SELF-SUFFICIENCY AND PRODUCTIVITY IN CHINESE AGRICULTURE. IMPLICATIONS FOR CHINA'S WTO ACCESSION.

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Abstract

In the past twenty years the growth of China's economy and agriculture has been extraordinary. However it seems unlikely that, without substantial interventions, China will attain self-sufficiency in agriculture by 2005. We build a CGE model to examine the main trade policy options available to Chinese policy makers. We compare the welfare effects of each policy and explore the potential of biotechnology for agricultural productivity increase.

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Paper presented at the Annual Meeting of the American Agricultural Economics Association, Tampa (Florida). July 30 - August 2, 2000

Self-Sufficiency and Productivity in Chinese Agriculture. Implications for China's WTO Accession

Since the announcement of China's *"duiwai kaifang zhengce"*, or "open door" policy (December 1978), the growth of China's economy and agriculture has been extraordinary. Between 1979 and 1984, GDP grew by an average of 8.5% per year and accelerated to 9.7% per year between 1985 and 1995, a significant increase over 1970s levels (4.9%). Correspondingly, agricultural output value grew by an average of 7.5% per year from 1979 to 1984 and 5.6% between 1985 and 1995, respectively, compared to only 2.3%, between 1970 and 1978 (Huang et. al., 1999). In spite of the unprecedented growth over the last two decades, scholars have raised concern over the capacity of China to feed itself in the future. Brown (1995) published the most pessimistic projections evoking the specters of soaring world prices and starvation in poor countries.

While the magnitude of Brown's estimates has been seriously questioned (Yang and Huang, 1997; Fan and Agcaoili-Sombilla, 1997), the emergence of a substantial grain deficit is now considered the likely scenario. Grain markets are projected to experience a sustained demand increase driven by growth of population (expected to reach 1.6 billion in 2020), rapid urbanization, rising income levels and the expansion of the livestock sector (as a consequence of growing meat consumption).

These factors are unlikely to be matched by compensating shifts in the supply of grains due to (i) the transition of land, labor and capital to non-agricultural uses, (ii) a slowdown in yield growth, and (iii) environmental degradation (erosion, salinization). As Yang and Huang (1997) have noted, with only 7% of world arable land but 22% of the world's population, China's comparative advantage is likely to shift from land-intensive commodities, to labor-intensive products.

In spite of this, the Chinese Government has set food self-sufficiency as a declared goal in its long-term plan for 2010. Even if the objective has not been clearly defined in terms of a precise commodity category, scholars interpret it as the requirement that national production of grains should meet at least 95% of the domestic demand (Yang and Huang, 1997; Anderson and Peng, 1998).

Given the more conservative scenarios drawn by economists, how can we evaluate the objective of self-sufficiency? In this paper we focus on three main policy options open to the Chinese Government to meet the objective of self-sufficiency: border measures, domestic support, and encouraging productivity improvements. The first two artificially restore the equilibrium between domestic supply and demand but would entail a significant price distortion. As such, these would introduce allocative inefficiencies and a loss of welfare for the economy.[1] Moreover, there may be a conflict with the target of accession to the World Trade Organization (WTO) set forth by the Chinese Government.

To encourage productivity improvements, the use of biotechnology, particularly the adoption of genetically modified (GM) crops, offers the potential of improved efficiency, increased yields and reduced production costs and appears *prima facie* the most "palatable" potential solution to the supply problem. To assess the objective of self-sufficiency, we utilize a multi-region computable general equilibrium (CGE) model to provide a stylized description of the Chinese economy and predict grain demand and production for 2005. We then simulate the potential policy responses to the estimated grain deficit.

[1] Welfare is considered in its restricted economic definition.

Supply and demand projections for China

The agricultural reforms implemented in China since the end of the 1970s were designed to foster the transition from a command economy to an incentive-based system with individual rewards tied to output (household responsibility system), specialization of agriculture, increase in procurement prices to stimulate production, the establishment of quasi-private property rights (land ownership now rests with the village, but land is leased to households for up to 30 years), and the progressive relaxation of the restriction to labor mobility out of agriculture.

The reforms resulted in a dramatic increase in grain production (+65% from 1978 to 1996), productivity (Huang et. al., 1999, calculated a 54% increase in total factor productivity for rice, 121% for wheat, 71% for soybeans, and 85% for maize, between 1979 and 1995) and in a net exports of grains in 1983 and 1984. However, by the second half of the 80s, it had become evident that the growth of supply was not keeping pace with the increasing demand that followed the accelerating growth of the economy and the expansion of industrial sectors.

Since the beginning of the 90s, domestic grain prices in China have reached levels comparable to international prices. In 1995 Brown predicted that, if present trends persist, in 2030 China would need to import 370 million MT of grain. Given that world exports of grain were about 200 million MT in 1995, this would have implied a significant increase in international prices and the prospect of starvation in low-income, food-importing countries. The weakness of Brown's methodology, which was based on simple extrapolations from time series data, is now widely recognized (Anderson and Peng, 1998; Fan and Agcaoili-Sombilla, 1997; Yang and Huang, 1997). Other attempts have been made to forecast the future international grain trade in China, adopting partial equilibrium approaches (Rosegrant et al., 1995; Huang et al., 1997; ERS/USDA, 1996; Mitchell and Ingco, 1993; OECF, 1995; Huang et al., 1999) and CGE models (Yang and Huang, 1997; Gilbert and Wahl, 1999). Almost all these studies forecast grain deficits (Table 1).[2]

[2] The only exception, to our knowledge is Huang et al. (1999), not represented in Table 1. There are major variations among these studies in the projections of grain supply and these variations are in turn explained by the assumptions

Table 1. Projections of grain deficit for China (million MT)

Year	Brown	Rosegrant et al.	Huang et al.	USDA	World Bank	OECF
2000	63	18	24	25	11	18
	(17.7%)	(5.1%)	(6.8%)	(7.0%)	(3.1%)	(5.1%)
2005	108	16	25	32	14	52
	(30.4%)	(4.5%)	(7.0%)	(9.0%)	(3.9%)	(14.6%)
2010	155	15	27	39	22	104
	(43.7%)	(4.2%)	(7.6%)	(11.0%)	(6.2%)	(29.3%)

Figures in brackets represent the deficit as percentage to 1995 grain domestic production (345 million metric tons)
Elaborated from Fan and Agcaoili-Sombilla (1997).

Nevertheless, the capacity of China to fulfil its grain requirement with its own production is still an important item in the agenda of policy makers (Reuters 1997; Information Office of the State Council of the People's Republic of China, 1996). In addition to national pride and food security issues, motivations for this target include protecting China from the fluctuation of grain prices in world markets, avoiding a shortage of foreign currency, fostering domestic grain production in order to protect farm incomes and counterbalance raising inequality between rural and urban households, and preventing the insurgence of social unrest, stemming from increased dependence on foreign staple commodities and increasing income inequality.

Achieving self-sufficiency in China

Given the political goal of self-sufficiency, we consider three possibilities: 1) increasing border protection, 2) domestic support and 3) productivity improvements. China could choose to increase the tariff rates on imported agricultural goods by artificially raising the prices of food commodities in domestic markets. This policy would both promote a reduction in the quantity of domestic demand and an increase in the quantity of domestic supply. Economic theory suggests that such an

on the growth of grain areas and yields. Variations in demand projections are less pronounced: assumptions on population growth are, in fact, quite close. There are different hypotheses on GDP growth rates (the most pessimistic is in Huang et al., the most optimistic in OECF), but other factors, such as urbanization, eventually reduce the divergences.

approach implies allocative inefficiencies. Moreover it may jeopardize China's WTO accession bid, given the major distortions to international trade that it is likely to introduce.

A second policy package would be to increase the domestic supply of food commodities by means of domestic support to agriculture. When properly designed, domestic support measures can *de facto* act in the same way as trade barriers (Sumners, 2000). These policies are also extremely costly, imply a reallocation of factors throughout the economy, and would entail a subtraction of resources from competing and strategic industries. The presence of inefficiencies and inter-sectoral competition will be highlighted in the following section, with the adoption of a general equilibrium model.

The third possibility would be to improve Chinese agricultural productivity. This implies no dichotomy with the pledge of future agricultural liberalization and it is not a source of inefficiency and welfare losses associated with tariffs and domestic support. Nonetheless, productivity improvements can not be reaped without effort; they require both investments in research and institutional innovation. In the next session we consider how biotechnology and genetically modified organisms (GMOs) may help in this regard.[3]

Biotechnology and productivity growth

New technological processes, first experimented in the mid 1980s, have been introduced for commercial cultivation since 1996. They have been rapidly diffused into 12 countries, including 6 developing economies: Argentina, China, Mexico, Rumania, Ukraine and South Africa (James, 1999). In 1999, the estimated total area cultivated with genetically modified crops was 39.9 million ha. Roundup-Ready (RR) soybeans were grown on 21.6 million hectares of land (the equivalent of 54% of the world area cultivated with GM crops), Bt-corn on 11.1 (28%), Bt-cotton on 3.7 (9%),

[3] This does not imply, of course, that productivity growth can be attained only through GMOs.

RR canola on 3.4 (9%).[4] GM crops were concentrated in 3 countries (USA, Argentina, Canada), accounting for almost 99% of total area of transgenic crops.[5]

China's genetically modified crop production was still extremely small in 1999, with only 0.1% of domestic crop area cultivated with GM varieties and a share of only 1% of the cropped area in the 12 countries. However, between 1998 and 1999, the increase in area cultivated with transgenic varieties has been as high as 300%, evidence of the growing interest in biotechnology. The primary transgenic crops have been Bt corn, Bt cotton (grown extensively in Hebei province where bollworms have seriously threatened local cotton production), and a virus-resistant tobacco.

From a purely biological standpoint, GM crops display diverse characteristics. In fact, following Nelson et al. (1999), we may distinguish between five types of technological changes generated by biotechnology: (i) increase of the biologically optimal yield, (ii) increase of the economically optimal yield, (iii) change in input composition, (iv) reduction of risks, (v) enhancement of output traits.[6] Bt-corn and Bt-cotton clearly represent two cases of increase in economically optimal yields: even if the biological maximum is not improved, the plant performs its own pest control. With traditional varieties the total control of parasites would require higher costs than the value of the corn saved.[7] By contrast, RR soybeans and canola are resistant to glyphosate, which can be used instead of a more costly combination of selective herbicides. RR soybean and canola enhance productivity through a change in input.

From a neoclassical modeling perspective, such differences tend to disappear, since the increase in output at a given cost of production or the reduction of cost at a given output level represent two

[4] James, 1999.

[5] Bt corn and cotton have been genetically modified to produce the toxins of the *Bacillus Thuringiensis* (Bt), a bacterium frequently present in the soils. Such toxins have strong inhibitory effects on the digestion in parasites as the European cornborer and no undesirable effects on mammals. However, the diffusion of Bt-corn has been associated with a higher mortality of monarch butterfly, a non-targeted insect (Losey et. al., 1999).
The DNA of RR soybean and canola has been modified in order to develop resistance to glyphosate, a non-selective herbicide.

[6] Technology improvement may increase the yields under optimal biological conditions, provide cost-effective control of pests, change the input mix so as to save costs, reduce the effects of natural hazards (e.g. flooding) that prevent cultivation in some areas, or, finally, improve the quality of the product and provide a price premium.

[7] There are also potato varieties using the Bt toxins. One of these is the New Leaf (NL) potato, mentioned in Table2.

sides of the same maximization problem. In this paper we concentrate on cases (ii) and (iii) and model both as a Hicks-neutral technical change.

Table 2 summarizes findings on the quantitative impact of genetically modified crops: it provides an illustration of the biological differences between type (ii) and (iii) of GMO impact on crops, as well as a general term of comparison for the simulations conducted in the next sections.

It is important to remember that the values presented in Table 2 are contingent upon the specific geo-climatic conditions of the concerned geographical areas and the endemic plant diseases and pests. As can be easily discerned, data for soybeans from North Carolina show no increase in farm revenues (due to a non-significant increase in yields) but an important reduction in herbicide costs with a net gain of 6 US$ per acre (22% of herbicide costs). Estimates for virus-resistant potatoes in the Columbia Basin show that, even though no appreciable yield gains have materialized, the input shift has been capable of increasing the net revenue gain per unit of cultivated land. In the case of potatoes, there is here a potential ambiguity in the classification of the technology between, higher economic yield and input-switching process.

Table 2. Evidence of the impact of GM crops

Geographical Area	R R Soybeans	NL Potato	Bt-Corn	Bt-Cotton
China			Hebei Province[a]	Hebei Province[a]
Yield Increase (%)			5 - 7%	4 - 15%
Net gain (US$/Acre))			n.a.	58-73
USA	National [d]	Columbia Basin[c]	Cornbelt & Lake States[d]	S/E United States[d]
Yield Increase (%)	0		4 to 8 %	6 to 12%
Reduced Insecticide Application (%)	-	-	n.a.	70%
Revenue Increase (US$/Acre)	0	0	13 to 26	64
Reduced Costs (US$/Acre) (Herbicides / Insecticide)	24	97	0.08	29
Biotech Cost (US$/Acre) (Seed and technology fee /acre)	5	46	10	34
Other Input Costs (Roundup application)	13			
Net gain (US$/Acre)	6 (22% of herbicide cost)	51	3 to 16	51

a. source: Buranakanonda, 1999, Biotechnology global update, 01 January 1999) and James (1998)
b. source: Flanders et al. (1999)
c. source: Source: Giannessi (1999)
d. source: Marra (1999), corresponding figures for Alabama give 10% increase in yields.
e. Source: Optimum Quality Grains, L.L.C., personal communication (2000).

Bt-corn has often resulted in an increase in yields per hectare (usually in the order of 5-10%), with exceptional cases of 45% increases in Kansas field trials (Higgins et al. 1999). The reduction in insecticide application is, on average, very low, given the fact that many farms did not control for pests with traditional varieties. Bt-cotton has guaranteed higher yields (4-15%), due to better insect control and often a remarkable reduction of the costs associated with insecticide application, with positive externalities on the environment, given the reduced amount of toxic substances released (70% reduced insecticide application).[8] There is no guarantee that, in future trials, similar outcomes may occur, but the results provide a perspective in the relative magnitudes. In the next sections we will see how these estimates compare with our simulation results for China.

Overview of Modeling Approach

In order to gain a better understanding of the self-sufficiency issue, we use a recursive dynamic computable general equilibrium (CGE) model of the world economy to project a baseline growth scenario to 2005.[9] We then implement various policy measures and compare the resulting equilibria to this baseline.

CGE models allow us to compare the effects of alternative scenarios within a single consistent framework, and also allow the feedback and flow-through effects of substantial policy changes to be consistently analyzed. As such they have become an important tool in trade policy analysis. The model used in this paper is based on the GTAP4 database (MacDougall et al, 1998) and utilizes an intra-period model developed from Rutherford (1998), of a well-established neo-classical form (the perfectly competitive Armington trade model with CES production and LES preferences). The inter-period linkage equations are similar to those found in Coyle and Wang (1998), and involve the standard capital accumulation function (subject to neo-classical steady-state properties), productivity growth in the form of Hicks-neutral technical change, and estimates of the growth

8 Potential negative environmental or food safety risks from GMOs should be acknowledged but, to date, minimal effects have been substantiated.

pattern of the various labor categories (skilled, unskilled and agricultural). These linkages differ somewhat from other models in this category in that the growth pattern reacts to changes in the economy in certain ways (for example, the rate of rural-urban migration is assumed to respond to changes in the rural-urban wage differential). A complete technical description of the model and the assumed growth path is contained in the appendix.

As part of the baseline scenario we include the implementation of the Uruguay Round (UR) agreement (without Chinese accession to the WTO). In our alternative scenarios we consider Chinese accession to the WTO, assuming commitments of a similar level to those required of developing economies under the UR. We examine the effect of self-sufficiency policies by endogenizing the wheat and grain tariff/domestic support levels, subject to a self-sufficiency constraint of 95 percent. Finally, we consider the productivity improvements that would be required to achieve self-sufficiency in the absence of other policy interventions.[10]

Results and Policy Implications

Table 3 presents the results of our simulations in terms of self-sufficiency ratios. The first column reports the degree of self-sufficiency in the year 1995, the second column presents the self-sufficiency ratio predicted for China by our model under the baseline for 2005, the third displays the 2005 results obtained under the WTO accession scenario. Columns 4 and 5 present the 2005 projections obtained when self-sufficiency is enforced by means of tariffs and domestic support measures, while columns 6 and 7 illustrate the effect of productivity growth for wheat and "other grains", under the WTO accession assumption.

A number of clear results emerge. First, in line with the other studies outlined in Section 2, there is a clear and substantial reduction in grain self-sufficiency levels between 1995 and 2005

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9 Our assumptions are presented in the Appendix Table 3. The baseline productivity growth should not be confused with the additional productivity growth required to attain self-sufficiency.

10 Owing to the particular construction of our model, we consider the productivity growth of wheat and "other cereals" as two separate cases. Combined with baseline 2005 and WTO hypotheses, this yields 4 combinations.

projected under the baseline. Starting from a level of almost 83 percent in 1995, the degree of wheat self-sufficiency is projected to decrease to 54 percent. The corresponding estimates for other grains are 91 and 70 percent. Rice is the only agricultural market where self-sufficiency levels are expected to be maintained (as in Yang and Huang, 1997). Interestingly, Chinese accession to the WTO does not appear to have major implications for self-sufficiency ratios. In fact, self-sufficiency for "other grains" is higher under the WTO accession scenario than the 2005 baseline scenario. This reflects an interesting feature of Chinese grain policy as embodied in the GTAP4 database, which records small export subsidies in the other grains category. The disciplines imposed on export subsidies by the Uruguay Round Agreement on Agriculture imply an improvement in self-sufficiency levels.

Table 3. Estimated Self-Sufficiency Ratios for China

Sector	1995 (1)	2005 Baseline (2)	2005 WTO (3)	Tariffs (4)	Domestic Support (5)	WTO & Technology Wheat (6)	WTO & Technology Other grains (7)
Paddy rice	100.0	100.0	100.0	100.0	100.0	100.0	100.2
Wheat	82.9	54.1	53.8	95.0	95.0	95.0	53.0
Other Grains	90.9	69.7	75.2	95.0	95.0	73.3	95.0
Vegetables and fruits	99.9	93.4	93.0	92.5	91.6	92.5	92.7
Non-grain crops	91.5	66.8	63.6	63.6	60.5	61.9	62.7
Other livestock products	99.6	88.3	88.1	86.3	85.8	87.7	87.9
Forestry	97.0	70.6	68.9	69.0	66.3	67.8	68.3
Fisheries	92.8	51.6	49.5	50.1	48.7	49.0	49.2
Processed rice	97.5	96.6	98.0	96.3	96.1	97.9	97.9
Meat products	94.4	69.7	70.6	67.3	66.7	70.2	70.4
Dairy products	85.5	78.4	88.2	76.9	76.9	88.0	88.0
Other food products	95.5	78.0	81.5	75.2	80.8	84.7	83.1

Now consider the effect of utilizing tariffs and domestic support interventions to increase self-sufficiency levels (Table 3, columns 4 and 5). Clearly, by construction we achieve the desired (95 percent) self-sufficiency ratio in both wheat and other grains. Note that either policy will also draw resources from other sectors (fisheries, meat, dairy and other food products), worsening the self-sufficiency levels in those sectors. The actual interventions required are substantial. According to our simulation results (not displayed in Table 3), the required import tariffs would be 58 percent for wheat and 70 percent for other grains. Alternatively, production subsidies of 81 percent for wheat and 49 percent for other grains could be used. These estimates are considerably higher than Yang and Huang (1997), and reflect the expanded import ratios under the baseline projection (Yang and Huang is a static simulation at 1993).

Table 4 presents a summary of the value of net grain exports under our policy scenarios.[11] The results indicate that our simulated effect of accession to WTO does not cause a major departure of estimates for net grain exports from the corresponding values for the 2005 baseline (in fact, the value of net imports falls slightly). As it has been observed, this is primarily due to the discipline imposed on export subsidies. Columns 3 and 4 show that the imposition of higher tariffs and the adoption of domestic support would dramatically reduce the net imports of grain, from $15.64 billion (under the 2005 baseline assumption) to $2.43 billion and $1.71 billion respectively. Out of the 15 regions that we consider in our model, Canada, Europe and the United States appear to be the most affected by tariffs and domestic support. In particular, US net exports of grain would decrease from $39 billion (baseline 2005) to $32.9 and $32.8 billion respectively.

Table 4
Net grain export of grains (paddy rice, wheat, other grains) by geographical area (US$ billion)

	Baseline 2005 (1)	**WTO Accession (2)**	**Domestic Support (3)**	**Tariffs (4)**	**WTO and Technology (Wheat) (5)**	**WTO and Technology (Other grains) (6)**
Australia	1.7	1.73	1.45	1.48	1.53	1.67
Canada	*9.43*	*9.73*	*7.01*	*6.94*	*7.43*	*9.6*
China	**-15.64**	**-14.79**	**-2.43**	**-1.71**	**-6.82**	**-10.87**
Europe	*7.14*	*6.56*	*4.06*	*3.91*	*4.83*	*6.1*
Indonesia	-1.26	-1.26	-1.28	-1.26	-1.26	-1.27
Japan	-7.26	-7.44	-7.21	-7.19	-7.38	-7.4
Korea	-4.68	-4.71	-4.66	-4.67	-4.69	-4.7
Malaysia	-1.05	-1.06	-1.04	-1.05	-1.04	-1.05
Mexico	-0.88	-0.88	-0.9	-0.91	-0.9	-0.88
New Zealand	-0.03	-0.02	-0.03	-0.03	-0.03	-0.03
Other APEC	-2.52	-3.96	-2.52	-2.53	-3.86	-4.55
Philippines	-0.59	-0.59	-0.58	-0.59	-0.59	-0.59
Rest of World	-26.68	-26.39	-27.42	-27.42	-26.8	-26.6
Thailand	-0.19	-0.18	-0.2	-0.2	-0.18	-0.18
USA	*39.08*	*38.96*	*32.92*	*32.85*	*35.82*	*36.26*

[11] Technological shifts for wheat and other grains are considered separately under the baseline and WTO accession assumptions (4 cases).

The basic welfare effects under the different policy scenarios are presented in Table 5. First note the substantial gains associated with accession to the WTO for China, over $33 billion. Results of similar magnitude have been obtained by Wang (1997). Given that WTO accession is unlikely to be compatible with tariffs or domestic support measures of the magnitude estimated above, the loss of these positive welfare effects should be included in the cost of intervention, leading to total losses of between $35 (tariffs) and $36 billion (domestic support). Hence we can conclude that policy intervention to achieve the desired self-sufficiency levels, while feasible, is likely to be extremely costly.

Table 5
Welfare Effects: Equivalent Variation as a Deviation from Baseline 2005 (US$ billions)

Region	China WTO (1)	Domestic Support (2)	Tariffs (3)	WTO and Technology (Wheat) (4)	WTO and Technology (Other grains) (5)
Australia	0.1	-0.06	-0.14	-0.06	0.02
Canada	*0.24*	*-0.11*	*-0.14*	*0.12*	*0.20*
China	**33.17**	**-2.60**	**-1.68**	**45.07**	**38.48**
Europe	4.84	1.55	2.03	5.80	5.24
Indonesia	-0.04	0.09	0.06	-0.02	-0.03
Japan	2.18	0.06	0.39	2.58	2.39
Malaysia	0.19	0.02	0.1	1.40	1.36
Mexico	-0.15	-0.01	-0.02	-0.17	-0.15
New Zealand	-0.04	-0.01	-0.04	0.19	0.17
Other APEC	0.63	0.08	0.2	-0.08	-0.06
Philippines	-0.49	0.04	0.02	0.70	0.42
ROW	0.47	0.49	0.61	-0.48	-0.49
South Korea	1.28	0.13	0.24	1.13	1.04
Thailand	2.11	-0.08	0.02	2.00	2.06
USA	*1.2*	*-0.39*	*-0.78*	*0.62*	*0.53*
World	**45.690**	**-0.800**	**0.870**	**58.80**	**51.18**

Although the benefits of WTO accession and the cost of trade protectionism are mainly reaped by China, they also accrue to other countries such as the United States and Canada, two major grain exporters. Other regional economies such as Japan, Thailand, South Korea would also benefit from China's trade liberalization and accession to WTO, due to their close geographical position and economic interdependence with China.

We have seen that by raising tariffs and using domestic support measures, China could attain self-sufficiency but it would pay a high price in terms of welfare losses. Alternatively, the same objective could be met with an increase in productivity (through a technological shift). This technological improvement does not necessarily have to stem from the diffusion of GM crops but here we consider this particular hypothesis. The question then is: does such a productivity enhancement seem feasible?

We have run a simulation by imposing self-sufficiency either in wheat or "other grains" into our model, in order to estimate the required productivity improvements. Assuming for simplicity a Hicks-neutral change (which might be regarded as the best-case hypothesis), under the 2005 baseline scenario, the required productivity increase to meet a 95% self-sufficiency goal would be 86 percent for wheat and 54 percent for other grains. However, in the case of WTO accession, the estimates are 84 percent for wheat and 26 percent for other grains, again reflecting the presence of export subsidies in the base year database.

Obviously, these are substantial productivity improvements. As noted in previous sections, China has achieved extraordinary agricultural productivity increases in the past. However, these were achieved by a fundamental shift to a market-based system. While there are certainly likely to be productivity gains associated with further reform, the gains achieved during the initial reform period are unlikely to be repeated.[12] What about the potential of biotechnology? The required productivity shifts computed in our simulations far exceed the results provided by field trials and survey results.[13] We do not possess clear data on the productivity gains on new genetically modified varieties of wheat, simply because they are currently under experimentation and private firms are reluctant to release such information. Nonetheless, possible optimal biological yield improvements in the region of 10-30 percent have been claimed (Jackson, 1999; Hoisington et al.,

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[12] Our baseline projections for 2005 are based on assumptions of productivity growth. Technological shifts to attain self-sufficiency are thus considered as further improvements.

[13] By definition, we do not know for certain the potential of GMOs for future technology improvements. Here we use historical values as a reference.

1999). Even if such values were confirmed, the gain in productivity called for by self-sufficiency in wheat would still be almost three times higher.

Regarding other grains, aggregation in our model implies a category comprising diverse cereals, for some of which no genetically modified varieties have been tested. At a first glance, the required productivity gain of 26 percent, under the WTO accession scenario may seem more realistic, given the fact that yield gains higher than 15 percent have been observed for Bt-corn. Nevertheless we need to be cautious: very high yields have been reported only under experimental conditions, while increases in the order of 5-10 percent are normally observable in actual commercial cultivation. It also has to be assumed that in China a 10-20 percent "refuge practice" will be adopted: a proportion (refuge) of the fields will have to be planted with non-Bt corn in order to retard the development of parasite resistance to *Bacillus Thuringiensis* toxins, that would thwart the adoption of the technology. It is also important to consider that yield increases are often calculated as averages of cross-sectional data and it is often impossible to control for different input combinations and other relevant variables such as the soil types. Nonetheless, our results suggest that the required technological shift in other grains is also unlikely to be attainable through GM crops only, by 2005.[14]

Alternatively, the Chinese Government could consider the less ambitious goal of preserving the 1995 level of self-sufficiency for wheat (82.9%) and other grains (90.9%) respectively. According to our simulations, under the baseline scenario, the required productivity growth would be 44% for wheat and 41% for other grains, while, for WTO accession, the corresponding values are 44% for wheat and 19% for other grains. With particular reference to other grains, the required technological shifts, although still high, are now closer to observed values.

[14] Accordingly, columns 5 to 8 in Table 4 and columns 4 to7 in Table 5 have been presented for reference only.

Conclusion

Following the economic reforms, China's agricultural growth over the last twenty years has been remarkable. Nevertheless, it is unlikely that China will be able to produce enough grains to completely satisfy national demand by 2005.

To assess the effects of self-sufficiency, we analyze three possible options: border measures, domestic support and agricultural productivity improvement (through transgenic varieties). As predicted by economic theory, the first two policy options are likely to inflict heavy welfare costs on China and are at odds with the WTO accession bid. By contrast, the productivity increase would enhance China's welfare gains and be perfectly compatible with the goal of WTO accession.

Even if various hypotheses of productivity growth can be considered, in this paper we restrict to the one generated by the diffusion of GMOs in agriculture. By applying a self-sufficiency constraint to our model on two categories of commodities (wheat and other grains) we simulate the required productivity growth. We then contrast our findings with the empirical values observed (or extrapolated) in field trials and commercial cultivation in the United States and China. The latter have been obtained as averages from several survey areas, thus it is difficult to control for differences in input composition. Accordingly, we treat them as general benchmarks.

We model productivity growth as a Hicks-neutral technical change. Since this implies an equal marginal productivity increase for all the factors, this could be considered as an optimistic assumption. The results of our simulation show that, in order to meet the self-sufficiency requirement, the productivity increase should be considerably higher than our reference benchmarks. However, when we assume the less ambitious objective of maintaining the 1995 self-sufficiency level for wheat and other grains, the projected values become closer to the ones claimed or observed in field trials and farm surveys.

Between the end of the 1970s and the mid 1990s, substantial increases in the total productivity of factors have been registered. However, such improvements were mainly the outcome of the agricultural reforms and thus are unlikely to materialize again. Our findings suggest that genetically modified crops should not be regarded as a panacea for the self-sufficiency problem in China. However, they present interesting opportunities for Chinese agriculture. Chinese growers may benefit from higher biological or economical yields, higher prices for enhanced quality of products, reduced exposure to climatic hazards, and less expensive input mix. Since GMOs can reduce the application of herbicides and insecticides, their impact on environment protection and health should not be neglected.

Of course, productivity growth can not be reduced to the mere diffusion of GM crops. We do not exclude a-priori that significant technological improvements may lead to self-sufficiency, particularly for "other grains", perhaps beyond 2005. However, our simulations suggest that the adoption of GMOs alone is unlikely to guarantee this productivity growth.

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Appendix Table 1: Structure of the Model

Production

$$Y_{ir} = \psi_{ir} (\sum_f \delta_{fir} FD_{fir}^{-\rho_i^{DM}})^{-1/\rho_i^{DM}} \quad (1)$$

$$FD_{fir} = Y_{ir} a_{fir}^F (p_r^F) \quad (2)$$

$$ID_{ir} = \sum_j Y_{jr} a_{ijr} \quad (3)$$

$$ID_{ir} = (\alpha_{ir}^I DI_{ir}^{\rho_i^{DM}} + \beta_{ir}^I MI_{ir}^{\rho_i^{DM}})^{1/\rho_i^{DM}} \quad (4)$$

Demand

$$G_r = \Gamma_r \prod_i GD_{ir}^{\theta_{ir}^G} \quad (5)$$

$$GD_{ir} = (\alpha_{ir}^G DG_{ir}^{\rho_i^{DM}} + \beta_{ir}^G MG_{ir}^{\rho_i^{DM}})^{1/\rho_i^{DM}} \quad (6)$$

$$GD_{ir} = \overline{G}_{ir} a_{ir}^G (p_{ir}^Y, p_{ir}^M, t_{ir}^G) \quad (7)$$

$$U_r = \sum_i \theta_{ir}^C \ln(CD_{ir} - \vartheta_{ir}) \quad (8)$$

$$CD_{ir} = (\alpha_{ir}^C DC_{ir}^{\rho_i^{DM}} + \beta_{ir}^C MC_{ir}^{\rho_i^{DM}})^{1/\rho_i^{DM}} \quad (9)$$

$$CD_{ir} = \vartheta_{ir} + \theta_{ir}^C \{M_r - \sum_j p_{jr}^Y (1+t_{jr}^C) \vartheta_{jr}\} \big/ p_{ir}^Y (1+t_{ir}^C) \quad (10)$$

$$\begin{aligned} M_r = {} & \sum_f p_{fr}^F F_{fr} + \sum_i t_{ir}^Y p_{ir}^Y Y_{ir} \\ & + \sum_{i,j} t_{ijr}^{ID} p_{ir}^{ID} Y_{jr} a_{ijr} \\ & + \sum_i t_{ir}^G p_{ir}^{GD} GD_{ir} + \sum_i t_{ir}^C p_{ir}^{CD} CD_{ir} \\ & + \sum_{i,s} t_{irs}^X p_{ir}^Y M_{irs} + \sum_{i,s} t_{irs}^M \{p_{ir}^Y M_{isr} (1+t_{isr}^X)\} \\ & - \sum_i p_{ir}^Y I_{ir} - \sum_i p_{ir}^G (1+t_{ir}^G) GD_{ir} - p_n^C B_r \end{aligned} \quad (11)$$

Bilateral Trade

$$MI_{ir} + MG_{ir} + MC_{ir} = (\sum_s \alpha_{isr}^M M_{isr}^{\rho_i^{MM}})^{1/\rho_i^{MM}} \quad (12)$$

$$T_{irs} = \tau_{irs} M_{irs} \quad (13)$$

$$\sum_{irs} T_{irs} = \psi_T \prod_{i,r} TD_{ir}^{\theta_{ir}^T} \quad (14)$$

$$M_{irs} = M_{is} a_{irs}^M (p_{ir'}^X, t_{ir's}^X, p^T, t_{ir's}^M) \quad (15)$$

Market Clearance

$$F_{fr} = \sum_i Y_{ir} a_{fir}^F \quad (16)$$

$$M_{ir} = ID_{ir} a_{ir}^{M,I} + GD_{ir} a_{ir}^{M,G} + CD_{ir} a_{ir}^{M,C} \quad (17)$$

$$Y_{ir} = ID_{ir} a_{ir}^{D,I} + GD_{ir} a_{ir}^{D,G} + CD_{ir} a_{ir}^{D,C} + I_{ir} + \sum_s M_{is} a_{irs}^M + Ta_{ir}^T \quad (18)$$

Appendix Table 1: Structure of the Model (continued)

Zero Profit

$$p_{ir}^{Y} = \sum_f a_{fir}^{F} p_{fr}^{F} + \sum_j a_{jir} p_{jr}^{ID}(1+t_{jir}^{ID}) \quad (19)$$

$$p_{ir}^{M} = \sum_s a_{irs}^{M}\{p_{is}^{X}(1+t_{isr}^{X}) + t_{irs} p^{T}\}(1+t_{isr}^{M}) \quad (20)$$

$$p_{ir}^{I} = \{(a_{ir}^{I})^{s_i^{DM}}(p_{ir}^{D})^{1-s_i^{DM}} + (b_{ir}^{I})^{s_i^{DM}}(p_{ir}^{M})^{1-s_i^{DM}}\}^{1/(1-s_i^{DM})} \quad (21)$$

$$p_{ir}^{G} = \{(a_{ir}^{G})^{s_i^{DM}}(p_{ir}^{D})^{1-s_i^{DM}} + (b_{ir}^{G})^{s_i^{DM}}(p_{ir}^{M})^{1-s_i^{DM}}\}^{1/(1-s_i^{DM})} \quad (22)$$

$$p_{ir}^{C} = \{(a_{ir}^{C})^{s_i^{DM}}(p_{ir}^{D})^{1-s_i^{DM}} + (b_{ir}^{C})^{s_i^{DM}}(p_{ir}^{M})^{1-s_i^{DM}}\}^{1/(1-s_i^{DM})} \quad (23)$$

Inter-period Linkages

$$K_r^{t+1} = (1-d_r)K_r^{t} + I_r^{t} \quad (24)$$

$$a_r = e^{l_r^t t} \quad (25)$$

$$l_r^{t} = l^{*} + (l_r^{0} - l^{*})^{f_r^T} \Big/ (GDP_r^t / POP_r^t)^{f_r^T} \quad (26)$$

$$S_r^{t+1} = S_r^{t}(1+\Delta_r^{t})(1+\Lambda_r^{t}) \quad (27)$$

$$A_r^{t+1} = A_r^{t}(1+\Delta_r^{t})(1+\Omega_r^{t}) \quad (28)$$

$$L_r^{t+1} = (1+\Delta_r^{t})(L_r^{t} + (p_{Lr}^{F0}/p_{Ar}^{F0})A_r^t\Omega_r^t - (p_{Lr}^{F0}/p_{Sr}^{F0})S_r^t\Lambda_r^t) \quad (29)$$

$$\Delta_r^{t} = \Delta^{*} + (\Delta_r^{0} - \Delta^{*})^{f_r^T} \Big/ (GDP_r^t / POP_r^t)^{f_r^T} \quad (30)$$

$$\Lambda_r^{t} = \Lambda_r^{0}\{1-(p_{Lr}^{Ft}/p_{Sr}^{Ft})\}^{y_{SL}} \Big/ \{1-(p_{Lr}^{F0}/p_{Sr}^{F0})\}^{y_{SL}} \quad (31)$$

$$\Omega_r^{t} = \Omega_r^{0}\{1-(p_{Lr}^{Ft}/p_{Ar}^{Ft})\}^{y_{AL}} \Big/ \{1-(p_{Lr}^{F0}/p_{Ar}^{F0})\}^{y_{AL}} \quad (32)$$

Notes:
Following Rutherford (1998), we have represented unit demand functions (a) in reduced form.
Key differences between the static model (1)-(23) and Rutherford (1998) are as follows:

a) The CET function across domestic/export production has been dropped (exports and domestic production are perfect substitutes).
b) The Armington elasticities at both the source-source and import-domestic level have been allowed to vary by sector.
c) The Cobb-Douglas value-added functions have been replaced by CES functions.
d) The Cobb-Douglas household utility function has been replaced by a Stone-Geary (LES) function.
e) The closure rule assumes a fixed marginal propensity to save, rather than a fixed level of investment.

Appendix Table 2a: Variable Definitions

Indexes

i,j:	Sectors	*r,s*:	Regions	*f*:	Endowments	*t*:	Periods

Variables

Y_{ir}	Output
FD_{fir}	Factor demand
M_{irs}	Exports at market prices
T_{irs}	Transportation services
TD_{ir}	Value of international transport sales
DG_{ir}	Government consumption of domestic goods
MG_{ir}	Government consumption of imported goods
DC_{ir}	Household consumption of domestic goods
MC_{ir}	Household consumption of imported goods
DI_{ir}	Intermediate consumption of domestic goods
MI_{ir}	Intermediate consumption of imported goods
CD_{ir}	Public expenditures
GD_{ir}	Private expenditures
ID_{ir}	Aggregate intermediate demand
U_r	Social welfare
M_r	Regional income
p_r^F	Factor prices
p_{ir}^Y	Domestic output prices
p_{ir}^M	Import prices
p_{ir}^{ID}	Intermediate prices
p_{ir}^{GD}	Government prices
p_{ir}^{CD}	Household prices
P_n^C *	Consumer price index in numeriare region
F_{fr} *	Factor endowments $\{K_r, S_r, A_r, L_r\} \subset F_{fr}$
I_{ir} *	Investment
$\overline{G}_{ir}$ *	Government expenditure
B_r *	Current account balance

Appendix Table 2b: Parameter Definitions

Taxes	
t_{ir}^{Y}	Indirect taxes (subsidies)
t_{jir}^{ID}	Intermediate input taxes (subsidies)
t_{isr}^{X}	Export taxes (subsidies)
t_{isr}^{M}	Import taxes (subsidies)
t_{ir}^{G}	Government consumption taxes (subsidies)
t_{ir}^{C}	Household consumption taxes (subsidies)
Calibrated Parameters	
y_{ir}	Shift parameter in CES production functions
d_{fir}^{Y}	Share parameters in CES production functions
$r_i^Y = 1/s_i^Y - 1$	Substitution parameters in CES production functions
$a_{ir}^{(IGC)}$ and b_{ir}^{IGC}	Share parameters in CES Armington functions (domestic-import)
$r_i^{DM} = 1/s_i^{DM} - 1$	Substitution parameters in Armington functions (domestic-import)
a_{isr}^{M}	Share parameters in Armington functions (source-source)
$r_i^{MM} = 1/s_i^{MM} - 1$	Substitution parameters in Armington functions (source-source)
y_T	Shift parameter in Cobb-Douglas transportation margin function
q_{ir}^{T}	Share parameters in Cobb-Douglas transportation margin function
q_{ir}^{C}	Share parameters in Stone-Geary utility function
g_{ir}	Subsistence parameter in Stone-Geary utility function
Γ_r	Shift parameter on Government demand function
q_{ir}^{G}	Share parameter on Government demand function
Recursive Dynamics	
d_r	Depreciation rate
$l_r^t\,(l^*)$	Productivity growth rate (target)
f_r^T	Productivity convergence parameter
$\Delta_r^t\,(\Delta^*)$	Labor growth rate (target)
$\Lambda_r\,(\Omega_i)$	Cumulative skilled (agricultural) labor growth rate
POP_r	Total population
f_r^L	Labor growth convergence parameter
y_{SL} and y_{AL}	Inter-period labor mobility parameters

Appendix Table 3: Assumptions Used in the Projections, Annual Percentage Growth Rates

Region	Labor[1]	Rural Labor[2]	Skilled Labor[3]	Capital[4]	TFP[5]
Australia	0.80	-0.68	6.65	3.00	0.30
Canada	0.60	-4.54	4.67	4.80	0.30
China	0.90	-0.39	2.58	10.70	1.60
Europe	0.00	-3.35	9.30	5.10	0.30
Indonesia	2.10	-0.26	7.64	7.10	1.60
Japan	-0.03	-4.20	4.73	5.90	0.30
Malaysia	2.80	-3.77	7.30	9.20	0.70
Mexico	2.30	-1.88	2.93	1.40	0.90
New Zealand	0.40	0.57	7.07	2.40	0.30
Other APEC	1.00	-2.14	4.95	7.90	1.60
Philippines	2.50	-1.23	3.22	2.20	0.50
ROW	1.70	-0.50	4.92	3.50	1.00
South Korea	1.20	-6.05	4.94	7.80	1.60
Thailand	0.90	-0.43	6.34	6.60	1.60
USA	0.70	-2.00	4.57	3.20	0.30

Notes:

1 World Bank (1999) projections 1997-2010.

2 Cumulative rates of growth, based on trend in preceding ten-year period (five years in China). Figures from FAOSTAT, except Taiwan from Taiwan Agricultural Yearbooks.

3 Cumulative rates of growth, based on projections of Ahuja and Filmer (1995) and trends from UNESCO(1997).

4 Growth rate based on projections in Anderson et al (1997a) and historical trend in preceding 10 year period (Penn World Tables). Depreciation rates on capital selected to calibrate to this rate in base year, thereafter growth rates endogenous.

5 Implemented as a Hicks-neutral change across all inputs. Figures based on estimates from Chen (1977), Young (1994), Drysdale and Huang (1997) and World Bank (1997a).