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Sources of Technological Innovation in Brazilian Agriculture

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Introduction

Most studies on technological innovation in agriculture tend to focus on public agricultural research only. They largely ignore the fact that a substantial part of the technology used in agriculture is being acquired by buying inputs from various industries or by means of technology contracts and spillovers. The acquisition of technology through purchased inputs has been the subject of a recent OECD study (OECD 1996a), which provides very useful and interesting insights into the technological interdependency between industries and countries. The study uses input-output matrix data to trace transfers of technology embodied in inputs from one industry to another.[1] In this paper we will apply an adapted version of this approach to the Brazilian agricultural sector as to improve our understanding of the contribution of the various sources of technological innovation to Brazilian agriculture.

The general S&T literature identifies four important sources of technological innovation, namely:

- Direct investments in R&D (either public or private);
- Acquisition of technology through the purchase of both current and capital inputs;
- Acquisition of technology through licenses and technology contracts; and
- Acquisition of technology (that is in the public domain) for free.

Adapting the OECD approach, the following technology intensity ratio can be constructed that takes into account the various sources of technological innovation:[2]

$$TI_i = (P_i + D_i + Q_i + LR_i + LC_i + MR_i + MC_i + W_i + Z_i) / X_i$$

TI_i represents the technology intensity of industry (i); P_i, D_i, and Q_i represent respectively public, private intramural, and private extramural R&D expenditures by or for industry (i); LR_i, LC_i, MR_i, and MC_i represent acquired technology through the purchase of recurrent inputs (R_i) and capital inputs (C_i) that are either produced locally (L) or imported (M);[3] W_i represents payments minus receipts for patents, licenses and other technology contracts by industry (i); and Z_i represents the value of technology that spills in minus that spills out without any market transaction taking place. X_i represents the value of total output by industry (i).

At the global level, technology payments and receipts as well as technology spill-ins and spill-outs should even each other out. These technology transfers do not add to the total volume of R&D investments as such, but make that technology is being applied to a larger volume of output than that of the firm that developed it. Most developing countries are usually net recipients of technology in both categories, but technology exchanges are the most intensive

[1] Other studies that have used a similar approach are: Terleckyj (1974), Scherer (1982), Debresson et al. (1996), and Amable and Palombarini (1998). See also the special issue of *Economic Systems Research* Vol. 9, No. 1 (March 1997) on intersectoral R&D spillovers.

[2] Compared to earlier approaches, we introduce two major improvements: (1) The inclusion of public R&D (particularly important in agriculture); and (2) Direct acquisition of technology by means of patents, licenses and technology contracts.

[3] In the case of locally produced inputs, inputs originating in industry (i) itself should be excluded in order to avoid double-counting.

between industries in developed countries.[4] Recent studies argue that the own R&D capacity of an industry plays an important role in the ability to absorb and use technology that is being developed elsewhere. In that sense, technology contracts and spillovers are more complements to than substitutes for own R&D.[5]

In this study we managed to quantify the direct R&D investments and the acquired R&D investments through purchased inputs, but not the technology payments (W) or spillovers (Z). Undoubtedly, the latter constitute important other components of the technology intensity equation, but for the time being they are difficult to measure. Moreover, such measures should be (made) comparable with the R&D investment data, so that apples are not added up with oranges.

This and similar studies are based on several limiting assumptions, most importantly:

- Technological innovations are always embodied in a product. When the product is used as an input in another local or foreign industry, the embodied technology travels with it. (In this way international trade data can be used to map technology transfers from one country or region to another, while within a country input-output matrices of the economy can be used to map technology transfers from one industry to the next.) To the extent technology is not being embodied, the technology spillover variable should in theory correct for that;
- Constant returns-to-scale and product homogeneity are assumptions implicit to the use of an input-output matrix. Product homogeneity implies that all products coming from a particular industry have the same technology intensity. In as far as this assumption severely deviates from reality, product groups have been broken up into more specific ones to the extent possible;
- The technology intensity used in the model relates current rather than an accumulation of past R&D investments to current output. While an R&D stock approach may be preferable in principle, in practice there is insufficient reliable information to do so.
- No distinction has been made between product and process innovation. One could argue that R&D investments targeting the latter type of innovation does not get embodied in a product in terms of improved product characteristics and therefore should be netted out. However, process innovations lead to lower prices and hence pass their impact on to the next level of production. In addition, it is very difficult to separate process from product innovation in the sense that new products often also require new processes.

This paper focuses in particular on the quantification of technology acquisition through purchased inputs. It starts with a description of the linkages between Brazilian agriculture and the rest of the economy, followed by a discussion of the structure and technological innovation characteristics of the various agricultural input industries. This forms the basis for estimating the accumulated technology intensity ratio for the Brazilian agricultural sector in the next section. The paper concludes with several policy suggestions and possible directions for further research.

Input-output linkages between agriculture and the rest of the economy

The input-output matrix for the Brazilian economy in 1995 (IBGE 1997) provides the necessary data for estimating the inter-industry linkages between primary agriculture and the rest of the economy. Figure 1 provides a stylized representation of these linkages.

In 1995, the total supply of agricultural produce (including output that is being used as input in agriculture such as seeds and animal feed) in Brazil yielded R 85.6 billion.[6] Most of it was produced locally (R 83.3 billion) and only a small fraction was imported (R 2.3 billion or 2.7% of the total supply). The local production required purchased current inputs worth some R 31.9 billion. Also of these inputs only a small fraction (3.7%) was imported. The difference between

[4] Evenson and Johnson (1997), for example, illustrate this very nicely at the hand of patent registrations.

[5] See for example Stoneman (1995) for a more in-depth discussion of these issues.

[6] In 1995 the Brazilian Real was equal to US$ 0.918.

the value of agricultural output and purchased current inputs constitutes value-added (R 51.5 billion). Unfortunately, the Brazilian national account statistics do not provide data on capital acquisition nor on the depreciation of the capital stock used during the year for specific economic activities. Only aggregate statistics differentiated by capital ownership are available. An estimate has been inserted instead.

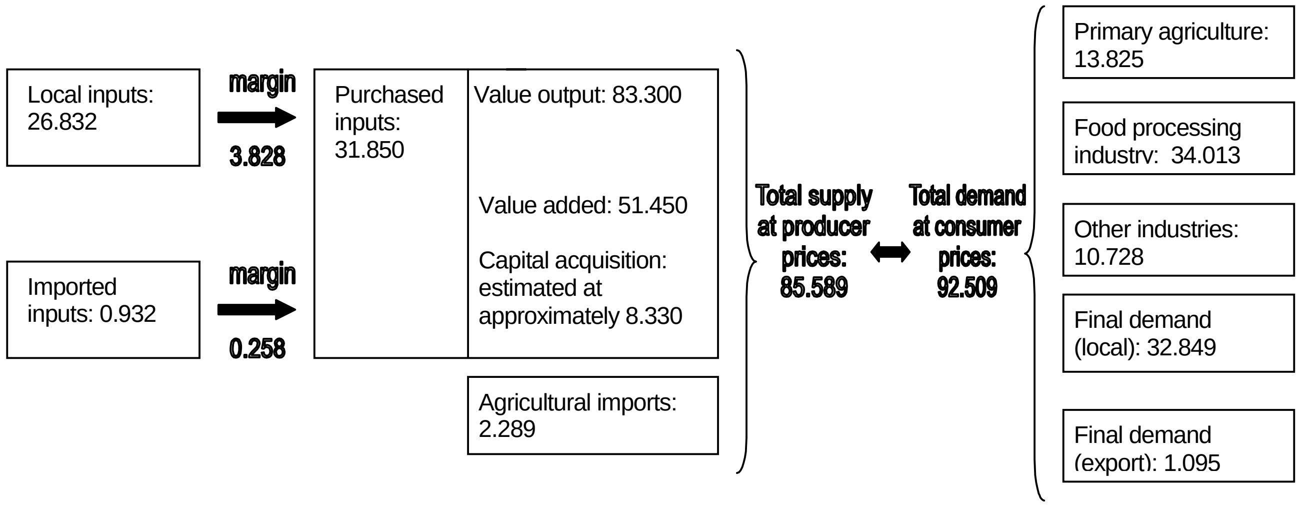

Figure 1: Input-output linkages of primary agriculture in 1995 – values in billion Reais

On the right-hand side of the graph a breakdown is provided of how agricultural output is being used as input in agriculture and other industries or consumed locally or abroad.[7] Despite the fact that Brazil is known to be an important agricultural producer, the share of primary agricultural production that is being exported is quite small. The technical explanation for this finding is that Brazil nowadays processes most of its agricultural products (including coffee) before it exports them. They are, therefore, recorded as exports stemming from the food processing industry rather than from primary agriculture.

Another phenomenon is that a substantial part of primary agricultural output (15%) is being used again as input in primary agriculture. Seeds, young animals, grains used as animal feed, but also agricultural services, are examples of agricultural outputs that are used as agricultural inputs. Intensive livestock production has probably a significant effect on the volume of this backward loop in the production column. With the growing importance of animal feed industries this backward loop is getting even more complicated as agricultural output first passes another industry before returning as an input into primary agriculture.

Food processing industries absorb about 37% of the total agricultural supply. Agricultural produce constitutes a sizable share (52%) of the inputs used by the food processing industry. Non-agricultural inputs such as semi-processed food products, chemicals, packaging material, and energy make up the other 48% of current inputs. In the total cost structure of the food processing industry (including labor and capital), agricultural produce constitutes on average 37% of total costs. Transport, distribution and retailing costs make that the share of the raw agricultural material in the cost price of the product on the supermarket shelf is even substantially lower.

Table 1 provides a breakdown of the inputs used in primary agriculture by industry of origin as well as a differentiation between local and foreign industries. Agricultural and processed agricultural products and services make up for 57% of the total inputs used in primary agriculture. Chemical and petrochemical industries represent another important cluster of industries providing inputs to primary agriculture (28%). The volume of inputs coming from

[7] Transport and marketing costs and taxes make up for the difference between the supply at producer prices and demand at consumer prices.

(agricultural) machinery and equipment industries is relatively small as it only represents the current inputs such as spare parts and services. As mentioned above, no industry-specific capital good data are available from the Brazilian input-output or national account statistics. However, based on some other sources capital costs have been estimated at 10% of the value of local agricultural output (i.e. R 8.3 billion), of which an estimated R 2.9 billion was spent on agricultural machinery, R 3.2 billion on construction, and R 2.2 billion on other capital items.[8]

Table 1: Use of agricultural inputs in primary agriculture – Brazil, 1995

Inputs	Local production	Import	Total	Import as a % of total
	(million Reais)			%
Agricultural products and services	12343	357	12699	2.8
Processed agricultural products	3227	35	3261	1.1
Minerals	288	2	290	0.8
Fuel and other petrochemical products	1883	35	1918	1.8
Fertilizers	3641	0	3641	0.0
Other chemical products (i.e., agrochemicals)	1839	419	2258	18.6
Pharmaceutical products	207	0	207	0.0
Fabricated metals	119	5	124	4.4
Agricultural machinery and equipment	206	21	227	9.3
Other industrial products	502	16	517	3.0
Services	2578	42	2620	1.6
Total (producer prices)	26832	932	27764	3.4
Margin (trade plus taxes)	3828	258	4086	6.3
Total (consumer prices)	30660	1190	31850	3.7

Source: IBGE (1997).

Note: The number of input-output categories has been condensed from more than 40 to just 10 in order to make the data more manageable.

On average, Brazilian agriculture imports only a small fraction of its inputs. Of the different input categories, agrochemicals and agricultural machinery and equipment are the most import-depended. These are also the input categories that are relatively technology-intensive.

On first sight, fertilizer and veterinary pharmaceutical inputs appear to be strictly locally produced. However, both these industries are important importers of inputs from chemical industries abroad. The Brazilian fertilizer industry, for example, produces most of its N and P but has to import all its K to produce the right NPK mix. Veterinary pharmaceutical industries also import substantial amounts of ingredients and often only package and distribute the product. The indirect import-dependency of the Brazilian agricultural sector via the input industries is probably substantially higher than the direct one.

Technology innovation characteristics of agricultural input industries

General

The overall picture that emerges from the S&T literature is that developing countries invest substantially less in R&D than the rich industrialized countries. Brazil is no exception, although it is doing somewhat better than most other Latin American and Asian countries but worse than the more advanced Asian tigers such as Taiwan and South Korea (Table 2).

[8] Data were obtained from IBGE on the breakdown of capital formation in agriculture for the years 1980, 1985, and 1990. The average of these three observations was used to split the capital formation estimate into a machinery, construction, and other capital component.

Table 2: Total public and private R&D expenditures as a percentage of GDP

Country	Year	Percentage
Brazil	1995	0.76
Latin America	1995	0.56
Indonesia	1995	0.30
Malaysia	1995	0.40
China	1995	0.50
Taiwan	1991	1.70
South Korea	1995	2.40
Western Europe	1995	1.85
North America	1995	2.50
Japan	1995	3.00

Source: UNESCO (1999) and RICYT (1999).

Until recently, the Brazilian R&D effort has been predominantly public. In 1990 the share of the private sector was estimated at a low 20%. In the developed countries the private sector share is about 40-70% (UNESCO 1999). Also the import of technology into Brazil by means of licenses and technology contracts has been rather restricted throughout the 1970s and 1980s. The relative lack of innovative activity in the Brazilian private sector has weakened the position of many Brazilian industries in the world market between 1970 and 1990 (Dahlman and Frischtak 1993). In an attempt to reverse this development, the Brazilian government has set out to increase the share of private-sector R&D investments to 40% by the year 2000, while maintaining public R&D investment levels. Several instruments have been introduced to stimulate private R&D investments in recent years, namely: (1) A tax deduction scheme for R&D expenditures (administered by PDTI/PDTA); (2) Relative cheap and long-term loans for R&D investments (FINEP); and (3) Direct subsidies to private R&D (CNPq and FINEP).[9] The latter instrument is being used rather sparsely and usually involves collaboration with public R&D agencies. In addition, the Brazilian government has adopted a far more liberal policy in the early 1990s with regard to technology imports.

Estimates of R&D expenditures by the Brazilian industry have been very sketchy to date. The National Association of R&D by Industrial Companies (ANPEI) launched its first systematic survey of R&D and technological innovation activities only in 1992. The survey coverage has improved substantially since, but there are still considerable problems in terms of how to interpret the results as the sample tends to be biased towards companies that conduct R&D.

Table 3 compares the Brazilian survey results for the years 1994-1996 with similar data for 14 OECD countries for the year 1993. For most industries the Brazilian results are fairly stable despite the fact that the survey coverage differs from year-to-year. Apparent anomalies are the low 1995 value for the industrial machinery industry and the high 1994 value for the plastic and rubber industry.

Per unit output, the manufacturing industry in the OECD countries spends on average three times more on R&D than its Brazilian counterpart. There are also large differences in R&D intensity between industries. Table 3 confirms the importance of differentiating between inputs coming from different industries as well as from industries in different countries. The remaining sections of this chapter focus on the structural characteristics of each of the major agricultural input industries.[10]

[9] PDTI/PDTA: Programs for Technological Development of Industry and Agriculture; FINEP: Funding Agency of Studies and Projects; and CNPq: National Council for the Development of Science and Technology.
[10] For a global overview of the various agricultural input industries see James (1996).

Table 3: R&D expenditures by Brazilian and OECD industries as a percentage of sales revenues

	Brazil (1994)	Brazil (1995)	Brazil (1996)	Brazil (1994-96)	OECD (1993)
All industries	0.84	0.69	0.74	0.76	2.40
Food	0.13	0.22	0.15	0.17	0.30
Primary metal	0.41	0.29	0.27	0.32	0.80
Pulp and paper	0.49	0.48	0.48	0.48	0.30
Metal products	0.82	0.78	0.35	0.65	0.70
Chemicals	0.75	0.80	0.56	0.70	4.80
Electric equipment	1.07	1.13	1.22	1.14	5.90
Plastic and rubber	2.01	1.19	0.89	1.36	1.10
Industrial machinery	1.78	0.40	2.55	1.58	2.00
Medical/scientific instruments	NA	2.14	1.60	1.87	6.20
Transport equipment (a)	1.50	4.29	6.81	4.20	5.00
Number of replies	500	560	328		
Share in industrial output (%)	41.0	49.7	31.9		

Source: Sbragia and Kruglianskas (May-June 1996), ANPEI (1996) and (1997), and OECD (1996b).

(a) Excluding the aerospace and aviation industry.

Agriculture

Primary agriculture is the most important provider of agricultural inputs. Seeds, young animals, animal feed, and agricultural services are just a few of the agricultural products that are being used as inputs in primary agricultural production. Each of these agricultural product groups has its own technological innovation characteristics. Seeds, for example, receive substantially more support from public and private R&D than most other agricultural products. As such, seeds are "R&D intensive" or "high-tech" agricultural products.[11] Unfortunately, the input-output data at hand do not permit differentiation among the various agricultural products. Moreover, the ANPEI survey on private business R&D investments does not cover agricultural companies whatsoever. As a consequence, we can only speculate about the amount of private, intramural R&D investments in primary agriculture in very broad terms. [12] Across the board, however, primary agriculture is being supported predominantly by public R&D agencies. Most of this R&D is also publicly financed.

The Brazilian seed market consists of three components: (1) Hybrid seeds (mainly hybrid maize); (2) Open-pollinating seeds of major crops; and (3) Horticultural seeds. In the late 1980s, the hybrid seed market was estimated at US$100 million, the open-pollinating seed market at US$ 600 million, and the horticultural seed market at US$25-30 million (da Silveira et al, 1990). Other sources that provide somewhat more recent data estimate the value of the Brazilian seed market at US$ 1000 million in 1989 (Contini 199?) and US$ 1200 million in 1996 (FIS 1999). Most seeds are produced locally, although in some instances under license. Foreign seed companies are quite active in Brazil, which probably also explains why Brazil is a major exporter of agricultural seeds (US$ 193 million in 1996), ranking number four on the list of seed exporters globally (FIS 1999). Many foreign seed companies use Brazil as their basis for their operations in Latin America.

Just a few private companies dominate the hybrid-seed market, which mainly consists of maize seed. Until recently, a Brazilian company (Agroceres) led the hybrid-seed market. In 1997, however, Agroceres sold its seed division to Monsanto. This has made the foreign dominance of the hybrid-seed market almost complete. After the takeover, there were some rumors that

[11] Seed industries in developed countries invest as much as 10% and more of their total sales in R&D (López-Pereira and Garcia 1997).

[12] In most OECD countries the business-sector S&T survey also covers primary agriculture. On average, this component adds another 10-20% to the public agricultural R&D expenditures.

Monsanto might close down Agroceres' research program on hybrid maize. For many years, this research program has been the largest and most successful private research program in the Brazilian seed business.[13] Other multinationals in this section of the market (e.g., Cargill, Braskalb, Pioneer, Germinal, and ICI) all have part of their breeding work located in Brazil, but follow a global R&D strategy similar to that of Monsanto.

Over time, the Brazilian maize-seed market has evolved from predominantly public to almost exclusively private. Initially, most maize-seed companies depended upon public R&D for the development of new varieties, but this activity has shifted increasingly to the private sector. By 1992, some 84% of the investments in maize breeding were private. Public funds for maize breeding now target mainly small seed companies servicing small farmers in marginal areas (López-Pereira and Garcia 1997).

Open-pollinating seeds of major crops are produced and marketed in Brazil by a large number of cooperatives and small, local businesses.[14] Plant breeding in this section of the market still depends almost completely on public breeding programs and financing. Until recently, the absence of plant variety rights protection has inhibited private R&D investments in this segment of the market. In 1998, however, the Brazilian Parliament approved a new Plant Variety Protection Act. Brazil became a member of the International Convention for the Protection of New Varieties of Plants (UPOV) in May 1999. As a consequence, we may also expect in the open-pollinated segment of the seed market a shift from public to private R&D, a restructuring and consolidation of the seed businesses and a stronger presence of foreign seed companies in the future.[15]

The horticultural seed market is the smallest of the three markets, but covers a very wide range of different crops. Both the supply and the demand side of the market are quite diverse and fragmented. The demand-side of the market ranges from large, professional growers to home gardeners. About 30% of the horticultural seeds are imported directly. This share is higher at the high-tech growers' end of the market. In addition, some of the horticultural seeds are produced locally under license. Both public and private R&D activities in this segment of the seed market are quite limited.

Food processing industry

Of all inputs used in agriculture, nearly 12% originate from the food processing industry, of which the animal feed industry is by far the most important. On average, the food processing industry invests relatively little in R&D (0.17%). We have no indication that the animal feed industry substantially deviates from this average picture. Nutritional and medical supplements are the more "R&D-intensive" inputs that the animal feed industry obtains from the pharmaceutical and chemical industries.

Fertilizers

Brazil consumed about 4.3 million ton manufactured fertilizers or 3.3% of the world fertilizer production in 1995 (FAOSTAT 1999). Fertilizer use has increased quite dramatically during the past 30 years from about 10 kg per hectare cropland in the early 1960s to 60-80 kg per hectare in more recent years. Fertilizer use is still lower than in the US, but substantially less so than 30 years ago (figure 2).

[13] In 1995 Agroceres employed in its breeding programs on maize, sorghum, and horticulture 17, 3 and 4 researchers, respectively (Beintema, Dias Avila, and Pardey 1999).
[14] Membership of the Brazilian Association of Seed Producers (ABRASEM) dropped from 850 in 1990 to 660 in 1995 (ABRASEM 1999).
[15] See de Carvalho (1997) for a more specific discussion about the possible impact of the introduction of plant variety rights' legislation in Brazil.

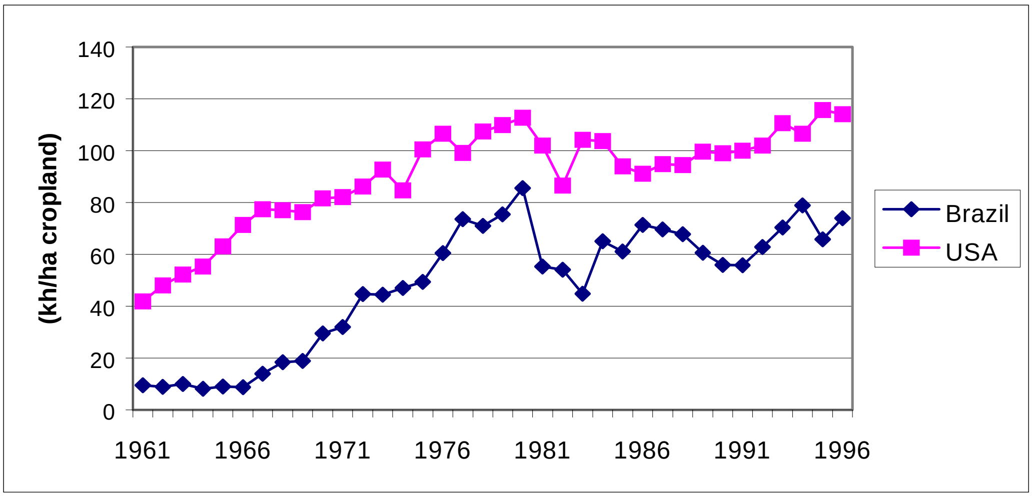

Figure 2: Fertilizer use per hectare cropland in Brazil and the USA, 1961-96

Starting in the 1950s, Brazil has developed a significant fertilizer industry. By the mid-1990s, the country was nearly self-sufficient in nitrogen (N) and phosphate (P), but imported most of its potash (K). The country has a considerable reserve of phosphate rock but of relatively poor quality. As a consequence, Brazilian phosphate fertilizers are relatively more expensive to produce but protected by the high transport costs of imported phosphate. The production of nitrogen is also hardly competitive since Brazil lacks large reserves of cheap energy. A study on the competitiveness of the Brazilian fertilizer industry in the early 1990s (Rappel and Loiola, 1993), sketched a rather bleak picture of a rather fragmented, loss-making industry with a substantial over-capacity and dominated by state-owned companies. Investments in new technology and new plants had completely halted in the early 1990s. In more recent years, however, many of the state-owned fertilizer companies have been privatized and production capacity has been restructured. The privatization has attracted a substantial amount of foreign capital, which probably also has provided access to foreign sources of technology.

Agrochemicals

Brazil consumes about 5% of the world's agrochemical production. A substantial part of this consumption is imported directly. Another part is imported indirectly as semi-processed inputs (active ingredients) used by the agrochemical industry. Brazil also exports agrochemicals. In 1995, it was the fourteenth exporter of pesticides in the world with a share of 1.2% in total world exports (FAOSTAT 1999).

Multinational companies cover about 75-80% of the Brazilian agrochemical market. National companies, which cover the remaining 20-25% of the market, sell mainly generic products for which there are multiple suppliers (Silveira 1993).

Brazil's import-substitution policy has levied in particular the import of active ingredients. In this way the government intends to further develop and diversify the chemical industry in Brazil.

The 5-10 multinational companies that dominate the agrochemical world market invest intensively in R&D. R&D investment-to-sales ratios of 10-15% in the agrochemical or life science sector of their businesses are not exceptional.[16] Despite the fact that these multinationals have started to spread their research capacity more globally in recent years (in the past most R&D capacity was concentrated at headquarters), they still concentrate the bulk of their R&D investments in just a few developed countries. Production and sales of these multinationals are geographically far more spread than their R&D. However, they can take the

[16] The bulk production of chemicals is far less R&D intensive. For that reason the average R&D intensity in the chemical sector is substantially lower than in the agrochemical industry.

results of their R&D quite easily from one location to another. Given the dominance of the multinational companies in the Brazilian agrochemical industry, local R&D expenditures by the agrochemical industry most likely underestimate the actual technology intensity of the industry more than in most other input industries.

Veterinary pharmaceuticals

In contrast to the human pharmaceutical market, of which 80% or more is in the hands of foreign companies, two local companies (Agroceres and Tortuga) hold a substantial part of the veterinary pharmaceutical market in Brazil. Both companies have annual sales of US$ 100 million or more, part of which is exported. In comparison to the average Brazilian company, both companies invest substantially in R&D, but less than most of their foreign competitors. Agroceres and Tortuga not only produce veterinary products, but also nutritional and medical supplements for the animal feed industry. This latter part of the business is a rapidly growing one worldwide. However, the R&D invested in developing these supplements only indirectly enter the agricultural production process through the animal feed industry.

Agricultural machinery and equipment

The structure of the Brazilian agricultural machinery and equipment industry is quite diverse. At one end of the spectrum there are just a few large companies that produce large and technologically advanced machinery such as tractors and combines. These companies are usually subsidiaries of foreign companies and have oftentimes been developed in conjunction with the Brazilian automobile industry. Their development has depended importantly on Brazil's import-substitution policy until the early 1990s. At the other end of the spectrum there are a large number of small, locally owned industries that produce agricultural implements and equipment that are relatively low-tech. R&D investments by these companies are usually low (Dahab 1993).

The Statistical Yearbook of the Brazilian Automobile Industry (ANFAVEA 1998) provides ample information on the agricultural machinery companies that dominate the high-tech end of the agricultural machinery and equipment market. In 1997, just 10 companies produced 31,657 agricultural machines, of which 22,464 wheel tractors, 3,715 combines, 2,599 loaders and backhoes, 2,035 crawler tractors, and 844 tillers. In each segment of the market there are just a few suppliers. For example, the three largest producers of wheel tractors manufactured 83% of all wheel tractors produced in Brazil in 1997.[17]

The Brazilian agricultural machinery market has been extremely unstable over the past 20 years. Sales of locally produced, agricultural machinery have been affected heavily by economic instability, high inflation and interest rates, and abrupt changes in agricultural credit schemes. Exports have been equally unstable due to exchange rate fluctuations and a high dependence on unstable Latin American markets. Local production of wheel tractors peaked in 1976 at more than 60,000, but has dropped since then to about 22,000 in 1997 (figure 3). Of these tractors, less than one percent was exported in 1976 compared to 29% in 1997. Several producers have not survived this collapse of the tractor market, and there are considerably fewer tractor companies in Brazil today than 20 years ago.

[17] AGCO (US), New Holland (previously owned by Ford, now by Fiat), and VALMET (Finland).

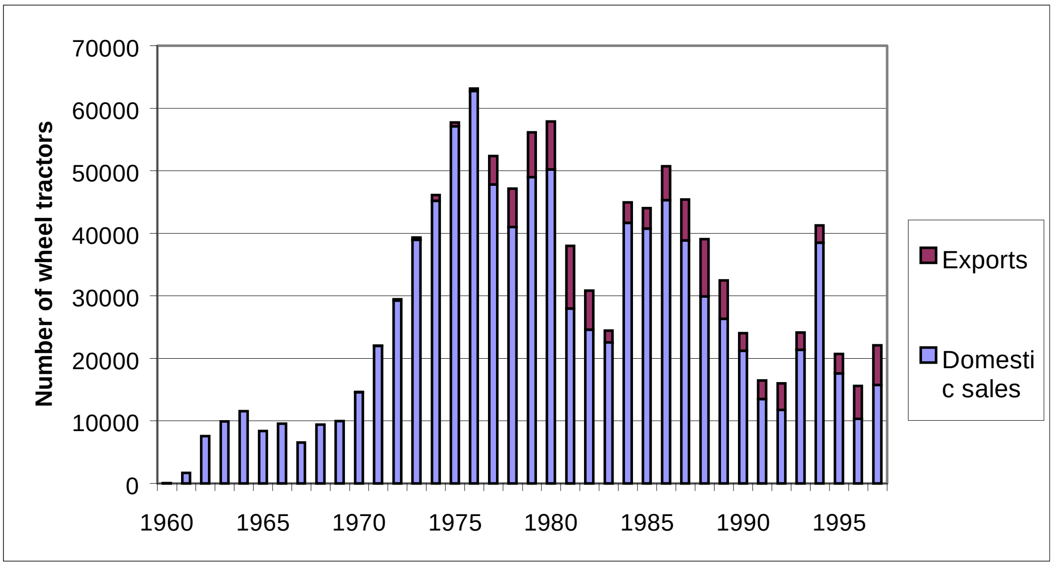

Figure 3: Number of wheel tractors sold by local tractor producers, 1960-97

Between 1970 and 1980 the Brazilian tractor fleet expanded quite phenomenally. Since 1980, however, the tractor fleet has stabilized at about half a million tractors (table 4). With local sales averaging about 18475 per annum throughout the 1990s, it takes nearly 27 years to replace the current tractor fleet.

Table 4: Brazilian farming mechanization level 1960-95

	Cultivated area	Wheel tractors fleet	Mechanization level
	(million hectares)	*(units)*	*(ha/tractor)*
1960	25.7	62684	410
1965	31.6	76691	413
1970	34.9	97160	359
1975	41.8	273852	153
1980	47.6	480340	99
1985	49.5	551036	90
1990	47.7	515815	92
1995	50.1	481316	104

Source: ANFAVEA (1998).

Cheap agricultural credit has played a very crucial role in the mechanization of Brazilian agriculture. During several periods over the past 25 years, interest rates charged for agricultural credit were substantially below the inflation rate. This constituted an implicit and sometimes quite lavish subsidy on agricultural machinery and other inputs. When the costs for these credit schemes escalated, cuts had to be made. The first such a sharp adjustment took place in the early 1980s, followed by another one in the early 1990s. Agricultural investment credit peaked at US$ 6530 million (at 1997 prices) in 1976. Twenty years later, it plummeted to a low US$ 560 million (at 1997 prices in 1996 -- figure 4).[18] The sales of tractors have also been plotted in figure 4. They show a very close correlation with agricultural investment credit. Of the total agricultural investment credit provided, about 10-25% is spent on tractors.

The R&D intensity of the Brazilian (agricultural) machinery industry about equals the R&D intensity measured for the (agricultural) machinery industry among the 14 OECD countries. In contrast, the Brazilian (agro-) chemical industry has a substantially lower R&D intensity than its OECD counterparts.

[18] Agricultural credit for investments constitutes only a minor component (10-20%) of all agricultural credit provided.

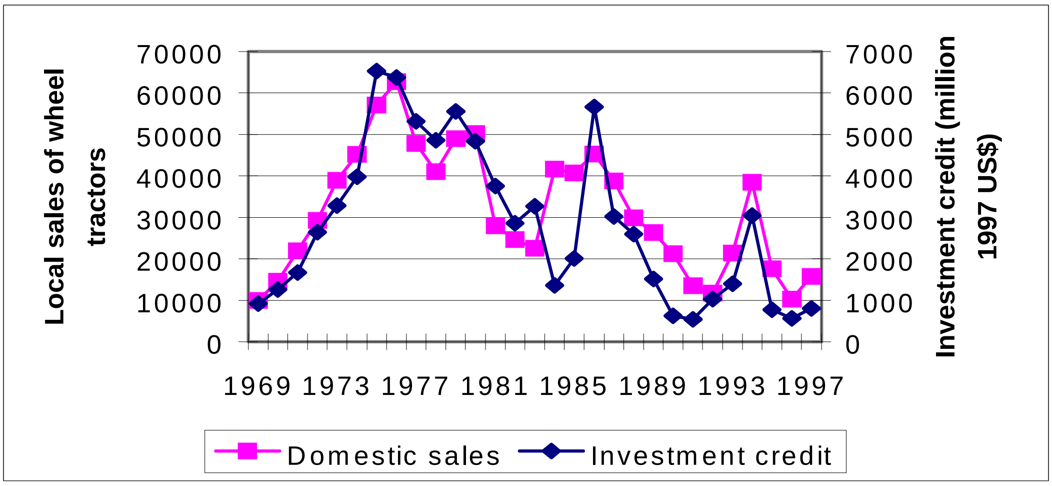

Figure 4: Agricultural investment credit versus sales of tractors, 1969-1997

Other input industries

In addition to the most important agricultural input industries mentioned above, agriculture also buys relatively small amounts of inputs from a whole range of industries that we lumped together under the heading of "other products." The R&D intensity of this rest category has been assumed to be about the industry average.

Two important input suppliers not covered by the industrial R&D statistics are services and construction. In the literature it is generally assumed that these two economic sectors invest very little in R&D. Both sectors typically acquire most of their technology by buying inputs from other industries. Computers, for example, have revolutionized the service sector.

Accumulated technology intensity in primary agricultural production

Investments in technology generation

A wide range of different actors conducts R&D that targets primary agriculture directly. They differ quite substantially in size and source of funding (table 5). The largest and predominantly publicly funded entity is EMBRAPA. In addition, there are various state-level agricultural research organizations as well as universities with agricultural research programs. Also these entities rely mostly on public funding. Some of the bigger commodity boards collect levies to support specific research programs in the public sector or to support their own research facilities. We placed this type of funding under "private-extramural." Intramural private R&D investments in primary agriculture are made by some large plantations, seed companies, animal breeders, and agricultural services. These entities also contract out some of their R&D to the public sector.

Although the executing research agencies identified in table 5 focus predominantly on primary agriculture, some of their research focuses on improvements in production and productivity of the agricultural processing industries or agricultural input industries such as agricultural machinery and agrochemicals. Public R&D investments that target off-farm processing have been separated as much as possible, while those that support primary agriculture only indirectly through agricultural input industries have not. Ideally we would like to separate the latter as well, but is not possible due to lack of detailed information. In 1995 direct R&D investments targeting primary agriculture yielded some 0.99% of the gross value of agricultural output and 1.60% of agricultural GDP. This latter percentage is significantly higher than that of the Brazilian economy as a whole (0.76% of GDP, see table 2), and also higher than the agricultural R&D intensity observed for most other Latin American countries (Cremers and Roseboom 1997).

Table 5: Agricultural R&D investments in Brazil, 1995

	Source of funding			
Executing agency	Public	Private-extramural	Private-intramural[a]	Total
	(million Reais)			
EMBRAPA	372.7	41.4		414.1
State-level organizations	169.2	18.8		188.0
Universities	152.3	16.9		169.2
Private sector			50.0	50.0
Total	694.1	77.1	50.0	821.3

Source: Adapted from Beintema, Avilla, and Pardey (forthcoming 1999).

Note: An estimated 6% of the R&D expenditures by the public agricultural research agencies target the food processing industry rather than primary agriculture. These have been netted out. In addition, it has been assumed that EMBRAPA, the state-level organizations, and the universities each derive some 10 percent of their funding from private sources (i.e., own income of sales of products and services, farmer contributions through collective funding schemes, contracts with private firms, royalty receipts). [a] Author's estimation.

Technology acquisition through purchased inputs

Table 6 provides an estimate of the total value of R&D acquired by primary agriculture through purchased inputs. The value of the purchased inputs have been derived from the input-output tables of the Brazilian economy, while the R&D intensities of the various input industries have been estimated at the hand of information obtained from the ANPEI survey. Assuming that in all three countries most imported inputs come from OECD countries, we have used OECD-average intensity ratios as a proxy for the R&D intensity of imported inputs (OECD 1996b).

The ANPEI publications provide R&D intensity profiles for some 10 broad-defined industries that are reported in table 3. By design, they do not cover agriculture, mining, construction, or the service industry. For unclear reasons, however, the ANPEI survey does not cover the oil refinery industry either. Upon request, more specific R&D profiles can be obtained from the ANPEI database, but this is bound by strict disclosure rules. If there are too few companies in a certain economic activity cluster, no data can be disclosed. The chemical industry, for example, comprises three important industries that provide inputs to primary agriculture, namely: (1) the fertilizer industry; (2) the agrochemical industry; and (3) the veterinary pharmaceutical industry. Each of them has its own R&D intensity. Unfortunately, the ANPEI database does not disclose the R&D intensity profiles of these three more specific industries. Therefore, the R&D intensities inserted in table 6 for these three industries are based on modifications of the average according to patterns observed in other countries. So the fertilizer industry was given a low R&D intensity ratio and the agricultural chemical and veterinary medicine industry a relative high one. For the agricultural machinery industry a specific R&D intensity profile was obtained from the ANPEI database.

The estimated R&D intensities for the imported inputs have been based on OECD data (OECD 1996). We have assumed that all imported inputs are imported from OECD countries and have relatively high R&D intensities compared to locally produced inputs.

In 1995 primary agriculture bought some R 36 billion of current and capital inputs, of which nearly R 2 billion was imported. The R&D intensity of the imported inputs is 4-5 times higher than the locally produced inputs (table 6). This large differential in R&D intensity is due to the fact that the imports are mainly coming from high-tech industries such as agrochemicals and agricultural machinery. Despite the low share of imports in total purchased inputs, imported inputs constitute a substantial transfer of technology. Of the R 194 million of R&D investments acquired through purchased inputs by primary agriculture, 29% was acquired through imported inputs.

Table 6: Estimation of R&D acquisition through purchased inputs, 1995

	Local production			Import			
	Value purchased inputs	Estimated R&D intensity	Estimated value of R&D appropriation	Value purchased inputs	Estimated R&D intensity	Estimated value of R&D appropriation	Total
	(million Reais)	*(percentage)*	*(million Reais)*	*(million Reais)*	*(percentage)*	*(million Reais)*	*(million Reais)*
Current inputs:							
Agriculture, forestry, and fisheries	12343		0.0	357	1.00	3.6	3.6
Food processing industry	3227	0.17	5.5	35	0.30	0.1	5.6
Oil refinery industry: fuel and oil products	1883	0.25	4.8	35	0.90	0.3	5.1
Chemical industry: fertilizers	3641	0.15	5.5	0	0.20	0.0	5.5
Chemical industry: agrochemicals	1839	1.50	27.6	419	7.00	29.3	56.9
Chemical industry: veterinary pharmaceuticals	207	3.00	6.2	0	10.70	0.0	6.2
Fabricated metals	119	0.65	0.8	5	0.70	0.0	0.8
Agricultural machinery and equipment	206	1.66	3.4	21	2.04	0.4	3.8
Other products	790	0.55	4.4	18	0.50	0.1	4.4
Services	2578	0.20	5.2	42	0.35	0.1	5.3
Subtotal	*26832*	*0.44*	*63.2*	*932*	*3.65*	*34.0*	*97.3*
Capital inputs:							
Agricultural machinery and transport	2146	2.89	62.0	753	2.45	18.5	80.5
Construction	3224	0.10	3.2	0	0.15	0.0	3.2
Other capital items	1876	0.50	9.4	331	1.00	3.3	12.7
Subtotal	*7246*	*1.03*	*74.6*	*1084*	*2.01*	*21.8*	*96.4*
Total	**34078**	**0.63**	**137.9**	**2016**	**2.77**	**55.8**	**193.6**

Sources: IBGE (1997), ANPEI (1997), ANPEI (1998), OECD (1996b), and Sbragia and Kruglianskas (1996a and b).

Note: The R&D intensity of inputs coming from local agriculture, forestry, and fisheries has been set at zero to avoid double counting.

Adding the estimated value of acquired R&D through purchased inputs (R 194 million) to the estimated direct R&D investments into Brazilian agriculture (R 821 million) increases the R&D intensity ratio with 24% from 0.99% to 1.22% of the gross value of agricultural output. This estimate of acquired R&D through purchased inputs only covers the first round effect. An accumulated effect would yield an even stronger contribution of purchased inputs to the technology intensity of agricultural production. [19]

Three factors can be identified that affect the relative importance of purchased inputs as a source of technological innovation, namely:

- The intensity with which inputs are being used;
- The type and range of inputs being used; and
- The technology intensity of the industries that provide the inputs.

As illustrated by the use of fertilizer and the sale of tractors, high-input agriculture rapidly raised in importance in Brazil during the 1970s. After 1980, however, the use of agricultural inputs seems to have reached a certain plateau, which in part can be explained by tighter agricultural credit and declining input subsidies. Despite the fact that low-input agriculture is still dominant in several parts of the country (and probably the reality for the majority of the Brazilian farmers), the bulk of Brazil's agricultural output is being produced under relatively high-input production regimes. While it is unlikely that Brazilian agriculture will become significantly more input-intensive than it currently is, there is major room for improving the R&D and technology intensity of the Brazilian agricultural input industries (in particular within the chemical sector) and for shifting towards more high-tech inputs. Therefore, agricultural input industries are most likely to play an even more prominent role in enhancing agricultural productivity in the future than they do today.

Technology acquisition through patents, licenses and technology contracts

An alternative for investing in the development of technology is to acquire technology from third parties by means of patents, licenses and technology contracts. Companies that operate at some distance from the technological frontier may find this an effective and efficient way of acquiring the necessary technology. In the case of Brazil, however, very restrictive policies regarding technology transfer payments were in place during the 1970s and 1980s. Also today all such payments have to be cleared by the Brazilian Industrial Property Office (INPI) in order for them to be accepted by the tax office as a cost and to make related foreign exchange transactions possible. INPI screens each contract on various criteria as well as evaluates whether the price charged is reasonable. In the past these criteria were quite strict, limiting the import of technology significantly. For example, no royalty payments were permitted between subsidiaries and their parents or between joint venture firms and foreign partners holding more than a 50% stake in the venture. In addition, royalty payments could not exceed 2-5% of net sales, depending on the type of industry. In essence, Brazil's technology transfer regime was designed to improve the bargaining position of national firms and minimize foreign exchange outflow. The Government's main concern was that foreign firms were using technology transfer payments as a way of remitting profits (Dahlman and Frischtak 1993). After adopting more liberal economic and intellectual property right policies in the early 1990s, foreign technology transfer payments have increased dramatically from about US$ 200 million throughout the 1980s and early 1990s to US$ 1523 million in 1997 (figure 5).[20]

[19] An input industry also buys inputs from other industries and therefore its R&D intensity is higher than direct R&D investments only. With an adapted version of a Leontieff inverse one can calculate this accumulative effect (OECD 1996).
[20] A substantial part of this increase is due to the inclusion of the technology transactions within multinationals and joint ventures in more recent years. In the past, such technology transfers may have taken place but without proper or explicit compensation.

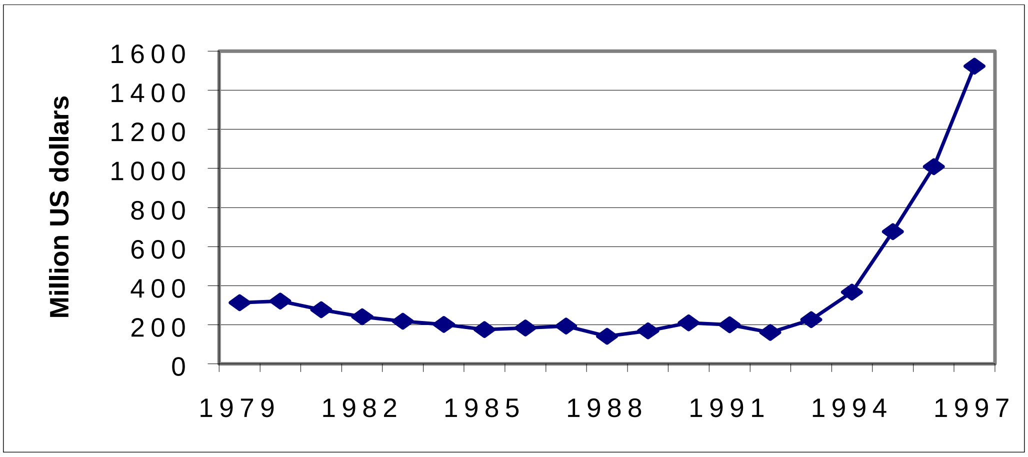

Figure 5: Foreign payments for technology transfer contracts 1979-1997

Buying technology through patents and the like makes sense when a company operates at a distance of the technological frontier of an industry, but it is a less attractive strategy when competing internationally in the most advanced markets. Licenses are often geographically restricted to one country or region, which substantially limits the market that can be reached. Therefore, companies that want to operate internationally and at the forefront of their industry can only do so by investing in their own R&D and developing their own technology. Conducting R&D is also an important factor in how successful a company is in absorbing technology developed elsewhere. In that sense direct purchase of technology can be a substitute for investment in own technology development to only some extent.

Foreign capital is another factor that positively influences the import of technology from abroad. The dramatic increase in foreign direct investments into Brazil in recent years (table 7) can be taken as an important indication of improved access to international sources of technology. Even before this major inflow of foreign capital, foreign companies already dominated several Brazilian agricultural input markets (i.e., hybrid-seeds, agrochemicals and agricultural machinery). Table 7 also shows that the privatization of government-owned companies has attracted substantial amounts of foreign capital.[21]

Table 7: Direct foreign capital investments into Brazil, 1992-98

	Inflows				
	Privatization	Other	Total	Outflows	Net inflow
			(million US dollars)		
1992	..	..	1752	169	1583
1993	..	..	1294	580	714
1994	..	..	2589	618	1971
1995	..	..	5475	384	5092
1996	2645	7851	10496	520	9976
1997	5249	13496	18745	1660	17085
1998	6121	22621	28742	2609	26133

Source: Banco Central do Brasil (1999).

The overall picture that emerges from these aggregate data is that the more liberal economic policies adopted by Brazil in the early 1990s have significantly enhanced the import of technology from abroad. Improved IPR legislation, including the recent introduction of plant breeders' rights, has been an important component of these more liberal economic policies. The importance of technology acquisition by means of licenses and technology contracts,

[21] Despite the relative instability of the Brazilian financial markets in 1998, the net inflow of foreign direct investments into Brazil reached a historical record. However, Brazil's stock market experienced a net outflow of foreign capital in 1998.

however, differs from industry to industry and depends on factors such as the technology involved, market structure, and ownership.[22]

Technology acquisition through patents, licenses, and technology contracts is far more common in agricultural input and processing industries than in primary agriculture itself. Therefore, the increased importance of this type of technology acquisition affects primary agriculture more indirectly than directly. In that sense, primary agriculture may increasingly become surrounded by agricultural input and processing industries that are largely dominated by or linked to foreign multinationals and technology.

Other sources of technology

In addition to the technology generation and acquisition that can be measured, there is a certain amount of spillover of knowledge and technology that is not easily observable or measurable. Particularly in primary agriculture, where a large part of the research activity takes place in the public domain, knowledge and technology tend to be less protected by means of patents, trade secrecy, and the like and are less treated as a tradable good. But also in the private sector, copying of technology without compensation is quite common. Conceptually, however, it is very difficult to measure such spillovers and to price them. In the context of this study the contribution of technology spillovers have not been explored in detail.

Conclusions

This paper has set out to document, quantify, and analyze the various sources of technological innovation that contribute to the productivity of primary agriculture. In addition to the approximately R821 million spent in 1995 on R&D investments that target Brazilian primary agriculture directly, the sector absorbed in that same year at least another R194 million of R&D investments by purchasing inputs from industries in Brazil as well as abroad. This estimate should be considered a lower bound estimate as we have only measured the first round effect and not an accumulated one (input industries also purchase inputs that embody technology and so on), nor the technological contributions stemming from patents, license, and technology contracts.

Although imported inputs represent only an estimated 5.4% of all purchased current and capital inputs, they represent 28.8% of the acquired technology through purchased inputs. Input imports consist mainly of high-tech inputs such as agrochemicals and agricultural machinery. These two industry clusters combined are good for 86% of the estimated value of imported R&D appropriation. Also among the inputs produced locally, agrochemicals and agricultural machinery stand out as the two most important industries from which R&D is being appropriated. However, there are also many other local industries that make small but significant contributions.

Given the relatively low technology intensity of many of the local agricultural input industries, there is ample room for improvement, and, hence, an increased contribution of agricultural input industries towards the technology intensity of primary agriculture.

Also the direct acquisition of technology by means of patents, licenses and technology contracts is relatively underdeveloped in primary agriculture. In part, this reflects the predominance of the public sector in the provision of agricultural technology worldwide and the difficulty to protect agricultural innovations by means of intellectual property rights. However, the recent introduction of plant variety rights legislation in Brazil has opened up the prospects for more licensing of variety material in the seed sector. Public breeding programs, for example, have already started to recover some of their costs by licensing new varieties rather than to give them away for free as in the past. In that sense, an increase in technology

[22] See Anderson and Larson (1991) for a more in-depth analysis of international technology transactions within the private sector and dealing with agriculture.

payments (W) as a result of stronger IPR legislation and enforcement should be neutralized (to some extent) by a decline in spillovers for free (Z).

In agricultural input industries the acquisition of technology by means of patents, licenses and technology contracts is far more common. There is ample circumstantial evidence that technology transfer transactions have increased quite dramatically during the 1990s as a result of improved IPR legislation and more liberal and outward-looking economic policies in general. The spurt in direct foreign investments in recent years is a strong indication that the Brazilian economy is more intensively linking up to foreign sources of technology. Also, the huge increase in foreign payments for technology contracts points in this direction. In addition, government policies to enhance private R&D activities may have helped local industries to increase their absorptive capacity of technology. Of the different agricultural input industries, foreign ownership is the strongest in the agrochemical and agricultural machinery industries. Particularly in those industries, we can assume that the acquisition of technology by means of patents, licenses and technology contracts counts for a good deal of the technology in use. Unfortunately, lack of detailed and reliable data on royalty and technology contract payments makes it impossible to quantify this source of technology.

The adoption of more liberal economic policies, the phasing out of strict import-substitution policies, the introduction of tighter IPR legislation, and government support for private R&D are all policy measures that are considered conducive to improving the technology intensity and profile of the Brazilian (agricultural input) industry. Although few of these measures target primary agriculture specifically and most have affected primary agriculture only marginally, it is through the purchasing of inputs that primary agriculture has gained access to the very large technological innovation capacity residing in multinational companies such as Monsanto and Novartis.

This paper is a first attempt to improve our understanding of the contribution of the (agricultural) input industries to technological innovation in agriculture. Further improvement and fine-tuning of our analysis would incorporate the following:

- Separate the seed industry from primary agricultural production in order to get a clearer picture of the contribution of the seed industry;
- Following from the above: Construct a separate R&D intensity for the seed industry that covers both public and private R&D investments;
- Differentiate imported agricultural inputs by country of origin. The assumption in this study that all imported inputs come from advanced economies/multinationals is too extreme;
- Conduct a more in-depth analysis of agricultural input industries in terms of structure and production and importation links;
- Estimate the accumulated technology acquisition effect rather than the direct effect only; and
- Further improve the estimation of the various parameters, including technology contract payments and spillovers.

Notwithstanding these opportunities for improvements, the approach adopted in this study opens up some interesting new avenues for analyzing the technological contribution coming from agricultural input industries vis-à-vis those stemming from within primary agriculture.

References

ABRASEM (Associação Brasileira dos Produtores de Sementes). http://www.abrasem.com.br/. Created in April 1998, accessed in June 1999.

Alcorta, L. and W. Peres. "Innovation systems and technological specialization in Latin America and the Caribbean." *Research Policy* Vol. 26 (1998): 857-881.

Amable, B., and S. Palombarini. "Technical Change and Incorporated R&D in the Service Sector." *Research Policy* Vol. 27 (1998): 655-675.

Anderson, M, and B.L. Larson. "International Technology Transfer: Private Channels and Public Welfare." *American Journal of Agricultural Economics* Vol. 73, No. 3 (1991): 892-897.

ANFAVEA. *Statistical Yearbook of the Brazilian Automobile Industry*. São Paulo: ANFAVEA, 1998.

ANPEI. Indicadores Empresariais de Inovação Technológica: Resultados da Base de Dados ANPEI – Año 5 (1995). São Paulo: Associação Nacional de Pesquisa e Desenvolvimento das Empresas Industrias (ANPEI), December 1996.

ANPEI. Indicadores Empresariais de Inovação Technológica: Resultados da Base de Dados ANPEI – Año 6 (1996). São Paulo: Associação Nacional de Pesquisa e Desenvolvimento das Empresas Industrias (ANPEI), December 1997.

Banco Central do Brazil. "Press Release - Foreign Sector (05.17.99)" http://www1.bcb.gov.br/ingles/economics.htm. Accessed in June 1999.

Beintema, N.M., A.F.D. Avila, and P.G. Pardey. *Agricultural R&D in Brazil: Policy, Investments, and Institutional Profile.* Washington, D.C.: IFPRI and EMBRAPA, forthcoming 1999.

Carvalho, S.M.P. de. "Proteção de Cultivares a Apropriabilidade Econômica no Mercado de Sementes no Brasil." *Cadernos de Ciência & Tecnologia, Brasília*, Vol. 14, No. 3 (1997): 365-409.

Contini, E. *Complexo Agroindustrial – O "Agribusiness" Brasileiro.* Brasilia: EMBRAPA, 199?.

Cremers, M.W.J., and J. Roseboom. *Agricultural Research in Government Agencies in Latin America; A Preliminary Assessment of Investment Trends.* ISNAR Discussion Paper No. 97-7. The Hague: ISNAR, December 1997.

Dahab, S. *Estudo da Competitividade da Indústria Brasileira: Competitividade da Indústria de Máquinas Agrícolas.* Campinas: Universidade Estadual de Campinas, 1993.

Dahlman, C.J., and C.R. Frischtak. "National Systems Supporting Technical Advance in Industry: The Brazilian Experience." Chapter 13 in *National Innovation Systems: A Comparative Analysis*, edited by R.R. Nelson. New York/Oxford: Oxford University Press, 1993.

Debresson, C., et al. *Economic Interdependence and Innovative Activity: An Input-Output Analysis.* Cheltenham, UK: Edward Elgar, 1996.

FAOSTAT. "FAOSTAT Statistics Database." http://apps.fao.org/default.htm. Accessed May 1999.

FIS (International Seed Trade Association). http://www.worldseed.org/~assinsel/fis.htm. Accessed July 1999.

IBGE. *Matriz de Insumo-Produto Brasil 1995.* Rio de Janeiro: Instituto Brasileiro de Geografia e Estatística (IBGE), 1997.

IFA. *The Fertilizer Industry and World Food Supplies*. Paris: International Fertilizer Association (IFA), March 1999.

James, C. *Agricultural Research and Development: The Need for Public-Private Sector Partnerships.* Issues in Agriculture No. 9. Washington, D.C.: CGIAR, December 1996.

Johnson, D.K.N. "Johnson-Evenson Patent Set." http://www.wellesley.edu/Economics/johnson/jeps/index.html. Last time updated April 1999, accessed September 1999.

López-Pereira, M.A., and J.A. Garcia. *The Maize Seed Industries of Brazil and Mexico: Past Performance, Current Issues, and Future Prospects.* CIMMYT Economics Working Paper No. 97-02. Mexico, D.F.: CIMMYT, 1997.

OECD. *Technology and Industrial Performance: Technology Diffusion, Productivity, Employment and Skills, and International Competitiveness.* Paris: Organization for Economic Cooperation and Development (OECD), 1996a.

OECD. *Science, Technology and Industry Outlook—1996.* Paris: OECD, 1996b.

Rappel, E., and E. Loiola. *Estudo da Competitividade da Indústria Brasileira: Competitividade da Indústria de Fertilizantes.* Campinas: Universidade Estadual de Campinas, 1993.

Radosevic, S. *International Technology Transfer and Catch-up in Economic Development*. Cheltenham, UK: Edward Elgar, 1999.

RICYT. *Principales Indicadores de Ciencia y Technología Iberoamericanos / Interamericanos 1990-1997.* Buenos Aires: Red Iberoamericana de Indicadores de Ciencia y Technología (RICYT), junio 1999.

Sbragia, R., and I. Kruglianskas. "R&D in Brazilian Industry: Recent Indicators." *Research Technology Management*, Vol. 39, No. 3 (May-June 1996): 30-35.

Sbragia, R., and I. Kruglianskas. "R&D at the Firm Level: A Comparative Analysis between ANPEI (Brazil) and IRI (United States)." Paper presented at the Fifth IAMOT, Miami, February/ March 1996.

Scherer, F.M. "Inter-Industry Technology Flows in the United States." Research Policy Vol. 11, No.? (1982): 227-245

Silveira, J.M.F.J. da, S.L.M. Salles Filho, A.M. Futino, and M.B. Bonacelli. *Inovações Biotecnológicas e a Indústria de Sementes.* Campinas: Universidade Estadual de Campinas, 1990.

Silveira, J.M.F.J. da. *Estudo da Competitividade da Indústria Brasileira: Competitividade da Indústria de Defensivos Agrícolas.* Campinas: Universidade Estadual de Campinas, 1993.

Stoneman, P., ed. *Handbook of the Economics of Innovation and Technical Change.* Oxford: Blackwell, 1995.

Terleckyj, N. *Effects of R&D on the Productivity Growth of Industries: An Explorative Study.* Washington D.C.: National Planning Association, 1974.

UNESCO. *World Science Report 1998.* Paris: UNESCO, 1998.