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Transition, development and the supply of wheat in China[†]

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The overall goal of this article is to better understand the factors that influence China's wheat supply. We assess trends in China's wheat output and develop a framework to measure the relationship between output and key determinants of China's wheat sector growth. Elasticity estimates and factor growth trends help decompose the growth of reform-era wheat supply into its component parts. The results show that growth in the early reform period was due to institutional change and technology. In the late reform period, however, with the returns to institutional change exhausted, all of China's growth in wheat supply was due to technology, a result that implies China's government should invest heavily in agricultural research and development.

1. Introduction

Despite the shallowness of the world's understanding of China's wheat economy, one fact is clear to all: rapid development inside the country and its emergence as a major world grain trader have brought new and sometimes destablising forces to bear on its domestic market and on global wheat markets. Since launching their reforms, China's leaders have witnessed both burgeoning stocks and relatively serious food shortfalls (Crook 1996). During the past eight years, real wheat prices in China have reached historic highs, plummeted to levels below those of the 1950s, and then swung up so

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fast that national leaders declared a national emergency (Rozelle *et al.* forthcoming).

In spite of recent interest by policy-makers inside and outside China in understanding future trends, clear predictions of national wheat balances, domestic price trends, and trade demand have evaded researchers and policy analysts in part because of the dearth of studies on the fundamental determinants of supply. In the past, major supply-side studies have focused either on grain, in general (e.g. Garnaut and Ma 1992; Carter and Zhong 1991; Huang and Rozelle 1995), or rice (Lin 1991; Fan, Cramer and Wailes 1994; Huang and Rozelle 1996). Only two published studies even mention China's post-reform wheat supply, and because of limited data availability, both use national aggregate data mainly from before 1978 and focus mostly on measuring the price response of supply. Carter and Zhong's book (1988) contains an analysis of wheat covering 1963 to 1985; Halbrendt and Gempesaw's article (1990) covers 1960 to 1987.

Much has changed in China since the two previous research efforts on wheat: both in terms of the nation's development, and in terms of access to new data sources. China's agriculture is undergoing a rapid modernisation that is bringing both opportunities of commercialisation and the stress of environmental pressures. The nation's state statistical system has also expanded its scope of data collection efforts and has opened its archives to researchers to an unprecedented degree. The importance of the wheat sector both to China's domestic food economy and world markets, its swift transition inside China, and new sources of information justify a fresh look at wheat supply. The changes both allow and demand that the analysis concentrate on measuring the effect of a broad array of socio-economic forces.

The overall goal of this article is to explore the special features of China's wheat production as a beginning step in improving our understanding of the nation's domestic wheat sector and its future participation in and influence on global markets. To meet the goal, the first two sections assess trends in China's wheat output, yields, area, and labour allocation and examine a series of factors, beyond prices, which may have an important impact on wheat supply. A wheat supply estimating framework is developed, accounting for friction in the economy that keeps resources from immediately adjusting, and measuring the relationship between output and a number of salient features of China's wheat sector. Elasticity estimates from the econometric analysis and factor growth trends help decompose the growth of reform-era wheat supply into its component parts. The results aid in speculating if China's wheat producers can meet the leadership's near grain self-sufficiency goals or if the country will increasingly rely on world markets.

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2. Wheat production and labour allocation

The growth of agricultural production in China since the 1950s has been one of the main accomplishments of the nation's development policies. Except during the famine years of the late 1950s and early 1960s, the country has enjoyed rates of production growth that have outpaced the rise in population. Even between 1970 and 1978, when the Cultural Revolution stifled economic activity in other parts of the economy, grain production grew at 2.8 per cent per annum (table 1, rows 1–3). After accelerating to 5.8 per cent per year in the early reform period, 1978–84, grain yield growth slowed to 1.8 per cent in the 1984–95 decade.

Wheat production in China has also expanded steadily throughout the last several decades. Production and yield growth rates have exceeded the average for total grain in each of the sub-periods (table 1, rows 7–9). In the 1970s and the early reform period, wheat yields increased at annual growth rates exceeding those of rice and maize. Wheat producers also maintained their sown area, unlike rice producers (who saw their sown area fall 0.6 per cent per year between 1978 and 1995), but they have fallen behind maize farmers, who recently have increased sown area rather sharply.

Table 1 Annual growth rates of agricultural production, sown area and yields in China, 1970–95

Commodity	Pre-reform 1970–78	Reform period 1978–84		
		1978–84	1984–95	1978–95
Grain				
Production	2.8	4.7	1.7	2.4
Sown area	0.0	−1.1	−0.1	−0.4
Yield	2.8	5.8	1.8	2.8
Rice				
Production	2.5	4.5	0.6	1.7
Sown area	0.7	−0.6	−0.6	−0.6
Yield	1.8	5.1	1.2	2.3
Wheat				
Production	7.0	8.3	1.9	3.9
Sown area	1.7	−0.04	0.1	0.2
Yield	5.2	8.3	1.8	3.6
Maize				
Production	7.4	3.7	4.7	4.1
Sown area	3.1	−1.6	1.7	0.8
Yield	4.2	5.4	2.9	3.3
Cash crop sown area	2.4	5.1	2.1	3.1

Notes: Growth rates are computed using the regression method.
Sources: ZGTJNJ (1980–96) and ZGNYNJ (1980–96).

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China's wheat basket has traditionally been and remains in the North China's maize-wheat region. In 1975, 68 per cent of wheat was sown in the North China Plain, the Northeast region, and several provinces in the Northwest. By 1995, while remaining above 60 per cent, the proportion of wheat in North China declined primarily because farmers in the Yangtze Valley moved out of two-season rice, favouring rice-wheat rotations. All but three of the largest producing provinces are located in North China.

Total wheat production rose to 103 million metric tons (mmt) by the mid-1990s (average of 1993–95), but utilisation was even higher (Huang, Rozelle and Rosegrant 1999). With no changes in stocks and importing 8 mmt, the total annual supply of wheat during this period was 111 mmt. While this supply was also used for seed and animal feed, wheat used for direct food consumption took up the greatest part of total supply, over 95 per cent.

2.1 Labour use

Increasing opportunities in the non-cropping and off-farm sectors have transformed labour use patterns (table 2, column 1). After putting ever-increasing amounts of labour into wheat production in the 1950s, 1960s, and early 1970s, farmers substantially reduced labour input in wheat production after the mid-1970s. Wheat farmers employ less than half the pre-reform levels of labour, using only 190 labour days per hectare in 1995, down from 402 labour days in 1975.[1]

Labour also shifted from farm to non-farm activities in wheat-producing areas. The increasing gap between the total number of rural labourers and the total number of agricultural labourers demonstrates that labour is flowing out of agriculture (ZGTJNJ 1980–96). Higher wages (table 3, column 2) have attracted tens of millions of workers to the industrial and commercial sectors during the reform period, some of the biggest flows coming out of the highest wheat-producing provinces: Sichuan, Hubei, Anhui and Henan (Rozelle *et al.* 1999).

[1] It should be noted that such trends only appear in the cost of production data, avoiding the problems with the labour data reported in the standard statistical yearbooks, discussed by Rawski and Meade (1998). The main difference is that the cost of production data is a survey targeted directly at enumerating inputs in cropping, including detailed data on the days actually spent working on a particular crop. The standard data are created by reports from village accountants who are responding to questions about primary employment participation by their villages. Since nearly all rural residents except migrants still work in agriculture, accountants will often indicate in their year-end reports that most of the villagers are still farmers (marking the agricultural employment category) and ignore their other jobs.

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Table 2 Important factors affecting wheat supply in China, 1975–95

	Labour		Agricultural research investment (million yuan in 1985 prices)		Irrigation investment (million yuan in 1985 prices)		Prices (yuan/ton in 1985 prices)		Housing land rights	Soil
	Input (days/ha)	Wage (yuan/day in 1985 price)	Expenditure	Stock	Expenditure	Stock	Wheat market	Fertiliser mixed	HRS (ratio)	Erosion (000ha)
1975	402	1.20	539	284	3439	34590	496	299	0.00	119202
1980	347	1.90	791	408	3209	47819	660	281	0.14	118936
1985	222	2.90	1104	573	2016	49928	467	370	0.99	127112
1990	210	2.80	1043	792	3006	53476	569	389	0.99	133859
1995	190	3.80	1474	1002	8124	74020	608	702	0.99	163000

Note: Research, irrigation and soil erosion are not crop-specific but for all crops.
Sources: Irrigation data computed by the authors based on data from MWR (1988–96). Research expenditure data are from: SSTC. Prices from State Price Bureau. Erosion data are from ZGTJNJ, SSB. Labour input and wage are computed by authors based on data from SPB (1978–96).

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Table 3 Estimated parameters of quasi-fixed inputs investment model using Seemingly Unrelated Regression estimates on linear forms of equations

	Investment equation	
Variables	Land (sown area)	Total labour input
Intercept	−164.82 (−1.64)	−73.74 (−0.84)
Land_{t-1} or M_{1j}'s	−0.18 (−5.73)	−0.05 (−1.90)
Labour_{t-1} or M_{2j}'s	−0.14 (−3.57)	−0.21 (−5.86)
$(P_{\text{Wheat}}/P_{\text{Cash}})_{t-1}$	665.54 (2.30)	54.93 (0.22)
$(P_{\text{Maize}}/P_{\text{Cash}})_{t-1}$	46.37 (0.15)	724.07 (2.71)
$P_{\text{Fert}}/(P_{\text{Cash}\,t-1})$	−88.03 (−0.96)	123.63 (1.53)
$q_{\text{Land}}/(P_{\text{Cash}\,t-1})$	0.06 (2.18)	−0.002 (−0.08)
$q_{\text{Labour}}/(P_{\text{Cash}\,t-1})$	−26.60 (−1.78)	0.74 (0.05)
Irrigation stock	0.005 (1.44)	−0.003 (−1.04)
Research stock	−0.26 (−0.93)	−0.36 (−1.48)
HRS	−18.14 (−0.38)	−68.08 (−1.64)
Provincial dummies	Not reported	

Note: *t*-ratios in parentheses.

Characteristics inherent to China's developing and transitioning rural economy have both facilitated and constrained labour mobility. The labour-intensive nature of Chinese farm management practices (without great investments in an expensive capital stock) allows labour to enter and exit the cropping sector without incurring high start-up or close-down costs. Employment opportunities in local township and village enterprises and the rapid expansion of the self-employed labour force may make the flow of labour between agriculture and industry more fluid. At the same time, natural barriers, such as moving costs (which exist within all economies), impede flows. China's factor markets also still contain a number of structural

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imperfections, such as employment priority for local workers, housing shortages, and the urban household registration system (Lin 1991). One of the costs of these kinds of barriers is that they may slow down the movement of factors among economic activities, reducing the efficiency of the sector's producers.

3. Structural change and government intervention in China's agriculture

China is a rapidly developing country in transition from a socialist system to one where an increasing proportion of its goods and services, including food, are being allocated by prices and other market forces (Sicular 1995). China's government, however, far from giving up its activist role as a major actor in the economy, remains deeply involved in guiding the nation's development process. Many forces arising from the development and transition processes, and the government's attempt to guide the process, may affect wheat supply.

3.1 Technology

Above all, technological change needs to be considered explicitly, since it has been the engine of China's agricultural economy, in general, and for fine grains, like wheat, in particular (Stone 1988). While less dramatic than the well-known story of hybrid rice discovery and extension (Lin 1991), continuous and fast technical change came to wheat farmers in recent decades. After importing rust-resistant, semi-dwarf varieties from the international agricultural research system in the late 1960s, China's breeders incorporated the traits into their own varieties. By 1977, producers planted about 40 per cent of China's wheat area with semi-dwarf varieties; by 1984, this number had risen to 70 per cent. Today in China, it is difficult to see anything but improved varieties. Certainly, the rapid diffusion of new technology contributed to wheat yield growth in the reform era.

Robust growth in the stock of research capital has in part been responsible for these dramatic changes (Fan and Pardey 1995; Huang and Rozelle 1997). Once the model of developing country research systems, China's agricultural science programs, however, may be suffering from neglect after more than a decade of its own reform (Rozelle, Pray and Huang 1998). Real annual expenditures on agricultural research fell between 1985 and 1990, before resuming real growth in 1990 (table 2, column 3). The slowdown in growth in annual investments in the 1980s will result in slower growth in the overall stock of research in the 1990s (table 2, column 4).

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3.2 Irrigation investment

China's progress in water control also has contributed to the cropping sector's productivity gains. Irrigated area increased from less than 18 per cent of cultivated area in 1952 to nearly 50 per cent in 1992 (ZGTJNJ 1993). In the initial years, most of the construction was based both on locally organised small-scale projects, and publicly financed, large-scale surface projects (Stone 1993). In the late 1960s and 1970s, tubewell development drove the expansion of irrigated area construction, especially in the North China Plain maize-wheat region. Development of the nation's water control infrastructure has continued during the 1980s, as the government launched a large number of new medium- and larger-scale water control projects (Stone 1993). While much of the labour for China's irrigation development was contributed by local residents, public irrigation expenditures financed a major part of the construction of the national water control network. Since reform, irrigation investment and the stock of facilities have followed patterns similar to those for research, first dipping then recovering in recent years (table 2, columns 5 and 6).

3.3 Price trends and marketing policies

Sicular (1991) argues that increases in commodity prices may account for a large part of the agricultural growth in the post-reform era. Wheat prices, like prices for other grains, have fluctuated throughout the reforms, peaking in the 1980, 1988, and 1994 years preceding strong growth in grain output (table 2, column 7). Wage and fertiliser price trends, however, may offset or amplify the rising and falling output price contours (table 2, columns 2 and 8). For example, although wheat prices rose around 10 per cent in real terms between 1990 and 1995, fertiliser prices in real terms almost doubled, and real wages rose by nearly 30 per cent. With stagnant input–output price ratios, aggregate output may not have moved much, given the observed rises in farmgate prices.

3.4 Other factors

Institutional change

Leaders first implemented decollectivisation policies in the late 1970s, focusing first on poorer regions of the nation, and then gradually extending the policy to the whole country. By 1980, 14 per cent of villages had returned land use rights to farm households, a figure that moved rapidly upward in the early 1980s, reaching and staying at a level of 99 per cent of villages in 1984 (table 2, column 9). McMillan, Whalley and Zhu (1989) and Lin (1992)

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argue that these reforms are responsible for most of the growth in the early reform era, though these are one-time effects that are exhausted by the mid-1980s.

Environment

Trends in environmental degradation, including erosion, salinisation and loss of cultivated land, show that there may be considerable stress being put on the agricultural land base.[2] For example, erosion has increased since the 1970s, although in a somewhat erratic pattern (table 2, column 10). Recent studies have demonstrated that erosion and other environmental factors (e.g. salinisation) affect grain output (Huang and Rozelle 1995, 1996).

4. A dynamic model of production, labour and land choice

In order to identify important determinants of wheat supply, a theoretical and empirical framework is needed which (a) contains all sectors of the crop economy since wheat is part of a larger cropping system; (b) accounts for key factors determining growth; and (c) is able to measure the way producers behave in China's dynamic rural economy. Analysis of the sources of agricultural output and growth has been undertaken by a number of researchers (McMillan *et al.* 1989; Lin 1992; Fan 1991; Huang and Rozelle 1996). Previous attempts, however, have not simultaneously accounted for all major supply determinants. None has looked at wheat.

A model of China's economy-in-transition also should pay attention to elements that facilitate or constrain producers from adjusting inputs and outputs to their optimal levels in response to exogenous shocks. The adjustment cost approach is particularly appropriate for modelling the production behaviour of China's farmers, because it accounts for the relationships among multiple agricultural outputs, inputs, and exogenous shifters and allows for the imperfect adjustment of resources due to non-market factors when external forces change. These slow-to-adjust factors, called quasi-fixed inputs, are endogenous variables, their levels and rate of change determined by farmers' response to exogenous factors. Quasi-fixed inputs also affect production in both the short run and the long run. Adjustment cost theory suggests that firms suffer short-run output loss as they adjust their stocks of

[2] Information on erosion and salinisation is collected by the Ministry of Water Resources and is enumerated at the county level before being aggregated to the provincial level. Land is classified as 'eroded' if the top soil, sub-stratum or underlying rocks on any relatively large piece of mountainous or hilly terrain are exposed to any significant degradation or disturbance and exhibits signs of soil loss. Land is classified as 'salinised' if 70 per cent of the plants in any given area do not grow to maturity due to the salinity and alkalinity content of the soil.

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quasi-fixed inputs over time. Based on the discussion in the previous section, it is highly plausible that the cost associated with adjustments in sown area and labour may be an important determinant of Chinese production behaviour. A theoretical framework, first suggested by Epstein (1981), is appropriate for explaining such production behaviour.[3]

4.1 Theoretical and empirical model

Facing adjustment problems with a set of their quasi-fixed inputs (K), farmers are assumed to select an optimal level of variable inputs (L), and an investment rate (I), for their quasi-fixed inputs. They make these choices to maximise the value (V) of their farms over an infinite time domain (t), given output prices (p), variable input prices (w), rental prices of quasi-fixed inputs (q), and the level of external constraints (Z — such as technology availability, public investment, institutions, and the natural environment).

This maximisation problem can be written as:

$$V(p, w, q, K, Z) = \text{Max}_{(Y,L,I)} \int_0^\infty e^{-rt}[p'Y - w'L - q'K]dt \qquad (1)$$

$$\begin{aligned} &\text{s.t.:} \\ &k = I - \delta K, \\ &K(0) = K_0 > 0, \text{ and} \\ &Y = f(K, L, I, Z), \end{aligned}$$

where r is the discount rate, k is the net investment in quasi-fixed inputs, $K(0) = K_0$ is the stock of investment at the base year, and δ is a diagonal matrix with positive depreciation rates on the diagonal. Earnings are measured as the difference between sales revenue and the cost of purchasing variable inputs and renting quasi-fixed inputs.

[3] Estimation of supply models implicitly assumes that producers are responding to prices in a way that is consistent with profit maximisation. While few question the assumption after the early 1980s when decollectivisation made households the residual claimant to farming activities, some of our data come from the commune era. Therefore the time period covering most of the sample should be characterised by decision-makers primarily motivated by profits. Before 1980, the assumption also may not be so extreme. The work on the behaviour of brigade and village leaders by Oi (1989), Rozelle and Boisvert (1994) and Benjamin and Brandt (1999) demonstrates that income maximisation was one of the primary (if not of overwhelmingly importance) motivations guiding the decisions of local leaders. The supply response framework for China also has been widely assumed in the literature, including work by McMillan *et al.* (1989), Lin (1992), Huang and Rozelle (1996, 1997), and others.

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Given the regularity conditions on $f(\cdot)$ and static price expectations, the value function in equation 1 satisfies the following Hamilton-Jacobi equation:

$$rV(p, w, q, K, I, Z) = \text{Max}_{(I)}[\pi^*(p, w, q, K, I, Z) - q'K + V'_K(p, w, q, K, Z)(I - \delta K)] \tag{2}$$

where π^* is variable profit (and represents the optimum solution for the profit maximisation in the short run), and V_K is derivative of V with respect to K and represents a vector of shadow prices associated with quasi-fixed stocks.

By applying the familiar principles of duality and the envelope theorem to equation 2, and assuming the following form for the value function, $V(\cdot)$:

$$\begin{aligned} V(p, w, q, K, Z) = {} & a_0 + [a_1 a_2 a_3 a_4][pwqK]' \\ & + 1/2[pwqK]\begin{vmatrix} A & F' & G' & H' \\ F & B & L' & N' \\ G & L & C & R^{-1\prime} \\ H & N & R^{-1} & D \end{vmatrix}[pwqK]' \\ & + [a_5 pwqK][T_0 T_1 T_2 T_3 T_4]'Z \end{aligned} \tag{3}$$

where $a_0, \ldots, a_5, A, F, G, H, B, L, N, C, R, D, T_0, \ldots, T_4$ are parameter matrices with the appropriate dimensions, one can generate the optimal solutions for investment (k^*), variable input derived demand (L^*), and output supply (Y^*) equations as follows:

$$\begin{aligned} k^*_{(t)} = {} & B_{12} + (rU + R)K_{(t-1)} + rRGp_{(t-1)} + rRLw_{(t)} + rRCq_{(t)} \\ & + T_{12}Z_{(t)} + e_{12(t)} \end{aligned} \tag{4}$$

$$\begin{aligned} L^*(t) = {} & B_{03} - rF'p(t-1) - rBw(t) - rL'q(t) - N'Kd(t) \\ & + T_{3Z}(t) + e3(t) \end{aligned} \tag{5}$$

$$\begin{aligned} Y^*_{12}(t) = {} & B_{45} + rAp(t-1) + rF'w(t) + rG'q(t) + H'Kd(t) \\ & + T_{45}Z(t) + e_{45}(t) \end{aligned} \tag{6}$$

$$\begin{aligned} Y_{3^*(t)} = {} & B_{06} + rA_4K^d_{(t)} - 0.5rp'_{(t-1)}Ap_{(t-1)} - 0.5rw'_{(t)}Bw_{(t)} - 0.5rq'_{(t)}Cq_{(t)} \\ & - rp'_{(t-1)}F'w_{(t)} - rp'_{(t-1)}G'q_{(t)} - rw'_{(t)}L'q_{(t)} + 0.5rK'_{(t-1)}DK_{(t-1)} \\ & - \overline{K}_{(t)}DK_{(t-1)} + ra_5T_{60}Z_{(t)} + Z'_{(t)}T^*_{61k}(t) + e_{6(t)} \end{aligned} \tag{7}$$

where $B_{12} = rRa_3$, $B_{03} = -ra_2$, $B_{45} = ra_1$, $B_{06} = ra_0$, $K^d = rK_{(t-1)} - k^*$,

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$T_{12} = rR^{-1}T_3$, $T_3 = -rT_2$, $T_{45} = rT_1$, and U is an identity matrix. Conditions for consistent aggregation requires $V_{KK} = D = 0$ (Epstein and Denny 1983), a condition which has been imposed in the final estimation. All matrices and vectors have the appropriate dimensions.

In this study, sown area and labour are considered as quasi-fixed inputs (equation 4) and fertiliser is the only variable factor (equation 5). The agricultural sector consists of three crops; Y_{12} is a two-element output vector for wheat and maize (equation 6), and Y_3 is cash crop output (an aggregate of rapeseed, peanuts, and cotton — equation 7). Prices for wheat and maize, fertiliser (the one variable input), and labour and sown area (the two quasi-fixed inputs) are normalised by cash crop price to satisfy the homogeneity condition. The Z vector is made up of six shifter variables: national research stock, irrigation stock, a variable reflecting the effect of institutional reform, and three environmental variables measuring the seriousness of the agricultural sector's salinisation, erosion, and natural disasters that are caused by the breakdown of the local environment.[4] Provincial dummy variables account for fixed provincial effects.

Empirical estimates are generated for China's main wheat-producing provinces in the northern part of the country. Accounting for over 60 per cent of China's wheat, the provinces include Shandong, Henan, Shanxi, Hebei, Beijing, and Tianjin on the North China Plain; Liaoning, Jilin, and Heilongjiang in the Northeast, and Shaanxi, Inner Mogolia, Gansu, Ningxia, and Xinjiang in the Northwest.[5]

4.2 Data

Provincial-level cross-section, time series data for 1975–95 are used in the analysis. The data for agricultural output were collected by the State

[4] The two quasi-input equations only contain a three-element vector as the three environmental variables are hypothesised to affect only the three output commodities. When explaining aggregate grain yields in China's provinces, Huang and Rozelle (1995) found four factors to have an important and robust effect: erosion, salinisation, damage due to the deterioration of the local environment, and soil fertility exhaustion from over-intense land use. The first three of these variables are included in this analysis.

[5] Data were not available for Tibet. Provinces in South China did not produce significant quantities of wheat. The only omitted wheat-producing provinces are Jiangsu, Anhui, Hubei, and Sichuan. The problem with their inclusion is that these province are in the transition zone from north to south China and have a wide range of cropping patterns that obscures estimation. For example, all four of the excluded provinces have areas with rice–rice, rice–wheat, and wheat–maize rotations.

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Statistical Bureau's rural data collection network and are the same data that have been extensively used by various studies of China's agricultural economy, particularly those analysing the growth of China's agriculture (e.g. Lin 1992; Fan 1991; Huang and Rozelle 1995, 1996). Output for wheat, maize and the cash crops is measured in kilograms and, after 1980, is from published statistical sources (ZGTJNJ 1980–1996; ZGNYNJ 1980–1996). Prior to 1980, data for the variables come from provincial yearbooks which are in the national library in Beijing. Data on total sown area in each province are from the same source.[6] Provincial-level implicit output quantity indices for cash crops are formed by summing the value of the output across individual cash crops and dividing by provincial-level cash crop producer price indices.[7]

Prices for grain, fertiliser and labour come from China's national 'Cost of production' survey. The cost of production data set almost certainly provides more accurate input and price series than those taken from aggregate statistics published by the State Statistical Bureau (SSB), which are typically incomplete, subject to periodic changes in definition, and based on less reliable and undocumented sources. In contrast, the cost of production data are generated as part of a data-collection program run by the State Price Bureau since the mid-1970s for the sole purpose of tracking changes in production practices and factors that affect production (SPB 1988–96).[8] Based on annual household surveys conducted by county Price Bureau personnel, detailed information is available *by crop* for over 50 variables, including both revenues and expenditures (in value terms) and quantity data. Prices are generated by dividing total revenues or expenditures

[6] It is generally accepted that the official data on sown area are underestimated by 30 to 35 per cent. Because almost all of the understatement of cultivated land mainly occurred in the 1950s and 1960s, the impact of such a data problem on crop sown area elasticities with respect to prices and other external shocks estimated from the 1976–95 data is likely to be small.

[7] As the varieties of cash crops (cotton, various oil-bearing crops, sugar crops, vegetables, and others) differ across provinces, the homogeneity assumption of commodities (for cash crops) is violated. The price differences among provinces may not reflect the commodity price changes but instead may be reflecting differences in commodity composition. Therefore, caution should be taken in interpreting the estimated parameters and elasticities for cash crops.

[8] 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. During the last several years, these data have been published as SPB (1988–96).

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by the quantity.[9] The price for cash crop is the cash crop producer price index from statistical bureaux of individual provinces. Data on land rental rates are not available by province for the period studied. The price for land is approximated as total revenue per unit of sown area for each commodity sown in the provinces minus that commodity's per land unit expenditures on labour, fertiliser and other variable inputs.[10]

Variables representing irrigation and technology enter the equation as irrigation and research stock shifters. Irrigation expenditures are from each province, and include all sources of investment in water control that pass through the financial system to the regional bureaux of water conservancy. These are documented in a statistical compendium published by the Ministry of Water Resources and Electrical Power (MWREP 1988–96). The irrigation stock variable, $Z_I(t)$, is created on the assumption that the average life of an irrigation system is 30 years, and applying the formula used by Rosegrant and Kasryno (1994) as: $Z_I(t) = E_I(t) + (1 - d)Z_I(t - 1)$. The variable, $E_I(t)$, is the annual expenditure on irrigation in time t. A number of alternative depreciation (d) schemes were tried and the results were robust to different definitions.

In creating the research stock variable, it is recognised both that there are substantial lags between the time of investment and the time that research begins to contribute to supply and also that the research stock depreciates over time. The research stock variable is estimated as $Z_R(t) = \sum_{t=0}^{n} \alpha(t)E_R(t)$, where $E_R(t)$ is the research expenditure in period t, $\alpha(t)$ is the timing weight for accumulation of new research expenditures to the stock of research. A set of weights estimated by Pardey *et al.* (1992) for

[9] Lin (1993) theoretically shows that if the producer's marketing quota is yield- or output-dependent (that is, if one year's quota is linked to a previous year's production performance), the producer's production decisions depend on both the quota and market price. The best specification would include both prices. Unfortunately, these data are unavailable and the 'mixed' price is used as a proxy. The construction of these average prices implicitly assumes that producers are responding to an average price, constructed of quantity-weighted state and market (or 'negotiated') prices. This assumption should not be considered as too restrictive since the actual average supply response with respect to the output prices is expected to locate between the elasticities of state procurement and market prices. Also, Wang (2000) shows with county data (intraprovincial data) that there actually is a high correlation between the average price and market price over time (e.g. 0.92 in Jiangsu between 1971 and 1997 for rice), since the quota quantity has not changed very much over time.

[10] To examine the validity of our proxy for the 'price of land', we compare our measures to land rental rates for 1988 and 1995 that we elicited in a community survey that we ran in 1996 in Guangdong, Zhejiang, Henan, Sichuan, Yunan, Shangdong, Hebei, Liaoning, Hubei, and Shaanxi Provinces. The high correlation coefficient (0.82) reveals that our proxy for the return to land is close to the rent received by the farmers who rent out their land to other farmers for crop production.

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Indonesia is used. Research expenditures on crop research for the nation are assumed to have the same impact on the production of each province, implicitly implying that breakthroughs spill over into all provinces. Since most of the national agricultural research budget passes through the national agricultural academy system, this may not be an unreal assumption. The data on crop research are from SSTC (1985–96).

5. Wheat supply and resource use in China

In presenting the results, the first sub-section tests the validity of the adjustment cost framework using a linearised version of the quasi-fixed input equation, and examines how fast resources are flowing within the cropping sector and between the farm and off-farm sectors. In the next sub-section, the complete, non-linear system is estimated, the quality of the parameter estimates are examined, and growth decomposition is carried out to identify important wheat supply determinants.

5.1 Land and labour adjustment

To test the initial assumption that changes in the use of labour and land require significant adjustment costs, the two equations embodied in equation 4 above are simultaneously estimated.[11] Although the equations in the original model are highly non-linear in the parameters, to facilitate testing of the adjustment cost hypotheses, the quasi-fixed input equations are linearised. An iterative, seemingly unrelated regression (SUR) procedure is used for estimation. The estimated parameters for the North China maize-wheat region are reported in table 3. The diagonal elements of the estimated adjustment matrix, $M = (rU + R)$, where $r = 0.04$, have the expected negative signs and are statistically significant. Because the model is written in terms of first differences, the eigenvalues of the adjustment matrix provide a check on the stability of the adjustment process of land and labour. The estimated eigenvalues for M in the North China maize-wheat region are -0.18 and -0.21, and since their absolute values are less than unity, the quasi-fixed demand system is stable.

In the formulation suggested by Epstein (1981), if the coefficients, M_{11} and M_{22}, are -1, and the rate of movement towards equilibrium of one

[11] The estimates for the coefficients found in the linear formulation of equation 2 are robust to the selection of the estimator; similar magnitudes of adjustment time are found in the estimates of the full model discussed below. The results of this model are used, however, since its linear form facilitates hypothesis testing and the assessment of the standard errors of the flexible, accelerator coefficients.

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quasi-fixed input does not rely on the adjustment rate of the other (i.e. $M_{12} = M_{21} = 0$), complete and independent adjustment to the optimal point of land and labour allocation is made in a single period, and adjustment costs are minimal. The high F-statistics in the tests of quasi-fixity of sown area by itself ($M_{11} = -1$ and $M_{22} = 0$) and labour by itself ($M_{22} = -1$ and $M_{21} = 0$), the joint test of the two quasi-fixed inputs ($M_{11} = M_{22} = -1$ and $M_{12} = M_{21} = 0$) point to the importance of accounting for dynamic adjustment costs in the analysis of agricultural sown area and cropping labour decisions by China's farmers.[12] Given that there are adjustment costs, the second test ($M_{12} = M_{21} = 0$) shows that the adjustment paths are not independent (the F-statistic is 7.49). Intuitively, the results of the first three tests suggest that after a change in some exogenous variable (e.g. wheat's output price), wheat sown area and labour move only part way to the point of optimality. The second test implies that movement of labour to its long-run equilibrium point is affected by the adjustment process of sown area (and vice versa).

In the North China region, the adjustment coefficients (M) for sown area and labour are -0.18 (with a t-ratio of 3.57) and -0.21 (with a t-ratio of 5.86), respectively (table 3). These coefficients imply that only about 18 to 21 per cent of the disequilibria in land and labour allocation patterns are corrected for in each year. In other words, after some shock, the full adjustment for crop area and labour to the long-run equilibrium value takes about 5 to 6 years (slightly longer for land, given its smaller coefficient). Frictions in the land and labour markets keep wheat producers from making instantaneous adjustments (within one year) to long-run equilibrium points. While the exact source of the friction is not identified, from the discussion in the previous section most likely these are caused by fixed costs (e.g. investment in equipment or technology), barriers to entry or exit (e.g. rules against hiring employees from outside an area or local regulations prohibiting the abandonment of grain area because of fears of local leaders that they may not be able to meet village-level delivery obligations), and/or informational problems.

Five-year adjustment lags do not mean that China's post-reform economy is abnormally fragmented or inefficient. Natural, behavioural and policy-created barriers exist in every agricultural economy. In fact, comparisons with the results of similar adjustment costs analyses in other countries show that China's crop sector adjusts rather quickly. With the exception of

[12] The F-statistic for the test of the hypothesis, $M_{11} = -1$ and $M_{22} = 0$, is 382.5; sown area does not completely adjust in a single period. The F-statistic for the hypothesis, $M_{22} = -1$ and $M_{21} = 0$, is 291.3; labour does not completely adjust. The joint test of the two quasi-fixed inputs, $M_{11} = M_{22} = -1$ and $M_{12} = M_{21} = 0$, generated an F-statistic of 482.3.

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Vasavada and Chambers (1986), who found soy bean sown area in the United States adjusts to a new optimum after two years, analysts estimate that land can take up to 15 years to adjust to disequilibrating exogenous changes (Warjiyo 1991); and labour requires 6 to 19 years (Warjiyo 1991; Vasavada and Chambers 1986; Vasavada and Ball 1988). It may be that despite the existence of policy-created barriers, the relatively labour-intensive nature of China's farming systems (which requires less fixed-capital investment), and less sophisticated character of the industrial sector (which requires lower levels of human capital for gaining entry, and lower learning costs, in general), ultimately make it less costly for resources to be reallocated among sectors.

5.2 Determinants of wheat supply in China's reforming economy

To estimate the relationship among the two quasi-fixed inputs (equation 4), one variable input (equation 5), and three outputs (equations 6 and 7), a non-linear, three Stage Least Squares estimator is used (Gallant 1977, as used in Warjiyo 1991). The estimator accounts for contemporarily correlated error terms. The 6 equation system for North China contains 117 parameters.

The estimated coefficients for equations 4–7 are reported in table 4. Most of the coefficients have relatively high *t*-ratios; the signs and magnitudes of most coefficients are as expected. A number of the results also appear to be robust to estimator choice. In particular, the flexible accelerator parameters, R_{11} and R_{22} (which are the counterparts of M_{11} and M_{22} in the two-equation, Seemingly Unrelated Regression specification discussed above and reported in table 3) are negative, significant and imply similar adjustment times for land and labour.

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 stocks), 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).[13] Convexity is satisfied for both sets of regional equations, since the parameters, A_{11} and A_{22}, are positive; fertiliser ($B > 0$); and both quasi-fixed inputs (the C matrix is positive semi-definite).

[13] Property of the value function are satisfied for all factors except labour. This property is shown by evaluating the derivative of value function with respect to the exogenous variables at the sample mean. As required for monotonicity, V_p is positive for the prices of wheat and maize; V_{k1}, V_{research} and $V_{\text{irrigation}}$ are all *positive for land price, research stocks* and *irrigation stocks*; But evaluating the derivative of the value function with respect to the wage produced the wrong sign, −1.4.

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Table 4 Parameter estimates of dynamic supply response system using three-stage, non-linear least squares estimator, Northern China

Parameter	Estimate	T-Ratio	Parameter	Estimate	T-Ratio
$B12_{Kland}$	68.03	1.36	$T12_{Kland-irri}$	0.005	1.67
$B12_{Klabour}$	41.02	0.91	$T12_{Klabour-irri}$	−0.002	−0.75
$B03_{Lfert}$	−402.56	−1.19	$T3_{Lfert-irri}$	−0.04	−2.27
$B45_{Ywheat}$	−1668.56	−2.13	$T45_{Ywheat-irri}$	0.06	1.86
$B45_{Ymaize}$	−2544.75	−3.61	$T45_{Ymaize-irri}$	0.04	2.15
$B06_{Ycashcrop}$	−118.48	−0.79	$T60_{Ycash-irri}$	0.82	5.03
$A11$	8150.09	0.21	$T61_{Ycash-irri^{*}land}$	−0.00	−0.87
$A12$	68249.47	1.77	$T61_{Ycash-irri^{*}labour}$	0.00	0.12
$A22$	79397.92	1.46	$T12_{Kland-res}$	0.02	0.12
$A41$	0.72	1.64	$T12_{Klabour-res}$	0.40	2.78
$A42$	−0.43	−0.84	$T3L_{fert-res}$	−0.11	−0.09
$R11$	−0.26	−8.71	$T45_{Ywheat-res}$	5.05	2.42
$R12$	−0.16	−4.26	$T45_{Ymaize-res}$	12.31	9.31
$R21$	−0.09	−3.30	$T60_{Ycash-res}$	−3.98	−0.34
$R22$	−0.26	−7.54	$T61_{Ycash-res^{*}land}$	−0.00	−0.40
$G11$	0.28	0.07	$T62_{Ycash-res^{*}labour}$	−0.00	−0.38
$G12$	6.50	1.45	Other shifters of Z:		
$G21$	−2067.62	−0.93	HRS:equation land	−24.47	−0.63
$G22$	−11443.99	−4.40	Equation labour	−143.96	−4.12
$L1$	−8.82	−3.53	Equation fert	615.92	2.78
$L2$	2361.87	1.69	Equation wheat	1044.08	2.65
$C11$	−0.00	−1.70	Equation maize	−757.60	−1.15
$C12$	1.02	1.95	Equation cash	227.26	2.76
$C22$	623.46	1.80	Disaster:		
			Equation wheat	−2320.44	−2.24
$F1$	−24283.26	−1.88	Equation maize	−3003.69	−3.34
$F2$	−43972.66	−2.88	Equation cash	−223.56	−1.15
B	48666.17	4.75	Erosion: equation wheat	−627.71	−1.63
$N1$	−0.14	−0.39	Equation maize	−1226.62	−3.67
$N2$	0.07	0.19	Equation cash	−131.50	−1.82
$H11$	3.52	5.39			
$H12$	0.18	0.32	Objective function*$N = 277$		
$H21$	−3.72	−5.05	Provincial dummy parameters: omitted		
$H22$	−0.36	−0.55	Number of parameters: 117		
			Number of equations: 6		

Note: The first capital letter corresponds to the parameter in equations 1–7 in the model section. The text in the model section defines the variables that we used in the empirical analysis and reported in this table. The letter is followed by dimension of the parameter's matrix, and further followed by equation and variables, i.e., $T61_{Ycash-res^{*}land}$ is parameter for variable res^{*}land (a product of research stock time land area) in equation Ycash (output equation for cash crop).

The estimated impacts of the government policy variables on agricultural production also are almost all as predicted. The positive signs on the res^{*} variables in the North China equations mean that investment in agricultural research increases the output of wheat and maize (the two $T45$ variables — table 4). The low t-ratio on res^{*} variable associated with cash cropping ($T60$)

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hints that the research system apparently has been grain-biased, an observation made by Fan and Pardey (1992).

The impact of irrigation on production practices and output is somewhat more complex. Irrigation positively affects wheat production in North China. Its coefficient (and the coefficient for maize), however, is much less significant than that for cash crops (*T*45 — table 4). Increased irrigation does raise wheat production. Because cash crops lead to higher profits in many places, however, new investment stimulates relatively more cash crop production.

The signs of the coefficients associated with the variables measuring institutional reform (HRS) imply that decollectivisation had a positive impact on the production of all crops, including wheat, the result found by most analysts (Lin 1992; McMillan *et al.* 1989; Fan 1991; Huang and Rozelle 1996). Decollectivisation-led output increases, however, did not come about by increased labour use. Consistent with the labour-use data in table 2, the institutional reforms led to substantially lower labour use (see the negative sign of the coefficient of the HRS-labour variable).[14] To compensate, wheat farmers in the post-reform period use chemical fertiliser to substitute for falling labour input, a trade-off described by Ye and Rozelle (1994) in their study of Jiangsu rice farmers. Short- and long-run elasticities (calculated from the parameters in table 4) are presented in table 5.

5.3 Growth decomposition

Between 1976 and 1995, wheat output from the 14 northern provinces included in the study grew 4.54 per cent annually (table 6, bottom row, column 3). Within the two reform sub-periods, wheat production grew faster during the early reform period, 1978–84 (7.63 per cent — table 6, column 6); and slowed in the late reform period, 1985–95 (2.12 per cent — table 6, column 9). To identify which factors have made the biggest contributions to the growth of China's wheat production, growth rates during the sample period and the key sub-periods can be decomposed into their component parts (table 6, rows 1–10). Each component is constructed by multiplying the short-run output elasticity of each determinant of wheat

[14] The signs of the environmental variables are consistent with those found by Huang and Rozelle 1995, 1996). Environmental factors have reduced the output of all crops, the erosion and deterioration of the local environment effects are particularly harmful to other grains, the crop grown in the most environmentally fragile regions.

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Table 5 Short-run and long-run elasticity of output supply evaluated at sample 1975–95 mean in Northern China

	With respect to the price of							
	Land	Labour	Fertiliser	Wheat	Maize	Cash crop	Research stock	Irrigation stock
Short-run elasticities								
Wheat	−0.002	−0.098	−0.140	0.049	0.293	−0.102	0.597	0.172
Direct	0.004	−0.088	−0.135	0.045	0.275	−0.101	0.467	0.312
Indirect	−0.006	−0.010	−0.005	0.004	0.018	−0.001	0.130	−0.140
Maize	0.088	−0.446	−0.224	0.343	0.292	−0.052	1.056	0.181
Direct	0.089	−0.445	−0.223	0.342	0.289	−0.052	1.044	0.190
Indirect	−0.001	−0.002	−0.001	0.001	0.003	0.000	0.012	−0.008
Cash crop	−0.111	0.706	1.211	−0.456	0.427	−1.776	−0.067	1.463
Direct	−0.112	0.705	1.210	−0.456	0.429	−1.776	−0.220	1.724
Indirect	0.001	0.001	0.000	0.000	−0.002	0.000	0.153	−0.261
Long-run elasticities								
Wheat	0.006	−0.084	−0.133	0.043	0.275	−0.108	0.431	0.346
Direct	0.004	−0.088	−0.135	0.045	0.275	−0.101	0.467	0.312
Indirect	−0.002	0.004	0.002	−0.002	0.001	−0.007	−0.036	0.034
Maize	0.089	−0.445	−0.223	0.342	0.289	−0.052	1.041	0.192
Direct	0.089	−0.445	−0.223	0.342	0.289	−0.052	1.044	0.190
Indirect	−0.000	0.000	0.000	−0.000	−0.001	0.000	−0.003	0.002
Cash crop	−0.109	0.355	0.635	−0.458	0.421	−0.834	−0.275	1.785
Direct	−0.112	0.705	0.575	−0.456	0.429	−0.776	−0.220	1.724
Indirect	0.002	0.004	0.060	−0.002	−0.007	−0.057	−0.055	0.061

supply (table 5) by the growth rate of each factor (taken from series cited in table 2).[15]

The results for the North China wheat decomposition show that while institutional innovations are important, government investment has contributed the most to wheat yield growth during the period 1976 to 1995. Improvements in technology from research expenditures have by far contributed the largest share, augmenting the annual growth rate of wheat

[15] The formula on which the decomposition is based is derived by totally differentiating the output supply equation, $Y_j = y_j(p, q, r, Z)$, and manipulating the results into the following form:

$$r_y = \sum e(x_i) r_{xi}$$

where, r_y is the growth of output (for wheat, maize and cash crops), $e(x_i)$ is the total short-run output elasticity with respect to output and input prices, p, q and r, and a series of shifter variables, Z, and r_{xi} is the growth of the p, q, r, or Z. The decomposition growth is robust to the use of short- or long-run elasticities.

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Table 6 Sources of wheat production growth in Northern China

		1976–95			1978–84			1984–95		
		Factor growth rate (%)	Source of growth		Factor growth rate (%)	Source of growth		Factor growth rate (%)	Source of growth	
	Output elasticity		Rate	(%)		Rate	(%)		Rate	(%)
I. Research stock	0.597	4.72	2.82	62	5.53	3.30	43	5.74	3.43	162
II. Irrigation stock	0.172	2.49	0.43	9	2.52	0.43	6	2.73	0.47	22
III. Institutional innovation (HRS)		0.99	1.63	36	0.99	3.86	51	0.00	0.00	0
IV. Input and output prices			0.16	4		0.86	1		−0.75	−35
V. Land and labour prices			−0.40	−9		−1.34	−18		−0.09	−4
— Land	−0.002	8.91	−0.02	−0.4	20.75	−0.04	−1	4.50	−0.01	−0.4
— Labour	−0.098	3.90	−0.38	−8	13.23	−1.30	−17	0.81	−0.08	−4
VI. Environment factors			−0.10	−2		0.31	4		−0.04	−2
— Disaster	−0.078	1.07	−0.08	−0		0.30	4	0.26	−0.02	−1
— Erosion	−0.021	0.65	−0.01	−2		0.01	0.1	0.95	−0.02	−1
VII. Residual			−0.01	−0		0.21	17		−0.90	−42
Total			4.54	100		7.63	100		2.12	100

Notes: HRS is measured by the cumulative proportion of households adopting production responsibility system in any given year. The impact of the HRS on the growth rate of the output is computed by the following two steps: (i) the output change due to the change in the HRS ratio is computed using the estimated coefficient of the HRS variable; (ii) these changes in the output are then transformed into changes in annual growth rates. Short-run elasticities are used in the analysis.

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output by 2.82 per cent (62 per cent of the total growth rate — table 6, columns 3 and 4). Decompositions for rice in the south (not shown here — see Huang and Rozelle 1997) show that research investment has created more wheat growth (2.82 per cent) than for rice (1.38 per cent). Part of the explanation may be that the initial growth from new Green Revolution technology for rice had already taken place (semi-dwarf varieties of rice were introduced in the late 1950s before anywhere else in the developing world — Stone 1988).[16]

The contribution of irrigation investment to wheat growth is only 0.43 per cent annually (9 per cent of total growth), a level falling well below the returns to research investment (table 6, columns 3 and 4). Part of this somewhat puzzling, but consistent result (the measured contributions of irrigation to rice and maize are 0.25 and 0.45, respectively) may come from a failure to identify the complex interactions and sequencing of agricultural investments. During the early Mao era, leaders may have made much of the initial, high payoff investment in water. If high returns to irrigation have already been exhausted, the lower impacts on growth may appear because new investment is in fact going into lower return project areas. Current investments also could be being channelled towards other necessary facets of water control, such as system upgrades and maintenance. If this is the case, in the same way that the study's methods and analysis period 'penalise' measured returns to rice research investment for its early start, water control's contribution to China's high *level* of wheat productivity could still be high. Also, the contributions from research could be picking up part of the returns from irrigation investment, since modern, high-yielding technology requires good water control to realise its maximum gains.

Between 1976 and 1995, the implementation of HRS was the second most important factor; institutional changes increased wheat output growth by 1.63 per cent per year (36 per cent of the total — table 6, columns 3 and 4). Part of the smaller contribution of HRS, relative to public investment, is because its implementation was started in 1978 and completed in 1984. The relatively high return to technology, however, has important implications for policy-makers in China, who at one time in the 1980s appear to have believed China could maintain its fast growth on the basis of institutional change, and for a time ignored research and water control investments.

[16] In contrast, the contribution of technology to maize output growth (4.98) exceeds that of wheat. One explanation may be that while maize improvements had started in the early 1960s with the release of hybrid cultivars, serious corn blight epidemics had reduced yields in the late 1960s and programs to develop and release disease-resistant single cross-maize hybrids did not really reach the farm level until the mid-1970s. Hence, maize research impacts could appear larger since it started from a lower base and all occurred during the study period.

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Interestingly, the returns from decollectivisation and other early reforms captured by the model's institutional change variable is greatest in the case of wheat (1.63 per cent) versus rice (0.89 per cent) and maize (which was either zero or negative). The somewhat lower returns from farming organisational changes in rice may be explained by the fact that there is a more pronounced collective element in rice production (e.g. transplanting, harvesting and threshing requires cooperation), that was lost when reformers disbanded the communes. When wheat farmers decollectivised, they may not have lost as much in terms of economies of cooperation, since individual households can plough and plant their own seed with little or no loss of efficiency even without the help of former production team members.

The net impact of fertiliser and wheat price changes is marginal for the whole sample period (only 4 per cent of the total growth rate). If the cross-price effects are considered, however, the contribution of price changes to wheat output growth rises somewhat (results not shown). Also, considering the 18-year period as a whole may obscure the true underlying relationships between prices and output growth. While the positive effect on wheat output of the real increases in its own prices enjoyed during the early 1980s is just cancelled out by the rise in fertiliser prices in the early 1980s (there is only a net contribution to growth of 1 per cent — table 6, columns 6 and 7), the more sluggish wheat price increases in the late 1980s and 1990s, coupled by rapidly increasing input prices lead to a significant fall in growth rates (−35 per cent, table 6, columns 9 and 10).

The positive impacts of government investment and institutional reform policies have been partially offset by the rises in land and labour prices. Overall during the 1976–95 period, growth would have risen by 9 per cent more had higher wages (primarily) not induced farmers to move out of wheat farming (table 6, column 4). The net impact was somewhat larger, 18 per cent, in the early reform years when the real wage grew quickly (table 6, column 7). However, given the massive shifts of labour out of wheat farming (nearly 50 per cent when measured on a labour days per hectare basis — see table 2), the drop is not very much, owing most likely to the efficiency gains from HRS. In contrast, the stagnation of real wages in the late reform period, 1985–95, has limited the impact of wheat and non-wheat competition for labour; output growth only fell by 4 per cent for wheat (table 6, column 10).

Environmental factors have had much less effect on wheat production than elsewhere in China's cropping sector. While drops in growth rates are as high as 8 per cent in the case of maize during the 1976–95 sample period (Huang and Rozelle 1997), and reach 47 per cent in the case of cash crops in the late 1980s (ibid.), environmental factors only reduced wheat output growth by 2 per cent during the sample period (1976–95 — table 6, column 4), the same rate that appeared during the late reform period (1985–95, table 6, column

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10). The loss from environmental factors equals those found in the study of rice (Huang and Rozelle 1995, 1996). This smaller impact might not be so unexpected since wheat (like rice) is typically grown in favourable areas, while maize and some cash crops tend to be grown in hilly and more ecologically fragile areas. These results suggest that if policy-makers want to address the adverse consequences of environmental stress, their efforts should target specific crops.

Perhaps the most important result for understanding future supply from China's wheat sector is that in recent years, 1985–95, almost all growth has come from public investment, especially in research (table 6, columns 9 and 10). Deteriorating price ratios, especially, and rising wages and environmental stress, to a lesser extent, have held back the expansion of wheat production. The one-time institutional reforms in the early 1980s have been exhausted and have not directly contributed to wheat output growth. Investment in research and irrigation have contributed 184 per cent ($162 + 22$ — table 6, column 10) of wheat growth during the past 10 years. By exceeding 100 per cent, the figures imply that not only can all growth be accounted for by public investment, it compensates for negative factors elsewhere in the economy. If these relationships hold in the future, wheat supply in the twenty-first century is going to rely heavily on increased investment in agriculture by policy-makers.

An implicit assumption of the exercise that decomposes growth by sub-periods is that the structural parameters have not changed between the early and late reform period since we are essentially evaluating growth at different means from the same estimated supply parameters.[17] Ideally, we would like

[17] The large residual (or an unexplained part of the growth) in the second period, −42 per cent, is suggestive that we carefully think about why our model is not as accurate in predicting growth in the second period. One reason is that the parameters may have changed, a possibility that we examine in table 7. An alternative interpretation may be that the government's grain marketing and pricing policy, argued earlier in the text to provide wheat farmers in many provinces with a disincentive to produce, may also be holding back growth. Yet another explanation may be that the elasticities of wheat production with respect to research stock decline over time (accounted partly for in table 7) or our use of short-run elasticities bias the results of what should be considered a longer-run effect. Either of these explanations would imply that the estimated impact of research stock may be over-reported (i.e. it should be less than 162 per cent). In fact, as we can see from table 5, the *long-run* elasticity of wheat output with respect to research (0.431) is smaller than the short-run one (0.597). In this case, using *short-run* elasticities in our decompositions may lead to a somewhat higher estimated contribution from research. Simple adjustments made in the calculations used for table 6 (i.e. using the long-run elasticity in place of the short-run one) illustrate that although using the long-run elasticities would reduce the estimated contribution of technology (and also reduce the unexplained negative residual in the late period), it would not reverse our main finding that technology has been the major driving force of wheat production growth in both sub-periods of the reform era.

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Table 7 Sources of wheat production growth in Northern China using a more 'flexible' model[a]

		1976–95[b]			1978–84			1984–95		
	Output elasticity[d]	Factor growth rate (%)	Source of growth: Rate	Source of growth: (%)	Factor growth rate (%)	Source of growth: Rate	Source of growth: (%)	Factor growth rate (%)	Source of growth: Rate	Source of growth: (%)
I. Research stock	0.592 (0.599)	4.72	2.82	62	5.53	3.27	43	5.74	3.44	162
II. Irrigation stock	0.172 (0.172)	2.49	0.43	9	2.52	0.43	6	2.73	0.47	22
III. Institutional innovation (HRS)		0.99	1.63	36	0.99	3.86	51	0.00	0.00	0
IV. Input and output prices[c]			0.16	4		0.86	1		–0.75	–35
V. Land and labour prices			–0.40	–9		–1.08	–14		–0.09	–4
— Land	–0.001 (–0.001)	8.91	–0.02	–0.4	20.75	0.02	0.3	4.50	–0.0045	–0.2
— Labour	–0.083 (–0.096)	3.90	–0.38	–8	13.23	–1.10	–14	0.81	–0.08	–4
VI. Environment factors			–0.10	–2		0.31	4		–0.04	–2
— Disaster	–0.078	1.07	–0.08	–0		0.30	4	0.26	–0.02	–1
— Erosion	–0.021	0.65	–0.01	–2		0.01	0.1	0.95	–0.02	–1
VII. Residual			–0.01	–0		–0.36	–5		–0.90	–42
Total			4.54	100		7.63	100		2.12	100

Notes: HRS is measured by the cumulative proportion of households adopting production responsibility system in any given year. The impact of the HRS on the growth rate of the output is computed by the following two steps: (i) the output change due to the change in the HRS ratio is computed using the estimated coefficient of the HRS variable; (ii) these changes in the output are then transformed into changes in annual growth rates. Short-run elasticities are used in the analysis.

[a] The elasticities in this table are estimated with the original model specified in the article plus a set of interaction variables that were created by interacting sub-period time dummies (1 = year > 1984) with those variables associated with the own price elasticities. This is an attempt at allowing for more flexibility and is therefore referred to as the 'flexible' model.

[b] These three columns are the same as those in table 6, and use the elasticities in column 1, table 6. Post-1985 elasticities are in parenthesis.

[c] Estimated with the parameters of the flexible model (see note a). Elasticities for the 1978–84 period are shown first; post-1985 elasticities are in parenthesis.

[d] The elasticity of wheat output with respect to wheat price in the early sub-period is 0.048 and in the late sub-period is 0.055 (versus 0.049 in table 5). The elasticity of wheat output with respect to fertiliser price in the early sub-period is –0.121 and that in the late sub-period is –0.127 (versus –0.140 in table 5).

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to have separate estimates for the early and late period. But lack of data makes this impossible; we currently have only 277 observations for the whole study period and there are 117 parameters to be estimated. If we were to divide the sample into two sub-periods, we would only have 3 degrees of freedom for estimating the first period's model and 31 for the second period's. As a compromise, we can re-estimate a more 'flexible model' by interacting the parameters associated with the own-price responses with a sub-period dummy variable ($D = 1$ for years before 1985 and zero otherwise). A Chow test shows no statistical difference between periods at a 5 per cent level of significance, but shows that there is a statistical difference at a 10 per cent level (although the paucity of data may partly account for this result). Some of the main elasticities from these estimates are presented in table 7. Using them in a growth decomposition exercise (table 7) demonstrates that our findings discussed above (and conclusions drawn from the findings) are robust to the period used for estimation.

6. Conclusion

This article presents the results of the first investigation that fully focuses on China's wheat supply during the reform era. Unlike any previous commodity study, we use sub-national data from the most important wheat-producing regions to examine the relationship between wheat production, sown area and labour allocations, on the one hand, and a series of the economic forces, policies and resource factors, on the other. Since the beginning of reform, price trends, decollectivisation, and environmental factors have shaped farmer output decisions. Their impact, however, pales against the influence of public investment in irrigation and research. Research and the technological change it has fostered have contributed more to wheat production growth than any other factor, even dominating the efficiency gains of institutional change in the 1978–84 period. After 1984, technological change has offset the adverse effects of rising wages, deteriorating input–output price ratios, and environmental effects, largely driving the 2 per cent per year growth in wheat output.

Will China's wheat supply grow fast enough to meet growing demand? Or will leaders be forced to rely on global markets even more than they have over the past 15 years? China's growing population and rising incomes will put ever greater pressures in the coming years on the nation's wheat-producing capabilities. Even with mitigating forces of low income elasticities (that will keep per capita wheat demand from growing too steeply with income rises) and urbanisation that will take some of the pressure off demand growth (since China's rural population consumes more wheat than its urban counterparts, meaning that as rural-to-urban migration occurs,

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incomes and prices constant, demand will fall — see Rozelle and Huang 1999), wheat supply still must accelerate in the future if the nation is to meet its goal of near self-sufficiency.

The results of our study show that China's leaders have a set of viable policy options. They could, like their East Asian neighbours, use price support policies to stimulate higher production. However, with its WTO membership pending and considering its national fiscal crisis, the nation may have neither the political flexibility nor the financial muscle to 'buy' high wheat output growth.

Carefully managed investments in agricultural research and other infrastructure, however, are within its financial limits, and will give the sector its biggest boost, if past trends hold. In fact, Huang, Rozelle and Rosegrant (1999) show that if leaders expand agricultural research expenditures by only 2 percentage points per year (increasing the annual growth rate from 4 per cent to 6 per cent) over the next two decades, China's wheat producers will not only meet growing demand, they may make their nation nearly self-sufficient in wheat by 2020, a dramatic turnaround from recent years.

While there are many assumptions on the projections, including the fact that technology must continue to contribute in the same magnitude as the past, that current cropping patterns do not change substantially, and that self-sufficiency in grain remains a priority (all of which may be contestable), China's leaders hold much of their destiny in their own hands. Falling wheat imports in the twenty-first century may not be good news for international wheat exporters. It will be good news, however, for those who are concerned that China's increasing emergence onto international markets will upset global food balances. With intelligent agricultural policies and investment commitments, China will not 'starve the world' as some have forecast, but may contribute to both China's and the world's food security.

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