Delta K_t^l) + IR_3 \times IRR_t + S_3 \times RES_t + DH_3 \times HRS_t + \in_t^3\end{aligned} \tag{A3}$$

$$\begin{aligned}Q_t^w = {} & \Theta_4 + rA_{11}P_{t-1}^w + rA_{12}P_{t-1}^m + rF_1P_{t-1}^f + rG_{11}q_t^a + rG_{21}q_t^l \\ & + H_{11}(rK_{t-1}^a - \Delta K_t^a) + H_{21}(rK_{t-1}^l - \Delta K_t^l) + IR_4 \times IRR_t + S_4 \times RES_t \\ & + DH_4 \times HRS_t + DI_1 \times DISA_t + ER_1 \times ERO_t + \in_t^4\end{aligned} \tag{A4}$$

$$\begin{aligned}Q_t^m = {} & \Theta_5 + rA_{12}P_{t-1}^w + rA_{22}P_{t-1}^m + rF_2P_{t-1}^f + rG_{12}q_t^a + rG_{22}q_t^l \\ & + H_{12}(rK_{t-1}^a - \Delta K_t^a) + H_{22}(rK_{t-1}^l - \Delta K_t^l) + IR_5 \times IRR_t + S_5 \times RES_t \\ & + DH_5 \times HRS_t + DI_2 \times DISA_t + ER_2 \times ERO_t + \in_t^5\end{aligned} \tag{A5}$$

$$\begin{aligned}Q_t^C = {} & \Theta_6 + A_{41}(rK_{t-1}^a - \Delta K_t^a) + A_{42}(rK_{t-1}^l - \Delta K_t^l) - \frac{1}{2}rA_{11}(P_{t-1}^w)^2 - \frac{1}{2}rA_{22}(P_{t-1}^m)^2 \\ & - rA_1 2P_{t-1}^w P_{t-1}^m - \frac{1}{2}rB(P_t^f)^2 - \frac{1}{2}rC_{11}(q_t^a)^2 - rC_{12}q_t^a q_t^l - \frac{1}{2}rC_{22}(q_t^l)^2 - rF_1P_{t-1}^w P_t^f \\ & - rF_2P_{t-1}^m P_t^f - rG_{11}P_{t-1}^w q_t^a - rG_{12}P_{t-1}^m q_t^a - rL_1P_t^f q_t^a - rG_{21}P_{t-1}^w q_t^l \\ & - rG_{22}P_{t-1}^m q_t^l - rL_2P_t^f q_t^l + rIR_{60}IRR_t + IR_{61}IRR_t(rK_{t-1}^a - \Delta K_t^a) \\ & + IR_{62}IRR_t(rK_{t-1}^l - \Delta K_t^l) + rS_{60}RES_t + S_{61}RES_t(rK_{t-1}^a - \Delta K_t^a) \\ & + S_{62}RES_t(rK_{t-1}^l - \Delta K_t^l) + DH_6HRS_t + DI_3DISA_t + ER_3ERO_t + \in_t^6\end{aligned} \tag{A6}$$

The variable names used in equations (1)–(6) correspond to the variable names used in the text, with the following exceptions. ΔK^a is used to represent the change in sown area; ΔK^l represents the change in the stock of labour; F represents fertilizer; P^f represents the price of fertilizer; *DISA* represents the disaster index; and *ERO* represents the erosion measure (the latter two are from Huang and Rozelle, 1997).

Appendix B

Means of selected variables

Table B1. Provincial means for selected variables, by year

Year	Outputs			Inputs and quasi-fixed Inputs			Prices		
	Wheat	Maize	Other crops	Fertilizer	Sown area	Labour	Wheat	Maize	Fertilizer
1976	2,694	2,856	237	1,290	2,858	1,208	0.37	0.25	0.28
1977	2,177	2,906	247	1,228	2,828	1,203	0.36	0.23	0.31
1978	2,762	3,308	278	1,178	2,895	1,267	0.36	0.24	0.30
1979	3,122	3,455	292	1,146	2,818	1,130	0.42	0.24	0.31
1980	2,597	3,547	627	1,274	2,863	1,073	0.42	0.28	0.30
1981	2,929	3,268	640	1,507	2,800	952	0.41	0.28	0.29
1982	3,143	3,336	849	1,717	2,746	835	0.43	0.28	0.29
1983	4,062	3,940	1,110	1,843	2,866	825	0.42	0.29	0.30
1984	4,319	4,255	1,359	1,697	2,949	820	0.50	0.28	0.30
1985	4,370	3,614	967	1,798	2,876	694	0.46	0.33	0.35
1986	4,561	4,068	935	1,826	2,954	653	0.45	0.31	0.37
1987	4,317	4,718	1,210	1,851	2,982	655	0.43	0.33	0.35
1988	4,259	4,723	1,236	1,738	2,962	666	0.40	0.31	0.37
1989	4,894	4,589	1,185	1,698	3,021	693	0.40	0.30	0.37
1990	5,057	5,898	1,488	1,859	3,135	744	0.38	0.30	0.38
1991	5,066	5,980	1,776	1,424	3,210	735	0.37	0.28	0.37
1992	5,087	5,610	1,238	1,345	3,029	640	0.39	0.27	0.52
1993	5,431	6,034	1,446	1,249	3,010	653	0.37	0.29	0.51
1994	5,051	5,838	1,903	981	3,032	701	0.48	0.30	0.53
1995	5,225	6,557	1,943	1,092	3,126	714	0.58	0.38	0.58

***Notes*:** All prices are normalized by the 'other crops' price index.

Appendix C

Parameter estimates

Table C1. 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
Θ_1	–45.25	0.73	H_{22}	–0.37	0.57
Θ_2	–148.27	2.54	IRR_1	0.0024	0.69
Θ_3	–494.11	1.41	IRR_2	–0.0069	2.16
Θ_4	–1799.31	2.16	IRR_3	–0.038	2.23
Θ_5	–2412.72	3.29	IRR_4	0.054	1.64
Θ_6	9.98	0.05	IRR_5	–0.0033	0.12
A_{11}	11,574.59	0.26	IRR_{60}	0.81	3.87
A_{12}	71,334.97	1.79	IRR_{61}	5.70*e*–06	0.36
A_{22}	73,741.03	1.33	IRR_{62}	1.64*e*–05	0.48
A_{41}	–2.87	1.64	RES_1	0.36	1.78
A_{42}	–0.92	0.36	RES_2	0.95	5.00
R_{11}	–0.16	3.65	RES_3	0.40	0.33
R_{12}	–0.21	4.22	RES_4	6.76	3.10
R_{21}	0.12	1.64	RES_5	17.30	8.93
R_{22}	–0.35	8.38	RES_{60}	–21.69	1.25
R_{11D}	–0.04	2.98	RES_{61}	0.0059	1.74
R_{22D}	–0.25	5.49	RES_{62}	0.00095	0.22
G_{11}	0.14	0.03	HRS_1	–31.59	0.80
G_{12}	6.41	1.37	HRS_2	–140.71	3.84
G_{21}	–3,257.79	1.30	HRS_3	564.06	2.50
G_{22}	–12,412.82	4.69	HRS_4	927.59	2.31
L_1	–8.60	3.14	HRS_5	–684.74	1.92
L_2	2,575.69	1.80	HRS_6	145.72	1.42
C_{11}	–0.001	0.73	DIS_1	–2,470.11	2.38
C_{12}	0.54	0.93	DIS_2	–3,141.24	3.51
C_{22}	879.83	2.32	DIS_3	–225.27	0.94
F_1	–31,364.86	2.27	ERO_1	–660.72	1.71
F_2	–39,668.19	2.52	ERO_2	–1,247.29	3.74
B	52,181.49	4.79	ERO_3	–74.67	0.81
N_1	–0.033	0.09			
N_2	–0.067	0.16	Objective function*N = 757.3		
H_{11}	4.02	5.97	Provincial dummies: not reported		
H_{12}	0.68	1.18	Number of parameters: 135		
H_{21}	–2.19	2.89	Number of equations: 6		

***Notes*:** Θ_i, i = 1, . . . , 6, correspond to intercepts in equations (7)–(10). The single letter parameters (e.g., A_{11}) correspond to matrices defined in equation (6), and the subscripts refer to the matrix position. The parameters IRR_i, RES_i, HRS_i, DIS_i, and ERO_i correspond to the estimates of T parameters in equations (7)–(10) and refer to the effects of the irrigation stock, research stock, household responsibility system, disaster index, and erosion index variables, respectively. The IRR_{6j} and RES_{6j}, j = 1, 2, parameters correspond to the T_{61} matrix in equation (10).

Irrigation and research stock calculation

C1 Irrigation stock variable

The irrigation stock variable, $Z_i(t)$, is created on the assumption that the useful life of an irrigation system is 30 years. We apply the formula used by Rosegrant and Kasryno (1994) for creating an irrigation stock variable from expenditures:

$$Z_i(t) = \dot{Z}_i(t) + (1 - \delta)Z_i(t - 1) \tag{C1}$$

where $\dot{Z}_i(t)$ are expenditures on irrigation in year t, and δ is the rate of depreciation of the stock. We experimented with a number of alternative depreciation rates and the results were robust to the different rates.

C2 Research stock variable

Measuring the research stock is more complex, and must take into account longer lags which exist between the time of a research expenditure and the period in which it affects production. Furthermore, the stock depreciates over time. The research stock variable, $Z_r(t)$, is measured as:

$$Z_r(t) = \sum_{s=0}^{n} \alpha(t - s)\dot{Z}_r(t - s) \tag{C2}$$

where n denotes the total time horizon over which research expenditures have an effect on production, and $\dot{Z}_r(t - s)$ denotes research expenditures in year $t - s$. We use a set of timing weights estimated by Pardey *et al.* (1992).

Table C2. Parameter estimates of dynamic supply response system using non-linear three stage least squares estimator, Northern China, with own-price dummies for 1985–95

Parameter	Estimate	t-Ratio	Parameter	Estimate	t-Ratio
Θ_1	−65.20	1.04	H_{12}	1.01	1.77
Θ_2	−162.73	2.76	H_{21}	−2.11	2.77
Θ_3	532.05	0.95	H_{22}	−0.19	0.30
Θ_4	−1,203.36	1.41	IRR_1	0.0017	0.49
Θ_5	−5,615.28	5.10	IRR_2	−0.0076	2.36
Θ_6	456.67	1.60	IRR_3	−0.033	1.92
A_{11}	−30,465.68	0.65	IRR_4	0.051	1.56
A_{12}	91,193.77	2.26	IRR_5	−0.0025	0.90
A_{22}	204,309.72	3.24	IRR_{60}	0.85	4.04
A_{22D}	−120,720.75	4.05	IRR_{61}	−9.01*e*–07	0.05
A_{41}	−2.74	1.40	IRR_{62}	2.29*e*–05	0.60
A_{42}	−1.41	0.48	RES_1	0.30	1.56
R_{11}	−0.15	3.32	RES_2	0.82	4.17
R_{12}	−0.22	4.40	RES_3	−2.15	1.41
R_{21}	0.08	2.65	RES_4	5.87	2.67
R_{22}	−0.37	8.73	RES_5	22.31	9.64
R_{11D}	−0.04	3.27	RES_{60}	−33.59	1.63
R_{22D}	−0.26	5.68	RES_{61}	0.0058	1.57
G_{11}	0.60	0.13	RES_{62}	0.0016	0.31
G_{12}	8.09	1.76	HRS_1	−30.78	0.79
G_{21}	−3,066.29	1.22	HRS_2	−141.26	3.84
G_{22}	−13,224.75	5.08	HRS_3	495.56	2.19
L_1	−8.15	2.99	HRS_4	1,061.08	2.62
L_2	1,823.21	1.25	HRS_5	−462.48	1.31
C_{11}	0.0036	0.67	HRS_6	62.47	0.53
C_{12}	0.17	0.17	DIS_1	−2,585.50	2.49
C_{22}	305.92	0.73	DIS_2	−3115.70	3.55
C_{11D}	−0.0039	0.83	DIS_3	−142.93	0.59
C_{22D}	904.40	2.87	ERO_1	−677.76	1.71
F_1	−16,790.07	1.17	ERO_2	−1,000.86	3.74
F_2	−48,192.05	3.03	ERO_3	−139.33	0.81
B	82,540.14	4.79			
B_D	−38,064.61	2.36	Objective function*N = 738.9		
N_1	0.11	0.31	Provincial dummies: not reported		
N_2	−0.027	0.07	Number of parameters: 139		
H_{11}	3.87	5.74	Number of equations: 6		

Notes: Θ_i, $i = 1, \ldots, 6$, correspond to intercepts in equations (7)–(10). The single letter parameters (e.g., A_{11}) correspond to matrices defined in equation (6), and the subscripts refer to the matrix position. The parameters IRR_i, RES_i, HRS_i, DIS_i, and ERO_i correspond to the estimates of T parameters in equations (7)–(10) and refer to the effects of the irrigation stock, research stock, household responsibility system, disaster index, and erosion index variables, respectively. The IRR_{6j} and RES_{6j}, $j = 1, 2$, parameters correspond to the T_{61} matrix in equation (10).