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CONTENTS

EDITORIAL

The *Journal of International Agricultural Trade and Development* (JIATD) is created at a time when globalization is at full swing, the borders between nations are becoming blurred, and the resulting economic growth in most of the world is at an unprecedented high. But globalization implies a decreasing level of sovereignty, and many countries are not willing to give that up. Famine is far from being eradicated in some parts of the world. Eating food represents the most basic human need. That is why international agricultural trade and development are so critically important to all nations and the entire human race. But economics is a science about incentives. Different countries or interest groups within a country may have different goals and incentives regarding the issues of agricultural and food production, trade, self-sufficiency, and security. And all of these countries and interest groups inevitably interact on a daily basis. That is why the economics of international agricultural trade and development is in need of constant intellectual contribution. JIATD will hopefully be an important forum for economists to share their ideas and push further the boundaries of our understanding of these problems.

It is hoped that the JIATD will serve as a link between agricultural economists and general economists with an interest in international and development economics. General economists are often perceived to be dealing with abstract theoretical issues detached from the real world occurrences. Agricultural economists are often perceived to be too closely attached to short-term policy interests, often without regard for the economic theory foundation. Bringing together the cold of the impersonal objectivity and emotional self- or group-interest should provide us with alternative views and solutions to the issues explored.

Although the JIATD is in its infancy, the editor and the editorial board members have been impressed by the resounding response of the profession. Your contributions are welcome.

Dragan Miljkovic, Editor
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CHINA'S HORTICULTURAL TRADE PATTERNS: IMPLICATIONS FOR WORLD MARKETS

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Abstract

China's WTO accession has important implications for the world horticultural industry, because China is the world's largest producer of horticultural products. This paper examines changes in China's horticultural trade patterns over the 1988-2001-time period, when there was a movement away from state-controlled trade. We find that China's horticultural trade patterns have been persistent, with or without adjusting the trade data for smuggling through Hong Kong. The implication is that China's horticultural trade may not fully reflect its comparative advantage in this industry.

Introduction

There is wide interest in the impacts of China's WTO accession on its agricultural sector and on world trade (Gilbert and Wahl, 2002). The U.S. agricultural industry (and especially California) is concerned about China's future export competitiveness in horticultural products in both the U.S. and in third markets. For instance, China has been the target of several recent U.S. antidumping cases dealing with horticulture, such as garlic, mushrooms, and frozen apple juice concentrate. These trade law cases were initiated largely because of surges in China's exports to the U.S. of trade sensitive products.

Most previous studies of China's agricultural trade have focused on the grain and oilseed sector, due to China's erratic trade behavior in these bulk commodities and the potential destabilizing role of China's trade liberalization (e.g., Colby, Price, and Tuan, 2000). Surprisingly, little effort has been devoted to studying China's horticultural sector, despite its global importance. [2] With an abundant rural labor force relative to its land base, it is broadly accepted that China's agriculture has a comparative advantage in labor-intensive horticultural

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[2] There are different ways to define horticulture. In this study, horticulture includes four broad categories: i) vegetables, nuts, fruits, and their products, ii) coffee, tea, cocoa, and spices, iii) tobacco, and iv) plant fibers. Please see Appendix 1 for a detailed list of products we define as horticultural.

crops, such as fruits and vegetables (Carter, Zhong, and Cai, 1996; Zhang, 2000) and could become a more significant player in world markets for these food products.

Horticulture is an important and growing component of China's agriculture, and its production has grown rapidly since economic reform, especially in the 1990s. The annual vegetable sown area expanded from 3.2 million hectares in 1980 to 6.3 million hectares in 1990, and then reached 16.4 million hectares in 2001 (National Bureau of Statistics of China, 2002). This is more than a five-fold increase in twenty years. Production of fresh vegetables grew 57% in volume between 1995 and 2000, and production of fresh and dried fruits grew 19% over the same period (Donovan and Krissoff, 2001). China currently is the world's largest producer of horticultural products, accounting for over one-third of world production in 2003 (FAO, 2004).[3]

The importance of horticultural products as a share of China's agricultural trade has increased somewhat, especially on the import side. China's horticultural exports rose from US$1.6 billion in 1980 to US$5.3 billion in 2002, accounting for 37% of China's total agricultural exports in 2002. The value of China's imports of horticultural products totaled US$1.8 billion in 2002, representing 11% of China's total agricultural imports that year, up from 4.4% in 1980 (FAO, 2004).

Table 1. Major Players in the International Horticultural Market

	Values (Million $)				**Share (%)**			
Country	1980	1990	1995	2002	1980	1990	1995	2002
Importers								
World	61847	89661	118019	117777	100.00	100.00	100.00	100.00
United States	7869	11084	13161	14972	12.72	12.36	11.15	12.71
Germany	10265	14668	17072	13584	16.60	16.36	14.47	11.53
United Kingdom	4916	7336	7985	8717	7.95	8.18	6.77	7.40
France	4729	7152	9450	8264	7.65	7.98	8.01	7.02
Japan	2893	5437	8996	7600	4.68	6.06	7.62	6.45
China	350	612	979	1807	0.57	0.68	0.83	1.53
Exporters								
World	54448	77412	108668	109759	100.00	100.00	100.00	100.00
United States	4891	7373	9782	10350	8.98	9.52	9.00	9.43
Spain	2114	4368	7456	8374	3.88	5.64	6.86	7.63
Netherlands	3397	6813	9181	8108	6.24	8.80	8.45	7.39
Belgium[a]	1028	2672	5921	6282	1.89	3.45	5.45	5.72
Italy	2657	4549	5415	5581	4.88	5.88	4.98	5.08
China	1626	2943	4393	5313	2.99	3.80	4.04	4.84

Source: FAO, 2004.

Note: [a] *These data are unavailable for Belgium for 1980, 1990, and 1995, so we report import and export values for Belgium-Luxembourg for these years*

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[3] These numbers are compiled from FAO data, which include Taiwan in China's data. The absolute numbers would be different if Taiwan was not included, but the trend would not be significantly affected. In the analysis following this section, we use alternative data from China's customs statistics (that exclude Taiwan).

However, in terms of world horticultural trade, China remains a moderate player. The international market is mainly dominated by developed countries (Table 1) and restrictive import trade barriers are commonplace. The United States and Germany are the two largest importers of horticultural products, accounting for 12.7% and 11.5% of the total import value in 2002, respectively. China's horticultural imports accounted for only 1.5% of total world imports in 2002, up from 0.6% in 1980. Total world exports of horticulture increased from US$54.44 billion in 1980 to US$109.76 billion in 2002. The United States is the largest exporter followed by Spain, with over 9.4% and 7.6% of world exports in 2002, respectively (see Table 1). China's horticultural exports accounted for only about 4.8% of the world total in 2002, up slightly from 3% in 1980.

Given China's favorable climate and abundant rural labor supply, the U.S. and other exporting countries view this nation as a potentially strong competitor in horticultural trade. This possibility has been identified by Donovan and Krissoff (2001), Shields and Tuan (2001), and by USDA FAS (2002). WTO membership will facilitate foreign direct investment in China's horticultural industry, improve its marketing channels, and help this nation raise product quality to realize its production and trade potential.

On the other hand, WTO membership will also significantly improve market access opportunities for exporting countries trying to sell horticultural products into China. Tariffs on horticultural imports into China will be reduced substantially. For instance, the ad valorem tariff on oranges dropped from the pre-WTO level of 40% to 12% in 2004, while the tariff on frozen potato fries dropped to 13% in 2004 from the pre-WTO level of 25% (FAS, 2002). In addition, China has agreed to the WTO's Sanitary and Phytosanitary rules and this will reduce China's ability to use non-scientific technical trade barriers. Moreover, the licensing and distribution system is being quickly liberalized and exporters can now do business with private traders in China more freely. All these factors lead some exporters to view China as a very attractive horticultural market (Huang, 2002; Perez, 1998), given the expected growth in demand for vegetables and fruits stemming from urbanization and rising income levels.

China's future horticultural trade patterns with WTO accession are therefore a complicated issue. Economic theory suggests that with freer trade, comparative advantage will play a more important role and trade patterns will become more consistent with China's resource endowment. However, any change in China's future trade patterns obviously depends on the current situation. If China's horticultural trade patterns have already experienced a strong shift, this implies that China's comparative advantage in horticulture has been exploited to some extent. In this case, WTO accession will not result in significant changes in China's horticultural trade patterns. On the other hand, if China's horticultural trade patterns have not shown much change, this is consistent with the view that China's comparative advantage in horticulture has not been fully realized. In this case, there would remain potential for China to more fully exploit its comparative advantage in this sector, and there could be dramatic changes in China's forthcoming trade patterns.

One important factor that has been left out of any previous analyses of China's agricultural trade is widespread smuggling through Hong Kong. According to Hong Kong exporters, smuggled horticultural products were a major feature of China's horticultural trade in the 1990s (Wong, 1998). Due to China's quarantine restrictions, import tariffs, and the business tax structure, a vast amount of horticultural products from various sources were shipped undocumented from Hong Kong to several wholesale markets and distributed within China. The importance of smuggling is now diminishing because of lower trade barriers in

China, but any examination of historical data should account for the smuggling that was prevalent.

Overview of China's Horticultural Trade

China is the world's largest producer of horticultural products (FAO, 2004). The diverse climate as well as a varied topography and soil allows for the year round production of a wide variety of horticultural products. These resources are complemented by a large rural labor force. There were 490 million rural workers in 2002 (National Bureau of Statistics of China, 2003). So farmers and processors in China have little difficulty in filling their labor needs even at a typical daily wage of $2 (Shields and Tuan, 2001).

Before economic reform, the horticultural sector was only a small part of China's agriculture, and the sown area and distribution system were under tight government control. With increased planting flexibility and a re-opening of local markets, horticultural production and output increased dramatically. In 1988, the Vegetable Basket Program was introduced by China's Ministry of Agriculture, which improved the rural infrastructure, developed a network of wholesale markets, and boosted China's horticultural sector.

The nominal value of China's exports of horticultural products rose at an annual growth rate of 1.9% during the 1988 to 2002 time period. The value of horticultural exports reached US$4.8 billion in 2002, up from US$2.5 billion in 1988. Similar to the pattern in the world horticultural market, there was a jump in China's horticultural exports in 1994 and 1995. The value of horticultural exports then dropped in 1996 and 1997, consistent with the lower value of world horticultural trade. After 2000, world horticultural exports rose again.

From 1988 to 2002, China's horticultural imports increased smoothly at a growth rate of 5.1%, from US$0.3 billion in 1988 to US$1.1 billion in 2002. The rapid increase in imports was partly due to a growing demand for high quality produce (e.g., broccoli, navel oranges, and grapefruit) and partly attributed to the relaxation of trade barriers in the 1990s.

Consistent with its comparative advantage, China has been a net exporter of horticultural products. For most years since 1990, horticultural exports have earned China enough foreign exchange to cover grain imports. Net exports grew by 1.3% annually and increased from US$2.2 billion in 1988 to US$3.7 billion in 2002.

After accounting for inflation, China's horticultural trade exhibits a similar picture (Figure 1), but the growth rate is much lower. The real value of horticultural exports increased from US$2.1 billion in 1988 to US$2.7 billion in 2002[4]. The average annual growth rate was only 0.7%. Real imports increased at a higher rate, 3.9%, rising from US$0.3 billion to US$0.6 billion. Because import growth outpaced export growth, real net exports only grew at a rate of 0.1% during that time period, reflecting worldwide protectionism in horticulture.

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[4] The real values were obtained by deflating the nominal values by the U.S. Consumer Price Index (CPI). The U.S. CPI was obtained from the Bureau of Labor Statistics and the base period is 1982-1984=100

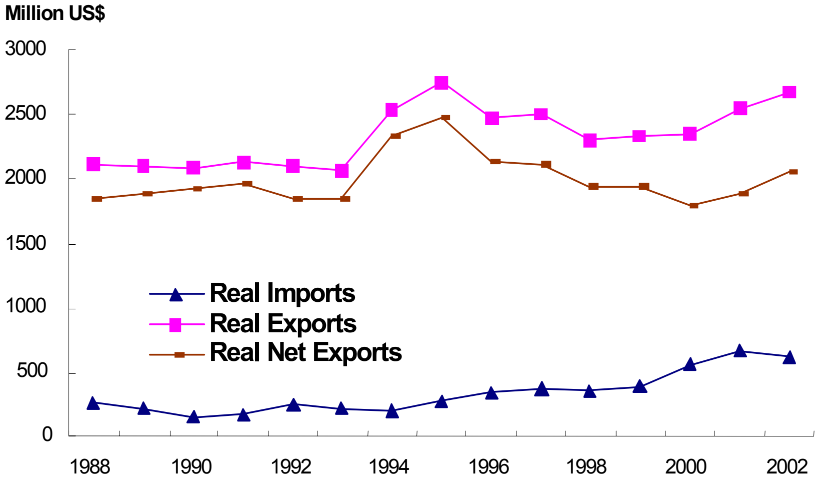

Figure 1. China's Horticultural Trade, 1988-2002

Source: China's Customs General Administration (1988-1996) and EIA CCS Information Service Center (1997-2002)

Decomposed horticultural trade data are presented in Figure 2. Among the four categories shown, the group comprised of vegetables, nuts, fruits and their processed products is by far the most important component and dominates China's horticultural trade. This group's share of China's horticultural exports increased from 76% to 84% during the 1988 to 2002 time period, while its import share rose from 41% to 67%. As shown in Figure 2, the real net export value of this group of products increased from US$1.5 billion in 1988 to US$1.8 billion in 2002, at a rather low annual growth rate of 0.5%.

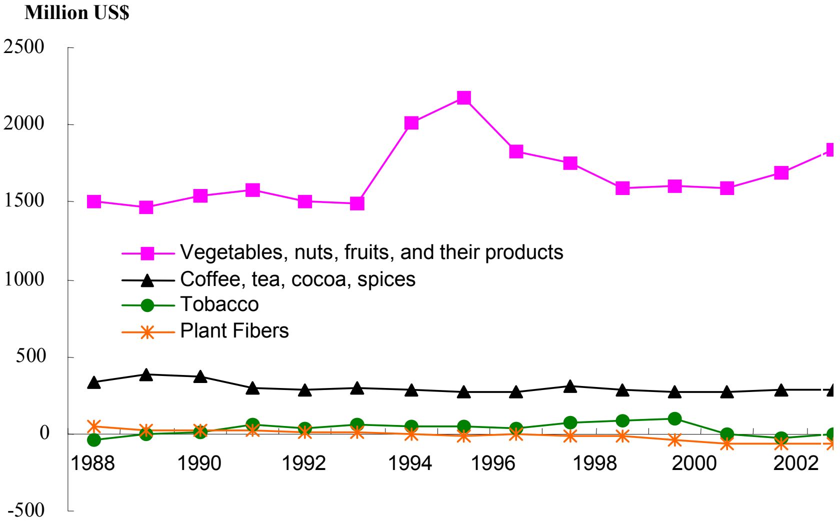

Figure 2. Structure of Real Net Exports: China, 1988-2002

The magnitude of the other three categories of products in Figure 2 is relatively small. The coffee, tea, cocoa, and spices group was in a net export position during the 1988-2002 time period, but the net export value decreased from US$340 million to US$286 million. China became a net importer of plant fibers after 1993. In the case of tobacco, net exports increased during the 1988–1999 time period. However, tobacco imports increased sharply after 1999 and China has become a net importer of tobacco since then.

Hong Kong has been a significant center for re-exports of imported agricultural commodities because of the absence of trade barriers in Hong Kong. It ranks as one of the top Asian import markets for farm products. It is also the second largest Asian market for U.S. horticultural products and 20% of U.S. fruit and vegetable exports are shipped to Hong Kong, and this share has been growing. Despite a relatively small population of only 6.5 million, Hong Kong imported US$2.1 billion in horticultural products in 1997, 3.5 times that of mainland China's official imports. Although Hong Kong's import and export values have decreased since 1997, it still imported US$1.5 billion horticultural products in 2001, higher than China's imports in that year. Surely, these imports are not all for domestic consumption purposes and, in fact, Hong Kong officially re-exports about 50 percent of its horticultural imports.

The conventional wisdom is that China is the primary destination for Hong Kong's re-exports. A large share of the processed food and consumer ready products are first imported into Hong Kong and then re-exported to mainland China. For example, almost all of the U.S. meat, fruit, and vegetable exports to China are routed through Hong Kong. Hong Kong is clearly a critical gateway to the mainland market. There is a large illegal trade in agricultural products in addition to the legal shipments from Hong Kong to China (USDA FAS, 1996; Wong, 1998). For example, in the late 1990s undocumented re-export shipments of fresh fruit may have accounted for up to 70 percent of Hong Kong's imports (Wong, 1998).

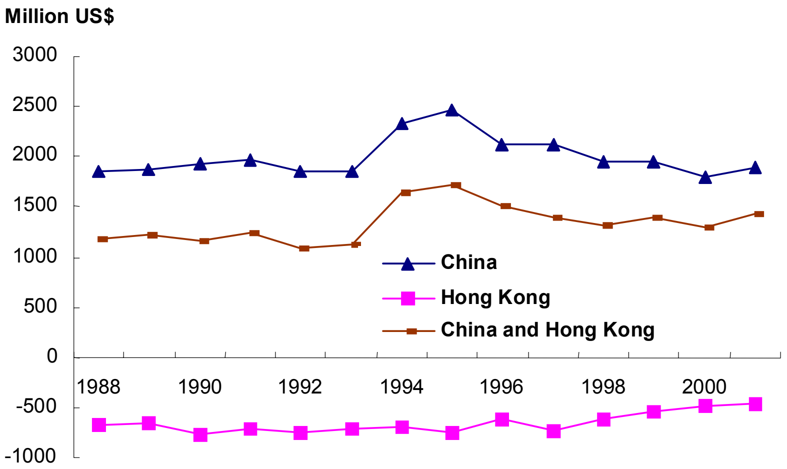

Figure 3. Real Net Horticultural Exports: China and Hong Kong

Source: China's data are from China's Customs General Administration (1988-1996) and EIA CCS Information Service Center (1997-2001). Hong Kong's data are from the Census and Statistical Department, Hong Kong (1988-2001)

To account for the effects of smuggling, it would be ideal to use the total value of undocumented horticultural exports from Hong Kong to China. However, it is impossible to obtain these smuggling data. As a proxy, Hong Kong's net imports are used to adjust China's horticultural trade to roughly illustrate the importance of smuggling. Figure 3 shows net exports of horticultural products from China, Hong Kong, and the two combined.[5] Hong Kong was a net importer of horticultural products during the studied time period and its net imports decreased after 1997, which may indicate that the importance of Hong Kong's role as a transshipment point was declining. China's net exports, on the other hand, rose during that time period. Adjusted for smuggling, the magnitude of China's real net exports was much smaller, only US$1.4 billion in 2001.

Role of State Trading Enterprises

Tables 2 and 3 show the ownership structure of China's horticultural trading enterprises in 1988 and 2002.[6] Most of China's horticultural exports and imports were controlled by state-owned enterprises (SOEs)[7] in the late 1980s and early 1990s (Table 2). In fact, 94.7% of horticultural imports and 98.3% of horticultural exports were handled by SOEs in 1988. Almost all the tobacco exports and imports were managed by SOEs, and these state traders dominated the other three commodity groups as well. For vegetables, nuts, fruits, and their products, 92.9% of the value of imports and 97.8% of the value of exports were channeled through SOEs in 1988.

The SOEs' dominating role in China's horticultural trade was reduced gradually from 1988 to 2002 (Table 3). By 2002, the proportion of China's horticultural imports and exports managed by SOEs dropped to 64.9% and 53.6%, from 94.7% and 98.3% in 1988, respectively. Sino-foreign equity joint ventures and foreign-owned enterprises now play a more important role in China's horticultural trade. Horticultural imports and exports handled by sino-foreign equity joint ventures increased from 0% in 1988 to 9.0% on the import side and to 16.1% on the export side in 2002. Only 3.8% of imports and 1.6% of exports were through foreign-owned enterprises in 1988. By 2002, these numbers increased to 6.0% and 14.7%, respectively. The share of horticultural trade conducted by private enterprises rose quickly after 1999. Private enterprises accounted for 12.8% of total horticultural imports and 7.9% of total horticultural exports in 2002, up from 0.4% and 0.6%, respectively, in 1999.

Among the four major horticultural groups in Tables 2 and 3, the most dramatic change in the type of trading enterprise took place in vegetables, nuts, fruits and their products. SOEs only accounted for 58.0% of imports and 49.9% of exports of these products in 2002. Private enterprises managed 18.4% of this group's imports. More than 36% of this group's exports were handled by joint ventures and foreign-owned enterprises. In contrast, trade in tobacco was still dominated by SOEs in 2002.

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[5] Our analysis of smuggling is conducted for the 1988-2001-time period because 2002 data for Hong Kong were not available.

[6] Comparisons between the three-year averages (1988-1990 and 2000-2002) are also available from the authors and show similar results

[7] State-owned enterprises refer to non-corporation economic units where the entire assets are owned by the state. Sole state-funded limited liability corporations are not included in this definition.

Table 2. Composition of China's Horticultural Trading Enterprises (1988)

	Type of Enterprises	Vegetables, nuts, fruits, and products (%)	Coffee, tea, cocoa, and spices (%)	Tobacco (%)	Plant Fibers (%)	Total (%)
Import	State-owned enterprises	92.9	92.2	99.8	79.8	94.7
	Sino-foreign contractual joint venture	0.0	0.0	0.0	0.0	0.0
	Sino-foreign equity joint venture	0.0	0.0	0.0	0.0	0.0
	Foreign-owned enterprises	5.6	4.6	0.2	20.2	3.8
	Collective enterprises	0.2	0.1	0.0	0.0	0.1
	Private enterprises	0.0	0.0	0.0	0.0	0.0
	Other	1.2	3.0	0.0	0.0	1.4
Export	State-owned enterprises	97.8	99.8	100.0	98.5	98.3
	Sino-foreign contractual joint venture	0.0	0.0	0.0	0.0	0.0
	Sino-foreign equity joint venture	0.0	0.0	0.0	0.0	0.0
	Foreign-owned enterprises	2.1	0.2	0.0	1.5	1.6
	Collective enterprises	0.0	0.0	0.0	0.0	0.0
	Private enterprises	0.0	0.0	0.0	0.0	0.0
	Other	0.1	0.0	0.0	0.0	0.0

Source: Same as Figure 1

Table 3. Composition of China's Horticultural Trading Enterprises (2002)

	Type of Enterprise	Vegetables, nuts, fruits, and products (%)	Coffee, tea, cocoa, and spices (%)	Tobacco (%)	Plant Fibers (%)	Total (%)
Import	State-owned enterprises	58.0	53.7	98.5	50.2	64.9
	Sino-foreign contractual joint venture	0.7	2.7	0.0	0.0	0.6
	Sino-foreign equity joint venture	7.6	17.9	1.5	27.8	9.0
	Foreign-owned enterprises	6.7	21.6	0.0	7.8	6.0
	Collective enterprises	8.5	0.8	0.0	9.7	6.7
	Private enterprises	18.4	3.2	0.0	4.4	12.8
	Other	0.0	0.0	0.0	0.1	0.0
Export	State-owned enterprises	49.9	63.3	99.7	84.9	53.6
	Sino-foreign contractual joint venture	2.1	1.3	0.0	0.0	1.9
	Sino-foreign equity joint venture	18.0	8.3	0.3	11.4	16.1
	Foreign-owned enterprises	16.3	9.0	0.0	0.0	14.7
	Collective enterprises	5.4	10.3	0.0	3.5	5.7
	Private enterprises	8.3	7.9	0.0	0.2	7.9
	Other	0.0	0.0	0.0	0.0	0.0

Source: Same as Figure 1

China's Horticultural Trade Patterns

In this section, we study the persistence of China's horticultural trade patterns at the disaggregate level to fully examine the question of whether or not China's trade patterns have changed dramatically for this industry.

China's horticultural trade statistics are derived from China's Customs data. These trade data are disaggregated at the 4-digit Standard International Trade Classification (SITC) level, so the effects of intra-industry trade are presumably eliminated.

Nominal trade data often reflect trends in macroeconomic factors such as inflation, growth, business cycles, and macroeconomic imbalances. In order to eliminate the effects of these factors and to capture the changes resulting from shifting comparative advantage, the trade data are first normalized. Following the methodology developed by Gagnon and Rose (1995), the normalized trade balance (NB) for commodity group *i* at time *t* is defined as:

$$NB_{it} \equiv \left(\frac{X_{it}}{\sum_i X_{it}} - \frac{M_{it}}{\sum_i M_{it}} \right) \rangle$$

Where X_{it} denotes the value of exports of subgroup *i* at time *t*, and M_{it} is the value of imports. The sum of NB_{it} is zero for any given year. After the data are normalized, the *NB* subgroups are then classified into three categories for each year: namely, trade surplus, trade balance, or trade deficit. Subgroups in trade surplus are defined as those goods whose NB is greater than one standard deviation above zero. Those subgroups with a *NB* within one standard deviation of zero are classified as being in balance. Finally, those subgroups with a value of NB more than one standard deviation below zero are classified as being in a trade deficit. As part of this classification procedure, the standard deviation is computed for each commodity's NB series.

After normalizing and categorizing each NB subgroup, we construct the two-way trade tables to examine changes in the direction of trade between the beginning period and ending period of the sample. Two-way tables provide a breakdown of trade values by the initial and final trade balance. In Table 4, China's horticultural trade value is broken down according to the initial period and ending period trade status. For the initial period, we chose a three-year period centered on 1989 and for the final period the three-year mean is centered on 2000 to eliminate any end-point erratic swings. The results in Table 4 suggest that for horticulture, the subgroups that were in surplus in 1988-90 accounted for 35.9% of the value of normalized horticultural trade in 1999-2001. Of these goods in surplus, subgroups accounting for 0.1% of the end-of-period trade moved to a balance, and a negligible percent of those goods moved to a trade deficit. At the same time, no trade categories moved from a deficit to a surplus. If we add up the diagonal elements in Table 4, we find that 62% of China's horticultural trade in the initial period had not changed its trade status by the end of the study period. Clearly, China's horticultural trade patterns have been quite persistent.

More rigorous statistical techniques yield consistent results. The Chi-square (χ^2) is 65.8, much higher than the critical value at the 99% significance level, indicating that categories ending in surplus are not distributed independently of those beginning in surplus. As a statistical measure of trade persistence, we also compute a transformation of the standard chi-squared test, Cramer's C-statistic, suggested by Carolan, Singh, and Talati (1998). The C-statistic lies between zero and one, with one representing complete association between the beginning and the ending trade balance. The calculated C-statistic is 0.57 for China's horticultural trade, also suggesting a persistent trade pattern rather than a dynamic pattern.

Table 4. Breakdown of 1999-2001 Horticultural Trade, China

	1999-2001 Surplus	**1999-2001 Balance**	**1999-2001 Deficit**	**1999-2001 Total**
1988-90 Surplus	35.8	0.1	0.0	35.9
1988-90 Balance	11.5	14.4	22.8	48.8
1988-90 Deficit	0.0	3.8	11.5	15.3
1988-90 Total	47.3	18.3	34.3	100.0
χ^2	65.8			
C-statistic	.57			
Observations	42			

To address the issue of smuggling from Hong Kong, we construct another two-way table (Table 5), which includes Hong Kong. Even stronger persistence appears if we include Hong Kong in the analysis. The subgroups that were in surplus in 1988-90 accounted for 34.4% of the value of normalized horticultural trade in 1999-2001. The share of trade that moved from a deficit to a surplus or from a surplus to a deficit is negligible. Summing up the diagonal elements in Table 5, we find that 65% of the trade in horticulture was persistent, which is higher than the 62% in Table 4. The Chi-square is higher than the critical value at the 99% significance level, and the C-statistic is larger than 0.5, indicating dependence of the ending period horticultural trade status on the initial period trade status. These measurements are also higher than those in Table 4.

Table 5. Breakdown of 1999-2001 Horticultural Trade, Adjusting for Smuggling

	1999-2001 Surplus	**1999-2001 Balance**	**1999-2001 Deficit**	**1999-2001 Total**
1988-90 Surplus	30.7	3.7	0.0	34.4
1988-90 Balance	14.8	0.2	10.8	25.7
1988-90 Deficit	0.0	5.7	34.2	39.9
1988-90 Total	45.5	9.5	45.0	100.0
χ^2	66.8			
C-statistic	.58			
Observations	42			

Rather than just comparing the beginning and the ending period, we also construct histograms to examine the intervening years. Histograms are drawn based on the number of years each commodity runs a surplus. For example, a commodity that was in surplus in each of the 14 years would be in the cell at the extreme right of the histogram. The bi-modality of the histogram in Figure 4 reveals that China's horticultural trade pattern is persistent over the period of 1988-2001, with 72% of trade in surplus either 0 or 14 years. Adjusting for smuggling, the bi-modality is still striking (Figure 5), with the fraction of trade in surplus either 0 or 14 years at 68%. The histograms, therefore, provide further evidence that China's horticultural trade patterns have been quite persistent during the studied time period.

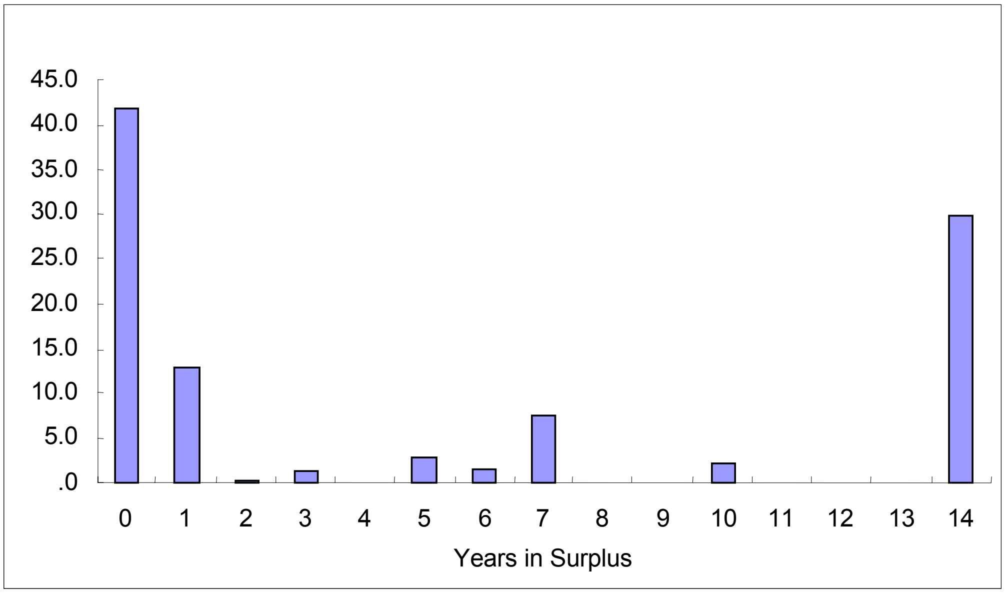

Figure 4. Weighted Horticultural Histogram: China, 1988-2001

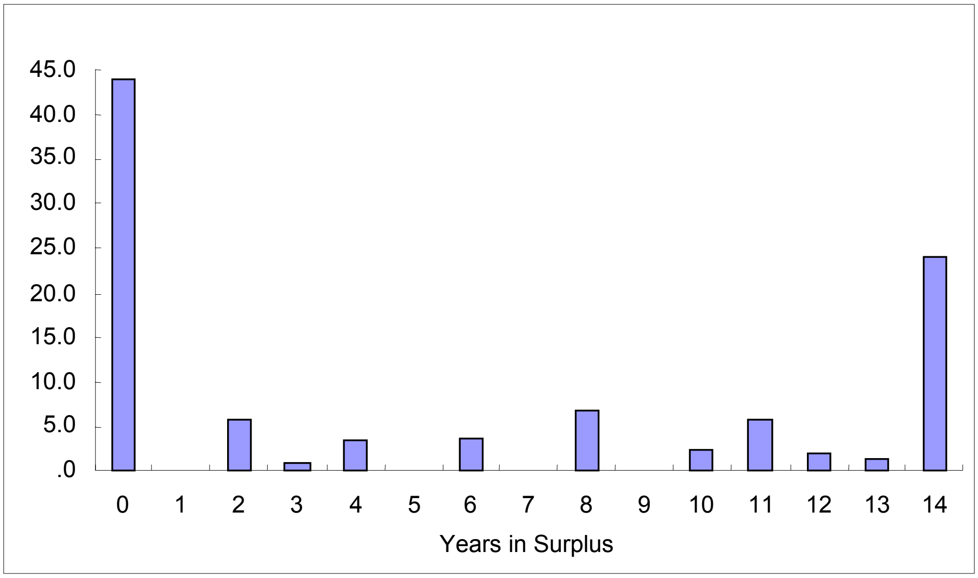

Figure 5. Weighted Horticultural Histogram: China adjusted for smuggling, 1988-2001

Additional information is obtained by regressing NB for the ending period on NB for the initial period. The results are reported in Table 6. In both cases, the regression slope coefficients are statistically significant. If we take into account smuggling, the slope coefficient is much higher and the correlation coefficient, R^2, is also larger. These results are therefore consistent with the two-way table analysis and show that China's horticultural trade patterns are more persistent if we account for smuggling through Hong Kong.

Table 6. Regression Results: $NB_{1999\text{-}2001}$ on $NB_{1988\text{-}90}$

	China	**China and Hong Kong**
Intercept	0	0
(t Stat)	(0)	(0)
X Coefficient	0.71	0.98
(t Stat)	(5.97)	(7.08)
R^2	0.47	0.56
Observations	42	42

Conclusion

An abundant rural labor force, together with favorable agronomic conditions, gives China a strong comparative advantage in horticultural products. Due to economic reform and market forces, a large amount of land has recently shifted from grains to higher valued horticultural crops in China. Consequently, horticultural output increased rapidly and China is currently the largest horticultural producer in the world. At the same time, China's high per capita income growth led to a sharp rise in domestic demand for horticultural products.

The role of state trading in China's horticultural products has declined, and this has contributed to the growth of China's horticultural trade. However, China remains a moderate player in the international horticultural market. The growth rates of China's horticultural real exports, real imports and real net exports over the 1988-2002 time period were 0.7%, 3.9%, and 0.1%, respectively. Vegetables, fruits and their processed products are the most important trade category. Eliminating the effects of some important macroeconomic factors, our analysis at the disaggregate level suggests that China's horticultural trade patterns have not changed much since 1988. After accounting for smuggling through Hong Kong, even stronger persistence is found in China's horticultural trade patterns.

The persistence in China's horticultural trade can be partly attributed to the fact that worldwide protectionism in horticultural trade has remained exceptionally high. In addition, increasing domestic demand absorbed most of the increase in China's horticultural production, which may have also contributed to the sluggish growth of China's exports. Moreover, these results suggest that China's comparative advantage in horticulture may not be fully realized, and the impacts of China's WTO accession on China's horticultural trade could be significant. As a result, the world horticultural market will be changed.

Appendix 1

Definition of Horticultural Products in this Study

Vegetable, nuts, fruit, and their products

0541-Potatoes, fresh or chilled (not including sweet potatoes)
0542-Beans, peas, lentils and other leguminous vegetables
0544-Tomatoes,fresh or chilled
0545-Other fresh or chilled vegetables
0546-Vegetables, frozen or in temporary preservative
0548-Vegetable products, roots and tubers, for human food
054X-Vegetable products, fresh, chilled, frozen/preserved; roots, tubers, not elsewhere specified (n.e.s.)
0561-Vegetables,dried,dehydrated or evaporated
0564-Flours, meals and flakes of potatoes, fruits and vegetables
0565-Vegetables, prepared or preserved, n.e.s.
056X-Vegetables, roots and tubers, prepared/preserved, n.e.s.
0571-Oranges, mandarins, clementines and other citrus
0572-Other citrus fruit, fresh or dried
0573-Bananas, fresh or dried
0574-Apples, fresh
0575-Grapes, fresh or dried
0576-Figs, fresh or dried
0577-Edible nuts (exclude nuts used for the extract of oil)
0579-Fruit, fresh or dried, n.e.s.
057X-Fruit and nuts (not include oil nuts), fresh or dried, n.e.s.
0582-Fruit, fruit-peel and parts of plants, preserved by sugar
0583-Jams, fruit jellies, marmalades, fruit puree, cooked
0585-Juices; fruit and vegetables (including grape must) unfermented
0586-Fruit, temporarily preserved
0589-Fruit otherwise prepared or preserved, n.e.s.
058X-Fruit, preserved, and fruit preparations, n.e.s.
2922-Shellac, seed lac, stick lac, resins, gum-resins, etc.
2923-Vegetable materials of a kind used primarily for plaiting
2924-Plants, seeds, fruit used in perfumery, pharmacy
2925-Seeds, fruit and spores, n.e.s., of a kind used for sowing
2926-Bulbs, tubers and rhizomes of flowering or of foliage
2927-Cut flowers and foliage
2929-Other materials of vegetable origin, n.e.s.
292X-Crude vegetable materials, n.e.s.
05XX-Vegetables and fruit, n.e.s.

Coffee, tea, cocoa, spices

0711-Coffee, whether or not roasted or freed of caffeine
0712-Extracts, essences/concent.of coffee and chicory
071X-Coffee and coffee substitutes, n.e.s.

0721-Cocoa beans, whole or broken, raw or roasted
0741-Tea
074X-Tea and mate, n.e.s.
0751-Pepper ; pimento
0752-Spices (except pepper and pimento)
07XX-Coffee, tea, cocoa, spices, manufactures

Tobacco

1211-Tobacco,not stripped
1212-Tobacco,wholly or partly stripped
1213-Tobacco refuse
121X-Tobacco,unmanufactured; tobacco refuse, n.e.s.

Plant Fibers

2640-Jute and other textile bast fibers, n.e.s., raw/processed
2651-Flax and ramie, flax tow, ramie noels, and waste
2652-True hemp, raw or processed, not spun; tow and waste
2654-Sisal and other fibres of agave family, raw or processed
2655-Manila hemp, raw or processed, not spun; tow and waste
2659-Vegetable textile fibers, n.e.s. and waste

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BAYESIAN ESTIMATION OF THE DOUBLE HURDLE MODEL IN THE PRESENCE OF FIXED COSTS

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Abstract

We present a model of market participation in which the presence of non-negligible fixed costs leads to random censoring of the traditional double-hurdle model. Fixed costs arise when household resources must be devoted *a priori* to the decision to participate in the market. These costs, usually of time, are manifested in non-negligible minimum-efficient supplies that require modification of the traditional Tobit regression. The costs also complicate econometric estimation of household behavior. These complications are overcome by application of the Gibbs sampler. The algorithm thus derived provides robust estimates of the fixed-costs, double-hurdle model. The model and procedures are demonstrated in an application to milk market participation in the Ethiopian highlands.

Keywords: market participation, fixed costs, random censored double-hurdle regression, Gibbs sampling.

In a classic paper, Cragg (1971) develops a model with two-part, non-sequential decision-making.

> "The basic situation being considered is as follows. There is an event which at each observation may or may not occur. If it does occur, associated with it will be a continuous, positive random variable. If it does not occur, this variable has a zero value." (Cragg, 1971, p. 829)

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This construct, commonly referred to as the double-hurdle model, has received extensive attention in the literature on habit formation (see especially Jones (1989) and Labeaga (1992)), the literature on food demand (see, for examples, Haines, Guilkey and Popkin (1988), Yen and Huang (1996) and Lin and Milon (1993)) and the literature on labor supply (see Smith (2002) for a fairly extensive list of applications to labor-market phenomena). The double-hurdle model has been used less extensively to model agricultural commodity supply decisions (see Mundlak (2002) for a comprehensive list of applications) and, to our knowledge, has rarely been applied to model subsistence household decision-making where market participation is at issue (Goetz (1992) and Key, Sadoulet and de Janvry (2000) are two notable empirical applications in this regard).

This paucity of applications in the development literature is somewhat surprising. Barriers to entry—perceived or real—are significant impediments to expanding the density of market participation (Stiglitz, 1989). Improving our understanding of the many complexities impeding the transition from subsistence to market-oriented production is important to understanding the path of agricultural development and economic growth. In this context, the potential significance of pecuniary or non-pecuniary fixed costs to market participation cannot be over-emphasized. Households commonly incur fixed costs in making the decision to trade in a market. These costs can involve cash expenditures, such as a fixed fee to enter a market in order to sell product. More commonly, the fixed costs of market participation involve time spent in search for and screening of counterpart transactors and in negotiating and enforcing contracts (Staal, Delgado and Nicholson, 1997). Such costs are known to exist irrespective of transactions volume and surely affect the decision about how much quantity to supply to the market (see Cogan (1981) for an example in a neoclassical model of labor supply). Yet the standard estimation of market supply equations fails to account for these fixed costs.

The purpose of this paper is to show explicitly how these costs can be accounted for in the classic double-hurdle setting proposed by Cragg (1971); how they pose particular difficulties in deriving inferences from the model thus derived; and how these difficulties are overcome through a fairly routine application of Markov chain Monte Carlo (MCMC) methods—Gibbs sampling, in particular—applied to data on participation decisions by subsistence households. In this regard, our principal objectives in this contribution are two. The first is to outline essential extensions of Cragg's double hurdle model to explicitly incorporate fixed costs. The second is to derive a robust estimation algorithm for applying the model to a prototypical data set on market participation and supply decisions.

In the next section of the paper we revisit the classic double-hurdle model and present the two extensions. In section three we present the estimation algorithm. In section four we present the application to the Ethiopian data and discuss the results. Conclusions are offered in section five.

The Traditional Double Hurdle Model and Extensions

The traditional setup is presented as equations (5) and (6) in Cragg (1971), where he discusses Tobin's (1958) supply presentation. Consider the Tobit model and, explicitly, for each i = 1, 2, .., N, consider the 'supply' equation

$$z_{si} = \mathbf{x}_{si}'\boldsymbol{\beta}_s + u_{si}, \qquad (1)$$

where $u_{si} \sim N(0, \sigma)$ and we observe $y_{si} = \max\{0, z_{si}\}$. In other words, suppose that a latent variable, z_{si}, is related to a K-vector of covariates $\mathbf{x}_{si}'$ through an unknown K-vector $\boldsymbol{\beta}_s$ and a normally-distributed random error term u_{si}. If the value z_{si} is positive we observe $y_{si} = z_{si}$ (positive supply) and if z_i is negative we observe $y_{si} = 0$ (zero supply). As Cragg (1971, pp. 830-31) notes (parentheses added):

> "While acquisition (y_{si}) may occur only when desired acquisition (z_{si}) is, in some sense, positive, there may be factors such as search, information and transactions costs which inhibit the carrying-out of desired plans. In such circumstances, failure for the variable to take on non-zero values may arise either because the desired change is not positive or because other factors inhibit carrying out changes which would be desired in their absence.
>
> We may model this sort of situation in several ways. First, desired acquisition may be represented by .. (equation (1)). .. If (z_{si}) is positive, .. (y_{si}) .. may still be zero because it has been decided not to carry out the adjustment. This aspect might be represented by a probit model. Then the probability that .. (y_{si}) .. is zero is the sum of the probabilities that .. (z_{si}) .. is negative plus the probability that the inhibition will be effective when .. (z_{si}) .. is positive .."

In other words, if we let y_{pi} denote another latent variable relevant to the participation decision and consider the probit regression

$$y_{pi} = \mathbf{x}_{pi}'\boldsymbol{\beta}_p + u_{pi}, \qquad (2)$$

where $\mathbf{x}_{pi}'$ denotes a vector of observations affecting participation, $\boldsymbol{\beta}_p$ denotes a corresponding vector of unknown coefficients and u_{pi} denotes a standard normal random variable, then the probability that y_{si} is zero can be written

$$\wp(y_{si} = 0) = \Phi(-\mathbf{x}_{si}'\boldsymbol{\beta}_s/\sigma) + \Phi(\mathbf{x}_{si}'\boldsymbol{\beta}_\mathbf{s}/\sigma)\ \Phi(-\mathbf{x}_{pi}'\boldsymbol{\beta}_\mathbf{p}) \qquad (3)$$

where $\Phi(\cdot)$ denotes the cumulative distribution function corresponding to the standard normal distribution. Correspondingly, the density for positive values of y_{si} is just the conditional normal probability density function multiplied by the probability that participation occurs. In other words,

$$f(y_{si}) = (2\pi)^{-.5}\ \sigma^{-1} \exp\{\ -.5\ \sigma^{-2}\ (y_{si} - \mathbf{x}_{si}'\boldsymbol{\beta}_s)'\ (y_{si} - \mathbf{x}_{si}'\boldsymbol{\beta}_s)\ \}\ \Phi(\mathbf{x}_{pi}'\boldsymbol{\beta}_p). \qquad (4)$$

As Cragg (1971, p. 831) goes on to note:

> "In this model two hurdles have to be overcome before positive values of .. (y_{si}) .. are observed. First, a positive amount has to be desired. Second, favourable circumstances have to arise for the positive desire to be carried out."

The two extensions that we propose are that the desired output equals observed output if and only if the desired amount exceeds some threshold level, say θ, and that the errors in the probit and Tobit components may be correlated. The strategy is to form a multivariate regression in the latent $\mathbf{z}_i \equiv (z_{pi}, z_{si})'$, derive conditional distributions for the parameters given the $\mathbf{z}_i$ and then derive distributions for the $\mathbf{z}_i$ conditional on the parameters. Two variants of the model emerge. One version assumes that the covariate vectors $\mathbf{x}_{si}$ and $\mathbf{x}_{pi}$ are different (participation and supply decisions depend upon different factors) and the other assumes that they are the same. In the first case, which may be more appropriate in certain situations, the latent-variables regression reverts to Zellner's seemingly-unrelated regressions formulation and in the second situation the model reverts to a traditional multivariate regression. It turns out that both situations can be easily handled using the Gibbs sampler (see Percy (1992) and Chib and Greenberg (1995) for discussion). Because our empirical application employs the latter formulation, we restrict attention to the multivariate regression:

$$\mathbf{z} = \mathbf{x}\,\boldsymbol{\beta} + \mathbf{u} \tag{5}$$

where $\mathbf{z} \equiv (\mathbf{z}_p, \mathbf{z}_s)$, $\mathbf{z}_p \equiv (z_{p1}, z_{p2}, .., z_{pN})'$, $\mathbf{z}_s \equiv (z_{s1}, z_{s2}, .., z_{sN})'$; $\mathbf{x} \equiv \mathbf{x}_p \equiv \mathbf{x}_s \equiv (\mathbf{x}_1, \mathbf{x}_2, .., \mathbf{x}_N)'$, $\mathbf{x}_1 \equiv (x_{11}, x_{12}, .., x_{1K})$, $\mathbf{x}_2 \equiv (x_{21}, x_{22}, .., x_{2K})$, .., $\mathbf{x}_N \equiv (x_{N1}, x_{N2}, .., x_{NK})$; $\boldsymbol{\beta} \equiv (\boldsymbol{\beta}_p, \boldsymbol{\beta}_s)$, $\boldsymbol{\beta}_p \equiv (\beta_{p1}, \beta_{p2}, .., \beta_{pK})'$, $\boldsymbol{\beta}_s \equiv (\beta_{s1}, \beta_{s2}, .., \beta_{sK})'$; and $\mathbf{u} \equiv (\mathbf{u}_p, \mathbf{u}_s)$, $\mathbf{u}_p \equiv (u_{p1}, u_{p2}, .., u_{pN})'$, $\mathbf{u}_s \equiv (u_{s1}, u_{s2}, .., u_{sN})'$. We assume that the rows of $\mathbf{u}$ are independent, each with a two-dimensional null vector mean and covariance given by the positive definite symmetric matrix Σ wherein (due to the usual identification problem in probit regression) the upper left component is restricted to be equal to one. The model is estimated with this restriction imposed.

With these details at hand, under a conventional, non-informative prior $\pi(\Sigma, \beta) \propto |\Sigma|^{-(m+1)/2}$, the full conditional distributions comprising the joint posterior for the unknown parameters and the latent data, $\pi(\Sigma, \boldsymbol{\beta}, \mathbf{z}_p, \mathbf{z}_s \mid \mathbf{y})$, have the respective forms

$$\begin{array}{rl}
z_p \mid \Sigma, \boldsymbol{\beta}, \mathbf{z_s} & \sim \text{Truncated-Normal}(Ez_p, Vz_p), \\
\mathbf{z_s} \mid z_p, \Sigma, \boldsymbol{\beta} & \sim \text{Truncated-Normal}(Ez_s, V\mathbf{z_s}), \\
\boldsymbol{\beta} \mid \mathbf{z_s}, z_p, \Sigma & \sim \text{Multivariate-Normal}(E\boldsymbol{\beta}, V\boldsymbol{\beta}), \\
\Sigma \mid \boldsymbol{\beta}, \mathbf{z_s}, z_p & \sim \text{Inverted-Wishart}(W, v);
\end{array} \tag{6}$$

where $E\mathbf{z}_p \equiv \mathbf{x}\,\boldsymbol{\beta}_p + \Sigma_{ps}\,\Sigma_{ss}^{-1}\,(\mathbf{z_s} - \mathbf{x}\,\boldsymbol{\beta}_s)$, $\mathbf{V}\mathbf{z}_p \equiv \Sigma_{pp} - \Sigma_{ps}\,\Sigma_{ss}^{-1}\Sigma_{sp}$; $E\mathbf{z_s} \equiv \mathbf{x}\,\boldsymbol{\beta}_s + \Sigma_{sp}\,\Sigma_{pp}^{-1}\,(\mathbf{z}_p - \mathbf{x}\,\boldsymbol{\beta}_s)$, $\mathbf{V}\mathbf{z_s} \equiv \Sigma_{ss} - \Sigma_{sp}\,\Sigma_{pp}^{-1}\Sigma_{ps}$; $E\boldsymbol{\beta} \equiv (\mathbf{x}'\mathbf{x})^{-1}\mathbf{z}$, $V\boldsymbol{\beta} \equiv \Sigma \otimes (\mathbf{x}'\mathbf{x})^{-1}$; $\mathbf{W} \equiv (\mathbf{z} - \mathbf{x}\,\boldsymbol{\beta})'(\mathbf{z} - \mathbf{x}\,\boldsymbol{\beta})$, $v \equiv N-k+m+1$; and the 2×2 matrix Σ has (scalar) components $\Sigma_{pp} = 1$, $\Sigma_{ps} = \Sigma_{sp}$ and Σ_{ss}. Consequently, simulations from the joint posterior can be undertaken through the algorithm:

Step 1: Select starting values $\mathbf{z}_p^{(s)}$, $\mathbf{z}_s^{(s)}$, $\boldsymbol{\beta}^{(s)}$.
Step 2: Draw $\boldsymbol{\Sigma}^{(s)}$ from the inverted-Wishart distribution.
Step 3: Draw $\boldsymbol{\beta}^{(s+1)}$ from the Multivariate-Normal distribution.
Step 4: Draw $\mathbf{z}_p^{(s+1)}$ from the Truncated-Normal distribution.
Step 5: Draw $\mathbf{z}_s^{(s+1)}$ from the Truncated-Normal distribution.

The algorithm is run for a predetermined number of times—commonly referred to as a 'burn-in'—after which samples $\{\boldsymbol{\Sigma}^{(g)}\ g = 1, 2, ..\ G\}$, $\{\boldsymbol{\beta}^{(g)}\ g = 1, 2, ..\ G\}$, $\{\mathbf{z}_p^{(g)}\ g = 1, 2, ..\ G\}$ and $\{\mathbf{z}_s^{(g)}\ g = 1, 2, ..\ G\}$ are collected. Inference about scales and locations of parameters is obtained from the collected samples. Three additional features of the algorithm are necessary for convergence. First, due to identification problems, the draw from the inverted-Wishart in step 2 is normalized on the parameter Σ_{pp}. Second, only a component of the vector $\mathbf{z}_s$, corresponding to the households in the censor set, are drawn from the conditional normal distribution and the draws for both $\mathbf{z}_p$ and $\mathbf{z}_s$ from steps 4 and 5, respectively, are made in accordance with the sign restrictions implied by the observed data. Finally, the samples collected in the last step can be used to draw inferences about any of the unknown quantities of interest. In the results reported below, the algorithm is run for a burn-in phase of $S^1 = 2{,}000$ observations followed by a collection phase of $S^2 = 2{,}000$ observations. Experiments suggest that these modest sample sizes are sufficient for convergence.

In closing this section it seems natural to ask the extent to which the well-known problem of sample selection bias may be problematic and whether there is need to apply correction procedures, such as those outlined in Heckman (1976, 1979) or Puhani (2000) and applied in Goetz (1992). Sample selection could arise in our context, in considering the effect upon sales of an increase in a level of a covariate, where some individuals who possess the covariate do not sell product. Had those individuals who do not sell been excluded from the sample then a selection bias exists due to the fact that only those respondents selling product are used to form an estimate of the response to the covariate. For example, if the covariate in question is related positively to sales, then only those respondents with a relatively strong response to the covariate will be included, leading to an upwards bias in the corresponding parameter estimate. However, because a latent (negative) sales quantity is simulated for each of the non-participating households and used as the dependent variable in a subsequent estimation step, no such bias exists. In short, the problem of sample selection bias is conveniently circumvented through the data-augmentation step in the Gibbs algorithm. In addition, related identification problems arising in frequentist applications, like the need to include non-identical covariate matrices in the probit and Tobit equations (as, for example, in Goetz (1992)) are similarly circumvented. Hence the Markov-chain Monte Carlo procedure appears to offer some attractive features.

The Complicating Presence of Fixed Costs

Given the layout of the model, together with its explicit conditional distributions, the extension to include a threshold below which zero supply occurs is now straight-forward. The presence of fixed costs, may or may not influence the participation decision but they are likely to influence the quantity decision. This is perhaps most apparent in the observation that, at least at the household level, trade is commonly discontinuous in time, with individual households selling in some periods and not selling in others. Plainly, such a household is a market participant, although it opts for zero sales volume in some periods. Put differently, the good it sells is *tradable* from its perspective even if it is not always *traded*. This is conceptually akin to households adopting a new technology, then discontinuing its use at some future date(s) when it proves unprofitable (Cameron, 1999). Consequently, the threshold level, θ, becomes the true point of censoring in the Tobit regression. It follows that θ becomes an additional parameter in the model and must be estimated, along with the system parameters $\boldsymbol{\Sigma}$ and $\boldsymbol{\beta}$, the latent $\mathbf{z}_p$ and the latent components of $\mathbf{z}_s$.

Holloway *et al*. (2004) consider the importance of non-zero censoring in an experimental setting using different approaches to justify alternative ranges of boundary values for the threshold parameter, θ. While each of the non-zero censoring alternatives appear to provide more accurate estimates of the tobit regression coefficients, the question remains as to the exact distribution of the threshold parameter. Here we derive its exact distribution.

The answer to this question lies embedded in a previous work (Albert and Chib, 1993) that has been extremely influential in show-casing the advantages of the Gibbs sampler in previously intractable problems in Bayesian estimation. The double hurdle model is yet another example. Some tedious algebra (available upon request) shows an explicit linkage between the ordered-probit model in Albert and Chib (1993) and the double-hurdle model with a random censoring point in the tobit regression. Specifically, in terms of the notation just established, we can conclude that the fully conditional distribution for θ is uniform on the interval $[\max\{z_{si}, i\in\mathbf{c}\}, \min\{z_{si}, i\notin\mathbf{c}\}]$, where $\mathbf{c} \equiv \{i \mid y_i = 0\}$ denotes the censor set. The bounds on the interval of this uniform distribution are quite intuitive. The left bound is simply the greatest value of latent sales from the non-participating household and the right bound is the minimum quantity of sales observed by the participating households. Consequently, the random censoring point, θ, can be estimated with a few basic modifications to the algorithm above. Essentially, three modifications are required. The first modification is to select, in Step 1, a starting value $\theta^{(s)}$. We select the minimum sales quantity observed, i.e., the upper bound of the feasible range for θ. Second, the draws in steps 2-4 are now conditional on the chosen value $\theta^{(s)}$. Third, below step 5, insert the additional step: Step 5a: Draw $\theta^{(s+1)}$ from the uniform distribution with bounds $[\max\{z_{si}^{(s+1)}, i\in\mathbf{c}\}, \min\{z_{si}, i\notin\mathbf{c}\}]$, where $\max\{z_{si}^{(s+1)}, i\in\mathbf{c}\}$ implies conditioning on the maximum component of $\mathbf{z}_s^{(s+1)}$ in step 5 and where $\min\{z_{si}, i\notin\mathbf{c}\}$ denotes the minimum sales quantity observed in the data.

In summary, a simple extension of the multivariate, latent-regression algorithm can be exploited to derive robust estimates of the double-hurdle model in the presence of fixed costs.

The Application

A background to the empirical application is presented in Holloway *et al.* (2004), which employs a different data set collected from the same households, and in Nicholson (1997). Early in the 1997 production year a sample of 68 households was selected based on their stratification of cross-bred cow ownership and their physical location relative to two milk cooperatives. Three visits were made to each household during the year, and at each visit weekly sales of fluid milk to the milk cooperatives were obtained from co-op records. Demographic, nutritional and socioeconomic characteristics of the households were recorded. The analysis focuses on the determinants of weekly sales of fluid milk at each of the 3 visits, a sample size of 204 observations. The choice of variables guiding the empirics follow from examination of previous work with subsistence households in diverse contexts (see, for example, Bellemare and Barrett (2004) and the works they cite) and from prior enquiry exploring different objectives with different data obtained from the same households (Holloway *et al.,* 2004). The seven covariates that are particularly influential in explaining milk production and marketing are (1) numbers of indigenous milking cows, (2) numbers of crossbred milking cows, (3) minutes, return time, to transport bucketed fluid milk to the milk cooperative, (4) years of formal schooling by household members, (5) the number of total visits by an extension agent discussing production and marketing practices, (6) a site-specific dummy variable corresponding to the 'Ilu-Kura' sample site (about 60 miles south-west of Addis Ababa) and (7) and a site-specific dummy variable corresponding to the Mirti sample site about (about 140 miles north-east of the capital city). Of the 204 observations, 20 correspond to participants and 79 correspond to non-participants at the Ilu-Kura site; 5 correspond to participants and 100 correspond to non-participants at the Mirti site. The potential significance of examining milk-price variation is precluded by the fact that prices are fixed at 1.00 and 1.25 Ethiopian birr, respectively, at the Ilu-Kura and Mirti sites. Thus, the specific impacts of inter-site variability in pricing are absorbed within site differentials corresponding to the two dummy variables. This variation, however, is likely of less importance than the inter-site variation in key covariates and the intra-site variations in weekly sales and daily production across participation status. Table 1 presents summary statistics across the two sites. Most noticeable in the table is the high degree of variability recorded in the weekly sales quantities, raising the inevitable question about the ability of the double-hurdle formulation to explain sales variability.

Table 1. Characteristics of households, by site

	Sample Means (and standard errors)	
	Ilu-Kura	**Mirti**
Sales, per week, per participant, liters	29.93	17.04
	(21.10)	(12.72)
Production, per day, per participant, liters	8.73	4.06
	(5.10)	(3.49)
Production, per day, per non-participant, liters	2.68	2.56
	(2.43)	(1.54)
Fluid milk price, per liter, Ethiopian birr	1.00	1.25
Distance to the milk group, minutes	53.12	36.00
	(34.89)	(19.02)
Education, years	0.36	3.37
	(1.23)	(3.99)
Crossbreed cows	0.62	0.58
	(0.88)	(0.70)
Local breed cows	1.49	1.31
	(1.06)	(1.16)
Extension visits	1.82	0.36
	(2.77)	(0.81)

Results

Results of the Gibbs-sampling, data-augmentation algorithm applied to these 204 observations are presented in table 2. The first column presents definitions and the remaining columns present the posterior means of the parameters in the multivariate probit-Tobit systems under traditional and non-zero censoring, respectively. Auxiliary statistics are reported in the lower portion of the table. The mnemonics in the first column refer, respectively, to θ ('Censor value'); minutes return time to transport bucketed-fluid milk to the milk cooperative ('Distance'); years of formal schooling by the household head ('Education'); the number of crossbreed cows being milked at the survey date ('Crossbred'); the number of indigenous-breed cows milked at the survey date ('Local'); the total number of visits in the twelve months prior to the survey date by an extension agent discussing production and marketing practices ('Extension'); a binary variable corresponding to the Ilu-Kura survey site (equals 1 if respondent is from Ilu-Kura and equals 0 otherwise); and a binary variable corresponding to the Mirti survey site (equals 1 if respondent is from the Mirti survey site and equals 0 otherwise). Numbers in parentheses below the parameter estimates are lower and upper bounds for the 95% highest-posterior density regions.

Considering, first, the traditional formulation with zero censoring in the Tobit regression, each of the parameter estimates are significant at the 5% significance level. (None of the 95% highest posterior density regions contains zero.) The signs of the posterior means all have the expected impact. Market participation is promoted by education, cow ownership and the level of extension services, but is mitigated by distance to market. Sales are also increased by the intellectual capital stock (education and extension visitation) and the animal stock (local and crossbreed animals) but is reduced by distance to market.

An important result in the context of two-step decision-making is the possibility that errors are correlated. Previous work (most notably, Key, Sadoulet and de Janvry (2000)) assumes independence. The estimated covariance parameters suggest strongly that the participation and the sales decisions are significantly positively correlated. Other features of the traditional model are the relatively large degree of variability in the sales equation error variance (posterior mean estimate of 1047.40 liters of milk per household per week); outstanding predictive performance among the non-participating 'households' (179 of the 204 total observations); but less satisfactory fit in the participating sample (25 observations in total). Because 85% of the sample observations are censored, the poor prediction in the participating sample is somewhat expected due to small sub-sample size. But the large error variance in the sales equation suggests that a number of other omitted factors may be responsible for weekly sales variability.

Before turning to examine differences between the first formulation and the formulation that does not restrict the censoring value to be zero, a word about the covariate 'Distance' seems in order. Recall that the purpose of relaxing the zero-restriction on the censoring value is to attempt to capture the importance of fixed costs and their effect on the minimum efficient supply quantity. There may be grounds for suspecting double counting with reference to some of the covariates. For example, it is certainly true that there is a fixed cost related to distance (e.g., the cost of transporting the individual, not the milk, to market). In this case, it may be argued that the covariate 'Distance' is capturing both proportional and fixed transactions costs. Put differently, θ may understate the fixed cost of market participation because of the distance-related fixed cost. Identification of proportional costs and separating them out from their corresponding contributions to fixed costs is problematic, as emphasized by Key, Sadoulet and de Janvry (2000). Whether it is possible to perform a similar decomposition using the current estimation strategy remains an interesting issue for possible extensions of the current effort.

Turning to the second, non-zero censoring formulation, the most interesting comparisons are three. First, the posterior mean estimate of the censor value suggests that the minimum efficient scale of operations for the household is a resource base consistent with delivery of 5.26 liters of milk per week for a household located at the market delivery point. Note, also that this estimate is measured at a considerable degree of precision (with 95% highest-posterior-density bounds of 3.75 and 5.97, respectively). Hence, one important conclusion emerging from the exercise is that a significant bias results from restricting the censor value to be zero.

Table 2. Double-Hurdle Model Equation Estimates

	Model			
	Zero Censoring		**Non-Zero Censoring**	
	Participation	**Sales**	**Participation**	**Sales**
Censor Value				5.26
				(3.75, 5.97)
Distance	-0.02	-0.46	-0.02	-0.31
	(-0.03, -0.01)	(-0.76, -0.17)	(-0.05, -0.01)	(-0.51, -0.12)
Education	0.17	4.21	0.22	2.59
	(0.08, 0.26)	(1.60, 7.35)	(0.08, 0.40)	(0.94, 4.53)
Crossbred	0.80	28.61	1.02	21.68
	(0.48, 1.20)	(20.45, 39.00)	(0.58, 1.64)	(16.18, 29.00)
Local	0.29	12.75	0.40	10.00
	(0.04, 0.55)	(5.59, 19.77)	(0.07, 0.80)	(5.64, 14.81)
Extension	0.16	4.39	0.20	2.87
	(0.06, 0.27)	(1.58, 7.37)	(0.09, 0.35)	(1.24, 4.49)
Ilu-Kura	-1.68	-64.82	3.12	-38.12
	(-2.53, -0.87)	(-98.00, -38.51)	(1.65, 4.31)	(-58.71,-22.51)
Mirti	-3.08	-102.57	1.33	-61.95
	(-3.97, -2.18)	(-150.09,-67.92)	(-0.98, 2.70)	(-91.09, -41.36)
	Covariance			
Participation	1.00	9.42	1.00	6.29
		(4.60, 14.99)		(3.46, 9.64)
Sales	(symmetric)	1047.40	(symmetric)	345.08
		(475.38,2045.15)		(154.72, 686.32)
	Auxiliary Statistics			
	Non-Participants			
R^2	0.97	0.91	0.98	0.87
Pos. pred.	3.00	4.00	2.00	8.00
Neg. pred.	176.00	175.00	177.00	171.00
	Participants			
R^2	0.92	0.33	0.84	0.39
Pos. pred.	11.00	11.00	25.00	13.00
Neg. pred.	14.00	14.00	0	12.00

Note: 95% highest posterior density values are reported in parentheses (Pseudo R^2 values are obtained by regressing latent variables on predicted values.)

Evidence of this potential bias is encountered in comparisons of the covariate estimates between the two models, which is the second important feature of comparison. In both the participation and supply equations, each of the continuous covariates' (i.e., other than the site dummies) coefficient estimates has the same sign across the two models. But the magnitudes of the mean estimates in the two equations exhibit an interesting pattern. In the participation equation each of the estimates in the non-zero censoring model is *greater* (in absolute value) than the corresponding estimate in the traditional model and in the supply equation each of the estimates is *smaller* (in absolute value) than the corresponding estimate in the traditional, zero censoring model. Further, in both the participation and supply equations, the site-specific dummy coefficients are *greater* under non-zero censoring than in the traditional formulation.

Hence, having concluded that the true point of censoring is not zero, these results suggest that ignoring the importance of potential fixed costs in the supply decision has three impacts on the double-hurdle estimates. First, it biases towards zero the estimates of the impact of the continuous covariates on participation. Second, it biases away from zero the estimates of the impact of continuous covariates on supply volumes and the impact of 'other factors' as depicted by the constant terms. Third, it biases downwards estimates of the impacts of other categorical covariates on supply, as manifest in the estimated coefficients of the site-specific dummies. In short, the net impacts of ignoring fixed costs are a lower prediction about the likelihood of participation and a higher prediction about supply response. Further evidence that the second formulation is a better description of the data is evidenced by the reports of dramatically lower error variances and the improved predictive statistics in the lower part of the table.

This is not just an idle methodological point. The practical implication for agricultural development efforts is significant because increasing market participation is central to expanded aggregate supply. Traditional price policy prescriptions that rest upon the assumption of ubiquitous market participation may not be the most effective means of increasing market supply or of generating intended welfare effects, as when efforts intended to stimulate milk prices do not benefit small milk producers because they rationally opt out of the market. Understanding who does and does not participate in markets and how supply responds to key household characteristics (e.g., extension visitation, cattle ownership) or market attributes (e.g., distance) amenable to intervention is fundamental to the design of effective agricultural development policy.

Conclusions

Collectively, these results demonstrate the importance of allowing for non-negligible fixed costs in empirical applications of the double-hurdle model. When these costs are ignored but are non-negligible, a bias in participation and supply estimation exists. Viewing this phenomenon from the Bayesian perspective permits robust estimation of participation and supply decisions affected by a potentially diverse set of factors. The estimation algorithm also leads to robust conclusions about the specific factors affecting participation and the thresholds impeding new entry into the market. Extension agents and policy makers seeking to expand participation and supply volumes in the Ethiopian context should target intellectual- as well as physical-capital stocks and minimum sales thresholds of approximately five liters of milk per household per week. More generally, the exercise, we hope, should also lead to further exploration about the usefulness of MCMC methods in applied development studies.

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SPATIAL HETEROGENEITY AND ADOPTION OF SOIL CONSERVATION INVESTMENTS: INTEGRATED ASSESSMENT OF SLOW FORMATION TERRACES IN THE ANDES

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Abstract

This paper presents an integrated assessment approach to quantify soil conservation investments. The integrated assessment approach is based on a statistically representative sample of data of individual decision units (farms) and spatially explicit bio-physical and economic models. The integrated assessment approach is applied in an economic analysis of investments in slow formation terraces in the Peruvian Andes. Under a plausible parameterization, the model predicts the observed regional level of terrace adoption, but also shows that returns to terrace investments are spatially variable and sensitive to key economic and bio-physical conditions and assumptions. The case study shows that even in a region with agriculture on steeply-sloped hillsides, adoption of conservation investments such as terraces is likely to be less than 100%, and may be less than 10% if farmers must pay for the full costs of the investment. The importance of heterogeneity provides an explanation why economic

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analyses of soil conservation technologies based on 'representative' data often find positive rates of return, yet the technologies are not widely adopted in the field. More generally, this finding suggests that heterogeneity may provide an explanation of incomplete adoption of technologies that does not rely on *ad hoc* behavioral assumptions such as risk aversion.

Keywords: *Spatial heterogeneity; Technology adoption; Soil conservation; Integrated assessment; Andes*

Introduction

Soil degradation is widely recognized as one of the most significant problems impacting the sustainability of agricultural productivity in many parts of the world (Veloz et al., 1985; Lutz et al., 1994a, 1994b; Pagiola, 1999; Scherr, 1999; Barrett et al., 2002; Gebremedhin and Swinton, 2003). Various technologies have been developed to prevent soil degradation and to restore already degraded soils (Lapar and Pandey, 1999; FAO, 2001; Shiferaw and Holden, 2001; Barrett et al., 2002). There is a large and growing literature on the private and social returns to investments in these technologies (Veloz et al., 1985; Lutz et al., 1994a, 1994b; Thampapillai and Anderson, 1994; Gonzales de Olarte and Trivelli, 1999; Hagos et al., 1999; Scherr, 1999; Vieth et al., 2001).

A persistent puzzle is why many farmers do not adopt conservation practices, or dis-adopt them after conservation projects end (Hudson, 1991; Lutz et al., 1994a). Data from various regions of the world indicate that adoption rates for conservation technologies are rarely if ever 100%, and are often below 50% and in some cases near zero. Numerous factors have been identified to explain adoption, including profitability and economic incentives, imperfect capital markets, land tenure, human capital, risk attitudes, and other farmer characteristics (e.g., Thampappillai and Anderson, 1994; Lutz et al., 1994a; Uri, 1999; Franzel, 1999; Place and Dewees, 1999; Adesina et al., 2000; Fuglie and Kascak, 2001).

Increasingly, spatial heterogeneity in biophysical and economic conditions is being recognized as an important factor affecting incentives for technology adoption (Tampapillai and Anderson, 1994; Lapar and Pandey, 1999; Pagiola, 1999; Scherr, 1999; Antle et al., 2001, 2003c; Antle and Stoorvogel, 2003). Yet most studies in the literature use 'representative' farm-level data and models to assess adoption potential within highly heterogeneous regions. Some studies account for heterogeneity by stratifying populations by physical characteristics and then doing representative analysis for each stratum. (e.g., Seitz et al., 1979; Veloz et al., 1985; Araya and Asafu-Adjaye, 1999; Gebremedhin et al., 1999; Hagos et al., 1999; Inbar and Llerena, 2000).

In this paper we present an integrated assessment approach to quantify the returns to soil conservation investments, and apply that approach in an economic analysis of investments in slow formation terraces in the Peruvian Andes. We use this approach to test the hypothesis that the returns to soil conservation investments, and thus their adoption, depend on complex interactions among site-specific biophysical and economic conditions. The integrated assessment approach is based on a statistically representative sample of data of individual decision units (farms) and spatially explicit bio-physical and economic models (Antle and Capalbo, 2001). These models can be simulated to represent the impacts of soil conservation technologies in a heterogeneous population of economic decision units, and results can be statistically aggregated for policy analysis. Thus, this approach is able to provide information about factors affecting the *distribution* of returns to conservation investments in a heterogeneous population – information that is not available from analysis based on 'representative' individual farm data extrapolated to a region, or from the use of aggregated data.

We implement the integrated assessment approach in a study of slow formation terraces in the Peruvian Andes. We use this model to identify the key bio-physical and economic parameters in this general class of models. We subject the model to sensitivity analysis of key parameters, and then assess how these factors affect the profitability of terrace investments in a heterogeneous population. This case study shows that even in a region with agriculture on steeply-sloped hillsides, adoption of conservation investments such as terraces is likely to be less than 100%, and may be less than 10% if farmers must pay for the full costs of the investment. In the final section of the paper, we discuss the methodological and policy implications of our analysis.

Integrated Assessment of Soil Conservation Investments

In this section we develop a conceptual model of soil conservation investments, such as the slow-formation terraces, and use this model to identify key bio-physical and economic model assumptions. We use the example of slow-formation terraces to illustrate the conceptual issues in assessing the economics of soil conservation investments. A slow-formation terrace is a barrier erected in a field that accumulates soil behind the barrier as soil movement occurs on the field. Like many other conservation investments, the productivity effects of slow-formation terraces occur over time as the terrace matures, and depend on site-specific factors including soils, topography, climate, and management. Following Stoorvogel et al. (2001, 2004) we define *inherent productivity* as the productivity attainable at a site (i.e., a parcel of land managed as a unit, such as a farmer's field) with a specified set of bio-physical conditions (soils, topography, micro-climate) and a standard set of management practices. The inherent productivity at a site will be indicated by the variable INP_{ist} for crop *i* at site *s* in period *t*. Inherent productivity can be estimated with bio-physical crop models executed with site-specific soils and climate data and a standard set of management practices (e.g., quantity and timing of fertilization, tillage, etc.).

Generally, soil conservation investments may have three effects on productivity. First, some conservation investments may enhance the productivity of an undegraded field. This 'augmentation effect' could occur, for example, by increasing soil depth on a steeply-sloped hillside where topsoil is thin. Following Figure 1, a terrace would have an augmentation effect if terraces were built in this field at time t_0 and the field's inherent productivity increased over time along the path I.

More typical is a situation in which a field begins to be cultivated without the use of conservation practices, soil productivity declines over time, and at some point conservation practices are introduced. Without the use of conservation practices, the field's soil would eventually be fully degraded (path II in Figure 1). However, suppose that a terrace were built in an undegraded field at time t_0 and productivity was maintained at the initial level INP_0. In this case we shall say that the conservation investment has an *avoidance effect* by preventing the productivity decline that otherwise would have occurred. However, if a terrace were built at a later time t_1 when productivity was at INP_3 and the terrace restores part or all of the productivity that had been lost due to erosion, we shall say the terrace has a *restoration effect.* When the investment is made at a time such as t_1 before the land is fully degraded, there will typically be both an avoidance effect (preventing productivity from falling from INP_3 to INP_2) and a restoration effect (raising productivity to some level above INP_3). In some cases, it will not be possible to fully restore productivity to the level of the undegraded soil, e.g., productivity with a mature terrace will be at a level $INP_4 < INP_0$. If the investment has the potential to augment productivity, then it is also possible that the mature terrace would achieve a level of productivity greater than was possible with undegraded soils, e.g., $INP_5 > INP_0$.

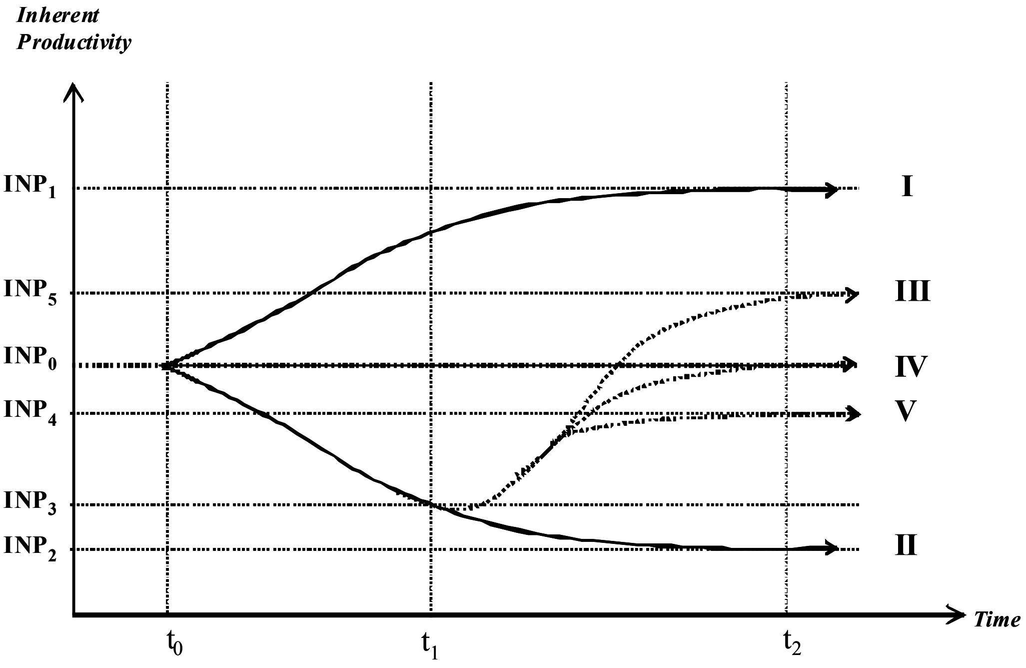


Figure 1. Modeling the Effects of Terraces on Productivity: The Augmentation, Avoidance, and Restoration Effects

An important implication of Figure 1 is that site-specific conditions must be known in order to estimate the productivity effects of the investment. One key site-specific factor that must be known in order to estimate the magnitude of the augmentation, avoidance, and restoration effects at each point in time is the initial condition of the system, i.e., the inherent productivity of the site at the time the investment is made (i.e., where the field is on the path II when the conservation investment is made). This initial condition determines the type of effect that the conservation investment has. If the field were undegraded at the time the investment was made, then the benefits of the investment would be a pure avoidance effect (and a possible augmentation effect), but it would not be necessary to estimate the capability of the conservation practice to restore lost productivity. On the other hand, if a field were fully degraded, in most cases only a restoration effect would be involved. Another key factor that must be known in order to infer productivity effects of soil conservation investments is the 'maturity' or length of time that has elapsed since the investment was made.

A number of studies report yields of crops planted on terraced fields versus non-terraced fields in Peru and other regions of the world (Table 1). While these studies generally show that terracing increases productivity, there is a considerable variation in the reported productivity effects. Most of these studies are difficult to interpret because they do not specify important information such as the initial soil conditions at the time of the investment or the maturity of the investment. Moreover, as we discuss below, none of these studies provide information about the dynamic path of productivity in response to terrace investments (Valdivia, 2002).

Economic Analysis of Terrace Investments

The productivity dynamics of Figure 1 now will be incorporated into an economic model for the economic assessment of returns to investments in the technologies. To simplify this presentation, farmers are assumed to maximize net returns on each land unit they manage. More generally, if there were farm-level labor or capital constraints, farmers would maximize the sum of returns across all land units subject to those constraints (Just et al., 1983). Net returns for activity *i* (crop, fallow, other land use) at site *s* in period *t* are defined as:

$$NR_{ist} = p_{ist}q_{ist} - \Sigma_j \, w_{ijst} \, v_{ijst} \tag{1}$$

where:

$q_{ist} = q_{ist}(p_{ist}, \mathbf{w}_{ist}, INP_{ist})$ = quantity supplied of output *i*
p_{ist} = expected price of output *i*
$v_{ijst} = v_{ij}(p_{ist}, \mathbf{w}_{ist}, INP_{ist})$ = quantity demanded of input *j*, $\mathbf{v}_{ist}$ is the corresponding vector
w_{ijst} = price of input j for output *i*, $\mathbf{w}_{ist}$ is the corresponding vector
INP_{ist} = inherent productivity of activity *I*

The output quantities supplied and input quantities demanded are derived from a static single-period expected profit maximization where input decisions are made at the beginning of the crop cycle, given known input prices and the expected output price. This decision model can be generalized to account for intra-seasonal dynamics and production risk (Antle and Capalbo, 2002). Inter-seasonal dynamics associated with crop rotations or dynamics of soil productivity can be captured by introducing land use and management variables from previous periods (Antle and Capalbo, 2001).

In should be noted that this model represents the effects of site-specific bio-physical conditions on economic decisions through the spatial variation in inherent productivity. Thus, this model utilizes a form of weak separability in the production model between underlying bio-physical factors such as soil type, slope, and climate, and the other variables in the economic production model.

Table 1. Percent Impact of Terracing on Crop Productivity, Various Studies

Crop	Rist and San Martin (1991)	Shulte (1996)	Garcia et al. (1990)	Treacy (1989)	Gonzales de Olarte and Trivelli (1999)	Proyecto PIDAE (1995)	Gebremedhin et al. (1999)
Potato	261%	4% to 25%	42% to 143%	40%	13% to 61%	14%	n.a.
Oca	n.a.	-20% to 38%	71%	n.a.	n.a.	6%	n.a.
Barley	n.a.	-20% to -100%	45% to 34%	43%	-5% to 43%	10%	n.a.
Barley forage	n.a.	n.a.	n.a.	44%	44%	n.a.	n.a.
Maize (Corn)	n.a.	n.a.	n.a.	65%	5% to 522%	20%	n.a.
Peas	n.a.	n.a.	n.a.	n.a.	n.a.	39%	n.a.
Fava bean	n.a.	n.a.	n.a.	n.a.	n.a.	18%	More than 40%
Wheat	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	More than 100%
Radish	187%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Onion	88%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Oat	n.a.	n.a.	38% to 36%	n.a.	n.a.	n.a.	n.a.
Quinoa	n.a.	n.a.	35%	n.a.	n.a.	n.a.	n.a.

In each crop cycle the farmer chooses the activity at site *s* to maximize expected returns by solving:

$$NR_{st} = \max_{\{\delta_{ist}\}} \Sigma_{\mathbf{i}}\, \delta_{ist}\, NR_{ist} \tag{2}$$

where $\delta_{ist} = 1$ if activity *i* is chosen and $\delta_{ist} = 0$ otherwise. We define the economic value of a production system *k* at site *s* as the net present value:

$$NPV_{ks} = \sum_{t=1}^{T} D_t(NR_{st} - CM_{kst}) - FC_{ks} \tag{3}$$

where:

T = number of decision periods in the planning horizon
$D_t = (1/(1+r))^t$ = discount rate with interest rate *r* per decision period
CM_{kst} = conservation investment maintenance cost
FC_{ks} = conservation investment fixed cost.

The economically rational farmer will choose to invest in a capital asset such as a terrace if the expected NPV of the production system with the investment is higher than the expected NPV without the investment. This model shows that there are several sets of variables and parameters that determine the net returns to a conservation investment at a site:

- bio-physical variables (soils, micro-climate, crop growth) and related parameters of crop and environmental process models that determine inherent productivity at the site in each time period.
- economic variables (prices and quantities of outputs and inputs) and parameters of behavioral equations (output supply and input demand functions) that determine expected returns at each site in each period.
- the variable and fixed costs of the conservation investment.
- the length of planning horizon and the discount rate.

Modeling Productivity Dynamics

Productivity dynamics in a farmer's field depend on biophysical conditions (soil depth, soil organic matter, etc.) and these conditions are in turn partly dependent on management (crop choice, tillage, fertilizer applications, etc.). In principle, biophysical models, such as the DSSAT crop models (Tsuji et al., 1994), could be used to etimate the productivity dynamics of a crop production system over time if the changes in soil properties that occurred over time were known. Alternatively, more complex agro-ecosystem models such as EPIC (Williams et al., 1983; Sharply and Williams, 1990) or Century (Parton et al., 1987), that jointly simulate crop growth and soil processes, could be used. However, these more complex models involve a large number of parameters – data that often are not available on a site specific basis.

Another limitation is that existing bio-physical models were not developed to represent soil processes in terraced systems. Therefore, there is a knowledge gap in the literature regarding the dynamics of crop productivity in under terraced conditions.

Given this gap in the biophysical science literature, in this analysis we implement a simpler modeling approach that allows us to utilize data from the scientific literature and field measurements (e.g., field slope, top soil depth, soil organic matter) that are related to bio-physical processes together with *a priori* assumption about the relationship between slope and terrace productivity. In the simulation analysis, we then subject the parametric values to sensitivity analysis. To implement this approach, we shall make two key assumptions. First, we assume that there is a monotonic increasing productivity path from the time the conservation investment is made to the time when the investment matures (i.e., when its full productivity potential is realized). Second, we assume that there is a monotonic relationship between field slope and the productivity potential of terraces. If slope is changed due to a terrace it will reduce soil erosion by water, provide more moisture retention for crop use, and make it easier to work the soil. In addition, reducing field slope through terracing has beneficial off-farm effects on water quality, by reducing sediment content in runoff water and reducing peak runoff rates.

As illustrated in Figure 1, the productivity potential of a terrace depends on the augmentation, restoration, and avoidance effects. To model these relationships, we define the parameter BATPROD as the maximum amount of productivity that can be gained from a terrace relative to a base value of 100, and we define BAEPROD as the maximum amount of productivity that could be lost through degradation relative to a base value of 100. ATPROD_s is defined as the site-specific productivity gain from terracing and the site-specific loss that would occur from degradation is defined as AEPROD_s. Thus, $100 \leq \text{ATPROD}_s \leq \text{BATPROD}$ and $\text{BAEPROD} \leq \text{AEPROD}_s \leq 100$. The base value of BATPROD=100 simulates the case of no terracing and the base value of BAEPROD=100 simulates the case of no productivity effect of erosion. Specifically, we assume that the site-specific impacts of terracing and degradation on productivity are functions of the field's slope:

$$\text{ATPROD}_s = (100+ (\text{BATPROD}-100)*(\text{PSLOPE}_s /100)**\text{ATCURV})/100 \tag{4}$$

$$\text{AEPROD}_s = (100 - (100-\text{BAEPROD})*(\text{PSLOPE}_s /100)**\text{AECURV})/100 \tag{5}$$

where BATPROD is the upper bound value of ATPROD_s attained when field slope (PSLOPE_s) approaches 100%, and BAEPROD is the lower bound value of AEPROD_s attained when field slope (PSLOPE) approaches 100%. ATCURV and AECURV are curvature parameters (both positive).

There are few if any data available data about the form of the relationship between slope and productivity in terraced systems. We hypothesize that a relationship with diminishing marginal effects of slope on productivity may exist on thin soils on steeply-sloped hillsides. However, when soils are deeper, the function may exhibit different curvature properties because some topsoil can be lost with little impact on productivity. Therefore, in the analysis presented below, we subject this assumption to sensitivity analysis.

Note that according to (4) and (5) ATPROD_s is equal to one plus the proportionate change in productivity after a terrace achieves it full potential (i.e., after it matures in TTIME years), hence (ATPROD_s – 1) is the proportionate change in productivity associated with a mature terrace. Similarly, we define ($AEPROD_s$ – 1) as the proportionate change in productivity associated with erosion over TTIME years. As a first-order approximation, we assume that the positive effects on productivity accumulate at a constant rate of ($ATPROD_s$ – 1)/TTIME per year, and that conversely without terraces erosion reduces productivity at a constant rate of ($AEPROD_s$ – 1)/TTIME. These assumptions imply that the total effects of terraces and erosion on inherent productivity over the period of TTIME years are proportional to the initial productivity level. To illustrate, let the productivity at the time the terrace is constructed at site *s* be INP_{As}. Then:

$$INP_{Ts} = INP_{As} * ATPROD_s \tag{6}$$

$$INP_{Es} = INP_{As} * AEPROD_s. \tag{7}$$

Figure 2 illustrates the relationships implied by Eq. (4) – (7). This model implies that the effects of terracing and erosion on productivity at each site depend on the initial conditions (the initial level of inherent productivity INP_{As}), the maximum potential gains or losses in productivity (parameters BATPROD and BAEPROD), the field slope ($PSLOPE_s$), and the functional relationship between slope and productivity (parameters ATCURV and AECURV).

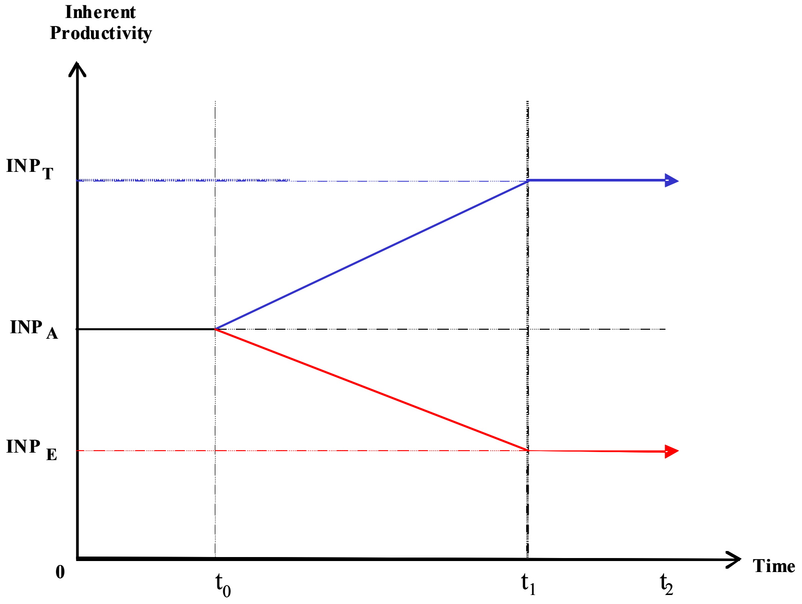


Figure 2. Effects of Erosion and Slow Formation Terraces on Inherent Productivity

Slow Formation Terraces in Northern Peru

In this section we apply the above model to the economic analysis of slow formation terraces in the La Encañada watershed, in the Cajamarca region of northern Peru. La Encañada is located between the parallels 7°00'00" and 7°20'00" South latitude and between the meridians

78°30'00" and 78°50'00" West Longitude. The altitude of the watershed varies from 3,200 to 4,000 meters above sea level. This region is characterized by three agroecozones, the valley floors, the lower hillsides, and the upper hillsides. Milk production dominates in the valley floors where access to irrigation allows for cultivation of permanent pastures. In the lower hillsides where little irrigation is available, field crops dominate the production system, including Andean tubers, legumes, cereals and pasture. Cultivation in this zone occurs in two seasons, December to May and June to September/November. In the upper hills where risk of frost is high, natural pastures dominate the landscape. There are about 1800 hectares of cropland in the La Encañada watershed, and it also produces about 3,500 liters of milk daily. We focus our analysis on the lower-hillside region where cropland is the principal land use.

The data used in this analysis were collected through farm surveys conducted in 1997-1999 for a random stratified sample of 40 farm households in five communities in the watershed (Valdivia, 1999). Table 2 presents summary statistics for some key variables, including crop yield, parcel size, farm size, input use, prevalence of terraces, parcel slope and altitude; see Valdivia (2002) and Valdivia and Antle (2002) for further details. The data show that crop yields are low and parcel size is small, as is typical of this type of semi-subsistence agriculture. Size distributions of the parcels and farm sizes are highly skewed, with a large number of very small parcels and farms and a small number of much larger parcels and farms. Input use is highly correlated with farm size, with larger farms more likely to use fertilizer on potatoes and to apply fertilizer at higher rates.

Table 2. Summary Statistics for the La Encañada Database

Variable	Potato & Tubers	Grains	Legumes	Pastures	Fallow	All Crops
Yields (kg/ha)	5150.80 (6913.540)	4132.64 (7519.830)	500 (679.06)	---	---	---
Parcel area (ha)	0.268 (0.520)	0.286 (0.359)	0.205 (0.365)	1.403 (3.019)	0.415 (0.606)	0.385 (0.764)
Slope (%)	23.485 (14.251)	23.233 (12.381)	27.055 (14.699)	25.764 (15.623)	26.214 (14.908)	25.363 (14.500)
Percentage of fields that use fertilizer	34.3%	0.8%	0.0%	0.0%	0.0%	5.6%
Percentage of terraced fields	25.0%	29.5%	29.3%	12.5%	28.9%	27.9%
Altitude (meters)	3402 (122.737)	3386 (127.779)	3356 (115.050)	3451 (128.633)	3392 (125.716)	3392 (125.674)
Farm size (ha)	---	---	---	---	---	6.804 (4.146)
Number of observations	400	386	181	72	1455	2494

Note: Means with standard deviations are given in parentheses

Econometric-Process Model

The simulation model used to implement the analysis was based on the econometric-process simulation model approach (Antle and Capalbo, 2001; Valdivia, 2002, Chapter 3; and Figure

3). This approach is based on the specification and estimation of log-linear output supply and input demand equations for each activity (potatoes and tubers, cereals, legumes and pasture in this application). These econometric models are estimated using the inherent productivity data derived from corresponding bio-physical crop models as inputs to represent spatial variation in productivity. These models are then used as the basis for the construction of a simulation model that characterizes, for each field, the choice of land use in each growing season (crop, pasture, or fallow), and the management (variable input use) for the selected activity in each season.

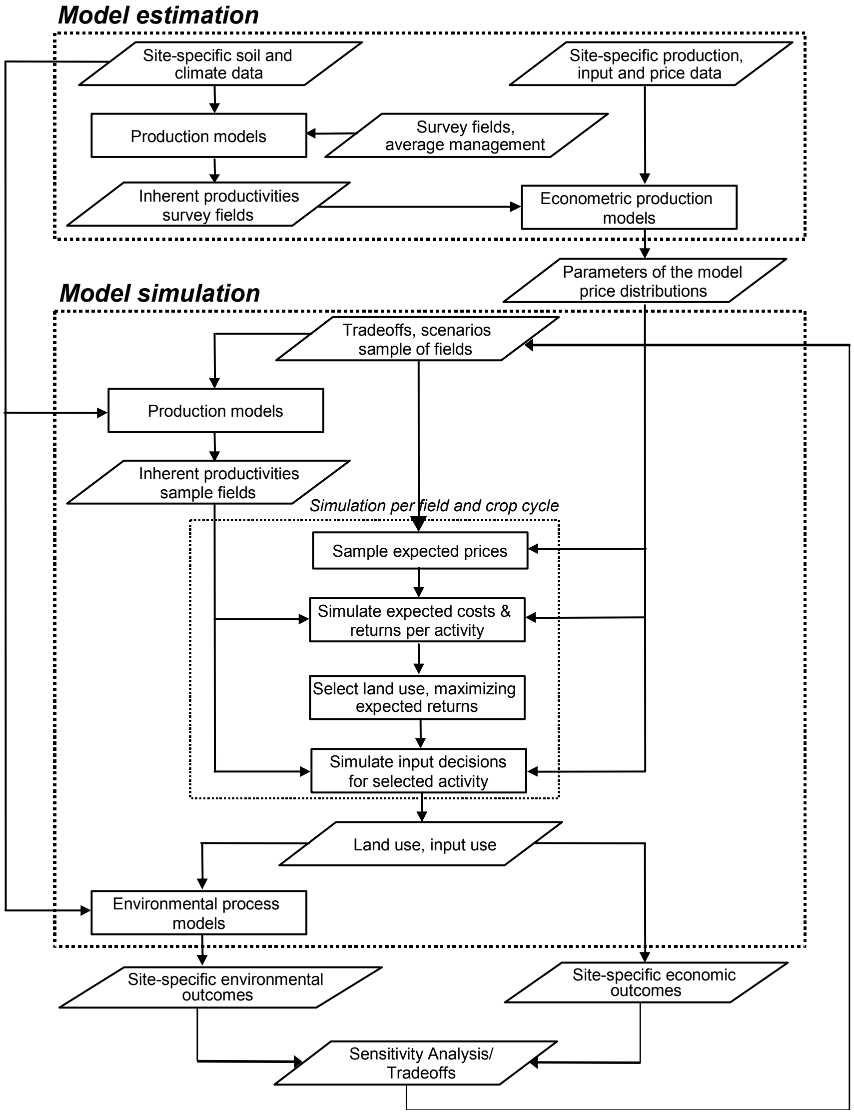


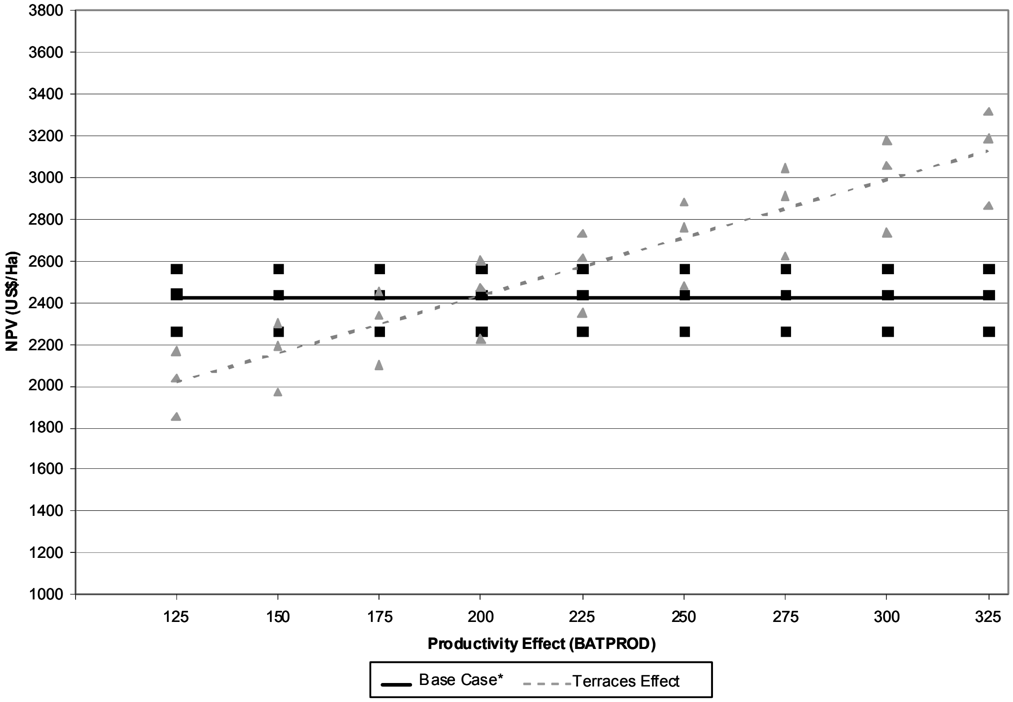
Figure 3. Structure of the Econometric-Process Simulation Model (source: Valdivia, 2002)

The simulation begins by randomly sampling a set of fields in the region, based on spatial distributions of field location, field size, prices, and related characteristics. For each site and each time period, expected returns and costs for the crops are simulated using the econometric models described above. The expected returns are compared and the land use with the highest return is selected. Land use and input decisions for the site are then passed to environmental process models and site-specific environmental outcomes are simulated. The site-specific economic and environmental outcomes can then be used to define spatial distributions of outcomes and can be statistically aggregated for policy analysis. For the analysis of terracing investments, for each scenario a sequence of land use and management decisions over a specified time horizon is simulated, and the net present value of returns for that scenario is calculated. Antle et al. (2003a) provide further details on the econometric and simulation models. These models and documentation are available at www.tradeoffs.nl.

Sensitivity Analysis

Following the presentation of the model in the preceding section, the key parameters in the model are the upper bounds on productivity effects of erosion and terracing (BAEPROD and BATPROD), the terrace productivity curvature parameters (AECURV and ATCURV), the terrace construction and maintenance costs (TERINV and TERMAN), the interest rate, and the number of cropping cycles required for the terraces to mature (TTIME). It is not possible to present the results for all possible combinations of these parameters, so we focus on some representative results for the effects of the terrace productivity parameter BATPROD and its interactions with some other key parameters. Accordingly, for the sensitivity analysis results presented here we set BAEPROD to the base value of 100 (no erosion effects). Based on experiments with different sample sizes, a sample of 100 fields was found to characterize adequately the spatial variability in the study area. Production was simulated over a 10 year (20 cropping cycle) period. The base model was simulated with multiple replications and a small number of replications were found to be adequate to account for stochastic properties of the model. The results presented here are based on three replications of each scenario. The simulations were implemented using the Tradeoff Analysis Software (Stoorvogel et al., 2001, 2004).

Figure 4 presents the base case and the mean NPVs for the fields in the sample according to a range of possible productivity effects of terraces, with other key parameters set to intermediate or representative values. The mean NPV in the base case is $2425 per ha, very close to the value for non-degraded agricultural land reported by Proyecto PIDAE (1995). The productivity parameter BATPROD is varied from a low value of 125 to a high value of 325. The low value means that the upper bound on the productivity effect of terraces is 25%, and results in an average productivity effect of about 12% across all fields in the sample. With an upper bound on the productivity effect of 100% (BATPROD = 200), the average increase in productivity for the sample of fields is about 50%. At this point, the average NPV is about $2430/ha, close to the base case. Higher values of BATPROD give NPVs that exceed the NPV of the base case. Note that lower values of BATPROD give lower average NPVs than the base case because the productivity benefits of terraces are not large enough to offset the construction and maintenance costs of the terraces.



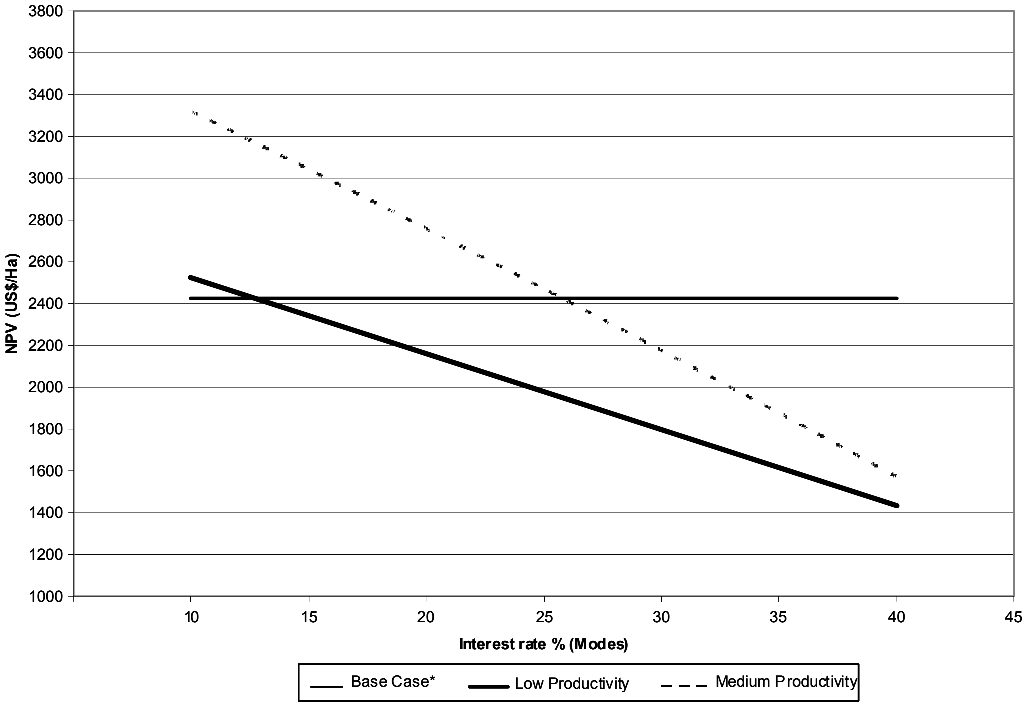
BATPROD: Upper bound for terraces productivity = 125 to 325
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (min, mode, max)
Minimum value = 20%
Modal value = 25%
Maximum value = 30%

*The Base case represents the scenario where no terraces were built in the field, so the BATPROD parameter is set to 100. This applies to all the figures where the base case is used to compare different scenarios.

Figure 4. Base Case and Terrace Productivity Effect

Effects of the interest rate

Market interest rates at the time of the study were in the range of 25%. However, the data show that none of the farmers in the watershed obtained formal credit, so the opportunity cost of money was likely higher than the market rate (Antle et al., 2003b). Moreover, in a situation where only informal credit is available, appropriate interest rates for the NPV calculations are likely to vary in the population of farmers. Accordingly, we assume that the interest rate is a random variable drawn from a triangular distribution T(min, mode, max) as defined in the note to Figure 5. We examine the effects of varying the interest rate parameters from a low range (a modal value of 10%), to a high range (modal value of 40%). Figure 5 shows the results for two levels of terrace productivity as the parameters of the interest rate distribution are changed. For the low productivity case (BATPROD=125) and low interest rates, terraces can be profitable relative to the base case giving an average NPV of about $2500/ha. At higher interest rates the average NPV falls to $1400/ha. Figure 5 also shows that for higher levels of productivity (BATPROD=200), returns to investment are more sensitive to the interest rate. With a low interest rate, these fields earn an average NPV of $3300/ha, but with higher interest rates the average NPV falls to $1600 per hectare. Thus, the profitability of terraces is found to be quite sensitive to the interest rate.



BATPROD: Upper bound for terraces productivity = 125 (low productivity) and 200 (medium productivity)
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (min, mode, max)
1 = Interest rate ~T(5,10,14)
2 = Interest rate ~T(10,15,18)
3 = Interest rate ~T(15,20,24)
4 = Interest rate ~T(20,25,30)
5 = Interest rate ~T(25,30,36)
6 = Interest rate ~T(30,35,42)
7 = Interest rate ~T(35,40,47)

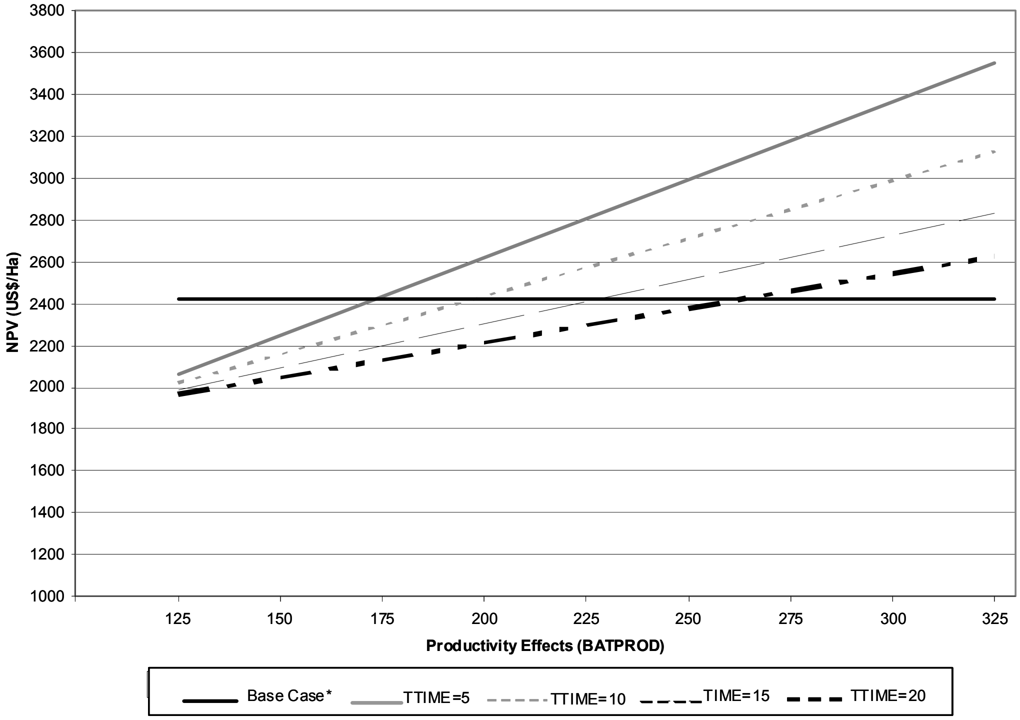
Figure 5. Changes in Interest Rate for Low and Medium Terrace Productivity

Effects of the maturity time of terraces

Different values for TTIME (time required to achieve full maturity of terraces) are compared in Figure 6. Results show that there is an inverse relationship between TTIME and NPV. The slope of the relationship between BATPROD and NPV increases as TTIME decreases, showing that there is an interaction between terrace productivity and time to maturity.

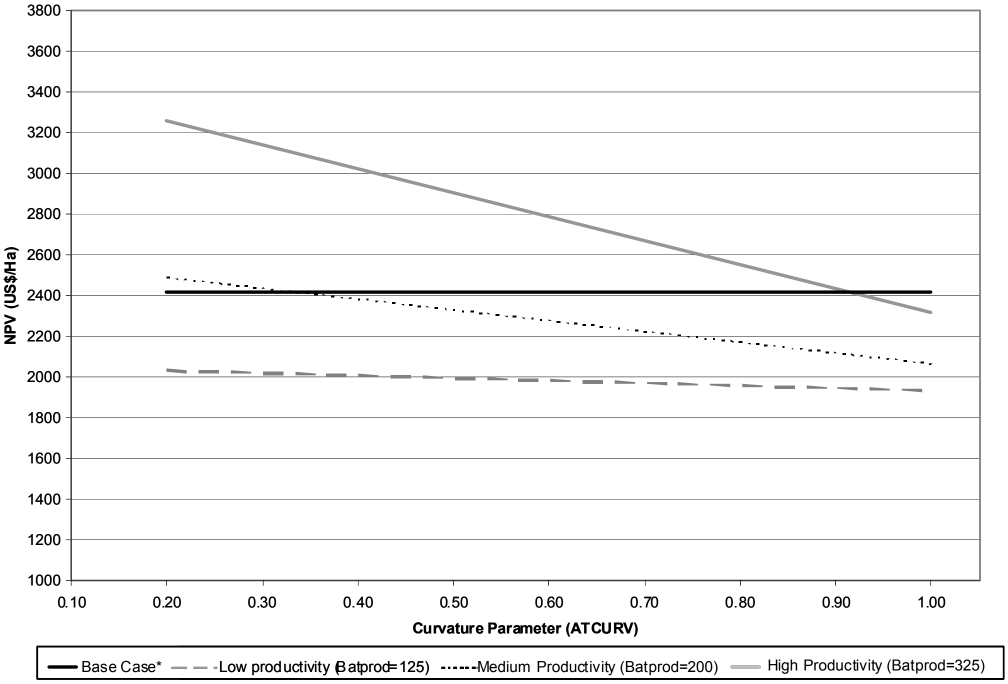
Effects of the functional relationship between slope and terrace productivity

Figure 7 shows effects of terraces with different values of the parameter ATCURV that determines the curvature of the relationship between slope and terrace productivity (Eq. 4). Returns to terrace investments are more sensitive to the parameter ATCURV when it has small values (i.e 0.2 or 0.3) and when the productivity levels increase. Figure 7 shows the effects of different values of ATCURV at different productivity levels (BATPROD is set at 125, 200 and 325). When the productivity is low (i.e., BATPROD=125), returns to terrace investment are not sensitive to the parameter ATCURV. But when the productivity is high (i.e., BATPROD=325), then returns to terrace investment are more sensitive to the parameter ATCURV.



BATPROD: Upper bound for terraces productivity = 125 to 325
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 5 to 20
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (20, 25, 30)

Figure 6. Effects of the Maturity Time of Terraces

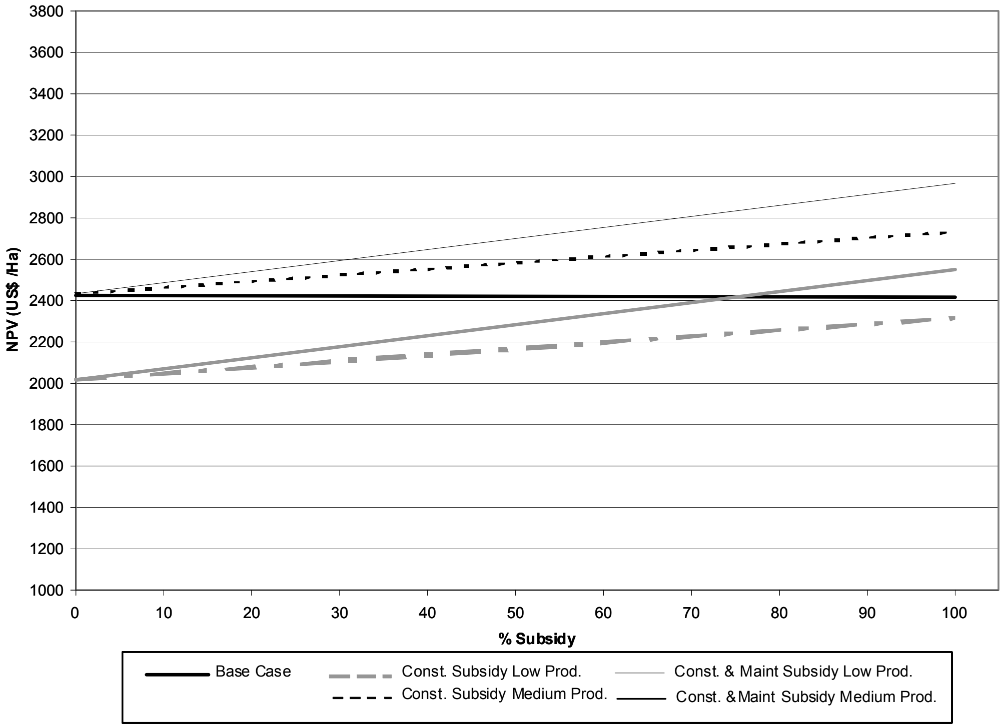


BATPROD: Upper bound for terraces productivity = 125, 200 and 325
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
ATCURV: Curvature parameter = 0.2 to 1
Interest rate: Interest rate follows a triangular distribution T (20, 25, 30)

Figure 7. Effects of the Curvature Parameter

Subsidies for Terrace Construction and Maintenance

Figure 8 shows the effects of various levels of subsidies for terrace construction and maintenance for both, fields with a low effect of terraces on inherent productivity and fields with a medium productivity effect. Results show that returns to investment on terraces are sensitive to the parameters TERINV and TERMAN. Terraced fields with low productivity effect are profitable relative to the base case only with about 80% of construction and maintenance subsidy; a construction subsidy alone would not make fields profitable relative to the base case. On the other hand, in fields with medium productivity effect with a zero subsidy level (no subsidy) the NPV in average is comparable to the base case; consequently, any amount of subsidy will make terraced fields profitable relative to the base case.

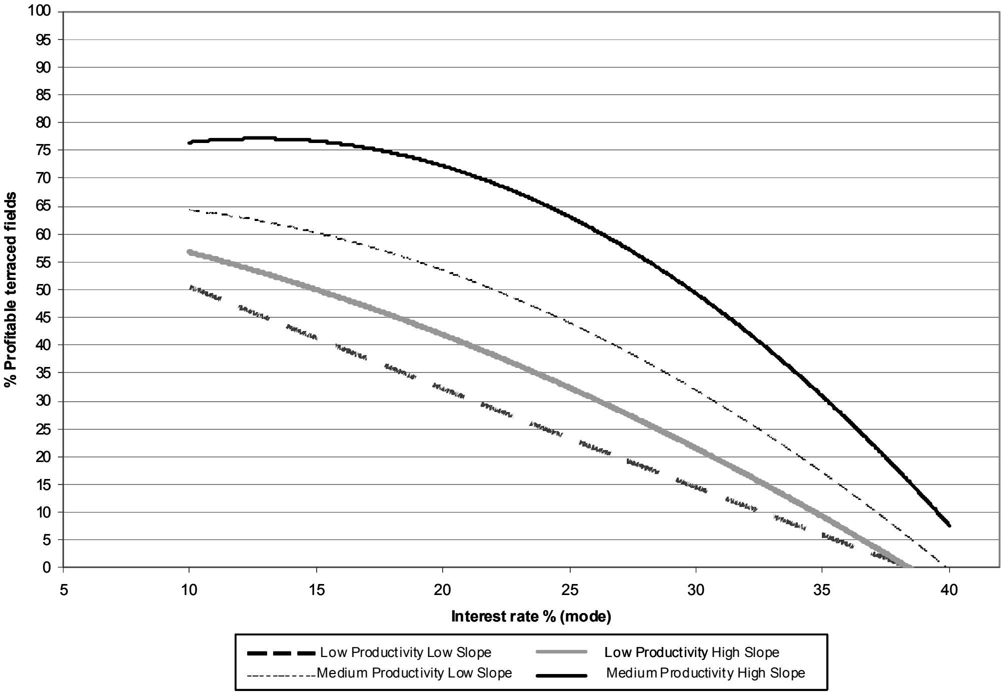


BATPROD: Upper bound for terraces productivity = 125 (low productivity) and 200 (medium productivity)
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (20, 25, 30)

Figure 8. Effects of Subsidies to Construction and Maintenance Costs

Spatial Heterogeneity and Terrace Investment

As noted at the outset, a fundamental fact of agriculture is *heterogeneity* in bio-physical and economic conditions. Location, discount rates, access to credit, physical features (e.g., soil characteristics and slope of their fields), wealth, and other characteristics may influence terrace investment decisions. In addition, as we showed earlier, the effects of terraces on productivity through the augmentation, restoration and avoidance effects depend on the initial conditions of the soil. In this analysis, we assume that fields are at a point in Figure 1 along path II where terraces have both avoidance and restoration effects, as portrayed in Figure 2. The erosion parameter BAEPROD is set to a value of 60, meaning that the productivity loss on a steeply-sloped, un-terraced field would equal 40% over the period of the analysis. According to our model (Eq. 5), the initial condition of each field is a function of field slope at each site. The average productivity loss associated with erosion for all fields in our sample with this parameter setting is about 25% after ten years.



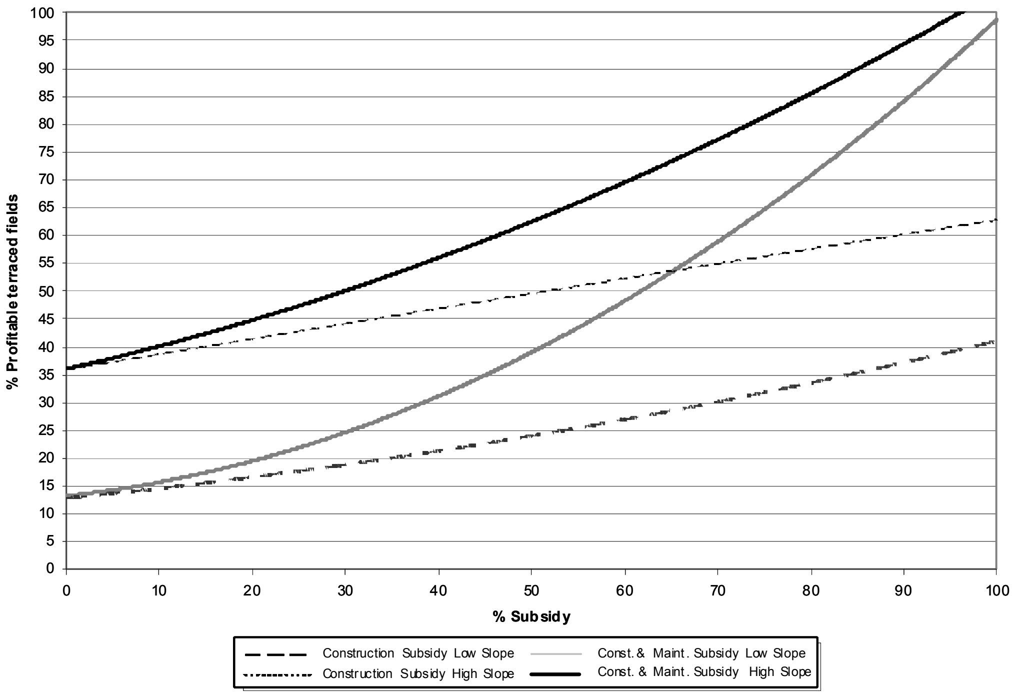
BATPROD: Upper bound for terraces productivity = 125 (low productivity) and 200 (medium productivity)
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
Slope: Low slope < 21%, High slope ≥ 21%
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (min, mode, max)

1 = Interest rate ~T(5,10,14)
2 = Interest rate ~T(10,15,18)
3 = Interest rate ~T(15,20,24)
4 = Interest rate ~T(20,25,30)
5 = Interest rate ~T(25,30,36)
6 = Interest rate ~T(30,35,42)
7 = Interest rate ~T(35,40,47)

Figure 9. Proportion of Fields with Profitable Terraces According to Slope, Productivity and Interest Rate

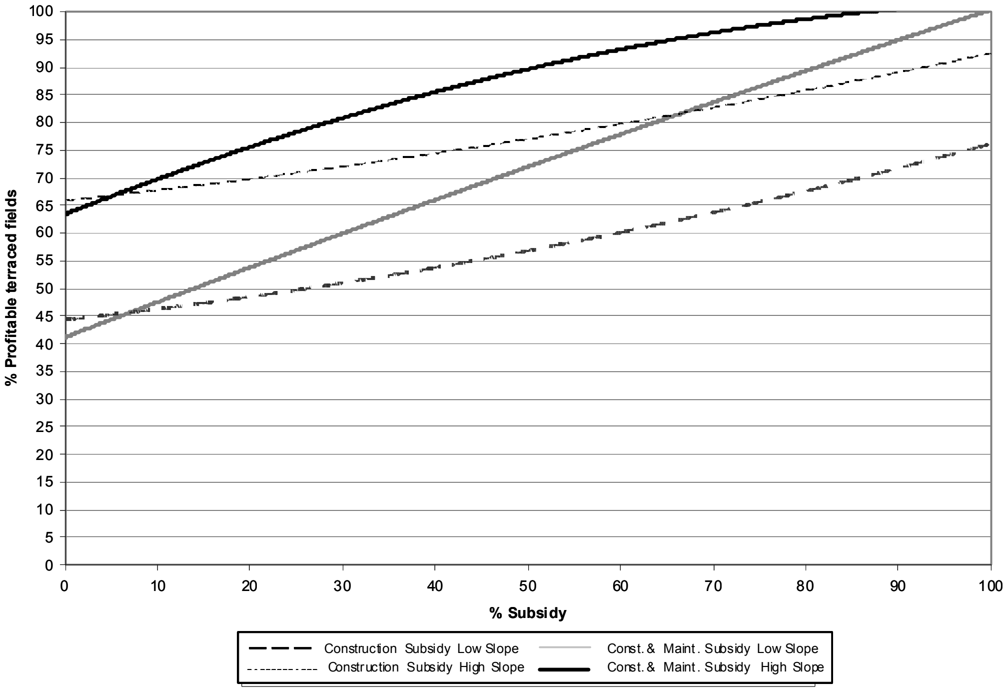
Define PNPV as the percent of fields that are profitable, i.e., the proportion with (NPV_T-NPV_E)>0, where NPV_T is the net present value for terraced fields and NPV_E is the net present value for an un-terraced, eroded field. To further illustrate the spatial differences in terrace profitability, we present the value of PNPV for fields stratified into groups with lower than average slope and higher than average slope. As Figure 4 shows, for high productivity levels, terraces are likely to be profitable for a large proportion of fields, so we focus this analysis on the cases of low to medium productivity effects of terraces. Theses are the cases where changes in assumptions are likely to have substantial effects on the proportion of terraces that are profitable.

Figure 9 presents results for unsubsidized terraces and different levels of interest rates and terrace productivity. Figure 9 shows that for one of the more plausible scenarios (medium terrace productivity), terraces are profitable for the actual number of terraced fields (about 28%) under the assumption of relatively high interest rates. As noted earlier, market rates during the study period were in the range of 25%, but formal credit was not generally available to farmers, implying that the opportunity cost of funds was actually higher. Figure 9 also shows that for the case of low productivity effects of terraces, the proportion of profitable terraces is considerably lower, but still highly sensitive to interest rates.



BATPROD: Upper bound for terraces productivity = 125 (low productivity)
TERINV: Terrace construction cost = US\$300.00/ha
TERMAN: Terrace maintenance costs = US\$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
Slope: Low slope < 21%, High slope ≥ 21%
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (20,25,30)

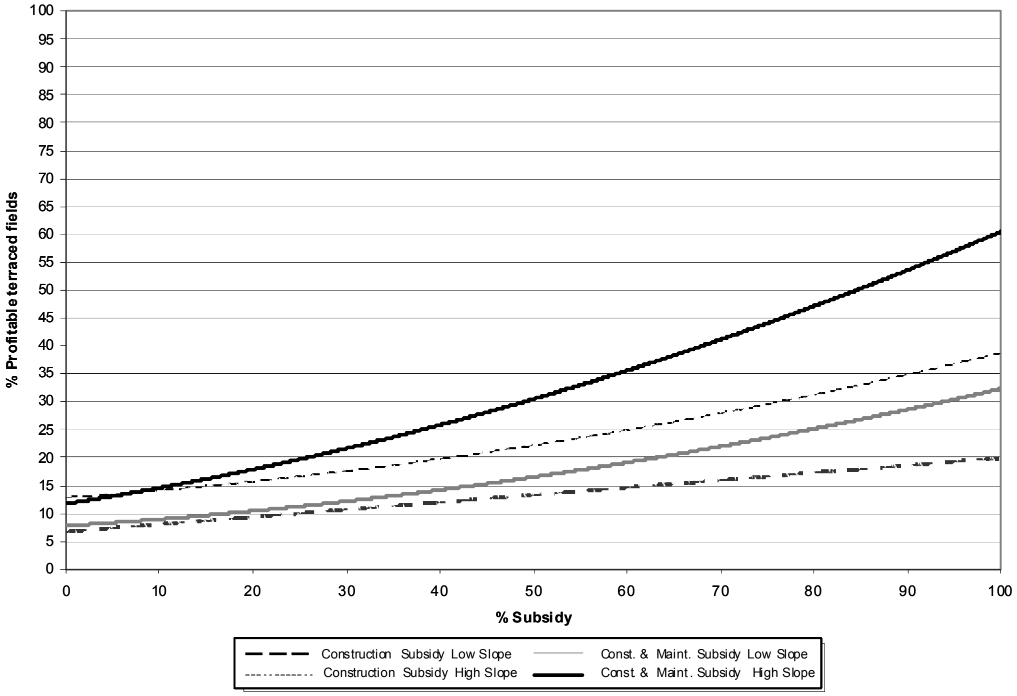
Figure 10. Effects of Subsidies on the Proportion of Profitable Terraced Fields with Low Productivity and a Medium Interest Rate



BATPROD: Upper bound for terraces productivity = 200 (medium productivity)
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
Slope: Low slope < 21%, High slope ≥ 21%
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (20,25,30)

Figure 11. Effects of Subsidies on the Proportion of Profitable Terraced Fields with Medium Productivity and a Medium Interest Rate

Figures 10 and 11 show the results for terrace investment subsidies ranging from zero to 100%, assuming interest rates are in the mid-range and assuming low and medium terrace productivity. Figure 10 shows that with no subsidy and low productivity, about 14% of terraced fields with low slopes are profitable, and about 36% of steeply sloped, terraced fields are profitable. On steeply sloped fields, a 90% subsidy on construction and maintenance costs makes terraces profitable on about 95% to 100% of these fields, but a 100% subsidy on construction subsidy only, achieves less than 65% adoption on fields with low slopes. With medium terrace productivity (Figure 11) and high slopes, terrace adoption approaches 100% with an 80% subsidy on construction and maintenance. Finally, Figure 12 shows the effect of assuming higher interest rates with medium productivity. Even on highly-sloped fields with a 100% subsidy, adoption only reaches about 60%, showing again the sensitivity of adoption to interest rates.



BATPROD: Upper bound for terraces productivity = 200 (medium productivity)
TERINV: Terrace construction cost = US$300.00/ha
TERMAN: Terrace maintenance costs = US$65.00/ha per crop cycle
NCYCLES: Period of analysis (crop cycles) = 20
TTIME: Time to achieve full maturity of terraces (cropping cycles) = 10
Slope: Low slope < 21%, High slope ≥ 21%
ATCURV: Curvature parameter = 0.3
Interest rate: Interest rate follows a triangular distribution T (35,40,47)

Figure 12. Effects of Subsidies on the Proportion of Profitable Terraced Fields with Medium Productivity and a High Interest Rate

Conclusions

In this paper we present an integrated assessment approach to quantify the returns to soil conservation investments that explicitly accounts for spatial heterogeneity in bio-physical and economic conditions. We implement the integrated assessment approach in a study of slow formation terraces in the Peruvian Andes. We use this model to identify the key bio-physical and economic parameters in this general class of models. We subject the model to sensitivity analysis of key parameters, and then assess how these factors affect the profitability of terrace investments in a heterogeneous population.

The analysis of terrace investments in the Peruvian Andes shows that, under a plausible parameterization, the model predicts the observed regional level of terrace adoption, but also shows that returns to terrace investments are spatially variable and sensitive to key economic and bio-physical conditions and assumptions. The case study shows that even in a region with agriculture on steeply-sloped hillsides, adoption of conservation investments such as terraces is likely to be less than 100%, and may be less than 10% if farmers must pay for the full costs of the investment. This finding confirms our hypothesis that returns to conservation investments, and thus rates of adoption of conservation investments, depend on complex interactions among site-specific biophysical and economic conditions.

Our findings also may help explain why economic analyses of soil conservation technologies based on ‘representative’ data often find positive rates of return, yet the technologies are not widely adopted in the field. First, we note that there is a tendency among proponents of soil conservation programs to make optimistic assumptions, or to use ‘representative’ data that are in fact biased in favor of the technology (see Hudson, 1991). Second, our analysis shows that the profitability of soil conservation investments is sensitive to key bio-physical and economic variables, such as initial soil conditions, discount rates and the long-term productivity effects of the investments. This means that any ‘representative’ analysis is likely to be wrong for a large proportion of the land units in a heterogeneous region. Analysis that better accounts for heterogeneity in key bio-physical and economic factors will provide a much more realistic assessment of the economic potential of these types of investments, and will help avoid over-optimistic assessments of development projects promoting them.

The modeling approach applied in this study requires a relatively large amount of site-specific data. This amount of data is often not available for economic feasibility studies. A key methodological challenge for researchers is to determine the minimum amount of data needed to obtain results sufficiently reliable to support informed policy decision making.

Finally, it is worth noting that the economics literature emphasizes behavioral explanations for the incomplete adoption of technologies (i.e., cost of information, risk aversion). The analysis and findings presented in this paper suggest that bio-physical and economic heterogeneity provide another explanation for the incomplete adoption of technologies that does not rely on unobserved behavioral factors.

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THE MULTIPLICATIVE EFFECT OF WATER SUBSIDIES AND PRICE SUPPORT PAYMENTS: THE CASE OF U.S. COTTON

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Abstract

The U.S. cotton policy is being challenged by Brazil through the World Trade Organization (WTO). Like the results reported in the popular press, our findings using standard welfare economics show that the U.S. cotton policy negatively impacts world cotton prices. The magnitude of the effect depends on several factors, including the base year chosen, how water subsidies are treated, supply and demand elasticities, the degree of policy decoupling, and the effect of non-U.S. cotton producer subsidies on world cotton prices. One can select certain parameters to show a small impact from the U.S. cotton policy, or alternatively one can show a relatively large price impact. However, even if the price impacts are small, the gains to both U.S. cotton producers and U.S. consumers/users are large.

Keywords: *Brazil, WTO, target price, loan rate, water subsidies, multiplicative effects*

Introduction

A major obstacle to free and fair trade is the subsidies enjoyed by agricultural sector. This was most notably emphasized by the breakdown of the Doha Round of negotiations in Cancun in September 2003. The recent victory of Brazil in their WTO trade dispute with the

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United States, over the subsidies provided to the U.S. cotton industry, only underscores the intensity of this issue, and highlights the huge stakes involved for producers, consumers, and governments worldwide. Such attention has renewed debate about the economic inefficiencies and rent-seeking behavior resulting from trade-distorting U.S. agricultural policy – particularly with respect to the case of U.S. cotton, which was identified as the main source of the impasse at Cancun (Laws, 2004).

Cotton production in the U.S. is dependent on at least three important policy instruments: a water subsidy, a counter-cyclical payment scheme, and a guaranteed loan rate. In this paper, we analyze the impact of U.S. cotton subsidies for the years 2002 and 2003. The results are highly dependent on several features, including the base year chosen, and how water subsidies are incorporated into the analysis. We show that water subsidies and price supports operate in a multiplicative manner, rather than additively. One cannot escape the general conclusion that U.S. cotton subsidies directly depress world cotton prices. We discuss, in the conclusions, how our general result fits with the findings supporting Brazil's claim that the U.S. cotton policy suppresses world cotton prices.

Sections 2 and 3 of this paper discuss, respectively, the theoretical considerations and the empirical data used to model the U.S. cotton industry. Section 4 examines in detail the social welfare implications of these subsidies; rents accruing to the various beneficiaries are calculated, as well as the cost of the program to the government and to society. Calculations are performed individually for the water subsidy and for a price support payment scheme. Section 4 presents the results of the combined effects of both subsidies applied simultaneously [the multiplicative effects (ME) model], which allows a comparison with the additive effects of the individual subsidies. Section 4.4 discusses the sensitivity of the results to parameter changes using 2002 as the base year. Section 5 contains simulation results generated from 2003 data, demonstrating the temporal fluctuation of subsidy effects. Concluding remarks are offered in Section 6.

Theoretical Model

The main focus of this paper is on the interaction of price supports (which for our purpose includes both counter-cyclical payments and loan-rate payments) and water subsidies.[1] We analyze these instruments taken together and individually, and demonstrate that they operate in a multiplicative rather than an additive manner. Figure 1 below presents a combined water subsidy and price support payment model; in addition, this figure explicitly represents each instrument separately. The model is based on standard welfare economics (Just, Hueth, and Schmitz, 2005). In the model, *S* and *S'* represent, respectively, the supply curve and the water-subsidized supply curve. D_d is the domestic demand curve, and T_D is the total demand curve. Export demand is implicit and is not shown directly in Figure 1.

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[1] In addition to water subsidies, the two main components of the 2002 U.S. Farm Bill are the loan rate provisions and the target price. The loan rate for 2004-2007 is $0.52/lb., while the target price is $0.724/lb (USDA, 2002). To put these into perspective, cotton prices were trading in the range of $0.45/lb on November 15, 2004. Although one is not technically obligated to produce cotton on cotton base acres to receive either direct or counter-cyclical payments, in practice most cotton base is planted to cotton; therefore, in this analysis we proceed "as if" the payments were coupled to production.

Under the multiplicative effects (ME) scenario illustrated in Figure 1, the intersection of the support price (P_s) and the subsidized supply curve (S') establishes both the output quantity q* (at point *o*) and the world price P_w (at point *b*). Domestic producers receive the area P_sonmeP_f as a net gain, while domestic consumers gain the area P_fdcP_w. The area *cdeb* – which is also referred to as "slippage" – represents the rents received by importing countries.[2] The cost to the government for the water subsidy is area *amno*, while the cost of the government price support payments equals the area P_sobP_w. Therefore, the combined net domestic cost to society of the two subsidies applied together is the shaded (and mottled) area *aedcb*. The net cost comparison is made with reference to point *e*, where P_f and q_2 are free from distortions caused by U.S. cotton subsidies.[3]

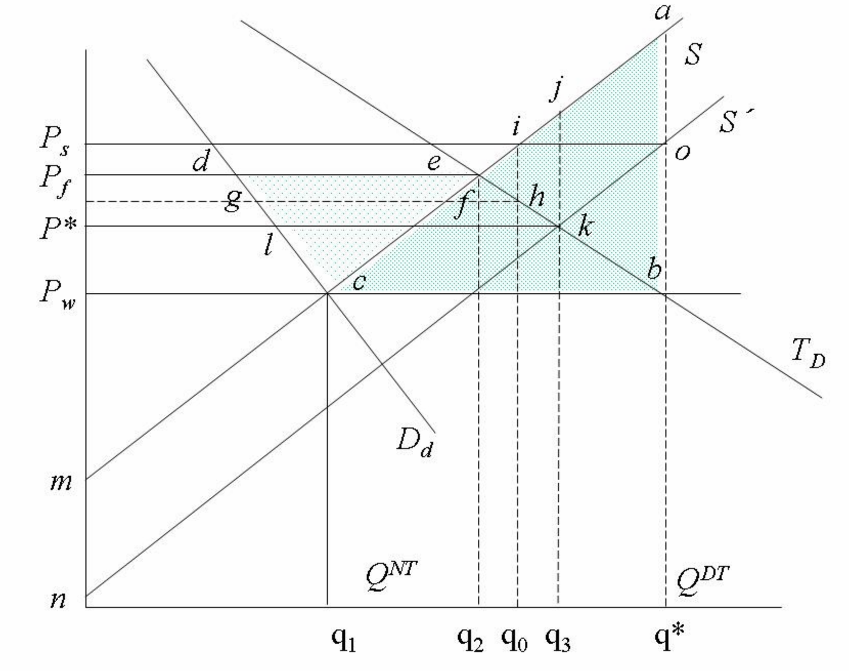

Figure 1. Individual and Multiplicative Effects of Water Subsidy and Price Supports

For the theoretical multiplicative effects (ME) model depicted in Figure 1, domestic producers gain more rents from the water subsidy (area *mnoi*) than from the price support payments (area P_sieP_f), while the majority of the price support payments from the government go to domestic consumers (area P_fP_wcd) and foreign countries (area *dcbe*), rather than to

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[2] The total demand in Figure 1 consists of domestic demand and an excess demand curve. The area under the latter represents the net welfare effect (i.e., consumer gains minus producer losses) from a price change.

[3] Compared to the state of unsubsidized autarky (point c in Figure 1), the net cost from subsidies combined with trade is the area abc. Hence there are "negative" gains from trade because the mottled area dce, which represents the "classic" gains from undistorted trade, is smaller than the shaded area abc). Note that the relative magnitude and distribution of the rents depends largely on the demand and supply elasticities, the amount of exports, and the per-unit cost of the water subsidy. For example, the more elastic the supply, the greater the deadweight loss will be; and the higher the percentage of domestic production that is exported, the greater the net cost of the combined subsidies. Unlike in the work by Schmitz, et al. (1997), the focus of this paper is not on measuring the size of the gains from trade in cotton. However, it is useful to keep in mind that the larger the subsidy, the greater becomes the likelihood that the gains from trade turn negative.

producers. However, the actual distribution of these rents is an empirical matter. The development of the empirical ME model in Section 4.3, and additional simulations presented in Appendix B, illustrate how parameter changes affect the calculation and distribution of the subsidy rents and welfare losses.

The following discussion illustrates how a combination of the two subsidies distorts output more than when they act alone, causing the ME of the two instruments to be greater than a mere summation of the individual effects. For example, the production quantity q* is established where the target price (P_s) intersects the water-subsidized supply curve (S') at point *o* in Figure 1 – instead of at point *i* (associated with quantity q_0) where it would otherwise be given a price support only. Thus, adding the water subsidy to the price support increases production from q_0 to q*. In addition to increased output, there is a significant decrease in the resulting price necessary to clear the world cotton market, P_w. Both of these effects increase the size of the price support payments made by the government; and, in conjunction with price supports, the aggregate size of the water subsidy is greater than without. Therefore, we refer to Figure 1 as the "multiplicative effects" (ME) model.

One can also observe the individual effects of water subsidies and price supports. In Figure 1, the net cost of the price support is given by *deihg*. The net cost of the water subsidy is *dejkl*. Note that the diagrammatical shape of the two instruments is the same, and in addition, each has the same shape as the combined impact discussed earlier.

Empirical Data

Results are presented for 2002 and 2003. Data were obtained from various sources (Table 1). Watkins (2002) provides USDA figures for the world price of cotton, as well as the U.S. target price (price support), in cents per pound. Both prices were converted to U.S. dollars per bale of cotton for all subsequent analyses, and U.S. dollars are used for all welfare comparisons throughout this paper. Import, export, and production quantity data for the U.S. were downloaded from the ERS website of the USDA (2003). Beach, et al. (2002) provide estimates of demand and supply elasticities for the domestic U.S. cotton market, while the export demand elasticity for U.S. cotton was taken from Karp, et al. (1995). However, these elasticity estimates are varied in Section 4.4 and Appendix A. The value of water subsidies was obtained from Schmitz, et al. (2002).

All calculations and empirical analyses were completed using Microsoft Excel. The price, quantity, and elasticity data shown in Table 1 were used to calculate the associated slope values from which demand and supply functions were subsequently derived. Once obtained, the two supply functions are used in conjunction with the domestic and total demand functions in order to derive various intersecting points along any given curve.[4]

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[4] For the purposes of this paper, U.S. domestic demand for cotton is assumed to be equal to U.S.production less exports, plus imports. Thus, beginning and ending stocks of cotton are not included in these analyses. Export demand is simply the excess demand for U.S. cotton given the world price, and corresponds to the amount of U.S. cotton exports officially reported by the USDA. The horizontal addition of these separate sources of demand results in a total demand curve facing U.S. cotton farmers.

Table 1. U.S. Cotton Industry Data for 2002 and 2003

Parameter	Description	2002	Source	2003	Source
P_s	Target price (cents/lb.)	72.40	Watkins	72.40	USDA
P_w	World price (cents/lb.)	42.00	Watkins	62.00	USDA
ws	Water subsidy($/bale)	29.00[a]	Schmitz et al.	29.00	Schmitz et al.
q*	US production (million bales)	17.21	ERS	18.2	ERS
X	US exports (million bales)	11.90	ERS	13.8	ERS
M	US imports (million bales)	0.07	ERS	0.05	ERS
Edd	Domestic demand elasticity	-0.40	Beach et al.	-0.40	Beach et al.
Exd	Export demand elasticity	-1.00	Karp et al.	-1.00	Karp et al.
Es	Domestic supply elasticity	0.49	Beach et al.	0.49	Beach et al.

[a] The water subsidy value is for the year 2000

There are two important points that we focus on later in the empirical analysis. First, what do we assume empirically is the appropriate cotton price support (i.e., P_s in Figure 1) that producers respond to in making production decisions? Second, how are the empirical results affected if other countries, in addition to the United States, distort world market prices (i.e., what happens if P_f in Figure 1 is not the free trade price)?

Welfare Effects of Government Subsidies

Water Subsidy

Theoretically, input subsidies simply shift the supply curve downwards and to the right. Empirically, however, the *subsidized* supply curve must necessarily be derived before the undistorted supply curve can be obtained. This is because the input-subsidized supply of U.S. cotton is what is observed in terms of actual production and export quantities. Therefore, the water-subsidized supply function was derived given the target price for U.S. cotton production, the subsequent quantity supplied at that price, and an estimate of the domestic supply elasticity. The undistorted supply curve was obtained by shifting the subsidized curve upwards by a fixed amount that corresponds to a $/bale estimate of the cost of the water subsidy.

The *free trade*[5] price (p) can be derived (Figure A1 in Appendix A) by substituting the supply function into the total demand function. This price can then be substituted back into

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[5] All references to "free trade" prices and quantities in this paper are made with the understanding that such theoretical prices and quantities are calculated given the absence of U.S. cotton policy distortions. We make no attempt to account for distortions caused by the cotton policies of other nations, and acknowledge that our 'free trade' prices and quantities are affected by distortions caused by countries other than the United States.

the supply function to obtain q_1, the quantity of cotton produced if the market was free of distortions caused by water subsidies to U.S. cotton farmers. The same process is used with the subsidized supply function to obtain a market-clearing price (p^*) and quantity (q_2) under the presence of a water subsidy. The two derived prices can then be substituted into the domestic demand function to obtain domestic quantities (q_d and q_d') consumed under each scenario. All points necessary for welfare calculations are labeled in Figure A1, which depicts the empirical representation of the U.S. cotton industry given the presence of a water subsidy.[6]

Although the water subsidy distorts the market (i.e., the world price is lowered and domestic production increases), this form of government support to the U.S. cotton industry is relatively small compared to the price support payment program modeled later in Section 4. With a water subsidy as the only policy instrument, U.S. producers gain from lower production costs that shift their supply curve down and to the right (*S* to *S'*). This shift causes the price of cotton to drop, while domestic and international consumption both increase. Therefore, there is an offsetting impact to producers: they lose welfare from lower prices (the narrow rectangle *pp*eb* in Figure A1), but gain the subsidy rents *fgeb*[7]. The net gain to the U.S. cotton industry under this scenario is $241 million (Table 2), while the gain to domestic consumers is $37 million.

Table 2. Simulated Welfare Impacts of U.S. Cotton Subsidies for 2002, by Individual Instrument ($ Millions)

Welfare Component	Water Subsidy	Price Support Payments	Difference
Producer rents	$241*	$1,530	$1,289
U.S. consumer rents	$37	$177	$140
Slippage	$71	$356	$285
Deadweight loss	$7.6	$164	$156
Government cost	$356*	$2,226	$1,870
Cost of water subsidy	$356*	$0.0	-$356
Net U.S. welfare loss	$78	$520	$442

* Values corrected for the underestimated cost of the water subsidy

Due to the fact that a very large share of U.S. cotton production is exported (nearly 70% in 2002), foreign countries end up gaining some of the rents from production subsidies. Such

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[6] Note that, because of the scale of Figure A1, the vertical lines linking points c and d to the quantities qd and qd' on the x-axis lie nearly on top of each other, due to the relatively slight change in domestic consumption.

[7] Economic theory indicates that points f and g in Figure A1 will in fact cross the y-axis. Therefore, the cost of the water subsidy (and subsequently the amount of producer rents) is corrected to reflect the underestimation caused by this empirical artifact, which is due to the use of point elasticity estimates and resultant linear supply curves. Further detail regarding this correction is provided at the end of Section 4.

rents are commonly termed *slippage* because, although they represent tangible welfare benefits, they are realized outside the borders of the subsidizing country.

Foreign countries gain nearly twice the amount of rent that domestic consumers receive from the water subsidy, as the slippage area *cdeb* is valued at $70.5 million. The deadweight loss is the area *abe*, equaling $7.6 million. Thus, the net loss of welfare to U.S. taxpayers of the water subsidy is $78 million: the value of the slippage plus the deadweight loss. The total cost to the government for providing the water subsidy to producers is $356 million. (This value accounts for the underestimated cost of the water subsidy as discussed earlier.)

Price Support Payments

Substitution of the undistorted supply function (*S*) into the total demand function allows the 'free trade' price (p_f) to be derived (Figure A2). This price is then back-substituted into the supply function to obtain q_2, the quantity of cotton theoretically produced prior to the market distortion caused by the U.S. price support payment program. This program imposes a support price (price support p_s) on the market, which induces U.S. cotton producers to increase supply from q_2 to q_3. The value of q_3 is obtained by inserting p_s into the supply function; the world price, p_c (which clears the market at q_3), is then solved for by substituting q_3 into the inverse total demand function. The domestic consumption values q_1 and q_1' are derived by inserting p_f and p_c, respectively, into the domestic demand function (Figure A2).

A key feature observed in Figure A2 is the target price (p_s), which provides U.S. cotton producers with a sizeable welfare gain of $1.53 billion (area $p_s p_f ca$), which is significantly greater than the gain from the water subsidies alone (Table 2). In addition, there are beneficiaries from lower prices. Domestic consumers receive $177 million in benefits (area $p_f p_c fe$), while foreign countries receive $356 million (area *efbc*). The cost to the U.S. government in the form of price support payments equals $2.23 billion, and is represented by area $p_s p_c ba$. The deadweight loss (*abc*) is $164 million, more than 21 times the deadweight loss incurred with the water subsidy. Together, the deadweight loss plus slippage represents the net loss of welfare to U.S. taxpayers (area *acefb*); this sum is valued at $520 million – nearly a quarter of the total cost of the government price support payments. Table 2 presents a comparison of the welfare effects of the individual instruments.

Price support payments cause a greater distortion of the cotton market than does the water subsidy. A price support (p_s) generates much more cotton production than does a water subsidy alone. The theoretical 'free trade' production quantity (q_1 in Figure A1, and q_2 in Figure A2) is equal to 14.08 million bales (Mb) of cotton before any distortions occur from U.S. subsidies. Under the water subsidy, domestic production increases to 14.6 Mb of cotton. Given a price support payment scheme only, domestic production increases to 16.5 Mb. Thus, the difference of nearly 2 million more bales of cotton on the world market in 2002 lowers the unit price from $p_f = \$247.51$ to $p_c = 212.69$, in contrast to a price difference of only $7.49 per bale calculated for the water subsidy scenario (Table 3). Clearly the distortionary impacts of price support payments are much greater than those resulting from a water subsidy. The price differential for the price support payments is roughly five times greater than that of the water subsidy.

Table 3. Price Effects Comparison for Each Cotton Policy Instrument for 2002 (U.S. $/bale)

Description	**Water Subsidy**	**Price Support Payments**
'Free trade' price	p = $247.49	p_f = $247.51
World clearing price	p^* = $240.00	p_c = $212.69
Difference	$7.49	$34.82

The Multiplicative Effects of Both Water Subsidies and Price Supports

It is important to stress that in the above model the support price used is the target price. This is a strong implicit assumption about the relationship between direct and counter-cyclical payments to owners/operators of cotton base acres and cotton production. Prior to the 1996 U.S. Farm Act, it seems appropriate to assume a coupled target price program (Schmitz, et al., 1997). However, the 1996 U.S. Farm Bill severed the perfect linkage by introducing full planting flexibility. We assume (heuristically) a coupling coefficient of one. Thus our simulations represent an upper bound on the price impact of U.S. cotton subsidies. More work is needed to determine the actual coupling coefficient, which likely lies somewhere above zero and below one.[8]

Because the U.S. cotton industry simultaneously receives both a water subsidy and price support payments, it is necessary to investigate the combined effects of the two subsidies together. In fact, as was discussed in Section 3, it is the observed price (P_w) and quantities (q*, X, M) resulting from the known target price (P_S) of the price support payments (in conjunction with the water subsidy) that provides the starting point for all subsequent analyses. Using the same back-substitution procedures discussed previously, all relevant prices and quantities necessary for calculations of rent distributions were derived.

The values calculated from the ME of the combined subsidies are presented in Table 4. The water subsidy has increased to $433 million, due to the addition of the price support payments. Thus, the ME of combining both subsidies results in rents accruing to U.S. cotton farmers valued at $1.99 billion, for the year 2002. As illustrated in Figure 1, domestic consumers receive gross welfare gains represented by the area P_fP_wcd, equaling $236 million, while the government incurs a cost of $2.94 billion ($P_sobP_w$ + *mnoa*) when paying for this program. Foreign countries gain $482 million (area *dcbe*) in surplus from the ME of the combined subsidies. The area *abe* represents the deadweight loss incurred by U.S. society, and equals $274 million. As before, combining the slippage with the deadweight loss results in a net loss of welfare to the U.S. taxpayers of $756 million – or 25.7% of the total government cost. Note the sizeable difference between the impacts when the policy

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[8] The more the cotton program is decoupled, the less is the impact on world cotton prices, because the greater the degree of decoupling, the less is the impact of a subsidy on domestic production. The reader should note that the more price inelastic the domestic supply curve for cotton, the more "decoupled" is the farm program (see Appendix B).

instruments are added versus when they operate in a multiplicative fashion. For example, producer rents are more than \$200 million greater under the multiplicative model. Also, government costs are more than \$360 million greater under the multiplicative framework.

The combined multiplicative effect (ME) results in the (*a priori* given) world price of P_w = \$201.60 per bale, which is \$45.89 per bale less (22.8% lower)[9] than the unobserved 'free trade' price (P_f) calculated for an undistorted cotton market (Table 5). The ME on price is \$45.89 per bale, while the additive effects total \$42.31 per bale. The multiplicative effects (ME) on price are greater than the sum of the two individual policy instruments.

What happens if P_f is not the free trade price, but is distorted by other countries' cotton policies? It can be shown theoretically that the greater the degree to which P_f is distorted, the greater will be the negative impact on world prices from a given price support to U.S. cotton producers. We do not test whether or not world market prices are distorted from other countries' policies. However, it is important to note that U.S. cotton producers argued in the Brazilian WTO challenge that countries such as China were providing subsidies directly and indirectly to their producers, thus distorting world cotton prices.

Table 4. Estimated Welfare Impacts of U.S. Cotton Subsidies for 2002 (\$ Millions)

Welfare Component	**Combined Multiplicative Effect**	**WS + SP Additive Effect**	**Difference**
Producer rents	\$1,988*	\$1,771*	\$218
U.S. consumer rents	\$236	\$214	\$22
Slippage	\$482	\$426	\$56
Deadweight loss	\$274	\$171	\$103
Government cost	\$2,944*	\$2,582*	\$362
Cost of water subsidy	\$433*	\$356*	\$77
Net U.S. welfare loss	\$756	\$598	\$158

* Values corrected for the underestimated cost of the water subsidy

Table 5. Price Effects Comparison for Each Cotton Policy Instrument and the ME Model for 2002 (U.S. \$/bale)

Description	**Water Subsidy**	**Price Support Payments**	**Multiplicative Effects**
'Free trade' price	p = \$247.49	p_f = \$247.51	P_f = \$247.49
World clearing price	p* = \$240.00	p_c = \$212.69	P_w = \$201.60
Difference	\$7.49	\$34.82	\$45.89

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[9] This difference is equivalent to 9.56 cents/lb., which corresponds fairly well to the estimated 11 cents/lb. increase in world price if U.S. production subsidies were removed (Watkins, 2002).

Sensitivity to Parameter Changes

We show the effects of varying the U.S. cotton supply elasticity. The U.S. domestic demand and supply elasticities chosen to construct the ME model were obtained from Beach, et al. (2002) for two reasons: these estimates are up-to-date; and, according to the authors, fall within the ranges found in the literature.[10] However, because there are uncertainties with regard to the accuracy of the initial elasticities utilized herein, results follow from two alternative models using different supply elasticity estimates. (Results from varying demand parameters are given in Appendix B.)

In Table 6, the domestic supply elasticity is increased while holding both demand elasticities constant. This effectively results in the supply curve rotating clockwise, which induces the theoretical 'free trade' world price (P_f) to rise. This price increase causes the 'free trade' quantity (q), and the amount of U.S. cotton exports under 'free trade' (X_f), to decrease.

Table 6. Simulated ME Welfare Impacts and Distribution by Domestic Supply Elasticity for 2002, Holding Edd and Exd Constant ($ Millions)

	Domestic Supply Elasticity (Es)		
	0.49	**0.77**	**1.35**
Welfare Components			
Producer rents	$1,988*	$1,668*	$1,294
U.S. consumer rents	$236	$315	$424
Slippage	$482	$626	$803
Deadweight loss	$274	$375	$519
Government cost	$2,944*	$2,938*	$2,982
Cost of water subsidy	$433*	$427*	$471
Net U.S. welfare loss	$756	$1,001	$1,322
Price Components ($/bale)			
P_f	$247.49**	$264.08	$287.73
$P_f - P_w$	$45.89	$62.48	$86.13

* Values corrected for the underestimated cost of the water subsidy

These results show that the more *elastic* the domestic supply curve for U.S. cotton producers, the *greater* is the impact of the U.S. cotton program on world prices. For example, if one changes the domestic supply elasticity from Es = 0.49 to Es = 1.35 (evaluated at the U.S. distorted equilibrium price and quantity), the price differential (impact) changes from $45.89 per bale to $86.13 per bale.

Producer rents decline when the supply elasticity increases (Table 6). As producer rents decline with increasing domestic supply elasticity, it follows that domestic consumers and foreign countries will gain as the rents are redistributed. Also, because both the slippage and deadweight loss increase, the net U.S. welfare loss increases substantially with larger supply elasticity estimates.

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[10] See Table 3.3 "Elasticity estimates for cotton" in Karp, et al. (1995)

The estimate of Es = 1.35 by Adams and Behrman (1976)[11] was used to represent the high end of the range for domestic supply elasticity estimates. This value is important, not only for the purpose of comparison, but because simulations based on this value were used to correct the underestimation of the cost of the water subsidy, which in turn affects the amount of producer rents received, and the total government cost of U.S. cotton policy. As first mentioned in Section 4 (footnote 4), the ultimate source of this underestimation is the fact that point elasticity estimates are used to derive the subsidized supply curve, *S'*.[12] With a domestic supply elasticity of 1.35, the intercepts of the supply and subsidized supply curves intersect the y-axis positively, and equal $119.10 and $90.10 per bale, respectively. This allows the calculation of the cost of the water subsidy to at least approximate the true value, and provides a basis with which to correct the underestimation inherent in calculations based on supply curves intersecting the x-axis.

The Results for 2003

We present simulation results for 2003 in this section. Because the world price of cotton rose to $297.60 per bale in 2003, the *a priori* expectation is that the U.S. cotton policy had a much smaller impact on prices than in 2002, a reduction in subsidy rents to all recipients, and a reduction in the costs of the program to the U.S. government and to U.S. society (i.e., net domestic welfare loss decreases). Results of these models show this to be the case. For example, Table 7 illustrates that producers received $830 million in ME rents for 2003, which is more than a billion dollars less than they received in 2002 ($1.99 billion).

Table 7. Comparison of the ME and SP Models for 2002 and 2003 ($ Million)

	2003		2002	
Welfare Component	**ME**	**SP**	**ME**	**SP**
Producer rents	$830*	$411	$1,988*	$1,530
U.S. consumer rents	$116	$51	$236	$177
Slippage	$350	$151	$482	$356
Deadweight loss	$53	$11	$274	$164
Government cost	$1,341*	$623	$2,944*	$2,226
Cost of water subsidy	$432*	$0	$433*	$0
Net U.S. welfare loss	$403	$161	$756	$520

* Values corrected for the underestimated cost of the water subsidy

There is also a reduction of more than $120 million for ME rents accruing to domestic consumers. The ME government cost of the program is lowered from nearly $3 billion for 2002 to $1.31 billion for 2003. The temporal difference in the ME net U.S. domestic welfare loss is also pronounced (reduced from $756 million in 2002 to $403 million in 2003).

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[11] See Table 3.3 "Elasticity estimates for cotton" in Karp, et al. (1995)

[12] All supply curves for Es < 1.0 will intersect the x-axis positively. Therefore, increasing the elasticity of supply causes the (empirical) x-intercepts to shift inwards toward the origin. This results in certain welfare areas to elongate

A significant result of these simulations is that the distortion of cotton prices is lessened in 2003 (Table 8). For the 2003 ME model, the calculated theoretical 'free trade' price (p_f = \$324.20) is only 8.9% higher than the 2003 world price, compared with a 22.8% differential simulated by the 2002 ME model. Because the export demand elasticity is unitary, this price differential imparts the same *percentage* impact to the amount of U.S. cotton exports: the 2003 ME theoretical 'free trade' exports equal 12.57 Mb, compared to the actual amount exported in 2003 (13.8 Mb).

Table 8. Price Effects Comparison for the 2003 SP and ME Models (U.S. \$/bale)

Description	Price Support Payments	Multiplicative Effects
"Free trade" price	p_f = \$323.60	P_f = \$324.20
World clearing price	p_c = \$311.86	P_w = \$297.60
Difference	\$11.74	\$26.60

Conclusion

We discuss the findings of this study with reference to the ongoing cotton debate that began during the Doha Round at Cancun in 2003, and that continues with the United States appealing the WTO's support for Brazil's case against U.S. cotton growers. One model used to rebut the Brazilian claims (a Texas Tech study using 2003 data) shows that world cotton prices would increase by 0.5% to 2% when U.S. price supports are eliminated (Laws, 2004). Also, our 2003 price support payment (SP) model shows only a 4% increase in world prices if the U.S. cotton policy is removed. On the other hand, Sumner (using data for the period 1999-2002) concluded that removing U.S. price supports would increase the world price by 12% (Laws, 2004), while our SP model for 2002 shows a 16% price increase in the absence of price supports. However, one can choose supply and demand elasticities that show smaller price impacts. Regardless, our results are consistent with previous results that the U.S. cotton policy suppresses world cotton prices.

We present the 2002 and 2003 results for our SP model in order to facilitate comparison with these other studies, and to emphasize just how important the selection of the base year is when analyzing the price and welfare impacts of U.S. cotton policy. The economic results discussed in the context of the WTO case brought by Brazil use different base years. We illustrate the multiplicative effects of both water subsidies and price supports. The other models referred to above do not explicitly address this phenomenon, since they exclude water subsidies. But even in the absence of water subsidies, our results (from the SP models) showed somewhat higher world price impacts from U.S. cotton subsidies than did these previous studies. However, our results are likely overstated because they assume that the U.S. cotton policy is totally coupled to production and that other competing countries do not use policies that are either production- or trade-distorting. More work is needed to empirically assess the realism of these assumptions.

Appendix A

Empirical Graphs for the Individual Policy Instruments

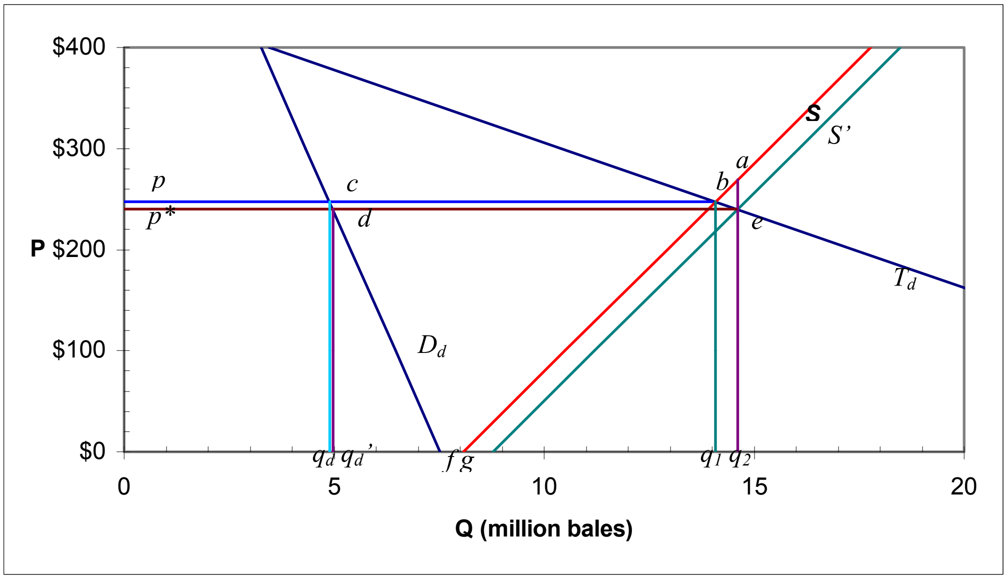

Figure A1. Empirical Representation of the U.S. Cotton Industry with a Water Subsidy (2002)

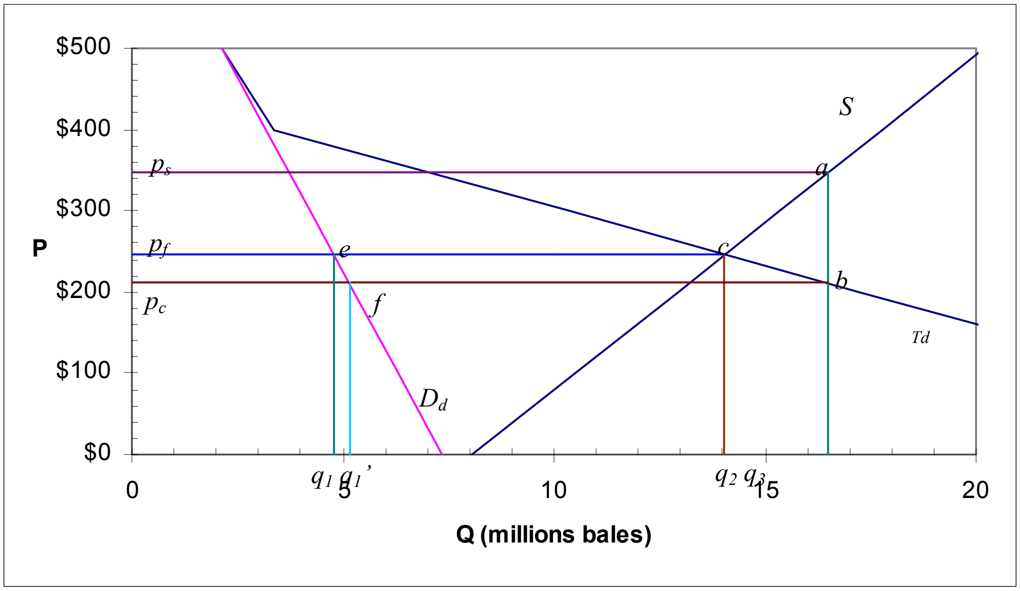

Figure A2. Empirical Representation of the U.S. Cotton Industry under a Support Payment Scheme (2002)

Appendix B

Additional ME Simulations for 2002

Because even Beach, et al. (2002) found their estimated export demand elasticity (-0.7) to be on the low end of the range of export demand elasticities found in the literature,[13] our original ME model presented in Section 4 incorporated the estimate of -1.0 by Babula (1987)[14] as a reasonable export elasticity value with which to begin modeling. However, given the concerns regarding the accuracy of the initial elasticity utilized, additional simulations were conducted, and are presented here, in order to observe how the 2002 ME model performed under alternative specifications defined by different elasticity estimates.

As footnote 12 points out, the export demand elasticity (Exd) of -1.0 might be a low estimate; thus for this set of simulations we hold the domestic demand and supply elasticities constant while substituting higher values for the unitary export demand elasticity value used previously. However, in order to model the changes resulting from increasing the export demand elasticity (specifically the impact to the world clearing price), it is necessary to calculate an associated Exd at an arbitrarily selected point that is independent of the world clearing price, P_w. This is because point elasticity estimates were necessarily used to construct the ME model: the export demand curve is derived from Exd = -1.0 for a point defined by the intersection of $P_w = 201.60$, and (export level) X = 11.9 Mb of cotton. As Exd is tied to this point, any increase (to Exd) will only rotate the export demand curve counter-clockwise around this "pivot point" – thus to allow P_w to vary, it is necessary to choose another pivot point along the export demand curve. Therefore, an alternative pivot point (p = \$275.00, q = 7.57) was chosen on the export demand curve approximately halfway between the target price and the world price; the elasticity calculated at this point is Exd = -2.145, which corresponds to Exd = -1.0 at the original point of analysis ($P_w = 201.60$, X = 11.9) of the ME model.

The principal impact of increasing the export demand elasticity will be to raise both the 'free trade' price (P_f), and the 'free trade' quantity produced (q); these effects result from the counter-clockwise rotation of the total demand curve about the alternative pivot point. The changes to P_f and q can be observed below in Table B1, along with the 'free trade' values for both domestic demand (q_{df}) and U.S. exports (X_f), and price and quantity differentials showing how the (theoretical) free world market would be affected by U.S. subsidies.

Each component of welfare will be affected in turn by these changes, except for the cost of the water subsidy, which is unaffected by changes to the export demand elasticity. Table B2 illustrates how the various welfare components are apportioned when the export demand elasticity is increased. Note that welfare values for the original simulation (Exd = -1.0) are in the first column of the data, and are compared to the scenarios in which Exd is increased: first doubled (Exd = -4.29 at the alternative pivot point), and then further increased to Exd = -10.0 (alternative pivot point).

It can be seen that a larger export demand elasticity results in less rents received by all recipients of U.S. cotton subsidies – domestic producers and consumers, as well as foreign countries. The total government cost, the deadweight loss, and the net U.S. welfare loss all

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[13] See, for example, Table 3.3 "Elasticity estimates for cotton" in Karp, et al. (1995).

[14] As cited in Karp, et al. (1995), this estimate itself appears to be on the low end of the long-run export demand elasticity range.

decrease. Thus, producer lobbyists could argue that U.S. cotton policy gains "economic efficiency" (and distorts the world price less) when modeled with higher elasticity estimates of export demand.

Table B1. Simulated ME on Selected 'Free Trade' Variables for 2002, Holding Edd and Es Constant

Variable	**Export Demand Elasticity (Exd)**			
	-2.145	**-4.29**	**-10.0**	**Unit**
P_f	\$247.49	\$258.10	\$266.66	\$/bale
q	14.08	14.34	14.54	Mb
q_{df}[a]	4.89	4.77	4.68	Mb
X_f[b]	9.19	9.56	9.86	Mb
Differences[c]				
$P_f – P_w$	\$44.93[d]	\$22.32	\$9.33	\$/bale
$Q^* – q$	3.13	2.87	2.67	Mb

[a] Domestic demand under free trade.

[b] Exports under free trade.

[c] 'Free trade' minus world price; and current minus free trade production.

[d] Value is slightly less than the differential presented in Table 3, due to the recalculation of the pivot point.

Table B2. Simulated ME Welfare Impacts and Distribution by Export Demand Elasticity for 2002, Holding Edd and Es Constant ($ Millions)

Welfare Component	**Export Demand Elasticity (Exd)**		
	-2.145[a]	**-4.29**	**-10.0**
Producer rents*	\$1,988	\$1,833	\$1,706
U.S. consumer rents	\$231	\$113	\$47
Slippage	\$472	\$239	\$101
Deadweight loss	\$272	\$202	\$159
Government cost*	\$2,928	\$2,356	\$1,985
Cost of water subsidy*	\$433	\$433	\$433
Net U.S. welfare loss	\$745	\$441	\$260

* Values corrected for the underestimated cost of the water subsidy

[a] Except for producer rents, the values in this column are slightly less than the ME values presented in Table 4; this is due to the recalculation of the pivot point.

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THE IMPACTS OF MFA ELIMINATION ON CHINESE FIBER MARKETS

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Abstract

This study develops a partial equilibrium model of Chinese fiber markets to analyze the effects of Multifiber Arrangement (MFA) elimination. The structural model incorporates regional supply response for cotton, substitutability between cotton, wool and man-made fibers at the mill level and appropriate linkage between cotton and textile sectors. One of the unique characteristics of this study is the use of a two-step approach to estimate fiber demand and specifically connecting textile outputs with fiber inputs. The simulation results suggest that the rise in textile exports due to quota eliminations as part of ATC will increase domestic mill use of cotton and man-made fibers. A rise in fiber mill use increases domestic fiber prices with cotton and man-made fiber prices rising by an average of 4 and 7 percent per year respectively. Since domestic fiber production particularly cotton is projected to grow at a slower pace than demand, the excess demand is fulfilled by higher imports. In the case of cotton, imports are expected to be approximately 50 to 60 percent higher than the baseline level whereas man-made fibers imports are projected to rise by 8 to 13 percent due to textile quota eliminations.

Key Words: MFA, China, Cotton and Man-made Fibers, JEL Classification: F17, Q31

The Impacts of MFA Elimination on Chinese Fiber Markets

Chinese accession into the World Trade Organization (WTO) in 2000 is regarded as one of the milestones of world economic development in recent history and has been seen as a great opportunity and challenge for the world. However, for commodities like cotton and man-

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made fibers, which are dependent on the growth in textile demand, the impacts of the implementation of Agreement on Textiles and Clothing (ATC) on Chinese fiber consumption and trade could be more significant. The ATC replaced the Multifiber Arrangement (MFA) in 1995 to incorporate the textiles and clothing sector into WTO rules and disciplines in a transitional ten-year period. The MFA, established in 1974, restricted exports of textiles and clothing products from most developing countries to developed countries through a mutually agreed upon set of bilateral quotas. Over time, many importing countries (Sweden, Switzerland, and Australia among them) have left MFA. However, since 1994, MFA members have been four importers (United States European Union, Canada, and Norway) and some 30 developing exporting countries with a total of more than 1,300 textiles and clothing bilateral quotas.

As shown in the figure 1, the ATC includes gradual integration of textiles and clothing trade into WTO rules in three stages. The first stage (1995-1997) involves the integration of 16 percent of the value of 1990 imports with an additional 17 and 18 percent for the second (1998-2001) and the third (2002-2004) stages of integration, respectively. Although in the final stage of integration, most of the 1,325 original quotas remain in place with only 219 being eliminated in the first seven years of integration (Malaga and Mohanty, 2003). Most of the integration has taken place in low-value products such as yarns, fabrics, and made-ups which are of little or no interest to developing countries, particularly China. The three largest importers (the United States, Canada and the European Union) on average have integrated 31 percent low-value products and less than 3 percent high-value products to get to their 33 percent ATC commitments (Malaga and Mohanty, 2003). The numbers of quotas that would remain in place for these three importers were as high as 701 out of 757 in the case of the United States, 164 out of 219 in the case of the European Union, and 241 out of 295 in the case of Canada at the end of the second stage of integration (Malaga and Mohanty, 2003).

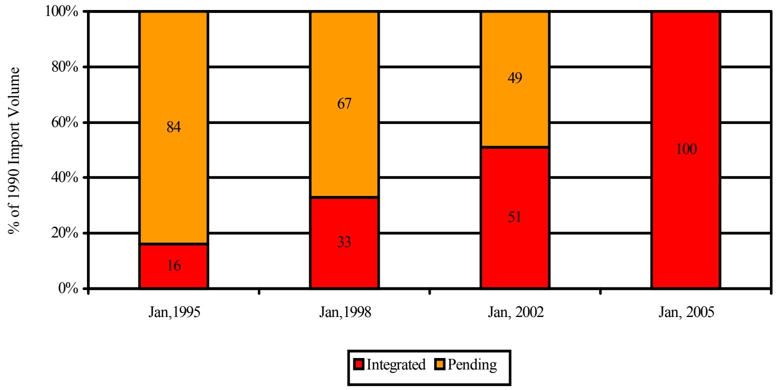

Figure 1. ATC Integration Process by Stages

However, the developed countries, particularly the United States and the European Union, still reaffirm their commitment to achieve full implementation of the ATC and pledge that all bilateral quotas on textiles and clothing exports from developing to developed markets will be eliminated by January 1, 2005. Past studies examining the effects of MFA elimination on textile trade have unanimously concluded that China would be one of the primary beneficiaries of quota eliminations with its textiles and clothing exports to the developed markets rising by at least 25 percent (Wang et al, 2001).

Rising textile export demand would definitely increase domestic mill consumption of fibers, particularly cotton and man-made fibers. Considering the resource constraints such as land and water to expand domestic cotton production, rising fiber demand in China may significantly alter the domestic and world fiber markets. In addition, China has already opened up its cotton sector as part of its WTO commitments with the establishment of tariff-rate-quotas (TRQs) for cotton imports. The commitments for the period 2002 to 2006 include an increase of Chinese cotton imports from 743 thousand metric tons (tmt) to 894 tmt with in-quota tariff on cotton imports declining from 3 to 1 percent. At the same time, the out-of–quota tariff is expected to decline from 76 percent to 40 percent. In the absence of non-tariff barriers, cotton imports will be dictated by domestic supply and demand rather than non-market forces such as state trading agencies.

In recent years, few studies (Fang and Babcock, 2003; Fuller et al., 2001; Colby et al, 2000; and Wang, 1997) have focused on Chinese cotton markets to analyze the impacts of WTO accession. However, most of these studies with the exception of Fang and Babcock (2003), have failed to take into account the regional differences in cotton production by estimating an aggregate supply model. More importantly, these studies have modeled cotton demand as a final consumer product rather than an input for textile mills. In addition, these studies have completely ignored the inter-fiber substitutability between cotton and man-made fibers. Considering the significance of MFA elimination on the Chinese fiber markets, a theoretically consistent framework that incorporates regional difference in productivity on the supply side and proper linkage between cotton and textile along with inter-fiber substitution on the demand side is essential in understanding the impacts on the fiber markets.

The objective of this study is to develop a non-spatial, partial equilibrium fiber model that incorporates regional supply response for cotton, substitutability between cotton, wool and man-made fibers, and appropriate linkage between cotton and textile sectors to measure the effects of MFA elimination on Chinese fiber markets. Once the model is estimated, a ten-year baseline for Chinese cotton and man-made fiber supply, demand, and prices will be developed under a set of plausible assumptions regarding macroeconomic and other variables along with the assumptions of a continuation of MFA and other policies. Next, a scenario is developed by raising Chinese textile exports by 25 percent due to MFA eliminations and compare to the baseline level to estimate the effects of MFA elimination.

In the next section, we describe the analytical approach, followed by a description of the data and the estimation procedure. Following this, we report the parameter estimates of supply and demand equations along with simulation results. The final section of the paper highlights the policy implications of the study.

Conceptual Model

A schematic representation of the fiber model that includes supply, demand, and price linkage equations for cotton and man-made fibers are shown in figure 2. As shown in the figure, fiber demand is estimated in a two-step process. In the first step, total textile consumption is estimated and in the second step, allocated among various fibers such as cotton, man-made fibers and wool based on relative prices.

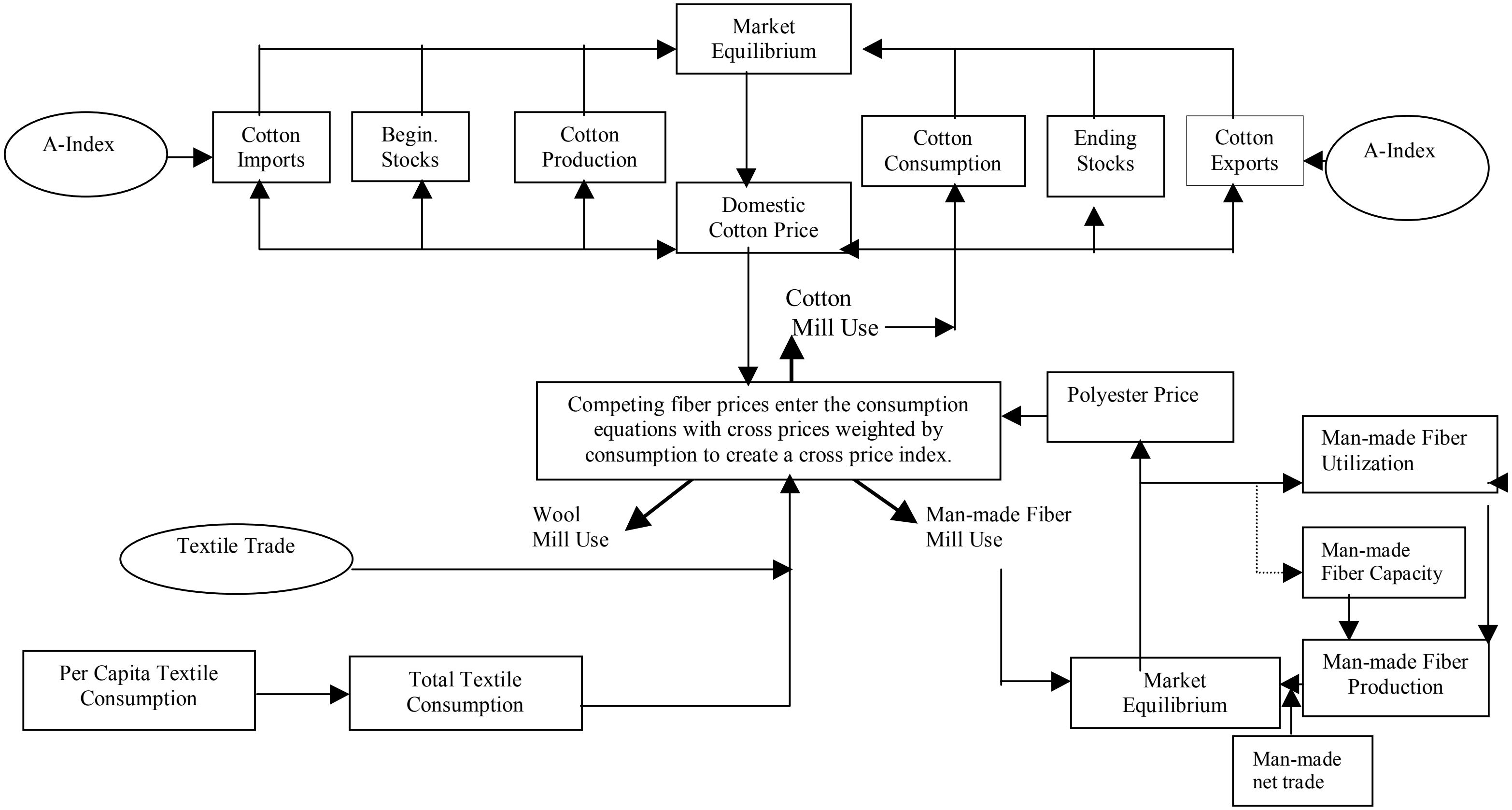

Figure 2. Schematic Representation of China's Cotton and Textile Model

Fiber Supply Estimation

In this study, cotton-producing areas in China are segregated into four regions in order to account for heterogeneity in growing conditions arising out of climatic differences, availability of water and other natural resources that influence the mix of crops in each of the regions. The four regions include the Xinjiang, the Yellow River valley, the Yangtze River valley, and the-rest-of-China. The i^{th} region acreage response is specified as:

$$ARC_i^t = f(NRC_i^{t-1}, NRCM_{i,j}^{t-1}) \tag{1}$$

$$NRC_i^{t-1} = PC_i^{t-1} \times YDC_i^{t-1} - CC_i^{t-1} \tag{2}$$

$$NRM_{i,j}^{t-1} = PM_{i,j}^{t-1} \times YDM_{i,j}^{t-1} - MC_{i,j}^{t-1} \tag{3}$$

where ARC_i^t stands for cotton acreage in the i^{th} region; NRC_i represents per hectare cotton net return in the i^{th} region; $NRM_{i,j}$ represents per hectare net return for the j^{th} competing crop in the i^{th} region; PC_i represents i^{th} region cotton farm price; PM_{ij} represents the j^{th} competing crop price in the i^{th} region; YDC_i represnts the i^{th} region cotton yield; $YDM_{i,j}$ represents the j^{th} competing crop yield in the i^{th} region; CC_i stands for the i^{th} region cost of production for cotton; $MC_{i,j}$ is the j^{th} competing crop cost of production in the i^{th} region. Last year's net returns were used as the measure of the expected return for this year.

In the Xinjiang region, wheat and corn are included in the acreage equation as the competing crops whereas in the Yellow River valley, only wheat is included as the competing crop. In the Yangtze River valley wheat and rice are included as the competing crops for cotton. Finally, rice is included in the rest-of-China as the only competing crop.

The cotton yield (YDC_i^t) is specified as:

$$YDC_i^t = f(NRC_i^{t-1}, T) \tag{4}$$

where NRC_i is per hectare cotton net return in the i^{th} region and T is the time trend to capture technological improvements. Both the area and the yield equations are estimated using Ordinary Least Square (OLS) procedure. Following this, cotton production for the i^{th} region is specified as:

$$CTPR_i^t = ARC_i^t \times YDC_i^t \tag{5}$$

Chinese total cotton production is calculated as:

$$CTPR^t = \sum_{i=1}^{4} CTPR_i^t \tag{6}$$

Following Meyer (2002), man-made fiber production is calculated by estimating capacity and utilization. Construction of new capacity takes several periods and is affected by expectations of market prices for several periods before construction actually begins or planning takes place. However, utilization mainly depends on current prices of inputs and output.

The production capacity of man-made fibers is specified as lagged prices of domestic polyester price, oil price and time trend. The lag length is determined by using minimum Akaike Information Criterion (AIC) method. The capacity equation is specified as follows:

$$MMFPC^{t} = f(PP^{t-i}, OP^{t-i}, MMFPC^{t-1}) \quad i = 3,4,...,7 \tag{7}$$

where $MMFPC$ is the man-made fiber production capacity; *PP* is the polyester price and *OP* is the crude oil price.

Unlike capacity, utilization depends on current input and output prices and is specified as follows:

$$MMFCU^{t} = f(PP^{t} / OP^{t}, MMFCU^{t-1}) \tag{8}$$

where *MMFCU* is the capacity utilization of man-made fibers

Finally, the total production of man-made fibers is calculated as:

$$MMFPR^{t} = MMFC^{t} \times MMFCU^{t} \tag{9}$$

where $MMFPR^{t}$ is the man-made fiber production.

Fiber Demand Estimation

As indicated earlier, a two-step procedure is followed in estimating fiber demand. In the first step, per capita domestic textile consumption in fiber equivalent is estimated using a double-log specification. Based on Houthakker (1957), double log specification is preferred if the income elasticity is similar over a considerable range. Since Chinese textile products as a group reflect such stability property, the double-log system is applied and is as follows:

$$Q_{TEX}^{t} = f(TPI^{t}, FPI^{t}, I^{t}) \tag{10}$$

where Q_{TEX} is the per capita textile demand; *TPI* is the textile output price index; *FPI* is the food price index and *I* is the per capita real income

Next, total textile production is calculated by adding textile net trade with domestic textile consumption. In the second step, total textile production is allocated among various fibers such as cotton, wool and man-made fibers using factor share equations derived from translog cost function.

$$S_{i} = W_{i} X_{i} / C = \alpha_{i} + \sum_{j=1}^{3} \gamma_{ij} \ln W_{j} + \rho \ln Q_{i} \tag{11}$$

where S_i is the ith fiber share (i = cotton, man-made fibers and wool); W_i is the price of ith fiber; X_i is the quantities of ith fiber and Q_i is the quantity of ith fiber textile.

The fiber demand system is estimated using seemingly unrelated regression (SUR) procedure after imposing symmetry, homogeneity and adding up constraints. Man-made fiber share equation is excluded in order to avoid the singularity of the variance-covariance matrix of disturbances and later retrieved using adding-up constraints.

In popular models of factor demand analysis, two commonly used summary measures of price responsiveness are the Allen-Uzawa partial elasticity of Substitution (σ_{ij}) and the price elasticity of demand (η_{ij}). Following Urga and Walters (2000), these measures for the translog cost function are as follows:

$$\begin{aligned} \sigma_{ii} &= \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \\ \sigma_{ij} &= \frac{\gamma_{ij} + S_i S_j}{S_i S_j} \end{aligned} \tag{12}$$

$$\begin{aligned} \eta_{ii} &= S_i \sigma_{ii} \\ \eta_{ij} &= S_j \sigma_{ij} \end{aligned} \tag{13}$$

Cotton Ending Stock and Trade Equations

Cotton ending stock is specified as a function of beginning stocks, farm price, and cotton production. Cotton trade equations are specified separately for exports and imports. The import equation is specified as the function of the ratio of domestic price to the imported cotton price, the ratio of lagged one year domestic price to the imported cotton price, and income. Imported cotton price is estimated by adding in-quota tariff to the world price expressed in domestic currency. Similarly, the export demand for cotton is modeled as the function of domestic price to the world cotton price, and the ratio of lagged one year domestic cotton demand to cotton production.

$$CTIM^t = f\left(\frac{PCM^t}{PCW^t(1+TR^t)}, \frac{PCM^{t-1}}{PCW^{t-1}(1+TR^{t-1})}, I^{t-1}\right) \tag{14}$$

$$CTEX^t = f(PCM^t / PCW^t, CTD^{t-1} / CTPR^{t-1}) \tag{15}$$

where *CTIM* represents cotton imports; *CTEX* represents cotton exports; *PCM* stands for domestic cotton mill price; *PCW* represents world cotton price; *TR* represents import tariff for cotton; CTD represents cotton mill use and *I* is the per capita real income.

In case of man-made fibers, the net trade (imports-exports) equation is estimated rather than estimating separate equations for exports and imports and is specified as the function of ratio of world to domestic polyester prices and lagged net imports.

Price Linkage and Market Equilibrium

Since supply equations depend on the farm price whereas demand equations depend on the mill price, a price linkage equation is estimated by setting up cotton mill price as a function of cotton farm price. Similarly, regional farm prices are connected with the national farm price by estimating a set of linkage equations where each of the regional prices is specified as function of national farm price.

Finally, domestic cotton and polyester prices are solved by setting total supply equal to total demand in each of the sectors. For cotton, total supply includes production, beginning stocks and imports whereas total demand includes domestic mill consumption, ending stocks and exports. But for man-made fibers, total supply includes production and net imports whereas total demand includes domestic consumption. Due to the non-availability of inventory data, we have assumed the carry over stock to remain unchanged from year to year.

Data Requirements and Results

Data for the period 1979 to 2002 is used in the estimation process. Data is obtained from several different sources. The macroeconomic data such as GDP, population, and Consumer Price Index (CPI) are obtained from various issues of *International Financial Statistics* published by International Monetary Fund. The price indices such as textile price index and food price index are collected from various issues of the *Chinese Statistics Yearbook*. Cotton data on acreage, yield, production, mill utilization, ending stocks, and trade are collected from the Foreign Agricultural Services of the United States. Cotton and the competing crops production costs are from the *Chinese Rural Statistical Handbook*. Cotton farm and mill prices are obtained from All China Federation of Supply and Marketing Cooperatives. The data on consumption and trade of textile and man-made fibers are obtained from various issues of the *China Industrial Economic Statistical Yearbook*, *Chinese Rural Statistical Yearbook* and *"Almanac of China's Textile Industry: 1979-99"*. Data on world cotton and polyester prices are obtained from the *Cotton and Wool Situation and Outlook Yearbook* published by the Economic Research Service, U.S. Department of Agriculture and Cotlook Ltd (2002). In this study, polyester price is used as the representative price for man-made fibers because the cellulosic sector accounts a small proportion of the Chinese man-made fiber industry. Wool price refers to the United Kingdom domestic wool 50s CIF equivalent and is collected from the International Monetary Fund.

Results

Regional cotton acreage and yield equations are estimated using OLS estimation technique. Parameter estimates along with t-values in brackets are reported in table 1. Generally, regional area equations are specified as a function of lagged net returns for cotton and competing crops. The positive values of the parameter estimates for cotton net returns imply that cotton area in each region increases with higher cotton net returns.

Table 1. Parameter Estimates of Regional Cotton Acreage and Yield Equations

	Xinjiang		**Yellow River**		**Yangtze River**		**Rest-of-China**	
	Area	**Yield**	**Area**	**Yield**	**Area**	**Yield**	**Area**	**Yield**
Intercept	344.40 (9.32)	-1.29 (16.44)	3302.10 (20.85)	-0.38 (3.20)	1886.33 (25.16)	0.79 (15.52)	134.17 (10.48)	0.67 (7.69)
Cotton Net Return$_{(t-1)}$	0.08 (5.32)	0.000008 (1.30)	0.14 (0.96)	0.000001 (0.16)	0.06 (1.11)	0.000001 (0.13)	0.01 (1.53)	0.000003 (0.14)
Rice Net Return$_{(t-1)}$					-0.02 (0.27)		-0.04 (4.28)	
Wheat Net Return$_{(t-1)}$	-0.01 (0.24)		-0.67 (2.81)		-0.14 (0.81)			
Corn Net Return$_{(t-1)}$	-0.07 (1.63)							
Shift-99			-1395.8 (2.33)		-635.15 (3.93)			
Dummy-86					-427.04 (1.95)			
Time		0.50 (12.91)		0.06 (8.47)		0.008 (1.57)		0.002 (0.28)
Adj. R^2	0.92	0.95	0.81	0.97	0.87	0.66	0.83	0.34
D-W Statistics	1.69	1.86	1.74	1.41	1.55	2.01	1.72	2.22

Note: t-values are given in brackets below the parameter estimates

Parameter estimates for competing crop(s) are found to be negative in all regions suggesting that an inverse relationship exists between cotton acreage and competing net returns. In the Xinjiang region, competing net returns for both wheat and corn are found to be negative but not significant. However, in the Yellow River region, wheat is the only competing crop included in the area equation and is found to be significant. Similarly, in the rest-of-China region, rice is the only competing crop and is found to be significant. In the Yangtze River region, both wheat and rice are included as competing crops. Parameter estimates for wheat and rice are found to be insignificant in this region. However, they do have the expected negative signs.

Generally, regional yield equations are specified as a function of the lagged net return of cotton and time trend. Time trend is included to represent technological improvements. The positive values of the parameter estimates for cotton net return and time imply that cotton yield in each region increases with higher cotton net return and more advanced technology. Cotton return is found to be significant in the Xinjiang region. In the other three regions, cotton net return is found to be positive but not significant.

The adjusted R^2 for the yield equations ranges from 0.70 to 0.97 except for the rest-of-China region. In addition, Durbin-Watson statistics reported in the table suggest no serious autocorrelation in the yield equations. The poor fitness of the rest-of-China region yield model (R^2=0.34) may be explained by various conditions in climate, fertilizer, and irrigation which comprise this region.

For the man-made fiber supply component, the OLS parameter estimates for the man-made fiber production capacity and utilizations are presented in table 2. The capacity equation is specified as a function of lag capacity, 3 to 7 year weighted average prices of polyester and crude oil. Although the price variables have expected signs, the estimates are found to be insignificant suggesting a lesser role of input and output prices in capacity building. The adjusted R^2 for the capacity equation is 0.99 suggesting that most of the variation in the capacity is explained by the independent variables included in the equation.

Table 2. Parameter Estimates of Man-made Fiber Capacity and Utilization Equations

	Capacity	**Utilization**
Intercept	-0.47(0.30)	-0.09(2.00)
Polyester Price$_{(t\text{-}3 \text{ to } t\text{-}7)}$	0.06 (0.65)	
Oil Price$_{(t\text{-}3 \text{ to } t\text{-}7)}$	-0.02 (0.07)	
Capacity$_{(t\text{-}1)}$	1.05 (18.38)	
Polyester Price / Oil Price		0.013 (0.51)
Utilization$_{(t\text{-}1)}$		0.55 (4.25)
Dummy-83		-0.30 (4.28)
Adj. R^2	0.99	0.66
D-W Statistics	2.17	2.22

Note: t-values are given in brackets below the parameter estimates

Similarly, man-made fiber capacity utilization is estimated as a function of previous year's utilization and the ratio of polyester to oil prices. Positive coefficient for the polyester to oil price ratio implies that as the ratio increases either by a decline in oil price or rise in polyester price, the utilization rate increases because of higher profit margins.

Fiber Demand Estimates

As explained earlier, a two-step procedure is followed to estimate fiber demand. In the first step, textile demand is estimated and then in the second step, allocated among various fibers such as cotton, wool, and man-made fibers. Per capita textile consumption is specified as a function of per capita income, textile price index and the food price index. The parameter estimates along with t-values in brackets are presented in table 3. As expected, income is found to be positive and significant at the 5 percent level. In addition, the textile price index found to be significant and negative, suggesting that textile consumption decreases with increase in textile price and vice-versa. However, food price index is negative but insignificant.

Table 3. Parameter Estimates of Textile Consumption Equation

Intercept	7.39 (5.69)
Per Capita Income	1.64 (5.93)
Textile Price Index	-1.20 (2.26)
Food Price Index	- 0.15 (0.40)
Adj. R^2	0.81
D-W Statistic	1.81

Note: t-values are given in brackets below the parameter estimates

In the second step, textile production is allocated among competing fibers, i.e, cotton, wool, and man-made fibers based on relative prices using translog model. The demand system is estimated using non-linear SUR with symmetry and homogeneity imposed. The man-made fiber equation is omitted from the estimated system to be later obtained through the adding-up constraint. The parameter estimates along with t-statistics are presented in table 4. All the parameter estimates are significant at the 5 percent level.

Table 4. Parameter Estimates of Fiber Demand System

Parameters	Cotton	Wool	Man-made Fibers
Intercept	3.67 (4.37)	-0.14 (2.01)	-2.53
Textile Outputs	-0.39 (3.8)	0.03 (2.17)	0.36
Cotton	0.11 (4.41)	-0.042 (3.29)	-0.07
Wool	-0.04	0.05 (3.34)	-0.01
Man-made Fibers	-0.07	-0.01	0.07

Note: Absolute values of t-values are reported in brackets

In order to shed more light on price responsiveness, the price parameters are converted into elasticities at the sample mean and are reported in table 5. As expected, all own-price elasticities are found to be negative and range from −0.07 to −0.33 with the lowest being for wool and the highest for cotton. However, own price elasticity of man-made fiber is more or less the same as cotton with −0.32.

The cross-price elasticities are all positive except between cotton and wool. Negative cross price elasticities between cotton and wool suggest complementary relationship between these two fibers. Unlike the cotton-wool relationship, man-made fibers-cotton and man-made fibers-wool cross price elasticities are positive. Overall, it may be concluded that cotton and man-made fibers are highly responsive to each other's prices whereas wool price has little or no effect in influencing either cotton or man-mad fiber demand.

Table 5. Fiber Demand Elasticities

Fibers	Cotton	Man-made Fibers	Wool
Cotton	-0.33	0.38	-0.05
Man-made Fibers	0.28	-0.32	0.04
Wool	-0.33	0.40	-0.07

Ending Stock and Trade Equations

The cotton ending stock is specified as a function of domestic supply and cotton farm price. The parameter estimates along with t-statistics are reported in table 6. The positive estimate of cotton beginning stocks and production implies that cotton ending stocks increase as cotton beginning stocks and production increase. On the other hand, the negative estimate of cotton farm price implies that higher cotton prices lower ending stocks and vice-versa.

Table 6. Parameter Estimates of Cotton Ending Stock and Trade Equations

Parameters	Cotton Ending Stock	Cotton Imports	Cotton Exports	Man-made Fiber Net Imports
Intercept	2.99 (9.04)	2.76 (1.38)	4.63 (22.68)	0.66 (0.88)
Domestic Supply	0.85 (11.98)			
Farm Price	-0.95 (3.06)			
Price Ratio^a_t		0.83 (0.42)		
Price Ratio$^a_{t-1}$		1.45 (1.03)		
Price Ratio^b			-2.80 (4.37)	
Price Ratio^c				0.03 (0.21)
Per Capita Real GDP$_{(t-1)}$		1.75 (1.77)		
Cotton Demand /Cotton Production$_{(t-1)}$			-3.57 (3.51)	
Man-made Fiber Net Import$_{(t-1)}$				0.92 (8.80)
Dummy-85		-6.45 (4.05)		
Shift-98		-3.02 (2.02)		
Dummy-80			-3.28 (3.42)	
Dummy-9596			-4.01 (6.18)	
Dummy-86				
Adj. R^2	0.84	0.75	0.79	0.9083
D-W Statistics	1.91	1.87	1.96	2.162

Note: t-values are given in brackets. a = Ratio of cotton domestic mill price to import price; b= ratio of cotton domestic price to world price and c = ratio of polyester domestic price to world price

For cotton, separate equations are estimated for exports and imports. The parameter estimates along with t-values are presented in table 6. Cotton import demand is specified as a function of lagged one year per capita GDP, the ratio of lagged domestic cotton mill price to the imported price, and the ratio of current mill price to the imported cotton price. Similarly, cotton export demand is specified as a function of the ratio of domestic mill price to the world price and the ratio of lagged cotton demand to production. As expected, the price ratio is found to be positive but not significant for the import equation. This is obvious in the case of China where the state trading agency has historically been responsible for making import decisions rather than the market. Unlike imports, prices appear to have some role in influencing the level of exports. The ratio of domestic mill price to the world price is found to be negative and significant, suggesting that higher domestic prices or lower international prices discourage exports and vice-versa.

In the case of man-made fibers, the net import equation is estimated rather than using separate equations for exports and imports. The net import equation is specified as a function of lagged net imports and the ratio of domestic to world polyester prices. The OLS parameter estimates for man-made fiber net imports are presented in table 6. The ratio of domestic price to world polyester price is found to be positive but not significant. This implies that as the price ratio increases, man-made fiber imports increase and vice-versa. On the other hand, lagged net import is also found to be positive and highly significant.

Price Linkage Equations and Model Validation

The OLS parameter estimates of price linkage equations of regional cotton farm prices are presented in table 7. Parameter estimates of regional prices are found to be highly significant and close to one for all the three regions.

Table 7. Parameter Estimates of Cotton Price Linkage Equations

Parameters	**Cotton Mill price**	**Xinjiang Farm Price**	**Yellow River Farm Price**	**Yangtze River Farm Price**
Intercept	-0.12 (0.37)	0.34 (5.11)	0.14 (2.15)	-0.36 (1.70)
Cotton Farm Price	1.01 (26.47)	0.96 (124.29)	0.99 (132.84)	1.04 (42.77)
Adj. R^2	0.9771	0.9984	0.9993	0.9919
Durbin-Watson	1.8361	1.9116	1.8395	2.0676

Note: t-values are given in brackets below the parameter estimates

The adjusted R^2 values for all three regional equations are higher than 0.99 suggesting that more than 99 percent of the variations in the regional prices are explained by the national prices. Another price linkage equation between cotton farm and mill prices is also estimated by specifying mill price as a function of cotton farm price. The adjusted R^2 for the estimated equation is 0.98. Finally, the model was validated using the Root Mean Squared percentage Error (RMSE) and Theil's U statistics. Overall, the model validation statistics suggest that the simulation model has reasonably good forecasting ability[1].

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[1] Detailed results of the model validation statistics are available upon request from the author(s).

Policy Simulation

The estimated econometric model is used to develop a ten-year baseline projection for cotton, man-made fibers, and textile supply, and demand and prices under a set of exogenous assumptions. Baseline projections normally assume the continuation of current policies. For example, Chinese WTO commitments are included in the baseline. In addition, the model is driven by a set of macroeconomic projections. The model uses forecasts of macroeconomic variables, such as real GDP, consumer price index (CPI), exchange rates, and population from 2003 World and U.S. Agricultural Outlook published by Food and Agricultural Policy Research Institute (FAPRI). For example, population growth is projected to increase from 0.64 percent in 2002 to 0.67 percent in 2012 (FAPRI, 2003). Similarly, real GDP is projected to grow at an average annual growth of 7 percent between 2002 and 2012. With increasing population growth, the GDP growth is translated into a per capita real GDP growth rate of 4.97 percent for 2002 to 2012. Projections of many other variables such as acreage, yield and prices for competing crops (wheat, rice and corn), and crude oil prices are also collected from the same source. Textile imports and exports are determined using historical trends. The model also assumes that normal weather will prevail in the projection period.

Tables 8 and 9 (reported in the appendix) summarize the supply and demand projections for cotton and man-made fibers over the next ten years (2003/04-2012/13)[2]. The domestic cotton price is projected to rise steadily throughout the baseline period rising from 10,490 renminbi (RMB) per metric ton in 2003/04 to 12,948 RMB per metric ton in 2012/13. Similarly, the polyester price is projected to steadily rise in the next ten years from 12,080 RMB in 2003/04 to 17,743 RMB in 2012/13. On the demand side, per capita domestic textile consumption in fiber equivalent is projected to rise from 7.7 kilograms in 2003/04 to 11.55 kilograms in 2012/13 (50 percent increase), primarily driven by rising income (figure 3). Following historical trend, textile exports are also projected to rise by more than 65 percent from 5 mmt in 2003/04 to 8.4 mmt in 2012/13. Rising textile demand in both the domestic and export markets translate into higher mill use of fibers, with cotton and man-made fibers rising by 47 and 62 percent, respectively. Most of the rise in cotton mill use is projected to be met by domestic cotton with production rising from 5.76 mmt in 2003/04 to 8.6 mmt in 2012/13. During the same period, cotton imports are projected to grow steadily from 523 thousand metric tons (tmt) to 695 tmt but remains well below WTO quota commitments (figure 4). Although total cotton production is projected to rise in the next ten years, most of this increase is attributed to the Xinjiang and Yellow River regions. In these regions, cotton area is projected to rise by more than 40 percent in the next ten years primarily due to weak competing crops prices such as wheat and corn. In the other regions (Yangtze and rest of China), cotton area is projected to remain flat or slightly decline in the next ten years.

Unlike cotton, man-made fiber imports are projected to rise by more than 40 percent during the baseline period to meet rising domestic mill use (table 9). On the supply side, man-made fiber production capacity is projected to expand from 9.99 mmt in 2003/04 to 13.37 mmt in 2012/13, an increase of approximately 34 percent. However, the capacity utilization rate is expected to remain flat, resulting in an approximate 33 percent increase in man-made fiber production in the next ten years.

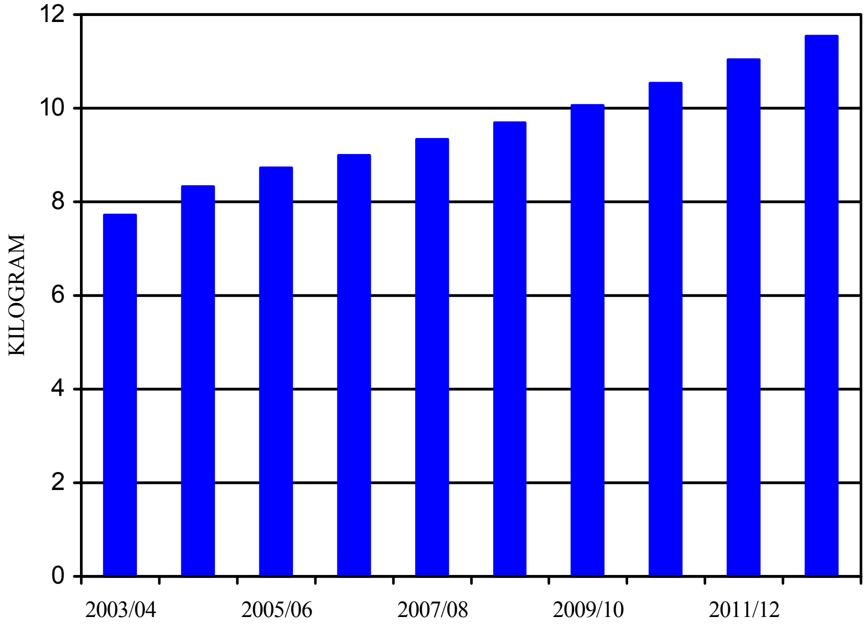

Figure 3. Baseline Per Capita Textile Consumption (2003/04-2012/13)

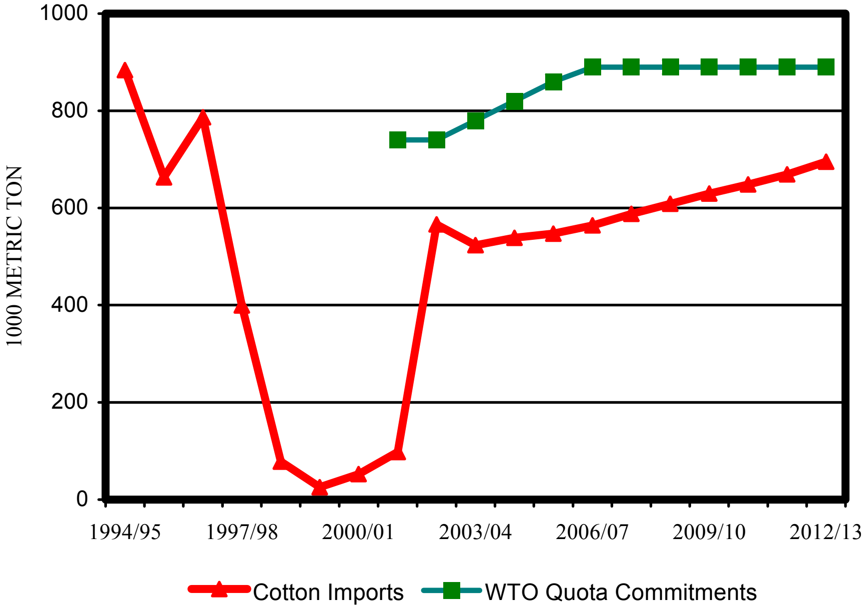

Figure 4. Baseline Cotton Imports vs. WTO Quota Commitments

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[2] Marketing year

Table 8. Chinese Cotton Supply and Utilization baseline 2003/04-2012/13 and MFA Elimination Scenario

	03/04	**04/05**	**05/06**	**06/07**	**07/08**	**08/09**	**09/10**	**10/11**	**11/12**	**12/13**
Production										
Baseline	5757	6187	6551	6665	7008	7244	7484	7880	8191	8613
Scenario	5757	6187	6816	6929	7276	7549	7785	8212	8513	8965
Change	0	0	265	264	268	305	301	333	322	352
Percent change	0.00	0.00	4.04	3.95	3.83	4.21	4.02	4.22	3.93	4.09
Domestic Supply										
Baseline	7783	8241	8697	8930	9338	9698	10042	10534	10977	11504
Scenario	7783	8241	8962	9217	9637	10033	10382	10903	11344	11899
Change	0	0	265	287	300	335	340	370	367	394
Percent change	0	0.00	3.04	3.21	3.21	3.45	3.38	3.51	3.35	3.43
Consumption										
Baseline	6177	6495	6837	7038	7358	7639	7912	8289	8649	9063
Scenario	6177	6495	7445	7680	8016	8324	8605	9005	9366	9799
Change	0	0	608	642	657	685	693	716	717	736
Percent change	0.00	0.00	8.89	9.11	8.93	8.97	8.76	8.64	8.29	8.12
End. Stocks										
Baseline	2055	2146	2265	2330	2454	2558	2654	2785	2891	3030
Scenario	2055	2146	2288	2361	2484	2597	2691	2831	2934	3082
Change	0	0	23	31	30	39	37	45	42	52
Percent change	0.00	0.00	1.04	1.34	1.21	1.52	1.40	1.63	1.46	1.70
Domestic Use										
Baseline	8231	8641	9102	9368	9812	10197	10566	11075	11540	12094
Scenario	8231	8641	9733	10041	10499	10921	11296	11836	12300	12881
Change	0	0	631	673	687	724	730	761	759	787
Percent change	0	0.00	6.93	7.18	7.00	7.10	6.91	6.88	6.58	6.51
Net Trade										
Baseline	-448	-400	-404	-438	-475	-499	-524	-541	-564	-589
Scenario	-448	-400	-771	-824	-862	-888	-914	-933	-956	-982
Change	0	0	-367	-386	-387	-389	-390	-392	-392	-393
Percent change	0.00	0.00	90.67	88.00	81.58	77.90	74.50	72.45	69.56	66.70
Farm Price						*RMB per Metric ton*				
Baseline	10,490	10972	11032	11391	11475	11694	12000	12251	12707	12948
Scenario	10490	10972	11604	11918	12056	12243	12592	12799	13290	13466
Change	0	0	571.15	526.44	581.54	549.64	591.61	547.69	582.92	517.47
Percent change	0	0	5.18	4.62	5.07	4.70	4.93	4.47	4.59	4.00

Table 9. Chinese Man-made Fibers Supply and Utilization baseline 2003-2012 and MFA Elimination Scenario

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Productive Capacity										
Baseline	10532	10961	11355	11647	11918	12226	12525	12822	13108	13373
Scenario	10532	10961	11355	11647	11918	12241	12574	12924	13283	13647
Change	0	0	0	0	0	15	49	103	175	274
Percent change	0.00	0.00	0.00	0.00	0.00	0.12	0.39	0.80	1.34	2.05
Capacity Utilization										
Baseline	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Scenario	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Change	0	0	0	0	0	0	0	0	0	0
Percent change	0.00	0.00	0.07	0.11	0.14	0.16	0.17	0.17	0.16	0.15
Production										
Baseline	8848	9177	9487	9723	9947	10205	10454	10701	10940	11161
Scenario	8848	9177	9494	9734	9961	10233	10512	10805	11104	11407
Change	0	0	7	11	14	28	58	104	164	246
Percent change	0.00	0.00	0.07	0.11	0.14	0.28	0.56	0.97	1.50	2.20
Consumption										
Baseline	8465	9293	9791	10260	10731	11272	11834	12459	13143	13792
Scenario	8465	9293	10612	11095	11599	12161	12763	13414	14143	14822
Change	0	0	821	836	868	889	929	954	1001	1030
Percent change	0.00	0.00	8.38	8.15	8.09	7.89	7.85	7.66	7.61	7.47
Net Import										
Baseline	2196	2305	2410	2515	2619	2721	2821	2916	3009	3099
Scenario	2196	2305	2716	2814	2912	3008	3101	3189	3275	3357
Change	0.00	0.00	306	299	293	287	280	273	266	258
percent change	0.00	0.00	12.70	11.90	11.18	10.53	9.93	9.36	8.83	8.31
Price					*RMB per Metric ton*					
Baseline	12081	12920	13094	13371	13678	14066	14526	15132	15888	16612
Scenario	12081	12920	14185	14499	14884	15299	15793	16372	17113	17743
Change	0.00	0.00	1090.89	1128.78	1205.3	1232.85	1267.73	1240.57	1225.14	1131.41
percent change	0.00	0.00	8.33	8.44	8.81	8.76	8.73	8.20	7.71	6.81

MFA Elimination Scenario

The model is then simulated by increasing textile exports by 25 percent relative to the baseline projections beginning from 2005. As expected, a rise in textile exports due to MFA elimination increases domestic mill use of cotton and man-made fibers. Starting from 2005/06, cotton mill use is likely to increase by 8 to 9 percent per year as compared to the baseline (figure 5). Similarly, man-made fiber mill use is also projected to increase by 7 to 8 percent annually during the same period. The increase in mill use of fibers is projected to raise domestic fiber prices. For cotton, between 2005/06 and 2012/13, domestic cotton prices are projected to rise by an average of 4 percent relative to the baseline level (figure 6). Man-made fiber prices are projected to rise by approximately 9 percent in the beginning year due to capacity constraints. However, towards the end of the projection period, the price increase is somewhat moderated with a 6.8 percent increase in 2012/13 as capacity expansion takes place (figure 5.5).

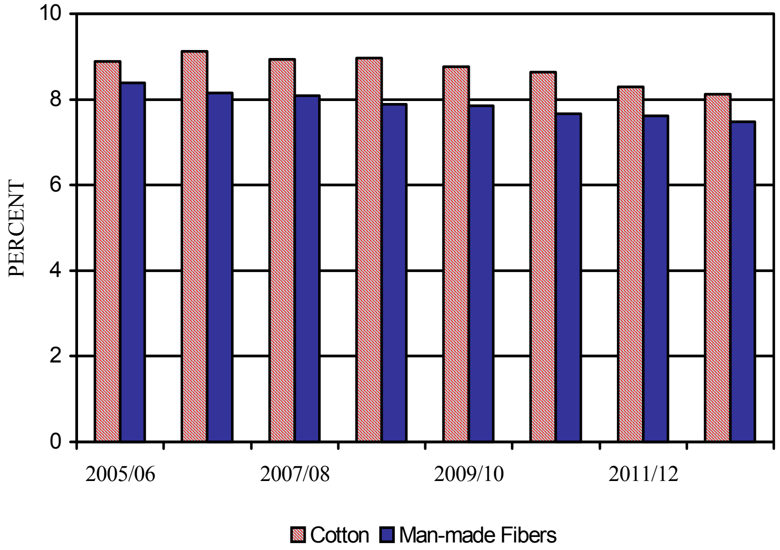

Figure 5. Percentage Change in Cotton and Man-made Fiber Mill Use (2005/06-2012/13)

On the supply side, cotton acreage is projected to rise by 3 to 4 percent annually in response to higher cotton prices. With some increase in yield, growth in cotton production is projected to be slightly higher than acreage growth. The Xinjiang and the Yellow River regions account for most of this increase. The acreage allocated to cotton in the Xinjing and the Yellow River regions rise by an average of more than 8 percent and 5 percent, respectively, and the production increases in the two regions are 9 percent and 6 percent, respectively, compared to its baseline level. On the man-made fiber side, production increase is negligible in the beginning years due to capacity constraints.

Since domestic fiber production is projected to grow at a slower pace than demand, the excess demand is fulfilled by higher imports. In the case of cotton, imports are expected to be 894 tmt in 2003/04 (63 percent rise relative to the baseline level) and steadily increases to 1,067 tmt (53 percent rise relative to the baseline level) by the end of projection period (figure

7). For the entire period under consideration, cotton imports remain above in-tariff quota commitments. Similarly, man-made fiber imports are also likely to rise by 300 tmt in 2003 to around 250 tmt increase in 2012/13 (figure 8).

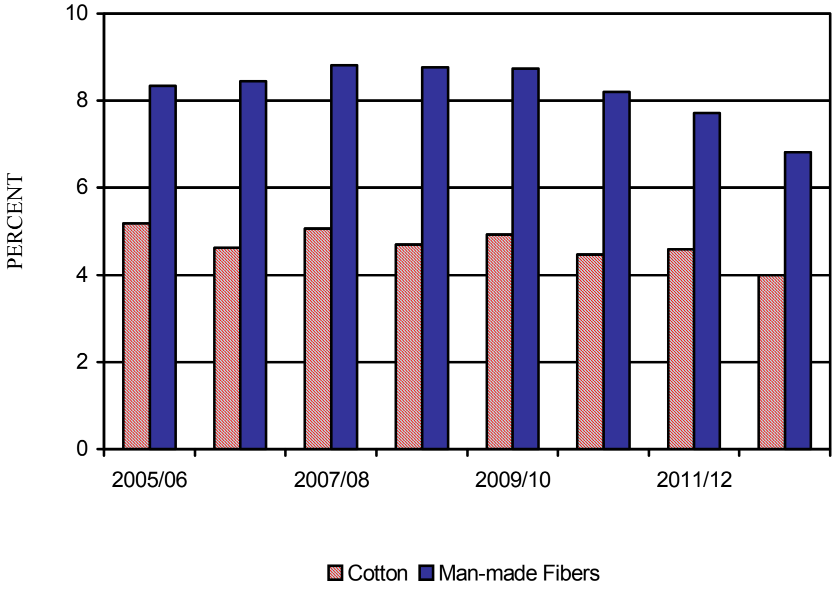

Figure 6. Percentage Change in Fiber Prices

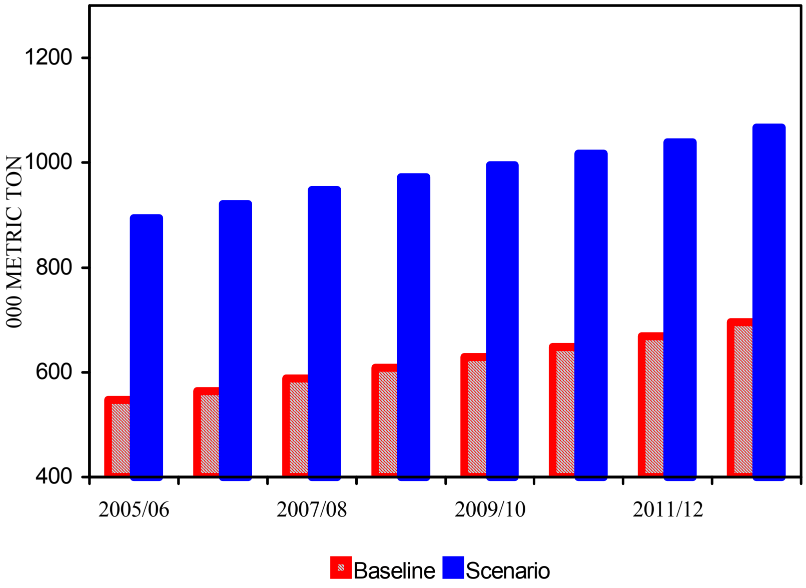

Figure 7. Chinese Cotton Imports (Baseline vs. Scenario)

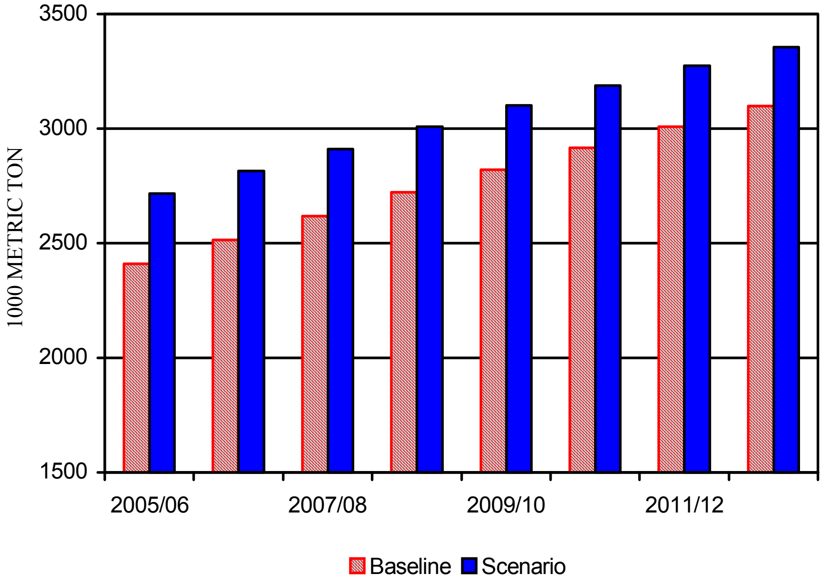

Figure 8. Chinese Man-made Fiber Imports (Baseline vs. Scenario)

Overall, the results suggest that elimination of MFA is likely to result in higher mill use of cotton and man-made fibers. Production expansion is unlikely to meet the demand growth causing the imports of cotton and man-made fibers to rise. Cotton imports are projected to rise by more than 50 percent whereas man-made fiber imports are likely to go up by 10 percent annually for the period 2005/06 to 2012/13.

Concluding Remarks

A partial equilibrium model of Chinese fiber markets particularly for cotton and man-made fibers is developed to quantify the impacts of MFA eliminations on the Chinese fiber market. The model includes behavioral equations of supply, demand, and trade for cotton and man-made fibers. In addition, the model also solves for domestic prices of fibers making it possible to incorporate tariff-rate-quotas for cotton. One of the unique characteristics of this study is the use of a two-step approach to estimate fiber demand and specifically connecting textile outputs with fiber inputs.

The simulation results suggest that the rise in textile exports due to quota eliminations as part of ATC will increase domestic mill use of cotton and man-made fibers. Cotton mill use is projected to increase by 8 to 9 percent per year whereas man-made fibers mill use is likely to increase by 7 to 8 percent per year. A rise in fiber mill use increases domestic fiber prices with cotton and man-made fiber prices rising by an average of 4 and 7 percent per year respectively. Since domestic fiber production particularly cotton is projected to grow at a slower pace than demand, the excess demand is fulfilled by higher imports. In the case of cotton, imports are expected to be 894 tmt in 2003/04 (63 percent rise relative to the baseline level) and steadily increases to 1,067 tmt (53 percent rise relative to the baseline level) by the end of the projection period. For the entire period under consideration, cotton imports remain above in-tariff quota commitments. Similarly, man-made fiber imports are likely to rise by 300 tmt in 2003, with a 250 tmt increase in 2012/13.

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