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Trade policy, biotechnology and grain self-sufficiency in China

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Abstract

Over the past 20 years the growth of China's agricultural economy has been extraordinary. However, it seems unlikely that China will maintain self-sufficiency in grains by 2005 without substantial intervention. We develop a CGE model to assess the options available to Chinese policy makers. We compare the welfare effects of import tariffs and domestic support, and explore the potential of biotechnology as a means to achieve self-sufficiency through improvements in agricultural productivity. Our results indicate that the price interventions that would be required to maintain China's desired self-sufficiency ratios are considerable, and are unlikely to be compatible with WTO accession. The productivity improvements required are also significant, and likely beyond the current potential of biotechnology.

JEL classification: C68; F13; O53; Q17

Keywords: Biotechnology; Chinese agriculture; CGE

1. Introduction

Since the announcement of China's *duiwai kaifang zhengce*, or 'open door' policy in 1978, the growth in China's overall and agricultural economies has been extraordinary. Between 1979 and 1984, GDP grew by an average of 8.5% per year, accelerating to 9.7% per year between 1985 and 1995 (a significant increase over 1970's levels, which averaged 4.9%). The value of agricultural output grew by an annual average of 7.5% from 1979 to 1984, and 5.6% between 1985 and 1995, compared to only 2.3% between 1970 and 1978 (Huang et al., 1999a). However, despite unprecedented growth over the last two decades, concern has been raised over the capacity of China to feed its population in the future. Brown (1995) published the most pessimistic predictions, evoking the spectres of soaring world grain prices and starvation in poor countries.

While the magnitudes of Brown's estimates have been seriously questioned (Fan and Agcaoili-Sombilla, 1997; Yang and Huang, 1997), the emergence of a substantial grain deficit in China is now considered likely. China's grain markets are projected to experience a sustained increase in demand driven by population growth, rapid urbanisation, rising income levels and the expansion of the livestock sector as a consequence of burgeoning meat consumption.

In the absence of intervention, the expected increase in demand for grains is unlikely to be matched by compensating shifts in supply. There are a number of factors which may limit supply response in China. Most important are land scarcity, the transition of land,

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Nomenclature

a	technological shift parameter
A	agricultural unskilled labour
GDP/POP	real GDP per capita
I	investment
K	capital stock
L	industrial unskilled labour
pf	factor return
r	regions
S	skilled labour
t	time period
Greek letters	
δ	depreciation rate on capital
Δ (Δ^*)	aggregate labour growth rate (target)
ϕ	convergence parameter for (T)echnology, (L)abour
λ (λ^*)	factor productivity growth rate (target)
Λ	marginal growth rate for skilled/agricultural labour
ψ	convergence parameter (labour movement)

labour and capital to non-agricultural uses, a slowdown in yield growth, and environmental degradation (erosion, salinisation). With roughly 10% of the world's arable land but 22% of the world's population, China's comparative advantage is likely to shift from land-intensive commodities to labour-intensive products.

Despite what economists have seen as an inevitable decline in agricultural comparative advantage, the Chinese government has set food self-sufficiency as a declared goal in its long-term plan. Although the objective has not been clearly defined in terms of a commodity category, it has been widely interpreted as meaning that domestic production of grains should meet at least 95% of domestic demand (Yang and Huang, 1997; Anderson and Peng, 1998).

Given the projections of substantial grain deficits, how can we evaluate the potential for meeting the objective of grain self-sufficiency? Clearly, declining self-sufficiency ratios are by no means inevitable, they are under government control. There are (at least) three possibilities for maintaining a given self-sufficiency level: border measures (tariffs), domestic support or improvements in productivity. The first two distort the prices faced by agents in the economy, altering the incentives to produce and/or import. Any given target ratio of grain imports can clearly be achieved, but at the price of introducing allocative inefficiency to the economy. Moreover, such policies may be in conflict with China's accession to the World Trade Organisation (WTO), approved late in 2001. The research question is effectively one of identifying the economic cost for China and the world economy of achieving self-sufficiency through these means.

The third possibility, productivity improvements, may arise from a variety of sources. A source of particular interest is through the use of biotechnology. The adoption of genetically modified (GM) crops offers the potential for improved efficiency, increased yields, and reduced production costs. The key question for China is whether or not, given what we know about potential yield increases with the adoption of GM crops and what we project about future grain deficits, it is feasible that self-sufficiency could be attained through the use of biotechnology.

To assess these questions we utilise a multi-region computable general equilibrium (CGE) model, which we project to 2005 and use to simulate various policy responses to the anticipated trade pattern. Our simulation procedure accounts for accession by China to the Uruguay Round Agreement on Agriculture (URAA). The remainder of the paper is organised as follows. In Section 2, we review grain supply and demand projections for China and the implications of possible policy responses. In Section 3, we look at the evidence on biotechnology as a source of productivity growth. Section 4 contains a description of the modelling framework utilised in the paper, while Section 5 presents the results of our simulations and policy discussion. Finally, Section 6 contains a summary and concluding comments.

2. China's grain deficit and self-sufficiency objectives

The agricultural reforms implemented in China from the end of the 1970s were designed to foster the transition from a command economy to an

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

Year	Mitchell and Ingco (1993)	Brown (1995)	OECF (1995)	Rosegrant et al. (1995)	ERS/USDA (1996)	Huang et al. (1999a)	Huang et al. (1999b)
2000	11 (3.1)	63 (17.7)	18 (5.1)	18 (5.1)	25 (7.0)	24 (6.8)	–
2005	14 (3.9)	108 (30.4)	52 (14.6)	16 (4.5)	32 (9.0)	25 (7.0)	20 (5.8)
2010	22 (6.2)	155 (43.7)	104 (29.3)	15 (4.2)	39 (11.0)	27 (7.6)	20 (5.8)

Note: Figures in brackets represent the deficit as a percentage of 1995 grain domestic production.

incentive-based system: individual rewards tied to output (the household responsibility system), specialisation of agriculture, an 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 restrictions on labour mobility out of agriculture.

The reforms resulted in a dramatic increase in total grain production (65% between 1978 and 1996). Agricultural productivity also increased sharply. Huang et al. (1999b) estimate a 54% increase in total factor productivity for rice, 121% for wheat, 71% for soybeans and 85% for maize, between 1979 and 1995. China even became an occasional net exporter of grains. However, by the second half of the 1980s, it had become evident that the growth in grain supply was not keeping pace with the increasing demand that followed the enormous growth of the Chinese economy and the expansion of industrial sectors.

Since the beginning of the 1990s, domestic grain prices in China have reached levels comparable to international prices. Brown (1995) predicted that, if present trends persist, in 2030 China would need to import 370 million metric tons (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 of historical data, is now widely recognised (Fan and Agcaoili-Sombilla, 1997; Yang and Huang, 1997; Anderson and Peng, 1998).

Several other attempts have been made to forecast the future international grain trade with China, utilising both partial equilibrium (Mitchell and Ingco, 1993; OECF, 1995; Rosegrant et al., 1995; ERS/USDA, 1996; Huang et al., 1999a,b) and general equilibrium approaches (Yang and Huang, 1997). Forecasts that allow quantity projections are summarised in Table 1, which is an extension of a summary table constructed by Fan and Agcaoili-Sombilla (1997). The studies all forecast grain deficits up to 2005, although Huang et al. (1999b) argue that the deficits will slowly decline thereafter, as population growth slows.[1] Nevertheless, the capacity of China to fulfil its grain requirement with its own production remains an important item on the agenda of policy makers. In addition to national pride and food security issues, motivations for this objective include protecting China from fluctuations in grain prices in world markets, avoiding a shortage of foreign currency, protecting farm incomes to counterbalance the raising inequality between rural and urban households and preventing the social unrest that might result from increased dependence on foreign staple commodities and increased income inequality.

From the perspective of the theory of commercial policy, the goal of self-sufficiency is termed a 'non-economic' objective. The analysis of non-economic objectives was pioneered by Bhagwati and Srinivasen (1969), but the case of a self-sufficiency objective was analysed even earlier by Johnson (1960). Here, we reconsider three possible approaches to achieving self-sufficiency: border protection, domestic support, and productivity improvements.

An import tariff on grain would have the effect of raising the domestic grain price relative to the world price, thereby constraining domestic consumption and encouraging domestic production. As is well known, such an approach introduces an allocative efficiency

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[1] The variations among these studies in terms of the projections of grain supply can be explained in terms of the underlying model assumptions. Fan and Agcaoili-Sombilla (1997) discuss these issues in detail.

(dead weight) loss to the economy, by forcing resources that would produce higher value elsewhere into grain production, and by eliminating grain consumption where the marginal social benefit of consumption exceeds the marginal social cost (the world price) but not the marginal private cost (the domestic price). It is therefore socially inefficient.

In effect, an import tariff is equivalent to a production subsidy combined with a consumption tax, with both applied at the same percentage rate. Either of these two policies could be used independently to achieve a self-sufficiency objective, although production subsidies are likely to be more palatable. A production subsidy achieves self-sufficiency exclusively by expanding grain production, and a consumption tax exclusively by curtailing domestic grain consumption. Clearly, either policy will introduce an allocative efficiency loss. Moreover, for a given import volume target, and assuming substitution in production and consumption, both a production subsidy and a consumption tax will be inefficient mechanisms to achieve self-sufficiency relative to a tariff because a tariff can simultaneously exploit both methods of constraining imports, which is the objective.

The use of both import tariffs and output subsidies on agriculture is constrained by WTO rules. Since it has now acceded to the WTO, China will be constrained in its ability to raise tariffs above bound levels. Moreover, it may face action over domestic support that can be shown to adversely affect trading partners, although there is considerably more latitude here than in the case of tariffs. It is also likely that pressure will continue to build in upcoming multilateral negotiations for agricultural trade liberalisation beyond that committed under the URAA. Hence, in addition to efficiency considerations, China may face political constraints on the use of the price mechanism to achieve its goals.

Another way of achieving a grain self-sufficiency objective is to improve Chinese agricultural productivity. As discussed above, the growth in China's agricultural productivity over the period of reform has been substantial, although we may debate the extent to which this merely represents moving towards the efficiency locus. Improving productivity implies no conflict with the pledge of future agricultural liberalisation. Moreover, at least in the absence of externalities and/or second-best effects, it should not result in allocative efficiency losses like those associated with tariffs and domestic support.

However, productivity improvements cannot be reaped without effort, they require investment both in research and institutional innovation, and there may be considerable uncertainty over the end result. Furthermore, little is known about the magnitude of productivity improvements that would likely to be required in order to achieve China's self-sufficiency objectives. In Section 3, we consider the extent of improvements that have been associated with the adoption of biotechnology and genetically modified organisms (GMOs).

3. Biotechnology and productivity growth

New technological processes, first developed in the mid 1980s, have been adopted to develop and or modify plants under commercial cultivation since 1996. Crops using biotechnology have been rapidly diffused into 12 countries, including six developing economies: Argentina, China, Mexico, Romania, Ukraine and South Africa (James, 1999). In 1999, the estimated total area cultivated with GM crops was 39.9 million hectares. 'Roundup-Ready' (RR) soybeans were grown on 21.6 million hectares of land (54% of world GM-planted area), *Bacillus Thuringiensis* (Bt) corn on 11.1 (28%), Bt cotton on 3.7 (9%), and RR canola on 3.4 (9%).[2] GM crops are concentrated in three countries (USA, Argentina, Canada), accounting for almost 99% of the total GM-planted area.

China's GM crop production was still extremely small in 1999, with only 0.1% of the domestic crop area cultivated with GM varieties, and a share of only 1% of the GM-planted area in the 12 countries. However, between 1998 and 1999, the growth in the area cultivated with transgenic varieties in China was 300%, evidence of the growing interest in

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[2] 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 digestion in parasites as the European corn borer 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.

Table 2
Evidence on the impact of GM crops

Geographical area	RR soybeans	NL potato	Bt corn	Bt cotton
China			Hebei province[a]	Hebei province[a]
Yield increase (%)			5–7	4–15
Net gain (US$ per acre)			n.a.	58–73
	National[b]	Columbia Basin[c]	Cornbelt and Lake States[d]	S/E United States[d]
USA				
Yield increase (%)	0	–	4–8	6–12
Reduced insecticide (%)	–	–	n.a.	70
Revenue increase (US$ per acre)	0	0	13–26	64
Reduced costs (US$ per acre)	24	97	0.08	29
Biotech cost (US$ per acre)	5	46	10	34
Other input costs	13	–	–	–
Net gain (US$ per acre)	6	51	3–16	51

[a] Buranakanonda (1999) and James (1999).

[b] Marra et al. (1999), corresponding figures for Alabama give 10% increase in yields.

[c] Gianessi and Carpenter (1999).

[d] Flanders et al. (1999).

biotechnology. The primary transgenic crops grown in China 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. Nelson et al. (1999) identifies five types of technological changes generated by biotechnology: (i) increases in the biologically optimal yield; (ii) increases in the economically optimal yield; (iii) changes in input composition without changes in yield; (iv) reduction of risks; and (v) enhancement of output traits. Bt corn and Bt cotton clearly represent two cases of an 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. By contrast, RR soybeans and canola are resistant to glyphosate, which can be used instead of a more costly combination of selective herbicides. RR soybeans and canola enhance productivity through a switch in inputs.

Table 2 summarises recent findings on the quantitative impact of GM crops. The table provides an illustration of the biological differences between types (ii) and (iii) of GMO impacts on crops, as well as a general basis for comparison for the simulations conducted in the following sections. 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 materialised, the input shift has been capable of increasing the net revenue gain per unit of cultivated land. In the case of potatoes, there is a potential ambiguity in the classification of the technology between higher economic yield and input-switching.

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 a 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).[3] There is no

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

guarantee that in future trials similar outcomes will occur, and 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. Nevertheless, the results provide us with perspective on the potential effect of adoption of GM crops.

4. Overview of the modelling approach

Although our principal interest in this paper is the grain sectors, we have highlighted the role of growth of non-agricultural sectors in drawing resources out of agriculture, reflecting the anticipated decline in China's comparative advantage in land-intensive crops. We have also noted the role of increasing consumption of meat products as a driver of increased grain demand. Moreover, trade policy changes under the URAA, which China will implement as part of its WTO accession agreement, go beyond the grain sector in terms of both direct coverage and indirect feedback effects. This suggests that general equilibrium techniques are an appropriate analytical tool for analysing policy responses to projected grain deficits.

Computable general equilibrium or CGE models are numerical implementations of general equilibrium theory. By integrating real world data with a complete structural description of the behaviour of agents within an economic system and the constraints that they face, CGE models allow quantitative examination of the effect of policy interventions within a consistent framework that accounts for important market interrelationships and second-best interactions. CGE models have been widely used in analysing China's trade policy reforms (Gilbert and Wahl, 2002).

The model that we utilise in this paper was introduced in Gilbert et al. (2000), and falls into a category that is termed *recursive dynamic* CGE. This means that the model solves iteratively, finding an equilibrium solution in each period, and then updating the growth parameters before searching for the next equilibrium. Agents in this class of model do not optimise in an intertemporal context. In this section, we focus on the simulation assumptions and data, and discuss the structural features of the model only briefly. A more comprehensive description of the model structure is contained in Appendix A.

The intra-period (equilibrium) model has been developed from the work of Rutherford (1998). It is a perfectly competitive model, based on relatively standard assumptions. The model is multi-regional, and in each region there is a single agent for government spending, investment, and household consumption. Each sector within each region is represented by a single competitive firm producing with constant returns to scale technology and making zero profits. Constant elasticity of substitution (CES) functions represent production, while a Stone–Geary utility function represents household demand (allowing us to specify non-unitary income elasticities). International trade is modelled along Armington lines, meaning that domestic production and imports (as well as imports from alternative sources) are treated as imperfect substitutes (CES functions are used to produce the composites). The model is closed by allowing factor prices to adjust to maintain full employment of endowments, by exogenising government expenditures and current account balances, and by letting regional savings be a constant fraction of income. The recursive dynamics update the values of endowments (capital and labour supply) and technical change parameters in response to the results of the previous solution, and/or a preset path. Further details can be found in Appendix A.

The initial equilibrium data used in the model is from the GTAP4 database (McDougall et al., 1998). We aggregate the database to 15 sectors (paddy rice, wheat, other grains, vegetables and fruit, other non-grain crops, livestock, forestry, fisheries, processed rice, meat products, dairy products, other food products, light manufactures, heavy manufactures and services), 15 regions (Australia, Canada, China, Europe, Indonesia, Japan, Malaysia, Mexico, New Zealand, other APEC, Philippines, Republic of Korea, Thailand, United States and ROW), and five endowment commodities (skilled labour, unskilled labour, land, natural resources and capital) with agricultural and industrial unskilled labour distinguished. Substitution parameters are also from GTAP4, with the exception that the Armington elasticities at both levels have been doubled to provide a better projection over the long-run (as in Anderson et al., 1997). We supplement the data with information on agricultural and non-agricultural labour counts from the FAOSTAT database, using the skill breakdowns in Liu et al. (1998) to obtain consistent measures of

Table 3
Baseline projections, annual percentage growth rates

Region	Total labour[a]	Agricultural labour[b]	Skilled labour[c]	Capital[d]	TFP[e]
Australia	0.80	−0.55	4.55	3.94	0.30
Canada	0.60	0.21	1.37	3.78	0.30
China	0.83	0.47	2.61	13.04	1.26
Europe	0.00	−1.31	4.49	3.40	0.30
Indonesia	1.69	1.33	8.75	10.29	1.33
Japan	−0.30	−0.85	3.54	3.27	0.30
Malaysia	1.90	1.12	7.83	12.53	0.60
Mexico	2.06	1.16	5.13	4.05	0.83
New Zealand	0.40	−0.20	1.84	3.34	0.30
Other APEC	0.80	−0.42	5.22	10.07	1.08
Philippines	2.40	1.22	5.93	4.62	0.50
ROW	1.51	0.99	5.21	6.55	0.92
South Korea	0.88	0.11	5.39	7.78	1.01
Thailand	0.79	0.34	6.31	11.70	1.24
USA	0.70	−0.28	2.79	2.81	0.30

[a] Average over a period of 1995–2005, based on World Bank (1999) projections 1997–2010 and model projections.

[b] Average over a period of 1995–2005, based on trend in preceding 10-year period (5 years in China) and model projections. Figures from FAOSTAT, except Taiwan (in the other APEC aggregate) from Taiwan agricultural yearbooks.

[c] Average over a period of 1995–2005, based on Ahuja and Filmer (1995), trends from UNESCO (1997) and model projections.

[d] Average over a period of 1995–2005, based on Anderson et al. (1997), historical trend in preceding 10 year period (Penn World tables) and model projections.

[e] Average over a period of 1995–2005. Implemented as a Hicks-neutral change across all inputs. Figures based on estimates from Young (1994), Drysdale and Huang (1997), World Bank (1997) and model projections.

the initial average unskilled agricultural wage, the unskilled industrial wage, and the skilled wage, as required by the recursive dynamic structure.

Our simulation design is as follows. First, we establish a baseline scenario to 2005, with which our alternative scenarios are compared. This baseline incorporates growth in each of the productive factors and productivity as detailed in Table 3. It also incorporates the completion of Uruguay Round trade liberalisation, without accession by China. The target end rates for tariffs are obtained from the GTAP3 database. As agreed under the Uruguay Round Agreement on Agriculture (URAA), agricultural domestic support is reduced by 24% for developed economies and 13% for developing economies (subject to the de minimis provisions). Agricultural export subsidies are reduced by 36 and 24%, respectively. The liberalisation is assumed to take place in annual linear reductions, by 2001 for developed economies and by 2005 for developing economies, with an appropriate adjustment made for liberalisation that should have occurred prior to the 1995 base.

In our alternative scenarios, we consider Chinese accession to the WTO, assuming commitments by China of the same level as those required of developing economies under the URAA (24% reductions in agricultural/food tariffs and exports subsidies, and 13% reductions in domestic support subject to a 10% floor, implemented as linear reductions by 2005). UR liberalisation commitments are also extended to China by the other economies in the model. We then examine the effect of self-sufficiency policies by endogenising the wheat and grain tariff/domestic support levels, subject to a self-sufficiency constraint of 95%. Finally, we endogenise the productivity improvements (above baseline levels) that would be required to achieve the 95% self-sufficiency target in the absence of other policy interventions, under both accession and non-accession scenarios.

5. Results and policy implications

Table 4 presents the results of our simulations in terms of self-sufficiency ratios. The first column reports the degree of self-sufficiency in the base year data (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 WTO accession as described above. Columns 4 and 5 present the 2005 projections obtained when self-sufficiency is attained by means of tariffs and domestic support measures, respectively, while columns 6 and 7 illustrate the outcomes of the productivity growth simulations for wheat and other grains, under WTO accession.

A number of clear results emerge. First, in line with the other studies outlined in Section 2, there is a substantial reduction in grain self-sufficiency levels between 1995 and 2005 projected under the baseline. Starting from a level of almost 83% in 1995, the degree of wheat self-sufficiency is projected to decrease to 54%. The corresponding estimates for other grains are 91 and 70%. Rice is the only grain market where

Table 4
Estimated self-sufficiency ratios for China

Sector	1995	Baseline 2005	WTO 2005	Tariffs	Domestic support	WTO and technology wheat	WTO and technology other grains
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	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

Source: Model simulations.

self-sufficiency levels are expected to be maintained. The broad pattern of the self-sufficiency estimates is consistent with that obtained by Yang and Huang (1997), although we estimate slightly larger declines in the ratios for most agricultural products. This difference stems from our use of an initial point where the ratios are already lower (Yang and Huang utilise a 1992 base year), and the fact that capital accumulates at a slightly faster rate over the simulation period in our model. This implies greater contraction of agriculture through the Rybczynski mechanism.

Interestingly, China's implementation of the URAA does not appear to have major implications for self-sufficiency ratios. In fact, self-sufficiency for other grains is higher under the accession scenario than the 2005 baseline scenario. This reflects a 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 URAA in fact imply a slight improvement in self-sufficiency levels.

Now consider the effect of utilising tariffs and domestic support interventions to increase self-sufficiency levels. Clearly, by construction, we achieve the desired (95%) 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), leading to a decline in the self-sufficiency ratios of those sectors relative to the baseline. The actual interventions required are substantial. According to our simulation results (not displayed in Table 4), the required import tariffs would be 58% for wheat and 70% for other grains. Alternatively, production subsidies of 81% for wheat and 49% for other grains could be used. These estimates are somewhat higher than Yang and Huang (1997), reflecting the expanded import ratios under our baseline projection.

Table 5 presents a summary of the total value of net grain (paddy rice, wheat and other grains) exports under our policy scenarios. The results indicate that our simulated effect of accession to the WTO does not cause a major departure of estimates for net

Table 5
Total net grain exports by geographical area (billion 1995 US$)

Region	Baseline 2005	WTO accession	Domestic support	Tariffs
Australia	1.70	1.73	1.45	1.48
Canada	9.43	9.73	7.01	6.94
China	−15.64	−14.79	−2.43	−1.71
Europe	7.14	6.56	4.06	3.91
Indonesia	−1.26	−1.26	−1.28	−1.26
Japan	−7.26	−7.44	−7.21	−7.19
Korea	−4.68	−4.71	−4.66	−4.67
Malaysia	−1.05	−1.06	−1.04	−1.05
Mexico	−0.88	−0.88	−0.90	−0.91
New Zealand	−0.03	−0.02	−0.03	−0.03
Other APEC	−2.52	−3.96	−2.52	−2.53
Philippines	−0.59	−0.59	−0.58	−0.59
Rest of world	−26.68	−26.39	−27.42	−27.42
Thailand	−0.19	−0.18	−0.20	−0.20
USA	39.08	38.96	32.92	32.85

Source: Model simulations.

grain exports from the corresponding values for the 2005 baseline (in fact, the value of net imports falls slightly). Columns 3 and 4 show that the imposition of higher tariffs or the adoption of domestic support would dramatically reduce the value of net imports of grain, from 15.6 (under the 2005 baseline assumption) to 2.4 and 1.7 billion US$ (bUS$) under the tariff and domestic support policies, respectively. Out of the 15 regions that we consider in our model, Canada, Europe and the United States appear to be the most affected by a self-sufficiency policy. In particular, US net exports of grain are estimated to decrease from 39 bUS$ under the baseline to 32.9 and 32.8 bUS$, respectively.

The net welfare effects associated with the different policy scenarios are presented in Table 6. These figures are an equivalent variation measure, expressed as the deviation from baseline at 2005. First note the substantial gains associated with acceding to the WTO for China, over 33 bUS$. Results of a similar magnitude are reported in Gilbert and Wahl (2002). Although the benefits of WTO accession 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 and South Korea also benefit from China's trade liberalisation and accession to WTO, due to their close geographical position and economic interdependence with China.

Table 6
Equivalent variation as a deviation from baseline 2005 (billion 1995 US$)

Region	China WTO	Domestic support	Tariffs
Australia	0.10	−0.06	−0.14
Canada	0.24	−0.11	−0.14
China	33.17	−2.60	−1.68
Europe	4.84	1.55	2.03
Indonesia	−0.04	0.09	0.06
Japan	2.18	0.06	0.39
Malaysia	0.19	0.02	0.10
Mexico	−0.15	−0.01	−0.02
New Zealand	−0.04	−0.01	−0.04
Other APEC	0.63	0.08	0.20
Philippines	−0.49	0.04	0.02
ROW	0.47	0.49	0.61
South Korea	1.28	0.13	0.24
Thailand	2.11	−0.08	0.02
USA	1.20	−0.39	−0.78
World	45.69	−0.80	0.87

Source: Model simulations.

The imposition of tariffs or domestic support to achieve a self-sufficiency level of 95% would result in estimated direct welfare losses of 1.7 and 2.6 bUS$, respectively. However, given that WTO membership is unlikely to be compatible with tariffs or domestic support measures of the magnitude estimated above, the loss of the positive potential welfare effects of accession should be included in the cost of intervention, leading to total losses of between 35 US$ (tariffs) and 36 bUS$ (domestic support). As we expect, import tariffs are the 'least-cost' mode of intervention, although the difference is marginal (reflecting limited consumption substitution possibilities). However, we can conclude that any policy intervention to achieve the desired levels, while feasible, is likely to be extremely costly.

Having demonstrated that by raising tariffs and using domestic support measures to achieve self-sufficiency China would pay a high price in terms of welfare losses, we now turn to improvements in productivity. This technological improvement does not necessarily have to stem from the diffusion of GM crops as discussed in this paper, the key question is whether or not it is feasible that self-sufficiency could be attained through productivity improvements.

In order to estimate the productivity improvements required to achieve 95% self-sufficiency, we run simulations that impose the self-sufficiency constraint in wheat or other grains, and then endogenise technical change at 2005. We assume a Hicks-neutral change, which, to the extent that we have GMOs in mind, is a clear simplification of the complex process by which biotechnology might affect production. (This might be regarded as the best-case hypothesis since it implies an equal marginal productivity increase for all inputs.) Under the 2005 baseline scenario, the required productivity improvement to meet a 95% self-sufficiency goal would be 86% for wheat and 54% for other grains. This additional increase should be attained in 10 years (1996–2005), which corresponds to an annualised compound growth rate of 6.4 and 4.4%, respectively. In the case of WTO accession, the estimates are 84% for wheat and 26% for other grains (implying, respectively, a 6.3 and 2.3% annual productivity growth).

It is important to note that the productivity improvement required is in addition to that assumed in the baseline (our assumed productivity growth in grain production in China averages 1.3% over the simulation period). Obviously, these are substantial requirements. By comparison, between 1979 and 1995, productivity for wheat, maize and soybeans grew at an annual rate of 5.1, 3.9 and 3.4%, respectively (Huang et al., 1999b). However, the rapid improvements in productivity that accompanied the move to market-orientation over this period are unlikely to be duplicated.

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 from GM technology. We do not possess clear data on the productivity gains on new genetically modified varieties of wheat, 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% have been claimed (Hoisington et al., 1999; Jackson, 1999). Even if such values were confirmed, the gain in productivity required for self-sufficiency in wheat would still be almost three times higher (and likely to continue to grow as China's industrial economy expands).

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% under the accession scenario may seem more realistic, given the fact that yield gains higher than 15% have been observed for Bt corn. Nevertheless we must be cautious: very high yields have been reported only under experimental conditions, while increases in the order of 5–10% are normally observable in actual commercial cultivation. It also has to be assumed that in China a 10–20% '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 for commercial application 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. Our results therefore suggest that the required technological shift in other grains is also unlikely to be attainable through GM adoption alone, by 2005.

As an alternative, the Chinese government might 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 additional productivity growth would be 44% for wheat and 41% (3.7 and 3.5% annually) for other grains, while, for the WTO accession case, the corresponding values are 44% for wheat and 19% (3.7 and 1.8% annually) for other grains. With respect to other grains, the required technological shifts, although still high, are closer to observed values.

The results of all CGE simulation exercises are known to be sensitive to the parameters used in specifying the substitution relationships in the models. For this reason, and the uncertainty surrounding parameter values, it is necessary to conduct analysis on the effects of altering important parameter values. In the current context, where our focus has been on import volumes (and subsequently self-sufficiency ratios), the most important parameters are the 'first level' Armington elasticities, which govern the substitution relationship between imports and domestic production. We therefore conduct sensitivity analysis by scaling the vector of elasticities by ±25 and ±50%. In Table 7, we present the effects of these parameter changes on some of our key results.

The first set of figures is the projected self-sufficiency ratios in the grain categories, under the baseline at 2005. A lower (higher) Armington elasticity

Table 7
Sensitivity of key results to first level Armington elasticities

	−50%	−25%	Central	+25%	+50%
Self-sufficiency ratios—baseline 2005 (%)					
Wheat	65.1	58.6	54.1	50.9	48.9
Other grains	78.1	73.2	69.7	67.2	65.6
Domestic support required to reach 95% self-sufficiency (%)					
Wheat	168.8	119.7	91.0	72.6	59.8
Grains	97.7	74.3	58.7	47.7	39.7
Import tariff required to reach 95% self-sufficiency (%)					
Wheat	136.5	91.2	67.2	51.5	40.6
Grains	140.3	102.3	80.3	65.9	55.7
Productivity growth required to reach 95% self-sufficiency (%)					
Wheat	152.5	110.9	86.0	69.8	58.3
Grains	84.9	66.5	53.8	44.6	37.8

Source: Model simulations.

implies that domestic production and imports are less (more) substitutable, this implies higher (lower) self-sufficiency ratios under the baseline projection. However, even with the elasticities halved, the decline remains significant, at 65% for wheat and 78% for other grains (compared with 83 and 91% in the base year).

While lower Armington elasticities result in smaller reductions in the estimated self-sufficiency ratios, they also increase the estimated difficulty of attaining the 95% objective. In the case of a tariff, the lower (higher) the elasticity, the higher (lower) the price change required to induce a given quantity shift in imports. The pattern is similar for the other policies.

In assessing the robustness of our results, we note that even with the Armington elasticities increased by 50% (triple the original levels in GTAP4), the domestic support or tariffs required for 95% self-sufficiency range between 40 and 60%, which is well beyond what is likely to be acceptable under China's WTO accession agreement. Similarly, the productivity improvements required (at 58 and 38%) remain well outside the potential of GMOs, and will be difficult to attain. We are therefore confident that, while our numerical results may vary somewhat over the range of feasible parameter values, our general policy conclusions are quite robust.

6. Concluding comments

To assess the feasibility of China's grain self-sufficiency objectives, we have analysed border measures, domestic support and productivity improvements using a CGE simulation model. In interpreting the results of CGE simulations, the usual caveats need to be borne in mind. Given the uncertainty over specification, we should concentrate our attention on the broad patterns that emerge and the magnitudes of the estimates, which in this case are robust to parameter changes.

As in the existing literature, our projections indicate that it is unlikely that China under the current regime will be able to produce enough grains to satisfy national demand by 2005. If China wishes to attain 95% self-sufficiency, it will need to put in place mechanisms to increase production and/or decrease consumption. The two obvious policy candidates (tariffs and domestic support) will inflict heavy economic costs on China and may be at odds with WTO membership. By contrast, productivity increases would enhance China's economic gains and be compatible with the WTO, the only question is one of attainability.

We have contrasted our simulation findings with the empirical values observed for GMO technology in field trials and commercial cultivation. The data have been obtained from several survey areas, making it is difficult to control for differences in input composition. We therefore treat the values as reference benchmarks. Nevertheless, serious questions have been raised. Our simulations indicate that in order to meet a 95% self-sufficiency requirement, productivity increases would have to be substantially higher than these reference benchmarks. 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 those claimed or observed in field trials. Of course, productivity growth cannot be reduced to the diffusion of GM crops and we cannot not exclude the possibility that other technological improvements may lead to self-sufficiency.

While our findings suggest that adoption of GM crops is unlikely to be sufficient to attain self-sufficiency, GM technology does present interesting opportunities for Chinese agriculture. Growers may benefit from higher yields, enhanced product quality, reduced exposure to climatic hazards, and a less expensive input mix. Since GMOs can reduce the application of herbicides and insecticides, their impact on the environment should also not be ignored. Likewise, there are also risks associated with GMOs. While largely speculative at this time, both the actual environmental and safety risks and consumer perceptions must be closely monitored. These are complex issues that warrant further study.

7. Disclaimer

The opinions expressed in this paper are solely those of the authors and do not necessarily reflect the opinions or orientations of the institutions to which they belong.

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Appendix A

In this appendix, we describe the recursive dynamic CGE model that was used to generate the results in this paper. The intra-period model is based on Rutherford (1998), and is of a well-established class. We therefore describe it in greatly streamlined form, following Gilbert and Wahl (2002). The global economy consists of M regions indexed by r. Let V^r be a vector (length F) of factor endowments in each region r, and P^r be a vector (length N) of prices in each region. We can define the GNP functions for each region as $G^r(P^r, V^r) = \max\{\boldsymbol{P}^r \cdot \boldsymbol{Y}^r : \boldsymbol{V}^r\}$, and the expenditure functions as $E^r(\boldsymbol{P}^r, U^r) = \min\{\boldsymbol{P}^r \cdot \boldsymbol{D}^r : U^r\}$, where U^r is aggregate utility in region r. The budget constraints are then:

$$S^r(\boldsymbol{P}^r, \boldsymbol{V}^r, U^r) = G(\boldsymbol{P}^r, \boldsymbol{V}^r) - E^r(\boldsymbol{P}^r, U^r) = 0 \quad r = 1, \ldots, M \tag{A.1}$$

where we have fixed the current account balance at zero. From the first order conditions to the GNP maximisation problem, we obtain sectoral supply functions by Hotelling's lemma, and Hicksian demand functions follow similarly from the expenditure function, hence:

$$S^r_i(\boldsymbol{P}^r, \boldsymbol{V}^r, U^r) = D^r_i(\boldsymbol{P}^r, U^r) - Y^r_i(\boldsymbol{P}^r, \boldsymbol{V}^r) \quad i = 1, \ldots, N;\ r = 1, \ldots, M \tag{A.2}$$

define Hicksian net exports. With trade there can be only one price vector ($\boldsymbol{P}$). Equilibrium requires:

$$\sum_{r=1}^{M} S^r_i(\boldsymbol{P}, \boldsymbol{V}^r, U^r) = 0 \qquad i = 1, \ldots, N. \tag{A.3}$$

By Walras' law these equilibrium conditions are not independent, and any one of them can be dropped. Hence, one element of $\boldsymbol{P}$ (say P_1) must be declared a numéraire price. The solution to the system of equations defined by (A.1)–(A.3) then yields a relative price vector, aggregate utility levels, and net exports. We can subsequently derive factor prices from the GNP function:

$$W^r_j = W^r_j(\boldsymbol{P}, \boldsymbol{V}^r) \quad j = 1, \ldots, F;\ r = 1, \ldots, M. \tag{A.4}$$

In this simple model, we have $M+MN+N+2MF-1$ variables, but we have only $M+MN+N+MF-1$ independent equations. In a neoclassical closure, the V^r are declared exogenous, enabling the system to be solved.

The simulation model adds considerable complexity, but does not alter this basic framework. Production utilises intermediate inputs. Final demands are distinguished between households, government, trade, and capital creation. There is imperfect substitution between foreign and domestic goods, and between alternative sources of imports (the Armington assumption)—and thus a three-stage optimisation procedure in both intermediate and final demand. Specific functional forms define the substitution relationships (CES functions in value-added and Armington, Leontief in intermediate use, Stone–Geary in household demand). Finally, distortions are introduced to the system by allowing taxes and subsidies to drive wedges between the prices faced by the various agents in the system.

The Eqs. (A.5)–(A.13) that make up the recursive dynamics of the model are given below:

$$\lambda^t_r = \frac{\lambda^* + (\lambda^0_r - \lambda^*)^{\phi^{\mathrm{T}}_r}}{(\mathrm{GDP}^{t-1}_r/\mathrm{POP}^{t-1}_r)^{\phi^{\mathrm{T}}_r}} \tag{A.5}$$

$$\Delta^t_r = \frac{\Delta^* + (\Delta^0_r - \Delta^*)^{\phi^{\mathrm{L}}_r}}{(\mathrm{GDP}^{t-1}_r/\mathrm{POP}^{t-1}_r)^{\phi^{\mathrm{L}}_r}} \tag{A.6}$$

$$\Lambda^t_{Sr} = \Lambda^0_{Sr}\frac{\{1 - (pf^{t-1}_{Lr}/pf^{t-1}_{Sr})\}^{\psi_{SL}}}{\{1 - (pf^0_{Lr}/pf^0_{Sr})\}^{\psi_{SL}}} \tag{A.7}$$

$$\Lambda^t_{Ar} = \Lambda^0_{Ar}\frac{\{1 - (pf^{t-1}_{Lr}/pf^{t-1}_{Ar})\}^{\psi_{AL}}}{\{1 - (pf^0_{Lr}/pf^0_{Ar})\}^{\psi_{AL}}} \tag{A.8}$$

$$a^t_r = \mathrm{e}^{\lambda^t_r t} \tag{A.9}$$

$$S^t_r = S^{t-1}_r(1 + \Delta^t_r)(1 + \Lambda^t_{Sr}) \tag{A.10}$$

$$A^t_r = A^{t-1}_r(1 + \Delta^t_r)(1 + \Lambda^t_{Ar}) \tag{A.11}$$

$$L_r^t = (1 + \Delta_r^t) L_r^{t-1} + \left(\frac{pf_{Lr}^0}{pf_{Ar}^0}\right) A_r^{t-1} \Lambda_{Ar}^t - \left(\frac{pf_{Lr}^0}{pf_{Sr}^0}\right) S_r^{t-1} \Lambda_{Sr}^t \tag{A.12}$$

$$K_r^t = (1 - \delta_r) K_r^{t-1} + I_r^{t-1} \tag{A.13}$$

The equations are of two types. Eqs. (A.5)–(A.8) are ‘adaptive’ equations. They adjust the growth parameters in response to the equilibrium outcome in the preceding period. Eqs. (A.9)–(A.13) are the ‘growth’ equations. They calculate the values of the technical shift parameters and factor endowments that will be used in the search for the subsequent equilibrium.

Eqs. (A.5) and (A.6) both reflect a widely accepted stylised fact of development, a decline in the natural rate of growth as economies mature. Hence in (A.5), the rate of productivity growth in developing economies approaches average developed economy levels as per capita GDP rises. Eq. (A.6) adjusts labour force growth rates in the same fashion. These adjustments are made to ensure that the growth path does not produce unreasonably large changes in the structure of the global economy over long simulation periods. The paths of these parameters are calculated in an initial simulation with no liberalisation, and thereafter fixed for subsequent simulations.

Eqs. (A.7) and (A.8) adjust the marginal growth rates of skilled and agricultural unskilled labour, respectively. Using (A.8) as an example, when the ratio of industrial to agricultural unskilled wages is the same as in the initial equilibrium, the rate of labour movement from agricultural to industrial activities equals its initial level. Should the ratio rise/fall, so will the rate of movement in the subsequent period. When the wages are equal, movement between the two activities in the next period is zero. Hence, shocks that alter the returns to different classes of labour in the intra-period model cause factor supply responses in subsequent periods, and movement between categories declines as the incentive diminishes. The primary purpose of these equations is to allow the movement of labour across categories (which is generally set exogenously) to respond to the price incentives within the simulation period.

The remaining five equations have straightforward interpretations. Eq. (A.9) calculates the technical shift parameter given the rate of productivity growth. Eqs. (A.10)–(A.12) calculate the new stocks of skilled, and agricultural and industrial unskilled labour. Finally, (A.13) calculates the new capital stock as the sum of the previous period’s depreciated capital stock, and investment (savings is a fixed share of income). This allows the model to capture changes in income that result from investment expansion with trade liberalisation. The steady state properties of the model do, however, imply that shifts in the growth rate are temporary.

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