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Soybean Technology and the Loss of Natural Vegetation in Brazil and Bolivia

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> Ten years ago, you couldn't find Mimosa on a map of Brazil. Back then, the town consisted of little more than a Shell truck stop on an asphalt highway, a backwater in the midst of 500 million acres of untamed scrub trees and grassland. That was before soybean farmers conquered the Cerrado. Today, this frontier boom town in the state of Bahia boasts a population of 15,000, a farm cooperative, two soybean processors, a phosphate fertilizer plant, three machinery dealers, half a dozen chemical dealers, a branch of the Bank of Brazil, a $49-a-night motel and a brand-new country club for the families of the nouveau riche. Dozens of young soybean tycoons traded their fathers' small stakes in Southern Brazil for 30 or 50 times more land in the north. Some quit comfortable $70,000-a-year white-collar jobs in Sao Paulo; others are descendants of Japanese immigrants, subsidized by Asian money . . . Gold may have drawn settlers to California's Wild West, but Mimosa owes its prosperity to soybeans and agricultural technology.
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> (Marcia Zarley Taylor, Farming the last frontier, *Farm Journal Today*, 16 November 1998)

1. Introduction

Thirty-five years ago, South American farmers grew virtually no soybeans. Now, Brazilian farmers plant almost 13 million ha of soybeans and Brazil ranks as the world's second largest exporter (Waino, 1998). Bolivian farmers cultivate an additional 470,000 ha (Pacheco, 1998).

Soybean expansion in southern Brazil contributed to deforestation by stimulating migration to agricultural frontier regions in the Amazon and the

Cerrado. Since producing soybeans requires much less labour than producing coffee or food crops, when soybeans replaced those crops many small farmers and rural labourers lost their jobs and moved to the frontier. Elsewhere, in the Brazilian Cerrado and in Bolivia, farmers cleared large areas of Cerrado vegetation (natural savannah and open woodlands) and semi-deciduous forest to plant soybeans.

Technology was the key in all this. In a sense, soybeans themselves were a new technology, since, up to the 1970s, Brazilian and Bolivian farmers knew little about how to produce them. The development of new varieties adapted to the tropics and the use of soil amendments permitted farmers to grow soybeans in the low latitudes and poor acid soils of the Brazilian Cerrado. More generally, new varieties, inoculants, pest control agents, postharvest technologies and cultural practices made growing soybeans more profitable in both Bolivia and Brazil and stimulated their expansion.

Favourable policies and market conditions reinforced the new technologies' effect. Together, they helped soybean production attain a level that justified establishing the associated services and infrastructure competitive soybean production requires. High international prices and government subsidies encouraged the spread of soybeans in Brazil. Export promotion policies, favourable exchange rates and preferential access to the Andean market stimulated Bolivia's production. In both countries, road construction, government land grants and rising domestic demand for soybeans accelerated the crop's advance. This in turn increased the political power of the soybean lobby and enabled farmers and processors to obtain further government support.

This chapter examines the relation between soybean technology and the loss of natural vegetation in south Brazil, central-west Brazil (the Cerrado) and Santa Cruz, Bolivia. We first present our theoretical framework. Then, for each case, we show how technology and other factors interacted to stimulate soybean expansion, look at the general equilibrium effects this generated in labour and product markets, assess the impact on forest and savannah and briefly comment on the resulting costs and benefits.

2. The Theoretical Framework as it Applies to our Case

Technological change makes agricultural activities more profitable and that leads to their expansion. In southern Brazil, improved soybean technologies mostly led to soybeans replacing other crops. In the Cerrado, they replaced mostly Cerrado vegetation, while in Santa Cruz, Bolivia, it was mostly semi-deciduous forest.

Potentially, general equilibrium effects in either the product or labour markets can dampen the expansionary effects of technological change. In the product market, rising soybean production can push down international prices, thus discouraging further expansion. This effect was significant in Brazil, due to the huge production increases involved. Since the early 1970s, Brazil has ceased to act like a 'small country' in the world soybean market (Frechette, 1997). Bolivia finds itself in a similar circumstance in regard to the Andean market, where its soybean exports have privileged access.

In regard to labour markets, the technology used to produce soybeans is highly capital-intensive and requires little labour. This means that rapid growth is unlikely to provoke labour shortages that push up wages and curtail subsequent growth. In situations, such as in southern Brazil, where soybeans replaced more labour-intensive crops, the advance of soybean production actually displaced labour. That labour then became available to migrate to the agricultural frontier. In other contexts, such as in the Brazilian Cerrado and the Santa Cruz expansion zone, where farmers have removed natural vegetation to plant soybeans, the demand for labour rises, but only slightly.

The profits resulting from technological change can also provide the capital required to expand agricultural production. Many farmers in southern Brazil used the profits obtained from soybeans to move to frontier regions and clear additional forest.

Three unique features of our theoretical framework compared with other chapters in this book are the roles we attribute to: economies of scale, the interaction between technology and other policies and the impact of technology on the political economy. To produce soybeans competitively, you need a large and modern processing, transportation, storage, financial, technological and marketing system. This implies that major economies of scale exist at the sector level. Technological progress can make it easier to profitably reach levels of production that justify installing ancillary services and infrastructure. Since one piece of agricultural machinery can cultivate a large area, mechanized soybean production also exhibits economies of scale at the farm level.

Technological advances and government policies interact in a non-linear fashion. For example, credit subsidies in the Brazilian Cerrado induced farmers to adopt agricultural machinery and soil amendment technologies that made growing soybeans more profitable than extensive cattle ranching. Once this process had begun, the economies of scale in soybean production accelerated it.

Figure 11.1 illustrates this process. The isoquant CR1 represents land and capital combinations for the Cerrado's traditional land-use system: extensive cattle ranching on natural pastures, which maintains most of the natural vegetation. The three SB isoquants represent the new soybean technology. In this case, farmers totally remove the natural vegetation. The numbers attached to each isoquant refer to how much revenue is generated. Hence, SB1 gives the same gross revenue as CR1. The SB isoquants show increasing returns to scale resulting from the use of agricultural machinery, and SB technologies enable farmers to get higher returns from their land, compared with CR1, by using more capital.

With cheap land, shown by a flat factor price ratio (FP), farmers produce at point X on CR1. As long as the capital/land price ratio remains high, farmers

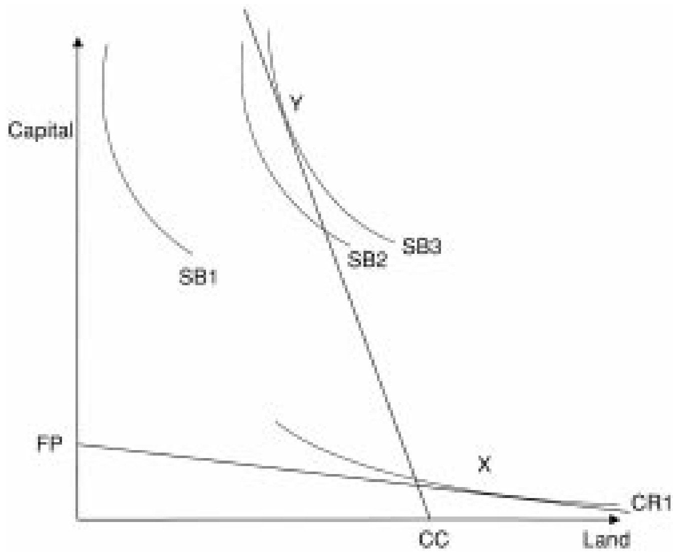

Fig. 11.1. Technology choice and land use under soybean and extensive cattle ranching (Brazilian Cerrado): impact of factor price ratios and economies of scale.

will not adopt SB technologies. But subsidized credit can tilt the factor price ratio to CC and persuade farmers to grow soybeans. Thus, policy can stimulate farmers to adopt a capital-intensive technology in a land-abundant area.

Even though soybeans increase the returns to land, their potential for 'land saving' is diluted because of economies of scale. Thanks to increasing returns to scale, the new factor price ratio of CC resulting from subsidized credit allows farmers to move to point Y on the SB3 isoquant, rather than to some point on SB1 or SB2. Thus, even though subsidized credit makes capital cheap compared with land, rather than using more capital and less land, farmers are inclined to use more of both.

Finally, technological change not only changes relative prices, it also modifies political relations. By favouring the development of a large, concentrated, agroindustrial sector, new soybean technologies facilitated the creation of powerful interest groups, which successfully lobbied the Brazilian and Bolivian governments to implement policies favourable to the soybean sector.

3. Southern Brazil

Southern Brazil includes Parana, Rio Grande do Sul and Santa Catarina. By 1960, farmers had settled most of this region, except for parts of Parana. Coffee, beans, maize and cassava covered large areas. Small farmers with less than 50 ha of land, many of whom were sharecroppers, tenants or squatters, planted much of that (Stedman, 1996).

3.1. Technologies and policies promoting soybean expansion

Coffee boomed in Parana and the other southern states in the 1950s, expanding from 7% of harvested area to 19% (Stedman, 1996). By 1960, Parana had become Brazil's top coffee-producing state. Soon after, however, low coffee prices, soil erosion, plant diseases and frost caused a crisis in the regional coffee economy (Diegues, 1992). In response, the government introduced a 'coffee eradication programme', designed to replace coffee with traditional food crops, wheat and soybeans (Stedman, 1996).

A handful of farmers in Rio Grande do Sul were already planting soybeans in the early 1960s. But Brazil still had less than 250 ha of soybeans. Yields averaged only 1060 kg ha^{-1} (Kaster and Bonato, 1980; Wilkinson and Sorj, 1992).

Then research centres in São Paulo and Rio Grande do Sul introduced varieties from the USA. Thanks to its similar climate, soils and day length, these varieties adapted easily to southern Brazil. The new varieties permitted average yields to increase 15% between 1960 and 1970 to 1141 kg ha^{-1} (Wilkinson and Sorj, 1992).

Government land, credit and price policies encouraged the spread of soybeans. The 1964 Land Statute gave tenant farmers and sharecroppers greater rights and many large landholders responded by expelling tenants and sharecroppers from their farms. Similarly, landholders reacted to new minimum wage laws by hiring fewer agricultural labourers. One way to achieve that was to plant soybeans and wheat, which required less labour, instead of coffee and traditional food crops. The government further accelerated the shift towards mechanized annual crop production by providing subsidized credit to purchase agricultural machinery (Sanders and Ruttan, 1978). Between 1965 and 1970, the coffee area in the south fell from 1.4 million ha to 1 million ha and, by 1970, farmers were growing more than 1.2 million ha of soybeans (Stedman, 1998).

Then, in 1973, a severe drought in the USA caused international prices to sky-rocket and the USA imposed an embargo on its own soybean exports in response (Smith *et al.*, 1995). This coincided with policies favouring soybeans in Brazil. Exchange rates became less overvalued. Agricultural credit rose almost fivefold between 1970 and 1980 and soybeans received over 20% of that (Skole *et al.*, 1994). The government gave incentives to domestic wheat producers to promote import substitution. This benefited soybean-growers, since farmers frequently rotated wheat with soybeans and the two crops shared the same machinery, equipment and labour (Wilkinson and Sorj, 1992). Rapid urbanization and rising per capita incomes increased domestic demand for soybean products.

Brazil's trade policies had more ambiguous effects. The government used subsidies and fiscal incentives to encourage domestic processing of soybean products, while restricting exports of unprocessed beans. On balance, these policies probably slowed soybean's expansion (Williams and Thompson, 1984).

In 1973, the Federal Government created the Brazilian Agricultural Research Corporation (EMBRAPA). EMBRAPA's National Soybean Research Centre, located in Parana, conducted its own research and coordinated the efforts of various universities, state-level research centres, farmer cooperatives and private companies. The International Soybean Program at the University of Illinois, financed by the US Agency for International Development, helped introduce new technologies from the USA (Wilkinson and Sorj, 1992). By 1981, Brazil had almost 1000 researchers and extension agents working on soybeans (Bojanic and Echeverría, 1990).

Their efforts paid off. By 1980, national breeding programmes had produced 26 of the 48 varieties recommended in Brazil and these varieties provided yields 36–63% higher than their predecessors (Kaster and Bonato, 1980). Researchers also introduced *Rhizobium*-based nitrogen fixation, biological agents for controlling soybean caterpillars, 'no-till' planting, the use of contour bunds across fields and new herbicides and fertilizers (Kaster and Bonato, 1980; Wilkinson and Sorj, 1992). This allowed producers to increase yields, reduce costs and degrade their soils less. *Rhizobium*-based nitrogen fixation alone saved farmers over 5 million t annually of nitrogen fertilizer and reduced fertilizer costs by 80% (Wilksinon and Sorj, 1992). Average yields in 1975 were 1720 kg ha^{-1}, 50% higher than in 1970. Kaster and Bonato (1980) attribute two-thirds of that increase to new varieties and the remainder to improved agronomic practices.

The combination of high international prices, government subsidies and technological progress led to a dramatic rise in the south's soybean area. The cultivated area jumped from 1.2 million ha in 1970 to 5.1 million ha in 1975 and 6.9 million ha in 1980 (Stedman, 1996). Simoes (1985) calculated that, for each percentage increase in expenditure on soybean research between 1973 and 1983, the soybean area grew by 0.28%. Moreover, this calculation ignores how new technologies interacted with other contextual factors, since the sum was certainly greater than the parts.

3.2. Soybean expansion and the loss of natural vegetation (Table 11.1)

We do not know what portion of the soybean expansion in the south directly led to deforestation within the region itself. It was probably less than a third, since the total utilized farmland in the south increased only 1.9 million ha during the 1970s (Stedman, 1996). It is worth noting, however, that virtually all of Parana was originally old-growth forest, with a high prevalence of *Arucaria* trees (M. Faminow, 1998, personal communication).

Table 11.1. Causes of soybean expansion and impact on natural vegetation: Brazil and Bolivia.

	Southern Brazil	Brazilian Cerrado	Frontier areas: Brazilian Cerrado	Bolivian 'expansion zone'
Causes of expansion				
Technology				
Improved varieties/cultural practices: increased productivity	✓	✓	✓	✓
Mechanization/economies of scale leading to:				
• Land concentration/increasing land prices (southern Brazil)		✓	✓	
• Sunk costs in machinery/ infrastructure leading to lobbying by soybean sector			✓	
• Expansion to frontier areas with cheap land		✓	✓	✓
Market conditions				
High international prices (mid-1970s–mid-1980s)	✓	✓		
Andean common market				✓
Government policy				
Subsidized credit	✓	✓		
Development projects		✓		
Land as hedge against inflation		✓	✓	
Structural adjustment				✓
Roads		✓	✓	✓
Private sector				
Settlement schemes/soybean infrastructure			✓	
Political economy: lobbying power				
Mid-1980s: uniform output/fuel prices			✓	
Mid-1990s: tax concessions, credit guarantees, export corridor			✓	
Export of Brazilian capital				✓
Impact on natural vegetation	Migrants to Amazon/ Cerrado	Conversion to agriculture	Conversion to agriculture. Export corridor: Amazonian deforestation?	Conversion to agriculture

General equilibrium effects: the product market

After 1980, soybeans in the south ran out of steam and the area contracted from 6.9 million ha in 1980 to 6.1 million ha in 1990 (Stedman, 1996). Technological change contributed to this process by depressing soybean prices and thus dampening the initial incentive it had provided to increase the area. According to Simoes (1985), falling international prices resulting from Brazil's increased productivity caused soybean farmers in the south and in São Paulo to receive 28% fewer benefits from agricultural research between 1973 and 1983 than they would have if Brazil had been a small player in international soybean markets. Stagnating yields, in part due to growing problems of soil erosion and compaction, the elimination of wheat subsidies and high port costs, also contributed to the decline in soybean area (Wilkinson and Sorj, 1992).

General equilibrium effects: the labour market and farmer incomes

The principal way the advance of soybeans in the south influenced deforestation was through the labour market. The shift to soybeans stimulated land concentration and agricultural mechanization. Many small farmers could not afford the machinery and chemical inputs required for growing soybeans. Rising yields, high soybean prices and subsidized credit pushed up land prices and poor farmers found it increasingly difficult to compete in the land markets (Brandao and Rezende, 1992). Subsidized credit went mostly to large farmers and this accelerated the concentration of landholdings (Goldin and de Rezende, 1993). The number of tractors in Brazil jumped from 134,500 to 545,200 between 1965 and 1980 and southern soybean producers accounted for a lot of this (Stedman, 1996).

As a result of these processes, more than 2.5 million people left rural Parana in the 1970s and the number of farms smaller than 50 ha declined by 109,000 (Diegues, 1992). During the same period, Rio Grande do Sul lost some 300,000 farms (Genetic Resources Action International, 1997).

The majority of migrants moved to urban areas. Nevertheless, a significant number went to the Amazon and cleared forest to grow crops. Sawyer (1990) cites Parana as an important source of migrants to the Amazon in that period.

While the expansion of mechanized agriculture destroyed the livelihoods of many migrants to the Amazon, in other cases soybean and wheat production provided the resources that allowed small farmers to purchase land on the agricultural frontier. Many better-off small farmers who moved to the Cerrado took advantage of land price increases in the south to sell their farms and buy larger areas in the Cerrado, where land was cheap (Coy and Lucker, 1993).

4. The Brazilian Cerrado

Just as soybean production stagnated in the south, it took off in the Cerrado. The term Cerrado refers to a characteristic set of vegetative types, which include natural savannahs and woodlands. This vegetation dominates 1.5 to 2 million km^2 in Brazil's centre-west states of Mato Grosso, Mato Grosso do Sul, Goias and Tocantins and in parts of Bahia, Maranhao, Minas Gerais and Piaui (Stedman, 1998). In northern Mato Grosso, one finds a transition between Cerrado vegetation and rain forest. The region's soils tend to be highly acidic and deficient in phosphorus (Smith *et al.*, 1998).

4.1. Technologies and policies promoting soybean expansion

Historically, the Cerrado had a low population density and large unoccupied areas, dominated by extensive cattle ranches (Mueller *et al.*, 1992). New soybean technologies, public road construction and subsidized credit, fuel and soybean prices changed that. The total annual crop area in the centre-west rose from 2.3 million ha in 1970 to 7.4 million ha in 1985. The soybean area soared from only 14,000 ha to 2.9 million ha and then reached 3.8 million ha in 1990 (Stedman, 1996). Heavily capitalized farms with between 200 and 10,000 ha grew most of this (Mueller *et al.*, 1992). In 1992, a farmer in Maranhao needed to invest almost $1 million to grow 1000 ha of soybeans (Carvalho and Paludzyszyn Filho, 1993).

Traditionally, the Cerrado's poor and heavy soils and lack of suitable varieties limited intensive crop production in the Cerrado. Farmers solved the first constraint by applying a lot of lime and phosphate and using machinery to plough heavy soils (Sanders and Ruttan, 1978; Goldin and de Rezende, 1993). To overcome the second constraint required local plant breeding. Existing soybean varieties were sensitive to photoperiod and performed poorly in the lower latitudes, where day length is uniform and short. They were also susceptible to aluminium toxicity and required large amounts of calcium (Spehar, 1995).

Beginning in the mid-1970s, the National Soybean Research Centre and other research centres worked to produce varieties adapted to the Cerrado, with the explicit goal of advancing the agricultural frontier (Kueneman and Camacho, 1987). By the early 1980s, they had largely succeeded. Thanks to these efforts, mean yields rose 45% between 1975 and 1983, from 1300 kg ha^{-1} to 1900 kg ha^{-1} (Simoes, 1985). Spehar (1995) estimates that the new varieties increased the annual earnings of soybean producers in the Cerrado by $1 billion.

Without new varieties, soil treatments and machinery, the rapid spread of soybeans into the Cerrado would have been impossible. Nevertheless, other factors also contributed. In particular, as noted earlier, credit subsidies proved an essential precondition for the rapid adoption of agricultural machinery and soil amendments. Between 1975 and 1982, one subsidized credit programme, the Programme for the Development of the Cerrado (POLOCENTRO), gave $577 million in agricultural loans, 88% of which went to farmers with over 200 ha. According to Mueller *et al.* (1992), this was responsible for the conversion of 2.4 million ha of savannah to agriculture. Without government subsidies, soybean production would probably have been restricted to accessible areas with better soils. Subsidies allowed farmers to grow soybeans profitably in more remote areas, such as northern Mato Grosso.

In the 1970s, new roads, such as BR163, which connected Cuiaba and Santarem, and BR158, between Barra do Garcas and Maraba, opened up northern Mato Grosso (Coy and Lucker, 1993). The Brazilian government also made land and credit available to large private companies, which built roads and other infrastructure and then resold part of the land in 50 to 400 ha parcels to enterprising small farmers from the south. By 1986, 104 private colonization schemes covered 2.9 million ha, of which 668,000 ha were planted with annual crops (Mueller *et al.*, 1992). Some large private investor groups used the proceeds from the land sales to grow soybean in the remaining areas and create local infrastructure for storing soybeans and carrying out the initial stages of processing to make vegetable oil. In recent years, they have also collaborated with EMBRAPA to develop improved varieties (Coy, 1992; Franz and Pimenta da Aguiar, 1994).

General equilibrium effects: the product market

From the mid-1980s, several factors turned against soybean production. International soybean prices fell. Higher soybean production in the Cerrado, generated by technological changes, may have contributed to this, but as far as we know no one has studied the issue. The Brazilian government also greatly reduced credit subsidies and real interest rates rose sharply (Goldin and de Rezende, 1993). The 1994 macroeconomic stabilization policy, known as the Real Plan, generated positive real growth rates and radically reduced inflation, both of which stimulated domestic demand for soybeans (Smith *et al.*, 1998). Nevertheless, the exchange rate became progressively overvalued and real interest rates remained high and volatile, causing severe financial stress among indebted soybean farmers (Smith *et al.*, 1999).

General equilibrium effects: the labour market

Thanks to in-migration from the south and the north-east and the limited labour requirements of soybean cultivation, the growth of the soybean area put little upward pressure on wages. Between 1970 and 1985, the area in crops rose by 172%, the cattle herd by 128% and the number of tractors by 660% (Mueller *et al.*, 1992). However, the agricultural labour force in the savannah region grew by only 45%, from 1.4 million to 2 million.

The soybean lobby

Despite low international prices, declining credit subsidies and an overvalued exchange rate, soybean production in the Cerrado has continued to expand, except for a few years in the early 1990s (Stedman, 1996). Soybean exports reached a record 8.3 million t in 1996/97 and the soybean area was projected to reach a record 12.9 million ha in 1997/98 (USDA, 1998).

Powerful interest groups linked to the soybean sector lobbied successfully for compensating government concessions whenever conditions turned unfavourable. This group, which includes processors and exporters, machinery and input manufacturers, investor groups and farmer organizations, has become a potent force in Brazilian politics (Pompermayer, 1984; Coy, 1992). Its great influence appears to be linked to the important contribution made by agricultural exports to meeting balance-of-payments deficits, particularly during the debt crisis of the 1980s and again in the mid-1990s. Between 1994 and 1996, the agricultural sector contributed over $25,000 million to the trade balance, of which soybeans and related products accounted for 26% (USDA, 1998).

To compensate for the decline in subsidized credit and to protect farmers from falling international soybean prices during the mid-1980s, the government purchased large quantities of soybeans from farmers at pre-established prices (Goldin and de Rezende, 1993). Farmers received the same price for their soybeans no matter where they were located, thus encouraging soybean's expansion into remote areas, where high transportation costs might otherwise have impeded commercial production.

The government also established uniform fuel prices, without considering the high cost of transporting fuel to remote areas. This not only made it feasible for farmers to transport their crops long distances to markets, but also lowered fuel costs for the use of agricultural machinery (Mueller *et al*., 1992).

In the 1990s, the private sector and government agencies initiated several projects designed to reduce the cost of transporting soybeans from the Cerrado to different ports. The US Department of Agriculture (USDA, 1998) reports that a north-west corridor project linking the northern Cerrado to the Amazon will lower soybean transport costs by around $30 t^{-1}, as well as reducing fertilizer costs. In 1990, private companies, banks and government agencies jointly established the northern export corridor initiative to increase soybean production in Tocantins, Maranhao and Piaui, with a goal of 500,000 ha by 1998. The initiative includes fiscal incentives, agricultural research, credit and infrastructure for transporting soybeans to the Amazon River (Carvalho and Paludzyszyn Filho, 1993).

The USDA (1998) also reports other recent policy changes that benefit the soybean sector. Soybean farmers benefited from the 1996 removal of a tax on primary and semi-manufactured exports. In response to the high interest rates of the 1990s, the government provided guarantees to commercial banks to allow exporters to obtain credit at rates similar to those available internationally.

4.2. Soybean expansion and the loss of natural vegetation

Over the last 20 years, soybean and pasture expansion dramatically affected the natural vegetation of the Cerrado. Between 1970 and 1985, conversion of the Cerrado's natural ecosystem was as rapid as in the Amazon. Farmers converted some 2 million ha of natural vegetation to agricultural uses each year, including 350,000–450,000 ha of forest (Smith *et al.*, 1998). Intensive annual crop production accounts for about 20% of this loss (Smith *et al.*, 1998). Only 35% of the Cerrado biome remains in a relatively natural state (Stedman, 1998). Some types of vegetation and fauna, such as mesotrophic woodland and the pampas deer, are becoming rare.

Whether the benefits of this transformation outweighed the costs remains uncertain. On the one hand, the Cerrado probably accounted for almost half of Brazil's $4.4 billion of soybean exports in 1996 (Spehar, 1995; Waino, 1998). On the other hand, the region has one of the richest savannah floras in the world, especially of woody species, and much of this could be lost (Klink *et al.*, 1993). Conversion has brought about large emissions of carbon dioxide into the atmosphere. Agriculture is estimated to be responsible for 50% of the organic matter that enters waterways, and sedimentation could cause serious problems, since the Cerrado forms part of the watershed of major rivers and drains into the Pantanal, one of the world's largest wetlands (Smith *et al.*, 1998).

5. Santa Cruz, Bolivia

Santa Cruz, Bolivia, has many of the same features as the Cerrado. Agricultural research and technology transfer there encouraged the rapid spread of soybeans and this led to large-scale deforestation. Again, however, it was not the only factor.

Bolivian farmers grew only 1000 ha of soybeans in 1970 and even in 1980 still had only 31,000 ha. This grew to 56,000 ha in 1985, 147,000 in 1990 and 470,000 in 1996 (Pacheco, 1998).

Approximately 1900 farmers grew soybeans in 1990 (Bojanic and Echeverría, 1990). Traditionally, Mennonite colonists and, to a lesser extent, Japanese colonists and Bolivian farmers grew most of them. In recent years, large Brazilian farmers have become important and now account for about a quarter of the production (Pacheco, 1998).

5.1. Technologies and policies promoting soybean expansion

As in Brazil, agricultural research and extension helped promote soybean expansion. Local researchers began testing varieties imported from the USA in 1953. Significant research got under way in 1975, when the Tropical

Agricultural Research Centre (CIAT) was established and created a small soybean programme. Through the Cooperative Agricultural Research Programme for the Southern Cone (PROCISUR), CIAT maintained close relations with the soybean researchers at EMBRAPA. All five soybean varieties released in the 1980s came from Brazil. CIAT also tested different products to control weeds, diseases and insects and conducted research on crop rotations, inoculants and fertilizers, direct planting and soil conservation. A local farmer organization (ANAPO), farmer cooperatives and various commercial establishments promoted the results of this research (Bojanic and Echeverría, 1990).

Average summer soybean yields rose from 1333 kg ha^{-1} in 1974–1979 to 1743 kg ha^{-1} in 1980–1984 and 2022 kg ha^{-1} in 1985–1990. Bojanic and Echeverría (1990) attribute between 40% and 60% of that increase to CIAT's research and the private sector's technology transfer efforts. Since the new technology involved only marginal additional costs, the increased yields clearly contributed to the commercial viability of producing soybeans.

The removal of price controls, a currency devaluation, fiscal incentives for exporters, low taxes, road construction and government land grants also contributed to the expansion of soybeans (Kaimowitz *et al.*, 1999). In the mid-1990s, Bolivian producers paid \$26.5 t^{-1} less in taxes than their Brazilian counterparts (Monitor Company, 1994). Between 1986 and 1991, the road network in Santa Cruz's so-called 'expansion zone' grew from 430 km to 650 km and in 1989 the World Bank's Eastern Lowlands Project began financing road improvements to facilitate soybean exports (Davies, 1993). The government reversed its policy of allocating land in the expansion zone to small agricultural colonists and began focusing more on large landholders, and this also encouraged soybean production.

Unlike Brazil, credit subsidies had only a minor role in Bolivia's soybean expansion. The government heavily subsidized credit in the early 1980s but eliminated the subsidies in 1985 as part of its structural adjustment programme. Access to capital, however, did not greatly constrain the advance of soybean production, since commercial farmers had large financial reserves and easy access to private credit and Brazilian investors brought additional resources into the area.

Bolivia's entrance into the Andean Common Market also greatly boosted its soybean exports. In 1995, a little more than 80% of Bolivia's soybean and soybean-product exports went to the Andean market, where the country enjoyed a \$37.17 t^{-1} tariff advantage over its Brazilian competitors (Monitor Company, 1994).

5.2. Soybean expansion and the loss of natural vegetation

Initially, most soybeans were grown in an area west of the Grande River, near the city of Santa Cruz, known as the 'integrated zone'. That area has been settled for a long time, has moderately high population densities and is dominated by large commercial farmers. Most soybean production there is on land where the natural vegetation had already been removed for other purposes. Although somewhat fragile and susceptible to wind erosion and compaction, the region has much better soils than the Brazilian Cerrado. Most farmers produce soybeans there without fertilizers or soil amendments (Barber, 1995).

Since 1990, most of the soybean growth has been just east of the Grande River in the ‘expansion zone’. There, the soybean area rose from 68,000 ha in 1990 to 278,000 ha in 1996 and has continued to expand rapidly since (Pacheco, 1998). Unlike the ‘integrated zone’, for the most part these lands were directly converted from semi-deciduous forest to grow soybeans and certain areas have climates and soil conditions that are less favourable for soybean production.

Largely as a result of greater soybean production, the annual deforestation rate in the expansion zone in 1989–1992 was 24,207 ha and in 1992–1994 it was 41,604 ha (Morales, 1993, 1996).

As in the Cerrado, we are unable to say whether the benefits of converting forests to soybean fields outweigh the environmental and social costs. Davies and Abelson (1996) attempted such an evaluation and concluded that the financial benefits from soybean production greatly outweigh the costs from reduced carbon sequestration and harvesting of forest products. However, they were unable to assign economic values to the loss of biodiversity and soil erosion and ignored equity. Hecht (1997: 4) has argued that the biodiversity values of these forests are particularly great since ‘they embrace Andean, Amazonian, and Chaco biotic elements, and include important (and threatened) centres of diversity for crop plants like peanuts and tomatoes’.

6. Conclusions

The technological changes related to soybean production in Brazil and Bolivia involve a new production system, more profitable production practices and the substitution of capital for labour. These changes directly and indirectly induced the conversion of large areas of natural vegetation to expand annual crop production. In the Cerrado and the Bolivian ‘expansion zone’, the availability of cheap land in frontier areas particularly favoured production systems characterized by economies of scale.

The low labour requirements of the new soybean technologies led to the displacement of existing agricultural labour in southern Brazil, some of which subsequently moved to the agricultural frontier. In the other regions, they ensured that the growth in soybean production did not put upward pressure on wages and feed back into lower profits.

The high capital requirements of the new technology might have constrained soybean’s expansion but it did not, except perhaps for Brazil in the 1990s. During the 1970s and 1980s, the availability of plentiful subsidized credit allowed Brazilian farmers to adopt heavily capital-intensive technologies. Bolivian farmers had ready access to private credit and the Brazilian farmers who moved to Bolivia brought large amounts of money.

The technology involved in the case of the Brazilian Cerrado was specifically suited for the environmental conditions of that region, which was an agricultural frontier area covered with natural vegetation. This undoubtedly increased the environmental impact of the technology's development and dissemination.

A particularly interesting feature of the expansion into the northern Cerrado is the role of political-economy factors. The expansion of soybean after the mid-1980s appears to be closely related to the lobbying power of the soybean sector, which enabled it to wring concessions from the government. By helping to create the soybean sector in the first place, technological developments inadvertently created a strong new political lobby.

Because of the huge production increases made possible by technological change in Brazil and the small size of the Andean market, which buys Bolivian soybeans, in both cases general equilibrium effects in the product markets reduced some of the expansionary impetus created by technological change. These dampening effects were not sufficient to avoid widespread loss of natural vegetation.

Rather than attempting to separate out the relative weight of technology and other factors in the spread of soybeans, we would like to emphasize the interaction between these factors. Changes in production systems of such a large magnitude require both appropriate technologies and favourable policy and market conditions.

Finally, the soybean case highlights the difficulties in determining whether the benefits outweigh the costs in cases where agricultural technology leads to the loss of natural vegetation. Soybeans provide substantial foreign exchange and much more income per hectare than cattle ranching (Davies and Abelson, 1996). The type of natural vegetation they replace typically stores much less carbon per hectare than do rain forests and has less biodiversity. Nevertheless, conversion still involves substantial carbon emissions and biodiversity losses and increases soil erosion. Moreover, both the Brazilian Cerrado and the semi-deciduous forests of Bolivia have richer biodiversity than people often realize (Klink *et al.*, 1993; Hecht, 1997). Mechanized soybean production provides little employment and a small group of wealthy farmers receive most of the income.

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