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**Technology Transfer, Policies, and the Role of the Private
Sector in the Global Poultry Revolution**

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ABSTRACT

With the Biotech Revolution, questions are being asked about what role the government should play in the process—does public research in developing countries play a role? Can governments speed the spread of technology by offering complementary services? Unlike the public investment–driven Green Revolution in cereals, the “Poultry Revolution” in developing countries was driven by the successful transfer of biological technology developed by the private sector in the developed world to developing countries. This paper uses a supply response function to measure the importance of different types of private technology and of public investments on poultry productivity. The findings confirm that imported private technology was important to the growth of the poultry industry but also emphasize the importance of complementary government investments such as veterinary services.

Key words: supply response function, private sector research, technology transfer, the poultry revolution

1. LIVESTOCK REVOLUTION

Over the last four decades, there has been rapid growth in livestock production and a rapid change in how animal products are produced, processed, consumed, and marketed. Growth in livestock production in both developed and developing countries has been led by poultry and was induced by increased demand, which was driven by increasing populations and rising per capita incomes (Delgado et al. 1999; Delgado et al. 2008; Narrod et al. 2008). The income elasticity for the period 1970–1995 in less developed countries (LDC's) was considerably lower for poultry than for pork, beef, and milk (see Table 1). If demand was the only factor, poultry production would have grown much slower than other meats and milk. The fact that poultry production grew fastest suggests that there must have been other important factors that increased the supply of poultry more rapidly than the supply of other meats and milk. Notably, by 2000, the income elasticity for poultry was much higher than other meat products, and the trend is projected to continue suggesting demand to be an important factor in the growth of the poultry sector in recent years.

Table 1. Production trends and expenditure elasticities of various livestock products

Region/ Product	Annual growth of total production 1961–1980	Annual growth of total production 1981–2005	Total production 1961*	Total production 1981*	Total production 2005*	Expenditure elasticities 1970–1995 LDCs	Expenditure elasticities 2000	Expenditure elasticities 2005
Developed								
Beef	2.5%	-0.6%	19	31	30		0.18	0.10
Pork	2.7%	0.4%	20	34	39		0.24	0.14
Poultry	5.0%	2.9%	6	19	37		0.66	0.56
Total	2.8%	0.7%	51	89	110		0.25	0.20
Meat								
Milk	1.2%	-0.4%	276	352	355		0.02	-0.08
Developing								
Beef	2.5%	3.4%	9	16	34	.65	0.69	0.62
Pork	7.3%	5.4%	4	19	63	1.10	0.52	0.46
Poultry	6.7%	7.8%	2	9	44	0.27	0.72	0.77
Total	4.4%	5.2%	20	47	155		0.60	0.48
Meat								
Milk	2.6%	3.7%	67	117	274	1.36	0.44	0.39

Source: FAO Statistics 2005, and Delgado Christopher, Mark Rosegrant, Henning Steinfeld, Simeon Ehui, and Claude Courbois 1999. Livestock to 2020: The Next Food Revolution. Tables 8 and 9. Projections to 2005 are from the July 2002 version of IMPACT.

Note: * -in thousands of tons

The primary objective of this paper is to examine the importance of various factors affecting poultry productivity and to determine what role the private sector played in the technology transfer that resulted from its own research and development activities to developing countries. We believe the technology transfer that facilitated increased productivity played an important role in the relatively rapid expansion of poultry production in LDCs, particularly in the early years. Unlike the Green Revolution, which was based on plant varieties developed by the public sector, the “Poultry Revolution” was based on biological technology—new poultry breeds that have been developed and spread primarily by the private sector (Narrod 1997; Narrod and Pray 2001). Like the Green Revolution, there were important complementary inputs that were required to increase productivity: high-quality feed, pharmaceuticals and biologicals to prevent disease, and buildings to confine the poultry. Like the Green Revolution, which

coincided with an increase in demand of plant products, the Livestock Revolution coincided with an increase in demand of livestock products (Delgado et. al. 1999; Delgado et al. 2008).

To get access to improved poultry breeds and the complementary inputs needed for high productivity, countries either had to develop their own breeds through public and/or private breeding or import improved breeds. This leads to the second purpose of this paper: to identify the importance of public investments and policies that stimulated the growth of the poultry industry in some countries. In this paper we use a supply response function to understand the role of various factors of interest had on poultry supply. We hypothesize that access to improved breeding stock, feed resources, and veterinary care are important factors affecting poultry productivity. Given the private sector has played such a significant role in the development of the poultry industry, we hypothesize that the role of the public sector in developing countries is minimal.

To test these hypotheses we use a panel data set consisting of variables that capture the impact of prices of inputs and outputs of poultry and competing products, and inputs related to technology, research, and institutional factors spanning a period of 33 years. The advantage of using panel data is that it enables us to capture the period before and after growth of the poultry sector accordingly, rather than analyzing factors that may have been only relevant in the later part of the growth of the sector.

2. TECHNOLOGY CHANGE AND STRUCTURAL CHANGE IN THE POULTRY

Technology change has been very rapid in the poultry industry. The move to confined poultry operations dramatically increased what one farmer could manage, facilitating the substitution of capital for labor in animal production, and led to a significant increase in labor productivity. Technology change in the poultry industry, led by advances in breeding that improved animal size, fecundity, growth rate, and uniformity, has enabled farmers to increase output per unit of feed, produce more birds per year, improve animal disease control, and decrease mortality (Narro 1997; Narro and Fuglie 2000).

In terms of management techniques, the move to production systems in which animals of different ages were segregated and raised apart has had a positive impact on disease control. The ability to control for the spread of poultry diseases through vaccines and pharmaceuticals helped expand the large-scale operations to allow farmers to achieve significant economies of scale and unit-cost reductions. Improvements in feed technology ensured that the improved breeds were using the ideal combination of ingredients at the lowest cost (Narro 1997; Narro and Fuglie 2000; Narro et al. 2008). Further, the introduction of evaporation shed cooling in hot climates such as Thailand's has had a tremendous impact on the industrialization of the industry (Poapongsakorn et al. 2003).

Throughout much of the world in both developed and developing countries, there has been a major structural change in the poultry industry (Narro 1997; Narro and Pray 2001; Delgado et al. 2008). Specifically, the commercial poultry industry in the developed world and in many developing countries has moved toward large-scale, vertically integrated broiler operations that contract grow-out operations to smaller farmers. Today, the commercial poultry industries in most countries are moving toward large-scale, vertically integrated operations. These operations are characterized by a high level of vertical control (ownership) or coordination among suppliers of production inputs, poultry growers, poultry processors, and marketers.

Henry and Rothwell (1995) suggest three reasons that vertical integration occurred: First, integration allowed companies to gain from economies of scale and optimize their capital resources. Second, integration was important for market ownership and margin control, which enabled companies to compete by lowering production costs and controlling the technical inputs into production at all levels. Third, the integration process enabled firms to maintain a certain amount of biosecurity and quality control. Delgado et al.'s (2008) study of rapidly developing livestock industries also found that vertical integration and contract farming provided a means for reducing transaction costs associated with relationship-specific transactions especially in regions of expanding production.

Aho (2003) notes, "When a chicken industry is young it usually consists of hundreds or thousands of independent growers, processors, hatcheries and feed mills who sell their products to each other. Through the process of vertical integration, independent businesses combine into a much smaller number of vertically integrated firms with at least one complex which includes the feed mill, hatchery, and processing plant. Then, the vertically integrated firms start combining with each other to form a small number of larger companies." This process appears to occur in both developed and developing countries.

The specific degree of integration varies between countries and firms. For the most part, integrated poultry operations involve most or all of the following segments: breeding flocks, hatchery, feed mill, production units, assembly of live birds or eggs, poultry slaughtering or packing plants, further processing units, delivery vehicles, and distribution centers in which fewer and fewer firms operate. Feed mills and further processing segments are not always included in the integration, although they are an essential part of the production system (Henry and Rothwell 1995). The move toward vertical integration appears to mirror the stabilization of the economy and the growth of the urban market. The expansion of these large, integrated operations has tended to occur in countries with developing or existing urban markets that supply the major cities. In countries that still sell chickens primarily in informal markets such as India and Indonesia, these forward linkages are less evident.

In different countries, integration took place under the auspices of different elements of the poultry industry. In some countries the feed industry was responsible for the initial integration, and in other countries it was either the breeding company or the hatcheries. In still other countries, integration was based on the potential market for further processing and fast food, as processors sought to add value to their business and thus become closer to the final customer.

3. CONTRACT FARMING

In many countries, the large, integrated firms contract out much of their production to local growers. The purpose of the contractual arrangement is to provide a minimum guaranteed payment for the grower, which is often adjusted based on feed conversion ratio, mortality, harvest recovery, and average live weight. It is designed to provide growers with appropriate incentives to manage their broiler farms so that the integrators' returns are maximized. In return, the grower seeks to optimize his net returns within the constraints of the contract.

The most common contractual arrangement in both developed and developing countries is for the poultry company to provide day-old chicks, feed, medicines, veterinary services, and technical advice in exchange for the finished birds at a predetermined price per kilogram of broiler meat (hence called a fee contract), with premiums or deductions according to certain performance criteria (notably, feed conversion ratio and mortality rates; Narrod 1997; Delgado et al. 2008). The contract farmer owns the land and buildings of the grow-out operation, provides the necessary labor and electricity, and handles the manure and dead animal disposal. These contract farms are served by a company's hatchery and feed mill. A variant to this resource-providing contract, called a price contract, can be observed in Thailand and the Philippines, where growing stock and feeds are provided by the integrator on credit and are later charged in full to the contract grower at the time of harvest and sale of output, when all costs are accounted for, before compensation is paid (Poapongsakorn et al. 2003; Costales et al. 2003). Similar to the broiler industry, the egg industry also has a supporting network, although it is less common, and production under contract is also less common.

Contract growers tend to live in close proximity to the processing plant so as to reduce transportation costs while enabling the firm to obtain better coordination, monitoring, and management control, and thus a high degree of operating efficiency. Many small-scale producers have remained in the poultry industry by entering into contracts with integrated operations (Delgado et al. 2008).

4. IMPACT OF CHANGES ON PRODUCTIVITY

The new technology and structural change of the industry enabled the substitution of capital for labor to increase output per unit of labor. These new technologies also led to an increase in animal productivity as seen in improved feed conversion in meat products (Fuglie et al. 2000). Table 2 shows a time series of partial productivity measures in the United States.

In many developing countries, however, production practices are such that the majority of producers still maintain small flocks that are kept outdoors and allowed to mingle with wild populations in backyard farming operations. Indeed, most of these “backyard” flocks are kept by poor farmers for subsistence purposes or as a source of income. These small backyard producers may be located in near with large-scale commercial operations, which increase the need for high levels of biosecurity to prevent the introduction of disease.

Table 2. Partial productivity measures

Animal Yield					
Year	Beef Cattle (lb beef/cow)	Hogs (lb pork/sow)	Dairy (lb milk/cow)	Broilers (lb/bird)	Layers (eggs/layer/year)
1955	590	788	5842	3.07	192
1965	591	1022	8304	3.48	218
1975	546	1167	10360	3.76	232
1985	680	1310	12994	4.21	247
1995	723	1503	16451	4.67	253

Beef cattle yield: Pounds (lbs) of beef produced divided by the number of cows and heifers that have calved. Hog yield: Pounds of pork produced divided by the number of farrowing sows.

Labor Productivity

Year	All farm	All livestock	Meat animals	Milk cows	Poultry
1955	1.00	1.00	1.00	1.00	1.00
1965	1.90	1.92	1.47	2.05	2.73
1975	2.97	3.54	2.42	4.26	5.40
1985	5.17	7.29	4.53	12.84	11.53

Index of output per hour worked: 1955=1.00

Labor productivity indexes for specific commodities are no longer published after 1986.

Source: Fuglie, K., C. Narrod, and C. Neumeyer. Public and private investment in animal research. In *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications*. Ames, IA: Iowa State University Press. 2000.

5. RESEARCH SUPPORTING THE POULTRY REVOLUTION

In general, the public sector is the source of most basic research (doing the original investigation that advances scientific knowledge but having no immediate commercial application), while the private sector focuses on market-oriented applied and development research (Fuglie et al. 1996). Table 3 illustrates the traditional roles of the public and private sectors in livestock research. In terms of livestock research and development, public and private sectors largely complement each other in research, with the public sector concentrating on areas where private incentives are weak. Incentives for private sector investments in research have been found to be where they can easily appropriate the returns to research (Narrod 1997; Fuglie et al. 2000; Narrod and Fuglie 2000).

Table 3. Roles of the public and private sectors in animal research by technology area

Animal technology area	Private sector ^a	Public sector ^a
Breeding and genetics	** - applied breeding where technology can be protected through trade secrets (hybridization), market structure (e.g., large market share), or patents on genetically modified animals	*** - basic studies in animal genetics, physiology, and biological efficiency - applied breeding where private incentives are weak - development of livestock genetic-improvement plans for producers
Disease protection and nutrition	*** - applied research on products that can be patented or protected through trade secrets (e.g., veterinary pharmaceuticals and compound feeds) - in vertically integrated systems, applied research on management systems for disease control and nutrition management	*** - basic research on animal pathology, nutrition, and metabolism - applied research on management systems to control diseases and improve feed efficiency
Mechanization	*** - applied research on new equipment and machines that can be protected by patents and trade secrets	* - little unless related to other technology areas
Management and economics	* - little except in large integrated systems	** - farm management, market statistics and analysis
Externalities (pollution reduction, food safety)	* - little unless producers and/or processors are subject to regulation and fines	*** - basic applied and development research

Source: Fuglie et al. 2000 Notes: ^a Stars indicate relative emphasis on research by sector:

*** major focus of research

** important but secondary focus of research

* little research conducted

Both public and private research has supported the Poultry Revolution. Initially the public sector invested a lot of research effort in poultry breeding, but over the years public sector research in breeding has declined in response to increasing private sector activities (see Fuglie et al. 2000; Narrod and Fuglie 2000). At the same time, many of the poultry science breeding programs throughout the world have closed. The impact is that the private sector had to work with the land grant universities to help them

identify new graduates to come to support private sector breeding efforts. Havenstein (1998) noted that the private sector has worked with the public sector to create a consortium of private sector breeders to attract students as interns to work specifically in the poultry industry. The benefits of this research have directly been transferred to developing countries through the sales of improved breeding stock. Developing countries have been able to increase productivity without having to directly invest in research themselves.

The remaining companies that specialize in poultry breeding are working on new ways to manipulate the genome to improve competitiveness and marketability of their products. Most of the poultry and swine genetics research for these companies is done at headquarters that are primarily located in the United States and Europe. These companies sell improved breeds to other countries through franchises worldwide. Through these franchises, the benefits from the multinational research companies can spill over to other countries, because breeds developed for confinement systems in the United States and Europe work well in confinement facilities elsewhere.

As with other types of investment, private research in the livestock industry is incentivized by the ability of the private company to sustain sales of the technology. The profitability of research can be undermined if other firms are able to copy a new technology and sell it to producers, or if farmers can reproduce the technology themselves.¹ Breeders of poultry, more so than other livestock, have successfully protected their intellectual property investment in superior breeds by exploiting heterosis, or hybrid vigor (Bugos 1991). Hybrid vigor is the yield advantage obtained when two or more pure inbred lines are crossed in a breeding scheme. While the offspring of this cross exhibits some superior yield performance, this yield advantage steadily declines if the offspring themselves are bred. Thus, by restricting access to the pure parent line stock (a form of trade secret), a breeder remains the sole supplier of the hybrid (Narrod and Fuglie 2002). Farmers need to repeatedly purchase new stock from the breeder to maintain high yields. They buy this stock from companies directly or from hatcheries who obtain the genetic stock from these companies within their own country.

Major advances have occurred in animal health in the recent years, necessitated by increased animal production in confined systems and by the spread of disease facilitated by trade. In the past, research efforts focused on biologics, feed additives, pharmaceuticals, and animal insecticides (Fuglie et al. 2000). Many companies have pulled their research efforts away from feed additives due to the increased concerns with antibiotic resistance and trade-related bans of products containing residues. Despite the decline in research of feed additives, these additives remain the most cost-effective and convenient method of administering drugs to poultry. Sales of poultry pharmaceuticals, animal insecticides, and biologics remain small.

Today, most animal health companies are subsidiaries of large international pharmaceutical companies and have exclusive rights to sell the products they develop until patents expire (Fuglie et al. 2000). After that, any company may produce and sell a generic copy, provided it is as safe as the original drug. Some drug companies market their products directly through veterinarians; the remaining products are distributed by veterinary wholesalers or directly to large livestock operations that employ their own veterinarians. According to industry survey data, private sector research expenditures for animal health products worldwide in 2003 totaled \$1.1 billion, or 9% of sales worldwide (Wood Mackenzie 2004).

¹ Copiers can afford to sell the technology more cheaply than the original inventor does because they do not have to recoup the initial sunk costs of research and development.

6. TECHNOLOGY TRANSFER

Countries can obtain benefits of technology developed in another country through the transfer of technology. Most studies on technology transfer in agriculture have emphasized the environmental sensitivity of biological technologies. The environmental sensitivity of technology implies the need for countries to adapt technologies developed elsewhere to local conditions and thereby facilitate the indirect transfer of the technology to meet their specific country's needs. For instance, the Green Revolution was successful in transferring a technology package of high-yield varieties of wheat and rice from temperate countries to countries of South and Southeast Asia, the Middle East, and Latin America through local adaptive research (Pray 1981).

One of the technologies associated with the Poultry Revolution consists of hybrid chicks imported initially from the United States or Europe, raised in containment facilities, and fed a compound feed containing additives and vaccines. This technology package appears to transfer relatively easily around the world, and any adaptive technology that is needed can be profitably developed by the private sector (Narrod and Pray 1995). Most of the top breeding companies are owned by or associated with multinational organizations, giving them the opportunity to operate worldwide, although there are also smaller farms producing pure lines for specialty markets. Table 4 shows the private sector poultry-breeding programs and franchise locations for the top seven poultry-breeding companies of 2000.² Today, with continual mergers, basically three companies remain who still maintain the original line names for recognition. These companies have operations set up around the world and can fill market orders, despite possible trade restrictions over outbreaks of various types of avian diseases in countries where breeding operations are located.

Table 4. Private sector poultry-breeding research programs and franchises

	Africa / Middle East	Asia / Australia	South America / Caribbean	North America / Europe	World
Poultry-breeding research programs	1	4	1	8	14
Franchises	30	66	26	49	171
Private scientist years in breeding	na	na	na	58.75 SY's Ph.D. (US)	na
Private research and development (in \$)	na	na	na	19.7 (US)	na

Source: Surveys by Narrod and Fuglie 2000 and Pray and Fuglie 2000.

Animal health products are another input that is relatively easily transferred, and most of the major pharmaceutical companies have worldwide operations marketing their health products. According to an industry survey, the World Animal Health market was worth \$15 billion in 2005, of which 60 percent went to food animals and 40 percent to companion animals. Of the \$15 billion 36 percent was directed to medicinal feed additives and veterinary biologicals (Wood Mackenzie Ltd 2005). North

². Since 2000, there have been more mergers, transfers of ownership to integrators, and franchises established in more countries. In 2000 Cobb-Vantress Inc. acquired the assets of Avian Farms and their product lines except for the Chinese bloodlines, which the Charoen Pokphand Group controls. Cobb-Vantress Inc. is owned and controlled by Tyson Foods. In addition, in 2000, Arbor Acres, Ross Breeders Ltd., and Indian River, meat lines previously owned by Lohmen, all merged to form the Aviagen Group Ltd., a holding company set up by BC Partners. Today it is estimated that it controls one-third of the world's broiler chickens. In 1997, a new company—Merial Animal Health—came into effect through the joint efforts of Merck & Co. Inc. and Rhône Poulenc, bringing together the breeding lines of ISA, Babcock, Shaver, BUT, and Hubbard.

America had 35.7 percent of the total market share; Latin America, 11.1; Western Europe, 20; Eastern Europe, 4.3; the Far East, 17; and the rest of the world, 3 (ibid).

With increasing globalization, demand, and access to new and improved technologies, more and more producers are altering their production practices. Thus the ability of developing countries to compete with more developed countries seems now to be determined by the developing country's ability to adopt the best practices and technologies already established in the industry and to ensure the safety of the animal population from animal diseases. Technological advances have reportedly been accompanied by shifts of production operations from a backyard or mixed system using family labor and farm-produced feed on smallholder crop farms to a more specialized market-oriented activity using hired labor, borrowed capital, and purchased inputs in systems producing more uniform quality (Delgado et al. 2003; Delgado and Narrod 2002; Sere and Steinfeld 1996; Delgado et al. 1999). If this is true, then it is unclear whether local research is an important factor responsible for poultry growth in developing countries, especially in countries that have ready access to trade and improved inputs on the open market or through franchises and sale by multinationals who often provide technical assistance with their supply of inputs. If producers, regardless of size, have access to improved inputs, then it is unlikely that this affects smallholders adversely.

However, structural changes that occurred in the poultry industry have resulted in high transaction costs in terms of access to information and assets for poultry producers, which can inhibit smallholders' participation to markets. Delgado et al.'s (2008) study of rapidly developing livestock industries found that vertical integration and contract farming provided a means for reducing transaction costs associated with farm-specific transactions, especially in regions of expanding production. Further, Tiongco et al. (2006) found that broiler farmers operating under contract with processors and integrated firms have benefited from the contractual arrangement in terms of increased knowledge (technical skills), stable incomes, and reduced transaction costs associated with the procurement of inputs and marketing of poultry meat through better access to improved technology, good quality inputs, and services. However, there was a growing concern that smallholders might be excluded in the process of vertical coordination as integrated firms would prefer to contract with large-scale poultry farmers to minimize transaction costs associated with searching and screening of prospective farms, negotiation of contracts, delivery of inputs and services, monitoring of grower's farm management, and enforcing contract terms and conditions.

7. POLICIES AFFECTING THE POULTRY INDUSTRY

For countries to benefit from the research conducted elsewhere, their producers must enjoy access to modern inputs. In the poultry industry, trade policies, regulations, and government investment have historically influenced poultry production by either encouraging or deterring the trade of inputs. These policies and standards can be grouped into four sets of government policies: (1) science and technology policies such as the public funding of research, intellectual property rights, and the government supply of modern inputs and veterinary service; (2) price, trade, and industrial policies such as protection of infant industries, export-led growth strategies, antitrust legislation, controls on foreign direct investment, controls on animal health and food safety, and price supports on poultry meat or on inputs into production; (3) environmental policies such as licensing policies that restrict locations and amounts of waste discharged into the environment, clean water and air legislation, regulation on disposal of poultry by-products, and improvements of markets for poultry by-products; and (4) private standards such as animal health, food safety, food quality, and animal welfare policies designed to protect consumer and animal health concerns, and private standards used to segment the market. The specific types of policies are listed in Table 5.

Table 5. Policies and standards affecting access to new poultry technologies

Science and technology	Price, trade, and industrial	Environmental	Private standards
Public funding of research	Protection of infant poultry input industries	Licensing policies that restrict location where certain amounts of pollutants are discharged	Requirements ensuring meeting certain private food safety standards and ability to conduct tracebacks
Intellectual property rights	Export-led growth strategy tax incentives for export	Clean water and air legislation	
Government supply of modern inputs	Antitrust legislation	Regulations on disposal of poultry by-products	Requirements on specific quality attributes
Provision of extension	Controls on foreign direct investments and trade	The improvement of markets for poultry by-products	
Provision of poultry science schooling	Strong legal protection on animal health and food safety standards	Animal health, food safety, quality, and animal welfare policies restricting the use of antibiotics as animal feed additives	
Provision of veterinary services	Price supports on poultry meat or on inputs to production	Policies restricting the use of meat and bone meal	
		Policies on stocking densities to support animal welfare concerns	

These policies and emerging private standards may affect the development of a country's agricultural industry by stifling technological progress and limiting farmers' access to modern inputs as well as access to certain markets in which producers can sell their products. These policies and private standards may be easier for larger producers to deal with, which may push the smaller producers out of business (Delgado et al. 2008). Many countries are now in the process of trying to increase domestic agricultural production by promoting policies that encourage the open trade of modern inputs and the transfer of technology from multinational companies. The lure of export markets and the requirements associated with these markets further drives some of these regulations as countries try to comply with import requirements in other countries, particularly those associated with sanitary and phytosanitary concerns, which may affect the sourcing of animals in the poultry supply chain. Furthermore, private standards on food safety and quality as well as traceability may impact poultry supply. At the same time, fear of zoonotic disease may result in some importing countries putting restrictions on access to certain types of breeding stock and hatching eggs, regardless of the level of risk. The impact of these requirements and standards on the poultry supply in certain countries remains unclear.

8. PREVIOUS STUDIES OF TECHNOLOGY CHANGE AND THE LIVESTOCK REVOLUTION

It is difficult to trace and quantify econometrically the impact of technology change and policies that affected the rate of technology transfer on agricultural sectors. Schultz (1958) was the first to attempt to quantify the benefits of public agriculture research and extension. He used an economic surplus approach to measure the social benefits of agricultural research with specific attention to increases in productivity in the United States. Griliches's 1957 study on the economic returns of hybrid corn research in the United States is the first to explicitly consider the role of research by private firms in the spread of agricultural technology. Since then, there have been numerous studies on technology change in different parts of agriculture.

The first study of technological change in the poultry industry was Peterson's study (1966) on the returns to public research in poultry science and to extension services in the United States. It found that there were high returns from such public sector investments. Subsequent studies on the poultry industry by Bredahl and Peterson (1976), Norton (1981), Smith et al. (1983), and Norton and Ortiz (1991) also indicated high rates of return on poultry research in the United States, varying from 21 to 61 percent.

The first study on the Livestock Revolution in developing countries was done by Delgado et al. (1999), who analyzed the nature, extent, scope, and implications of the Livestock Revolution. This study argued that the Livestock Revolution, particularly in developing countries, was fundamentally propelled by demand. Although people in developing countries are increasing their consumption from the very low levels of the past, they have a long way to go before coming near the averages of those in developed countries. In an updated study, Delgado (2003) argue that from 1996 to 1998 people in developing countries consumed an annual average of 25 kilograms (55 pounds) per capita of meat and 44 kilograms (97 pounds) per capita of milk, which is one-third of the meat and one-fifth of the milk consumed by people in developed countries. Nevertheless, the caloric consumption per capita of meat, milk, and eggs in developing countries in the late 1990s was still only one-fourth that for developed countries and 10 percent, accounted for only half the share of calories from animal sources observed in the developed countries.

Delgado et al. (2008) looked at factors promoting scaling up in the livestock sector using a stochastic profit frontier to measure technical efficiency. It attempted to understand the forces that affected the relative competitiveness of different scales of livestock production operations and to quantify the relative contribution of transaction-cost barriers and market distortions to lack of competitiveness of the small-scale operation. They found that, among other things, in most cases scaling up was not driven by technical and allocative efficiency issues in production but rather by transaction costs.

Although studies on technology change in the livestock sector, on the role of demand in promoting the Livestock Revolution, and on technical efficiency among different producers do exist, we are aware of no studies on factors affecting the response of poultry to technology transfer and other inputs of interest over a large group of countries for a period of time. Part of the difficulty of studying technology transfer has been the lack of both time series and cross-sectional data on prices of specific technologies. This study uses price data obtained from the Food and Agricultural Organization, data on the transfer of breeding stock obtained from a survey of the private sector conducted by Narrod and Fuglie (2000), and improved genetic stock in the form of hatching eggs from hatcheries to estimate the response of poultry productivity to technology transfer. In addition, it looks at the impact of research and various institutional factors on poultry supply.

9. POULTRY RESPONSE FUNCTION

To observe the response of poultry to access to new technologies, public and private research, intellectual property, and veterinary services, a single equation response model is used to capture the dynamic response of expectation formation and decision making under uncertainty. Alston et al. (1995) suggest that such a method may be preferable to using a production or cost function because it permits the dynamics of productivity responses to prices to be modeled along with the productivity response to research in order to estimate the returns to research.

In its most general form, this response function is given as

$$Q = f(P, \tau, Z)$$

where Q is the output produced given the vector of output price expectations and expected prices of conventional inputs P , factors related to technology τ , and other exogenous shifters of interest Z .

This approach was used by Zentner and Peterson (1984) to specify a wheat response function that was flexible so that social or unconventional variables representing research and technology could be included as exogenous variables. In their study, the response of wheat was postulated to be a function of expected input and output prices, marketing opportunities, government programs, climatic factors, and the level of public wheat and extension expenditures. Peterson (1997) suggests the output/input price ratio should be used in cases where data on input prices are scarce for the following three reasons: First, the ratio tends to reflect the full cost of inputs and the net price of output after transportation costs, indicating how farmers react under prevailing conditions. This is important because, although the market prices of inputs often fail to include the price of transport, the price of outputs usually includes such costs. Second, because many governments in less developed countries impose ceilings on prices of outputs and/or inputs, the use of the ratio enables the researcher to capture the effective price that buyers would pay to obtain the quantity they purchase. Last, the ratio reflects expected prices and thus captures what farmers believe will be the average level of prices in the future.

Given the scarcity of price data on many poultry inputs, we chose to use the output-to-input price ratio to estimate factors affecting the productivity of poultry to response of technology and policy factors of interest. This paper defines the poultry productivity response as kilograms of meat per broiler. We are interested in estimating the effect of four groups of variables loosely characterized as prices, technology, research, and institutional factors on poultry yield in developed and developing countries.

The poultry response function is as follows:

$$Q_{it} = \beta_i + \sum_j \beta_{jit} P_{jit} + \sum_k \beta_{kit} R_{kit} + \sum_l \beta_{lit} \tau_{lit} + \sum_m \beta_{mit} Z_{mit} + \mu_{it}$$

The indexes are defined as follows:

$i = \{24 \text{ countries}\}$

$j = \{\text{Prices—price of broiler meat to price of corn, price of pig meat to price of corn}\}$

$k = \{\text{Research—public research, private research}\}$

$l = \{\text{Technology—improved breeds, percentage of improved breeding stock}\}$

$m = \{\text{Institutional factors—veterinarians, patent index, number of franchises}\}$

$t = \{\text{Time index}\}$

where:

Q_{it} = poultry yield

P_{it} = vector of input and output price ratios for poultry and competing products

τ_{it} = vector of shifters related to technology

R_{it} = vector of shifters related to research

Z_{it} = vector of shifters related to institutional factors

μ_{it} = the error term

$\alpha_{jit} = \alpha_j$ = the regression coefficients for j for all i and t

$\alpha_{kit} = \alpha_k$ = the regression coefficients for k for all i and t

$\alpha_{lit} = \alpha_l$ = the regression coefficients for l for all i and t

$\alpha_{mit} = \alpha_m$ = the regression coefficients for m for all i and t

β_i = the fixed intercept for each country

The countries studied in the equation above are indexed by i, and the time periods t index the years from 1961 to 2005. Logarithms of all variables are used except the use of grandparent stock, which is a dummy variable. An error term μ_{it} represents random shocks to output per bird. Dummy variables for all years but one are used to allow for country-invariant shifts in the response function over time. This specification is equivalent to a two-way fixed effects model, which we estimated using SAS statistical software. The variables, units of measurement, and sources of data are listed in Table 6. Data have been collected for the 24 countries listed in Table 7. Table 8 reports the summary statistics of variables used in the model.

Table 6. Model data

Index	Definition	Source
Broiler productivity	Kg of broiler meat/1,000 broilers	Food and Agricultural Organization (FAO)
Price ratio for chicken meat	Price of chicken meat/price of corn	FAO
Price ratio for pig meat	Price of pig meat/price of corn	FAO
Improved broiler stock	Metric tons of hatching eggs of improved breeds per broiler and layer stock	FAO
Improved foreign breeds	No. of chicks of foreign breeds/ chicks of all breeds	Narrod and Fuglie (2000) (extrapolated to 2005)
Public research 1	1-(no. of improved breeds/all breeds)	CAB International abstracts
Public research 2	No. of articles	CAB International abstracts
Private research	10-year research-lagged one-hoss shay approach	
Veterinarians	Weighted no. of breeding programs	Narrod and Fuglie (2000) (extrapolated to 2005)
Franchises	No. of veterinarians per broiler and layer stock	FAO Animal Health
Patent protection	No. of companies with franchises in a specific country for a given year	Narrod and Fuglie (2000) and updated to 2005 with company reports
Grandparent stock vs. parent stock	Index	Ginarte and Park (1997), Park and Wagh 2002
	Dummy variable GP=1; PS=0	Interviews with companies (2000) and updated to 2005 with company reports

Table 7. Countries used in the model

Argentina	France	Malaysia	Spain
Australia	India	Mexico	Thailand
Brazil	Indonesia	Netherlands	Turkey
Canada	Italy	Nigeria	UK
Chile	Japan	Philippines	United States
Egypt	Korea	South Africa	Zimbabwe

Notes: Countries with breeding companies that sell parent stock: Australia, Canada, Italy, Japan, Korea, Malaysia, Nigeria, Philippines, Spain, Thailand, Turkey, UK, United States

Countries with breeding companies that sell grandparent stock: Argentina, Brazil, Chile, Egypt, France, Indonesia, India, Mexico, Netherlands, South Africa, Zimbabwe

Table 8. Summary statistics of variables used in the model

Index	N	Mean	Standard deviation	Minimum	Maximum
Broiler productivity (Carcass wt. per 1,000 broilers)	1125	13299	3201	7669	23378
Price ratio for chicken meat (ratio in local currency)	913	11.91	8.92	0	75
Price ratio for pig meat (ratio in local currency)	726	8.48	7.42	0	173.80
Ratio of improved broiler stock to local stock (1-no. of improved breeds/all breeds)	319	0.92	0.28	0	1.00
Improved foreign breeds (metric tons of hatching eggs per broiler and layer stock)	1075	176.77	1537	0.07	15829
Public research 1 (no. of publications)	900	38.11	39.40	0	223.00
Public research 2 (10-year research-lagged one-hoss shay approach)	900	302.37	322.93	0	1951
Private research (no. of research stations)	1125	11.41	38.54	0	318.00
Veterinarians (no. of veterinarians per broiler and layer stock)	1061	29.88	263.86	0.0009	2725
Franchises (no. of companies with franchises in a specific country)	1125	2.57	1.75	0	7.00
Patent protection (index)	1107	2.72	1.02	0	5.00
Grandparent stock vs. parent stock (dummy variable GP=1; PS=0)	1125	0.56	0.50	0	1.00

A fixed-effects model is used to eliminate the bias in the coefficient estimates. The fixed-effects method allows for the inclusion of a dummy variable to correct for such changes that might occur due to omitted variables. This choice was made for several reasons. First, it is known that there is variation in our large sample size across countries and over time. Second, it is known that the historical development of the poultry industry in these countries varies in terms of the amount of public and private involvement. Thus, it is possible that one of these missing variables is a relevant explanatory variable (one that does not change over time or one that changes over time but has the same value for all cross-sectional units) and is causing changes in the cross-sectional intercepts of the model. The disadvantage of using this method is that it may decrease the efficiency of the regression due to an increased number of parameters that need to be estimated.

Description of Data Used and Expected Results

Prices

Historically, most of what is known about producer responses to price changes comes from empirically estimated supply functions with prices rather than quantities on the right-hand side. Sources of data on price of inputs for the poultry industry for a large group of countries are scarce. Using Peterson's (1997) rationale stated earlier, the annual price of meat relative to the annual price of corn is used to measure a farmer's actual behavior with respect to changes in prices. It is expected that this ratio will be positively correlated to the response of poultry to changes in price. Although few commodities have a close price elasticity of substitution with poultry, swine is the closest livestock product. The ratio of the price of pig meat to the price of corn is used to capture the effect of competing products on the response of poultry. It is expected that this proxy will be negatively correlated with poultry response.

Technology

Access to improved technology may affect the poultry response. One of the most important technological changes that occurred in the poultry industry is embodied in breeding stock coming from the United States and parts of Europe. The data on imported genetic material entering countries for a long time period is scant, coming in a variety of forms that have changed over the years. We use two measures to capture the transfer of breeding technology. The first measure is for a short time period (1986–1997), from which we have a direct measure of the use of improved breeding technology from multinational companies. These data come from estimates provided by a broiler multinational company of placements of improved breeding stock by multinationals versus local breeding stock. Given that some countries still use a large number of local breeds, the percentage of improved birds used within a country is used as a direct measure of technology transfer. It is expected that this variable will have a positive and significant effect on the response of poultry. The results of the use of this variable are compared with that of the second variable, which is hatching eggs, and used to capture the effect of the transfer of genetic material used in hatcheries. The use of these data is appropriate because most “modern” operations rely on day-old chicks coming from hatcheries and use imported stock with different male and female lines that they cross themselves to suit the taste of local consumers. Given that annual metric tons of hatching eggs is the only measurement available, metric tons of hatching eggs per cumulative broiler and layer stock is used to capture the productivity-enhancing effects of improved technology and local adaptations to that technology. It is expected that this variable will have a positive and significant effect on the response of poultry.

Research

Research is another important factor that may affect the poultry response, enabling either more measured output to be produced with the same inputs or the same amount of output to be produced with a smaller quantity of measured inputs. Because much research is basic in nature, it is difficult to quantify the benefits arising from such research. Boyce and Evenson (1975) were among the first to develop a proxy for public sector research in their initial work on agricultural research programs, representing the “state of the art” or “stock of knowledge available” based on a series of investments. They did this because of the considerable lags between investment in research and the generation of usable technologies.

Drawing from Boyce and Evenson (1975) this study uses the number of poultry-related publications to measure public research (output) in terms of the actual number of poultry research publications abstracted in the CAB International abstracts in a specific country in a specific year. This has the advantage that publications are screened worldwide and meet international levels of research quality. The problem with this is that the incentives to publish in many less-developed countries are probably smaller than in more-developed countries (Echeverria 1991). To account for the lag between research and the poultry response, two measures are used. The first uses the direct effect of the number of research

articles on supply. The second uses a one-hoss shay approach to take into account the cumulative effect of research over a ten-year period (Peterson 1997). It is expected that this variable will have a positive and significant effect on the response of poultry.

Much of poultry breeding research is done by the private sector enterprises located in a few developed countries as seen in Table 4. Data on breeding research carried out by the private sector is particularly difficult to obtain because of the private sector reluctance to divulge proprietary information. The measure used here is the number of research stations of the major multinational companies dealing with poultry breeding in each country and multiplied by the number of years the stations had been in operation. This data was obtained through a survey conducted by Narrod and Fuglie (2000). This method is similar to the method used by Echeverria (1991) in his study of maize research and seed trade. This variable is used to capture the local effort of multinational corporations involved in poultry-breeding research, but it underestimates total private research in countries where there are smaller private research programs than top multinational breeding companies. It is expected that this variable will have a positive and significant effect on the response of poultry.

It is recognized that the private sector tends to focus its research efforts in areas where it can appropriate the benefits of such efforts. As noted by Fuglie et al. (2000), private incentives for animal research are strongest where markets for improved technology are large, where technical advances can be made relatively easily and quickly, and where intellectual property can be protected. Further private animal research and development tends to concentrate on projects that are likely to result in market applications in the near future.

Institutions

Changes in institutional support such as political environments that allow access to improved technology, patent protection, and animal health provision may create incentives for private investment in a specific country. Today, only a few companies are involved in the breeding effort. These companies do research in only a few countries and transfer the results of that effort to various countries through franchises. These franchises sell improved breeding stock to local customers and often provide technical assistance to aid their customers in obtaining the best productivity possible. We use the number of companies having franchises in a country for a particular year, obtained from the Narrod and Fuglie (2000) survey described above and updated for this paper from company reports, as an indicator of how receptive a country is toward imported technology and how comfortable a company is in establishing such a franchise. We expect this to have a positive and significant effect on the response of poultry.

Access to grandparent stock, which enables a country to set up its own breeding program, also plays an important role in terms of achieving the benefits of new technology domestically. Countries that only have access to parent stock are unlikely to do adaptive research on their own. Although liberalization has occurred for many countries, many multinationals have chosen only to provide parent stock, which would only allow for the development of hybrid birds. In part this is because many multinationals who desire to keep the trade secret in-house and who have found the environment in which intellectual property remain weak are reluctant to sell grandparent stock. We expect access to grandparent stock to have a positive effect on productivity.

Patent protection has been considered a major incentive for innovation, providing an inventor with monopoly control on an invention for the period of time of the patent. Evenson and Putman (1990) were among the first to show the importance of patent protection for certain types of agriculture by using dummy variables to denote the existence of patent protection. More recently, Ginarte and Park (1997) and Park and Wagh (2002) developed an index that analyzes the characteristics of countries that have high levels of intellectual property protection. This index relates measures of economic development, research and development activities, human capital, and political and economic freedom. They found the index to vary most significantly with the level of market freedom in a country and with the relative size of a country's research sector. Because much of the breeding technology in the poultry industry is protected through trade secrets, the need for a patent is not as important as it may be for other types of agricultural

technologies (Bugos 1991). This index is thus used to provide an indication of whether an intellectual property rights regime within a country affects technology transfer in the poultry industry. It is expected that this variable will be significant on the response of poultry.

The provision of livestock services is a factor enabling transferred technologies to reach their full potential (Umali, Feder, and de Haan 1992). If this is true for the poultry industry, it is likely that increases in the number of veterinarians per total population available to producers will result in higher productivity due to reduced losses associated with disease. Veterinary services include curative and preventive care as well as the provision of pharmaceuticals including vaccines and extensionlike services. This is a very important factor in poultry production due to the short life span of poultry (6 to 10 weeks for broilers and 2 to 4 years for layers). It is possible that as the size of poultry operations increases the number of veterinarians and auxiliary health personnel within a country will affect the response of poultry by altering the potential for the reduction of disease and the potential for improved technology (hybrid breeds in this case). In this study, the number of veterinarians is used to estimate the role that provision of livestock service has on the response of poultry. It is expected that this variable will have a positive and significant effect on the response of poultry.

Results and Discussion

Results are presented in Table 9. Due to limitations in the data, the number of years included in the runs differs depending on the variables included in the model. In each case, the dependent variable is the kilograms of broiler meat per bird. Each independent variable except for the grandparent versus parent stock, which is a dummy variable, is expressed in logarithmic form. Country and time dummies are estimated but not presented.

Table 9. Broiler response results

	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6	Spec. 7
Intercept	9.41 (115.84)	9.47 (77.37)	9.26 (89.81)	9.08 (97.45)	9.33 (122.86)	9.46 (83.37)	9.42 (59.85)
Price of broiler meat to price of corn	-0.01 (-0.92)	0.03 (1.14)	-0.02 (-1.02)	-0.05 (-2.60)	-0.05 (-2.43)	0.003 (0.12)	0.001 (0.05)
Price of pig meat to price of corn	-0.02 (-4.59)	-0.02 (-2.98)	-0.02 (-4.66)	-0.03 (-6.46)	-0.02 (-5.92)	-0.02 (-3.27)	-0.02 (-3.27)
No. foreign breeds	0.04 (3.52)		0.05 (3.77)	0.06 (4.53)	0.05 (3.60)	0.11 (5.29)	0.11 (5.24)
Ratio of improved stock to local stock		0.05 (7.21)					
Veterinarians per broiler and layer stock	0.02 (1.62)	0.10 (7.75)	0.01 (1.30)	-0.05 (-4.07)	-0.04 (-3.07)	0.07 (5.06)	0.07 (5.14)
Public research (annual number of publications)	0.05 (4.57)	0.04 (2.32)			0.06 (4.83)	0.03 (1.89)	
Public research (10-year one-hoss shay lagged approach)			0.05 (4.80)	0.08 (6.62)			0.03 (1.46)
Private breeding research	0.004 (1.75)	0.004 (1.15)	0.003 (1.52)	0.008 (3.29)	0.009 (3.80)	-0.002 (-0.77)	-0.002 (-0.61)
Franchises	0.007 (1.44)	-0.01 (-0.72)	0.006 (1.37)	0.0002 (0.06)	0.0001 (0.03)	0.009 (0.63)	0.009 (0.60)
Patent index	0.06 (6.58)	0.07 (4.33)	0.06 (6.58)	0.05 (5.51)	0.05 (5.29)	0.09 (5.63)	0.09 (5.58)
Grandparent vs. parent stock	0.08 (4.67)	0.10 (3.85)	0.08 (4.44)	0.07 (3.37)	0.08 (3.81)	0.08 (3.50)	0.08 (3.50)
R-sq	0.34	0.47	0.33	0.50	0.46	0.40	0.40
no. countries	24	24	24	24	24	24	24
no. years	33	13	33	16	16	17	17
				1961–85	1961–85	1986–2005	1986–2005

Note: t-statistics in parentheses; time dummies are not reported. All variables but the grandparent versus parent stock, which is a dummy variable, are logged.

Two different variables are used to capture the transfer of improved breeding stock. The number of hatching eggs from hatcheries is used in all specifications except specification 2. For this variable, data are available from 1961 to 2005, and 33 years are used in specification 1. The ratio of improved stock to local stock is used in specification 2 to capture the effect of the direct impact of transferred technology by foreign multinationals. Data are only available from 1988 on; thus a shorter time series including only 13 years is analyzed. In addition in order to compare the significance of the various factors being considered in the earlier years when the industry was first forming to later years when it was more established, the analysis also compared the period 1970–1985 with 1985–2001 in specifications 4–7.

Two different variables are also used to capture the effect of public sector research. In specifications 1, 2, 5, and 6 of the model, the direct number of research publications for the specific year is used to capture the effect of public sector research. Specifications 3, 4 and 7 of the model lag the effect of research using a one-hoss shay 10-year lagged research approach. In all models looked at, the R² was low (50 percent) and below.

The signs of the price variables were as expected in some but not all specifications, and significant, supporting our hypothesis. The coefficient of the ratio of price of broiler meat to price of corn was positive but not significant in some cases. However, in cases where data was grouped by period, results from earlier years (1961–1985) was negative and significant. This was expected, as we would assume that when the price of corn goes up, farmers start to conserve on inputs. This would result in a change of productivity, with some bit of a lag, which is likely the reason that this coefficient was not significant in the later period. The coefficient of the ratio of price of pig meat to price of corn was negative and significant in all of specifications of the models. Given that pig meat is a close substitute for poultry meat, this was expected.

In terms of factors capturing private sector activities, we expected that both technology variables capturing improved breeds would be positive and significant for all regressions. Both measures of improved breeding stock consistently had positive and significant impact on broiler yield in most specifications of the model, supporting our hypothesis. The number of franchises and the length of time they were in a country had a positive but not significant effect on yield. If it was significant, it would suggest the positive spillover effects such as biological and management technology associated with the multinationally owned franchises.

The sign of the private sector research variable was positive and significant during the earlier years (1961–1985). This is not surprising because it is likely that the private research may have been important in a few countries at this time. At this same time the importance of technology transfer was less important because there were lots of barriers in terms of transfer of inputs. Similarly, it was not surprising that after 1985 to 2005, this variable turned out negative although not significant. The reason it is not surprising is that it is likely that as the market improves, the importance of private breeding in a country declines. What the specifications of the various models show is that the importance of foreign breeds goes up if we compare specifications 4 and 5 with 6 and 7 in terms of size of coefficient, indicating that access to private sector research in a specific location is no longer important. The public sector research variable was positive and significant in all specifications using both measures of public sector research for the long-time series. Using the shorter-time series, which included only from 1988 onward, the public sector research showed a positive and significant effect, which indicates that there were benefits from public adaptive research at the national level.

The patent protection index was positive and highly significant in all specifications of the model. Since the most important products for poultry that patents would protect are pharmaceuticals, this might indicate that countries would get more access to the latest veterinary pharmaceuticals if they have strong patents. Pharmaceutical firms would be willing to either export to the country or produce them locally with stronger intellectual property rights. As the patent-protection index captures the general business stability of a country, it may also reflect the willingness of multinational companies to establish franchises in other countries.

We expect that variables measuring public sector technical assistance would have a positive effect on yield. The veterinarian variable was positive and significant in some specifications of the models

as hypothesized. It is likely that the positive effect of the number of veterinarians indicates the importance of the provision of technical assistance and disease control in confined environments, particularly after 1986. These findings suggest that countries that are in the process of trying to improve their poultry productivity may also want to increase their number of veterinarians. However, when data was limited to earlier years (1961–1985), the sign turned negative, possibly because there was a limited number of veterinarians to have an effect on animal disease control.

10. CONCLUSIONS

The objective of this paper was to examine the importance of various factors on poultry productivity and to determine what role the private sector played in the transfer of technology developed by its own research and development activities to developing countries. The most important inputs into poultry productivity are breeding stock, feed, and medicines. Some of these are relatively easy to transfer, such as breeding stock and medicines, but others are difficult, and the comparative advantage of one country over another depends on its ability to provide such inputs. We found that modern imported inputs such as foreign breeds of broilers and grandparent stock were very important when we looked at productivity over 33 years. We also found that though private poultry breeding was important in earlier periods, franchises were not necessarily significant. Poultry inputs supplied by public sector poultry research were very significant and positive. Surprisingly, the number of veterinarians in a country was somewhat important, which was not what was originally thought. Policies such as trade that allow imports of foreign breeds and intellectual property also seem to have important implications.

The policy recommendations based on these findings are that governments should remove policies that limit the transfer of technology. Further, governments should implement policies that ensure that intellectual property rights are maintained. Lastly, governments should continue to support local poultry research to increase poultry productivity.

REFERENCES

- Aho, P. 2003. Consolidation. *Arbor Acres Broiler Economics Bulletin*. Vol. XI, No 5.
- Alston, J., G. Norton, P. Pardey. 1995. *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting*. Ithaca, NY: Cornell University Press.
- Boyce, J., R. Evenson. 1975. *National and International Agricultural Research and Extension Programs*. New York: Agricultural Development Council.
- Bredahl, M., W. Peterson. 1976. The productivity and allocation of research: US agricultural experiment stations. *American Journal of Agricultural Economics* 58:684–692.
- Bugos, G. 1991. Intellectual property protection in the American chicken-breeding industry. *Business History Review* 66 (Spring): 127–168.
- CAB International, Abstract database 1972–2004.
- Costales, A.C., C. Delgado, L. Lapar, M. Tiongco, S. Ehui, A. Bautista. 2007. Scale and access issues affecting smallholder hog producers in an expanding peri-urban market: Southern Luzon, Philippines. IFPRI Research Report No. 151. Washington, D.C.: IFPRI.
- Costales, A., C. Delgado, M. Catelo, M. Tiongco, A. Chatterjee, A. delos Reyes, and C. Narrod. 2003. Policy, Technical, and Environmental Determinants and Implications of the Scaling-Up of Broiler and Swine Production in the Philippines. – Annex I, Final Report of IFPRI-LEAD-FAO Livestock Industrialization Project: Phase II. Submitted to the Food and Agricultural Organization.
- Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, C. Courbois. 1999. *Livestock to 2020: The next food revolution*. Food Agriculture and Environment Discussion Paper 28. Washington, D.C.: IFPRI.
- Delgado, C. L. 2003. Rising consumption of meat and milk in developing countries has created a new food revolution. *Journal of Nutrition* 133 (11), Supplement 2 on Animal Source Foods: 3907S–3910S.
- Delgado, C., C. Narrod. 2002. Impact of the changing market forces and policies on structural change in the livestock industries of selected fast-growing developing countries. Final Research Report of Phase I submitted to the Food and Agriculture Organization of the United Nations by the International Food Policy Research Institute. June 28, 2002.
- Delgado, C., C. Narrod, M. Tiongco. 2008. Determinants and implications of the growing scale of livestock farms in four fast-growing developing countries. IFPRI Research Report No. 157. Washington, D. C.: IFPRI.
- Delgado, C., C. Narrod, and M. Tiongco. 2003. “Policy, Technical, and Environmental Determinants and Implications of the Scaling-Up of Livestock Production in Four Fast-Growing Developing Countries: A Synthesis.” Final Research Report of Phase II Project on Livestock Industrialization, Trade and Social-Health-Environment Impacts in Developing Countries Submitted to the Food and Agricultural Organization, 2003.
- Echeverria, R. 1991. Impact of research and seed trade on maize productivity. In Pardey, Roseboom, and Anderson (eds.) *Agricultural research policy: International quantitative perspectives*. Cambridge: Cambridge University Press.
- Evans, T. 2003. Personal communication. Head of Animal Health, Wood and Mackenzie Limited. Edinburgh, UK.
- Evenson, R., J. Putman. 1990. Intellectual property management. In G. J. Persley (ed.) *Agricultural biotechnology: Opportunities for international development*. 332–366. Wallingford: CAB International.
- Food and Agricultural Organization Statistical Yearbooks. 1961–2005.
- Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee. 1996. *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions*. Agricultural Economic Report 735. Washington, DC: Economic Research Service, U.S. Department of Agriculture.

- Fuglie, K., C. Narrod, C. Neumeyer. 2000. Public and private investment in animal research. In *Public-private collaboration in agricultural research: New institutional arrangements and economic implications*. Ames: Iowa State University Press.
- Ginarte, J., W. Park. 1997. Determinants of patent rights: A cross-national study. *Research Policy*, Vol. 26, 283–301.
- Griliches, Z. 1957. Hybrid corn: An exploration in the economics of technological change. *Econometrica* 25 (4), 501.
- James, C. 1997. Progressing public-private sector partnerships in international agricultural research and development. ISAAA Brief 4. International Service for the Acquisition of Agribiotech Applications. Ithaca, NY: Cornell University.
- Johnson, N., V.W. Ruttan. 1997. The diffusion of livestock breeding technology in the U.S.: Observations on the relationship between technical change and industry structure. *Journal of Agribusiness* 15 (Spring):19–35.
- Havenstein, G. 1998. Mid-Atlantic poultry consortium: A department head's viewpoint on regionalization. *Poultry Science* 77: 201–207.
- Henry, R., G. Rothwell. 1995. *The world poultry industry*. International Finance Corporation Global Agribusiness Series. Washington, D.C.: World Bank.
- Narrod, C. 1997. *Technology transfer in the poultry industry: An examination of supply factors and externalities associated with increased production*. Ph.D. Dissertation. Philadelphia: University of Pennsylvania.
- Narrod, C., K. Fuglie. 2000. Private-sector investment in livestock breeding. *Agribusiness: An International Journal* 4 (6) 457–470.
- Narrod, C. C. Pray. 1995. *Technology transfer in the poultry industry: Factors and externalities associated with increased production*. In K. Steele (ed.) *Animal wastes and the land-water interface*. Boca Raton: CRC Press.
- Narrod, C., C. Pray. 2001. *Technology transfer, policies, and the global livestock revolution*. In *Proceedings of the International Agricultural Trade Research Consortium Symposium on Trade in Livestock Products*. Auckland, New Zealand.
- Narrod, C., M. Tiongco, A. Costales. 2008. "Global Poultry Sector Trends and External Drivers for Structural Change." *FAO proceedings on "Poultry in the 21st Century,"* http://www.fao.org/AG/againfo/home/events/bangkok2007/docs/part1/1_1.pdf
- Narrod, C., M. Tiongco, C. Delgado. 2008 *Socio-Economic Implications of the Livestock Industrialization Process: How will Smallholders Fare? To be published in 2009*. in "Livestock in a Changing Landscape." .
- Norton, G., J. Ortiz. 1991. *Reaping returns to research*. Staff Paper 91-6. Blacksburg, VA: Department of Agricultural Economics, Virginia Polytechnical Institute and State University.
- Norton, G. 1981. "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations Revisited." *North Central Journal of Agricultural Economics* 3 (January): 1-12.
- Peterson, W. 1997. *Production function and supply analysis*. St. Paul: University of Minnesota.
- Peterson, W. 1966. *Returns to poultry research in the United States*. Ph.D. Dissertation. Chicago: University of Chicago.
- Park, W., S. Wagh. 2002. *Index of Patent Rights in Economic Freedom of the World 2002 Annual Report*.
- Poapongsakorn N., V. NaRanong, C. Delgado, C. Narrod, P. Siriprapanukul, N. Srianant, P. Goolchai, et al. 2003. Policy, technical, and environmental determinants and implications of the scaling-up of swine, broiler, layer and milk production in Thailand. Annex IV, Final Report of IFPRI-FAO Livestock Industrialization Project: Phase II. Washington, D. C.: IFPRI.
- Pray, C. 1981. The Green Revolution as a case study in transfer of technology. *The Annals of the American Political and Social Science* 548: 68-80.

- Pray, C. and K. Fuglie. 2000. "The Private Sector and International Transfer of Agricultural Technology," in Public-Private Collaboration in Agricultural Research (K. Fuglie and D. Schimmelpfennig, eds.). Ames: Iowa State University Press.
- Schultz, T. 1958. Reflection on agricultural production, output and supply. *Journal of Farm Economics* Vol. 38 (3) 748–762.
- Seré, C. & Steinfeld, H. 1996. World livestock production systems: current status, issues and trends. *Animal production and health paper* No. 127. Rome, FAO. 82 pp.
- Smith, B., G. Norton, J. Havlicek Jr. 1983. Impacts of public research expenditures on agricultural value-added in the US and the Northeast. *Journal of the Northeastern Agricultural Economic Council* 12 (fall): 109–114.
- Tiongco, M., C. Narrod, C. Delgado. 2006. Equitable intensification of market-oriented smallholder dairy and poultry production in India through contract farming: A synthesis. Final Report of IFPRI–FAO Contract Farming of Milk and Poultry in India Project. Washington, D. C.: IFPRI.
- Umali, D., G. Feder, C. de Haan. 1992. The balance between public and private sector activities in the delivery of livestock services. *World Bank Discussion Papers* #163. Washington, D.C.: World Bank.
- Wood Mackenzie Ltd. 2005. Animal Health Industry 2005 Report prepared for International Federation of Animal Health. www.ifahsec.org/annual_report/RA_IFAH_2005_global%20final.pdf.
- Zentner, R., W. Peterson. 1984. An economic evaluation of public wheat research and extension expenditures in Canada. *Canadian Journal of Agricultural Economics* 32(2) 327–353.

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