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TECHNOLOGY, POLICIES, AND THE ROLE OF THE PRIVATE SECTOR IN THE GLOBAL POULTRY REVOLUTION[1]

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TRADE IN LIVESTOCK PRODUCTS

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Abstract:

With the Biotech Revolution questions are already being asked about what role the government should play in the process - does public research in developing countries have a role to play? Is public international research needed? Can governments speed the spread of technology by offering complementary services? Unlike the Green Revolution, the "Poultry Revolution," was based on biological technology developed by the private sector and spread by the private sector. The ease of poultry technology transfer between countries and the ability of producers of key inputs to prevent copying through physical means induced private firms to spread this technology throughout the world. This paper attempts to measure the importance of different types of private technology and of public investments on poultry productivity. The findings are important because they confirm that imported private technology was important to the growth of private research but also emphasize the importance of complementary government investments such as veterinary services, which are provided by the public sector in many countries. The policy implications are that the barriers to technology imports could slow productivity growth and neglecting public investments in veterinary services also could slow growth.

Key words: Private sector research, technology transfer, and Poultry Revolution

LIVESTOCK REVOLUTION

Over the last three decades there has been rapid growth in livestock production. Table 1 shows that growth in livestock production in both developed and developing countries has been led by poultry. The consensus of economists is that the growth in livestock production was induced by increased demand, which was driven by increasing populations and rising per capita incomes (Delgado et al. 1999). The income elasticity of demand for poultry in developing countries is far lower than those of milk or other meats (see last column in Table 1). If demand were the only factor poultry production would have grown much slower than other meats and milk. The fact poultry production grew fastest suggests that there must have been other important factors that shifted out the supply of poultry more rapidly than the supply of other meats and milk.

Insert table 1 here.

We believe that increased productivity is the major factor responsible for the expansion of poultry production in LDCs. The purpose of this study is to try identifying the factors and the government policies that led to this productivity growth. Unlike the Green Revolution, the "Poultry Revolution," was based on biological technology – new poultry breeds – which appear to have been developed primarily by the private sector and spread by the private sector. 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.

To get access to improved poultry breeds and the complementary inputs needed for high productivity, countries either had to develop their breeds through public and/or private breeding or import improved breeds. To get access to feed, medicines, and buildings; countries had to start producing their own or import them. The second purpose of this paper is to identify the importance public investments and policies that can stimulate poultry productivity growth.

TECHNOLOGY CHANGE IN THE POULTRY INDUSTRY

Technology change has been very rapid in the poultry industry. The move to confined poultry operations dramatically increased what one farmer could manage which facilitated 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, better control animal disease and decrease mortality. In management, 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-scaled operations where poultry farmers were able 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 least cost.

These new technologies enabled the substitution of capital for labor to increase output per unit of labor. These new technologies also led to increase in animal productivity as seen in improved feed conversion in meat products. Table 2 shows two partial productivity measures in the US that indicates this productivity increase. Henry and Rothwell (1995) in their study of the World Poultry Industry show similar changes in poultry partial productivity measures worldwide.

Insert table 2 here.

RESEARCH SUPPORTING THE POULTRY REVOLUTION

Both public and private research has supported this revolution. Major advances have occurred in the past decade in applying the tools of quantitative and molecular genetics to enhance animal productivity. Over the past several decades a few multinational companies have emerged that specialize in poultry breeding. Most of the poultry genetics research for these companies is done at headquarters that are primarily located in the US and Europe. However, they sell improved breeds to other countries through franchises. Through these franchises the benefits from these multinational research companies can spillover to other countries since poultry technology developed for confinement systems in the US and Europe work will in confinement facilities elsewhere.

Fuglie, Narrod, and Neumeyer (2000) looked at both public and private sector breeding research for individual livestock commodities in the US. Their study indicated a declining role of the public sector in poultry research and an increasing role by the private sector. They argued that private incentives for animal research are strongest where markets for improved technology are large, technical advances can be made relatively easily and quickly, and where intellectual property can be protected. Thus, they argue that the relatively short gestation and fecundity cycle of poultry makes it an attractive research investment for the private sector because research gains can be made rapidly.[2] In poultry most the research effort is in quantitative genetics compared to other livestock commodities (see table 3). However the research intensity (research per sales) is much higher for poultry than other livestock commodities.

Insert table 3 here.

As with other types of investment, the ability of the private company to sustain sales of the technology is an important incentive for private research. 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.[3] Poultry breeders more so than other livestock

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[2] The biological cycle for poultry is 5 months from the time an egg is fertilized until the hatched chick is old enough for breeding. Moreover, chicks retained for the breeding flock comprises only a small proportion of the total production flock. Swine require less than 12 months (from the time a sow is bred and farrowed) to reach breeding age. Fecundity in swine has been increasing: most sows are currently farrowed at least twice a year and produce nearly nine pigs per litter. With cattle, however, the production cycle is considerably longer. Each cow can produce one offspring per year and it takes about 24 months from the time is cow is bred for her calf to reach breeding age (Fuglie, Narrod, and Neumeyer, 2000)

[3] Copiers can afford to sell the technology more cheaply than the original inventor does because they do not have to

commodities have successful 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. Farmers need to repeatedly purchase new stock from the breeder to maintain high yields.

Research in other areas such as animal health products, feed, and machinery also has affected poultry productivity. The demand for animal health products has increased markedly in recent years because of the growth in global animal production and in confined animal production systems, especially for poultry and swine as seen in figure A. The dense animal populations produced in large, confined systems intensify disease problems, especially the risk of epidemics among herds and flock. Veterinary pharmaceuticals and medicated feeds are widely used to help control the incidence and spread of animal diseases in these systems particularly in the poultry industry. Many producers also use biosecurity measures to control the introduction of disease, however the effectiveness of these measures in all countries, particularly those with larger numbers of small-scale producers is questionable.

Insert figure A here.

Fuglie, Narrod and Neumeyer (2000) estimated investment in other areas of livestock research in the United States (see table 4). They estimated that the private sector spent about $473 million for research on animal commodities in 1996, compared with $667 million by public agricultural research institutions. They found that while private-sector animal breeding expenditures were less than public-sector breeding expenditures, the private sector was a major investor in basic poultry research.[4] They also found that both the public and the private sector were about equally involved in animal health and protection and feed, nutrition and maintenance research and development in terms of dollar amounts. However in the area of supporting research for new machinery for animal production, which is relatively easy to protect through patenting, research was conducted almost entirely in the private sector. Research on animal economics and production externalities (pollution control and food safety) were primarily public-sector responsibilities because the private sector finds it difficult to appropriate research benefits in these areas.

Insert table 4 here.

TECHNOLOGY TRANSFER IN THE POULTRY INDSUTRY

Countries can obtain benefits of technology developed in another country through the transfer

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recoup the initial sunk costs of research and development.

[4] They suggest that the willingness of the private sector to make investments in basic poultry research may be due to high degree of market concentration and vertical coordination in these industries, which reduce technology spillovers.

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 needs. For instance, the Green Revolution was successful in transferring a technology package consisting of high-yielding varieties of wheat and rice from temperate countries to countries of South and South-east 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 (US) or Europe, raised in containment facilities, and fed a compound feed containing feed 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). Table 5 shows the private-sector poultry breeding programs and where the franchises are located of the top 7 poultry breeding companies. As can be seen most of the breeding research programs are in North America and Europe, while franchises are located through out the world.

Insert table 5 here.

Another technology associated with the poultry revolution is the use of improved animal health products and feed additives. Today most animal health companies are parts of divisions of large international pharmaceutical companies and have exclusive rights to sell the products they develop until patents expire.[5] 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 remainder 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 was $324 million in 1996 (PhRMA, 1997). Globally, the market for animal health products was estimated to be $14,370 million in 1995 with veterinary pharmaceuticals represented slightly under one-half this market, and nutritional feed additives accounted for around one-third (Wood Mackenzie 1997 in James 1997). Of these sales, by commodity, poultry had the most sales in feed additives, but sales of poultry pharmaceuticals were relatively small (see table 6).[6]

Insert table 6 here.

With increasing globalization, demand, and access to new improved technologies more and more producers are altering their production practices. Henry and Rothwell (1995) suggest that the

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[5] In 1995, the ten largest animal health companies in terms of sales were Hoffmann-La Roche ($1,440 million), Rhône-Poulenc ($1,357 million), Pfizer ($1,250 million), Merck ($792 million), Bayer ($754 million), Novartis ($743 million), BASF ($738 million), Hoechst ($512 million), Eli Lilly ($512 million), and Mallinckrodt ($459 million) (Wood Mackenzie 1997 in James 1997).

[6] Pharmaceuticals are more important for cattle and household pets because the animals live longer and rely more heavily on curatives than on the preventatives provided in feed.

ability of developing countries to compete with more developed countries seems now to be determined by that country's ability to adopt the best practices and technologies already established in the industry. It is unclear whether local research is an important factor responsible for poultry growth in developing countries, if they have ready access to trade and improved inputs on the open market or through franchises and sale by multinationals.

TRADE 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 interfering with trade of inputs. These can loosely be grouped in the following sets of government policies: (a) science and technology policies such as the public funding of research, intellectual property rights, and the government supply of modern inputs and veterinary service; (b) price, trade and industrial policies such as protection of infant industries, export led growth strategies, anti-trust legislation, controls on foreign direct investment, controls on animal health and food safety, and price supports on poultry meat or on inputs into production; and (c) environmental policies such as licensing policies which restrict locations where certain amounts of pollution may be discharged, clean water and air legislation, regulation on disposal of poultry by-products, and improvements of markets for poultry by-products. The specific types of policies are listed in table 7.

Insert table 7 here.

These policies may affect the development of a country's agricultural industry by stifling technological progress and limiting farmers' access to modern inputs. 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.

PREVIOUS STUDIES OF TECHNOLOGY CHANGE

It is difficult to trace and quantify econometrically the impact of technology change or other factors, which affected the rate of technology transfer on agricultural sectors. Schultz (1958) was the first attempt to quantify the benefits of agriculture 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 US. Griliches (1957) study on the economic returns of hybrid corn research in the US 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 technical 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 US. It found that there were high returns from such public sector investments. Subsequent studies on the poultry industry by Bredahl and Peterson (1976), Smith, Norton, and Havlicek (1983), and Norton and Ortiz (1991) also indicated high rates of return on poultry research in the US varying from 21 to 61 percent. We are aware of no studies that looked at 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 has been the lack of both time series and cross-sectional data on prices and similar data on specific technologies. This study uses price data obtained from FAO and data on the transfer of breeding stock obtained from a survey of the private sector conducted by Narrod and Fuglie (2000).

MODEL OF DETERMINANTS OF TECHNOLOGY CHANGE IN POULTRY

To observe the response of poultry to access to new technologies, public and private research, intellectual property, and to 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:

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

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, other exogenous shifters of interest Z, and uncontrollable variables μ.

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. Given the scarcity of data on poultry, we chose to use this method to estimate factors affecting the response of poultry to similar factors of interest. In this paper the poultry response is defined 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 of interest on poultry yield in developed and developing countries.

Description of the Model

This poultry response function is given as:

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

i = {25 countries index}
j = (price of broiler meat to price of corn, price of pig meat to corn}
k= {public research, private research}
l = {improved breeds, percentage of improved breeding stock, compound feed consumption}
m = {veterinarians, patent index, # of franchises}
t = {time index}

where:

Q_{it} = poultry yield
P_{it} = vector of input and output prices 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 unobserved country specific effects, $\mu_{it} \sim i.i.d.(0, \sigma^2)$
$\alpha_{jit} = \alpha_j$ = 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 equation (2) are indexed by *i* and the time periods *t* index the years from 1961 to 1996. A generalized least-squares estimation procedure is then applied to the pooled time series and cross sectional data to estimate the response function. Logarithms of all variables except the patent index were used. An error term, μ_{it} is added to represent 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. The variables, units of measurement, sources of data, and dates of data are listed in table 8. Data have been collected for the twenty-six countries listed in table 9 covering the period 1961-1996.

Insert table 8 and 9 here.

Description of data used

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 prices of inputs for the poultry industry for a large group of countries are scarce. Peterson (1997) suggests the output/input price ratio is acceptable to use where data are scarce. First, the ratio tends to reflect the full costs of inputs and the net price of output after transportation costs reflecting how farmers react under prevailing conditions. This is important because though the market prices of inputs often fail to include 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 capture what farmers believe will be the average level of prices in the future.

Using Peterson's (1997) rationale, the price of meat relative to the price of corn and the price of eggs relative to the price of corn are used to measure a farmer's actual behavior with respect to changes in prices. This measure is appropriate in the case of the poultry industry because though under normal circumstances one would base expected prices on some weighted average of past prices, in the case of the poultry industry past prices are in the same year when using annual data.[7] It is expected that this ratio will be positively correlated to the response of poultry to changes in price. Though 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 technical changes that has occurred in the poultry industry is embodied in breeding stock coming from the US 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, which have changed over the years. The quantity of hatching eggs produced in a country is used to capture the effect of the transfer of genetic material used in hatcheries. This data is available for over thirty years. The use of this 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 only annual metric tons of hatching eggs is 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 effect on the response of poultry.

Recognizing that this is not necessarily the "best" measure, an alternative technology transfer variable for which data is only available for a shorter time period (1986-1998) is also used for comparison purposes. This data comes 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 to that of the hatching egg variable for the same years to understand if this affected the response of the poultry.

The increased use of compound feed, containing feed additives and many disease preventing drugs, is another important technology change that has occurred. Much research and development has gone towards designing compound poultry feed to produce the best animal that produces the most meat or eggs in the shortest time period. In addition to being a source of feed, compound feeds also represent a low cost method of providing many disease prevention measures. Further, the use of compound feed was limited in the early emergence of the poultry industry for many countries.[8] Data

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[7] This is because there are approximately six growout periods in one year. Thus prices in the current year, which reflect an average of the prices observed in each growout period, are a better measure of producers' expectations than prices in the previous year because individual producers can change their behavior after each growout period.

[8] Most production was in traditional backyard units that relied on readily available kitchen scraps for feed as opposed

on compound feed for all livestock is available on a national basis.[9] The amount of compound feed used is assumed to be annual amount of compound feed available per population. It is expected that there will be a positive and significant effect of this variable 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 proposes to use the number of poultry-related publications to measure the impact of public research (output) in terms of the number of poultry research publications abstracted in the Veterinary Abstracts and the Breeding Abstracts of CABI 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 negative to 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 delay associated with research on the poultry response two lagged measures are used. The first uses the cumulative affect of the number of research articles the previous ten years. The second uses a one-hoss shay approach to take into account the cumulative effect of research over a ten-year period. It is expected that this variable will have a positive effect on the response of poultry.

Much of poultry research is done by the private sector enterprises located in only a few developed countries as is seen in table 5. Unfortunately, data on 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 underestimates total private research in countries where there are smaller private research programs than the top multinational breeding companies. It is expected that this variable will have a significant effect on the response of poultry.

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to the purchase of prepared feed. However the industry has now expanded with many large-scale operations requiring the use of compound feed imported from outside the operation.

[9] In most developing countries (with exceptions to China and Taiwan), compound feed is used mainly by the poultry industry. It is thus reasonable to assume that the amount of compound feed imported to a country is a good proxy for the amount of compound feed available to the poultry industry. It is recognized that this measure may bias our results by assuming that compound feed is used solely for the poultry industry. This is particularly true for countries with high levels of pork raised in confined production units (e.g., the United States).

Institutions

Changes in institutional support such as political environments, which 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. Though liberalization has occurred for many countries, not all countries allow the importation of just the parent stock, which would only allow for the development of hybrid birds. This is in part because of the multi-national's desire to keep the "trade secret" in-house. 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, as an indicator of how receptive a country is towards imported technology and how comfortable a company is in establishing such a franchise.

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 amongst 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) have developed an index, which analyzes the characteristics of countries, which 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 per se is not so 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 insignificant on the response of poultry with regard to genetics. This variable however may be important with regards to other technologies.

The provision of livestock services are factors 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 extension like 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 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 of the provision of livestock service has on the response of poultry.

Description of estimation of the model

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 in reality 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 also 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.

The poultry response function was then tested against a data set of pooled time series and cross-sectional data for twenty-six developed and developing countries. The time period for the study was either 1965-1996 (when using the moving research variable), 1971 to 1996 (the first ten years were dropped since a 10-year one-hoss shay approach was used to estimated the stock of poultry research), or 1988-1996 (when a technology transfer variable which only had 8 years of observations available was used). It is recognized that a number of observations are lost when the percentage of foreign breeds is used to capture the transfer of new breeding technology, which only has 8 observations. This variable however is a direct measure of the adoption of the technology within a country and can be compared to the longer series which uses the number of hatching eggs that are produced domestically, assuming that these hatching eggs come from hatcheries using improved genetic stock. Thus for comparison purposes two independent variables for capturing improved breeding stock were used. The first captured the amount of improved breeding stock available. The second captures the percentage of improved breeding stock used. Two research variables were also used and compared. The first was a five-year moving research variable, the second used a 10 year lagged approach.

Results

Results are presented in Tables 10-12.[10] In each case the dependent variable is the kilograms of broiler meat per bird. Each independent variable except for the patent index are expressed in logarithmic form. Country and time dummies are estimated but not presented. Table 10 shows the results using the shorter time frame (8 years) and the percent-improved breeding stock as the technology transfer variable and the five-year moving research variable. Table 11 shows the results using both the amount of breeding stock available and the five-year moving research. Table 12 shows the results using both the amount of breeding stock available and the lagged research variable. The R^2 was low (below 52%) for all the models we looked. The interaction effects of either the private research - franchise effect or patent protection - franchise was positive and significant.

Insert table 10, 11, and 12 here.

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[10] Due to limitations in data, the number of years and countries covered by the models varies.

The signs of the price variables were correct in most specifications. The coefficient of the ratio of price of broiler meat to price of corn was positive in all models containing the longer time series, but not significant. The coefficient of the ratio of price of pig meat to price of corn was negative in all of the models and significant. 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 the three technology variables, improved breeds, percentage of foreign breeds used, and compound feed, would be positive and significant for all regressions. Both measures of improved breeding stock consistently had positive and significant impact on broiler yield. This supports our hypothesis. The third technology transfer variable, compound feed was positively correlated but insignificant in all specifications of the longer time series models. It was expected that this would be positive and significant, as compound poultry feed is important in enabling hybrid chicks to reach their genetic growth potential. The specifications of the model, which had a shorter time series, were consistently negatively correlated and insignificant in most specifications of the model. It is possible, given that this variable is measuring the direct transfer of technology, that firms, using this imported technology are mixing their own feeds rather than relying on imported compound feed. It is also possible that in the earlier years, compound feed was more important, than in recent years in enabling birds to obtain their highest productivity.

The number of franchises and the length of time they were in a country had a positive and significant effect on yield for most specifications of the model that used the longer time series which utilized the amount of improved breeding stock as a measure of technology transfer. This would suggest that biological and management technology is being transferred internationally through franchises also. The number of franchises was not so important in the shorter time frames. Countries desiring to increase their poultry productivity should encourage the establishment of such franchises. It had a negative but insignificant effect on yield for most of the models using the percentage of improved stock. It is unclear as to why this occurred but it is possible that it is an artifact of a shorter time period being considered or the reflecting the importance of it in the early establishment of the industry.

The private sector breeding research variable was positive and significant in most specifications of the model. Given that the private sector is doing most of the applied research in poultry breeding this is not surprising. The public sector research variable however was negative and significant in most specifications using both measures of public sector research. This indicates that there is little benefit from public adaptive research at the national level. Patent protection was positive and 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. Pharmaceuticals firms would be willing either to export to the country or produce them locally with stronger intellectual property rights.

We expect that variables measuring public sector technical assistance would have a positive effect on yield. The number of veterinarians variable was consistently positive in all broiler regressions. 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. These findings suggest that countries that are in the process of trying to improve their poultry productivity may also want to look to increasing their number of veterinarians.

CONCLUSIONS

The objective of this paper was to examine the importance of various factors on poultry productivity. We found that some modern imported inputs such as foreign breeds of broilers and compound feed were very important when we looked at productivity over 26 years. Some of these important factors such as improved broiler feed did not contribute much when only the last 8 years were considered. It is possible that in the recent years that more producers are mixing their own poultry feed to get the best possible nutrient mix and not relying on imported feed as expected. Private poultry breeding research and franchises, which we see as, a measure of the transfer of management technology was consistently important. Their interaction also had a positive effect, as did the interaction of patent protection and franchises. Of the inputs supplied by the public sector, veterinarians did have a consistently positive effect. In contrast public sector poultry research does not have a positive impact. This supports the initial hypothesis that there was very little payoff to public sector research when private technology can be so easily transferred.

Several policy implications can be drawn from these econometric results for countries exhibiting low poultry productivity. Countries that have tariff and non-tariff barriers on foreign breeds, compound feed, and restrict franchising could increase poultry yield by reducing these barriers. Countries that do not have policies promoting the public investment in veterinary services could increase productivity by promoting such investments. Countries that have weak intellectual property might be able to increase poultry productivity by increasing such protection so as to encourage the transfer of technology such as improved veterinary pharmaceuticals. Future analysis will look at the simultaneous effect on yield of modeling the price of pig meat to price of corn and per capita GNP separately in as part of a simultaneous equation.

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Table 1: Production trends and demand elasticities of various livestock products

Region/Product	Annual growth of total production 1982-94	Total Production 1983	Total Production 1994	Expenditure Elasticities 1970-1995 LDCs
	(percent)	(million metric tons)		
Developed				
Beef	0.1*	36	35	
Pork	0.7*	35	37	
Poultry	3.2	19	27	
Meat	1.1	90	100	
Milk	-0.4*	365	348	
Developing				
Beef	3.1	16	22	0.65
Pork	6.1	21	39	1.10
Poultry	7.8	9	21	0.27
Meat	5.4	51	88	
Milk	3.7	113	164	1.36

Source; Delgado Christopher, Mark Rosegrant, Henning Steinfeld,Simeon Ehui, and Claude Courbois. 1999. Livestock to 2020: The Next Food Revolution Tables 8 and 9.

* not statistically different from 0 at the 10% level

Table 2: US livestock 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	5,842	3.07	192
1965	591	1,022	8,304	3.48	218
1975	546	1,167	10,360	3.76	232
1985	680	1,310	12,994	4.21	247
1995	723	1,503	16,451	4.67	253

Beef cattle yield: lbs of beef produced divided by the number of cows and heifers that have calved.
Hog yield: lbs 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 indices for specific commodities are no longer published after 1986.

Source Fuglie, K., et al. “Public and Private Investment in Animal Research,” in *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications*. Iowa State University Press. 2000.

Table 3: Public and private research in animal breeding and genetics, 1996

		Layers	Broilers	Swine	Beef & Dairy	Total
Private sector	Breeding Firms	3	6	11	6	26
	PhD (SY)	9.0	29.25	18.6	16.5	73.35
	MS (SY)	4.0	16.0	14.25	20.0	54.25
	Molecular biology (SY)	4.0	4.5	8.6	5.0	22.1
	Breeding & genetics (SY)	9.0	40.75	24.25	31.5	105.5
	Total (SY)	13.0	45.25	32.85	36.5	127.6
	US Res. Exp. (mill. $)	19.7	81.0	19.1	18.6	138.4
	World Res. Exp. (mill. $)	35.7		29.6	18.6	
Sales (mill $)	US	60	200	850	56	1166
	World	146	780	6700	56*	7082*
Res. Intensity	US	33%	41%	2%	33%	-
	World	26%		0.4%		-
USDA & SAES	Molecular biology (SY)	5.0	6.5	29.1	60.5	101.1
	Breeding & genetics (SY)	3.3	6.9	13.5	72.7	96.4
	Total (SY)	8.3	13.4	42.6	133.2	197.5

Sources: Private sector research from authors' survey. Public sector research derived from USDA's *Current Research Information System.*

Artificial Insemination sale figures are only for the US industry and thus underestimated.

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.* Iowa State University Press. 2000.

Table 4: Summary of public and private investments in animal research in the United States, in millions of dollars 1996

Technology area	Private		Public
Breeding and biological efficiency	138.4		284.0
Health and protection	252.8		
Feed, nutrition and maintenance	48.5	}	310.0
Machinery	33.5		0.7
Management and economics	?		36.0
Externalities (pollution control and food safety)	--		36.0
Total	473.2		666.7

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.* Iowa State University Press. 2000.

Table 5: Private sector poultry breeding research programs and franchises

	Africa / Middle East	Asia / Australia	South America / the 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 PhD. (US)	na
Private R&D in $	na	na	Na	19.7 (US)	Na

Source: Surveys by Narrod and Fuglie 2000 and Pray and Fuglie 1999

Table 6 Global sales of animal health products, 1995

Animal Species	Nutritional Feed Additives	Medicinal Feed Additives	Biologicals	Pharmaceuticals	Total
Cattle	1,025	440	610	2,475	4,550
Pigs	1,100	730	285	1,120	3,235
Sheep	130	95	145	485	855
Poultry	1,065	765	500	240	2,570
Pets/Other	470	60	600	2,030	3,160
Total	3,790	2,090	2,140	6,350	14,370

Figures are for 1995 in millions of U.S. dollars.

Source: Wood Mackenzie cited in James (1997).

Table 7: Policies affecting access to new poultry technologies

Science and technology	Price, trade and industrial	Environmental
Public funding of research	Protection of infant poultry input industries	Licensing policies which restrict location where certain amounts of pollutants are discharged
Intellectual property rights	Export led growth strategy tax incentives for export	Clean water and air legislation
Government supply of modern inputs	Anti-trust legislation	Regulations on disposal of poultry by-products
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	
Provision of Veterinary Services	Price supports on poultry meat or on inputs to production.	

Table 8: Model data

Index	Definition	Source	Notes
Broiler productivity	Kg of broiler meat/'000 broilers	FAO Production	1961-1996
Price ratio for chicken meat	Price of chicken meat /price of corn	FAO Prices Received by Farmers	1961-1996
Price ratio for pig meat	Price of pig meat /price of corn	FAO Prices Received by Farmers	1961-1996
Improved broiler stock	No. of hatching eggs of improved breeds/population	FAO	1961-1996
Foreign breeds	Numbers of chicks of foreign breeds / chicks of all breeds	Narrod and Fuglie, (2000)	1988-1996
Improved broiler feed	MT of Compound Feed/ population	FAO Production	1961-1996
Public 1 research	No. of articles in previous 10 years	CABI(VET and BEASD abstracts)	1971-1996
Public 2 research	Lagged number of research articles	CABI(VET and BEASD abstracts)	1971-1996
Private research	Weighted no. of breeding programs	Narrod and Fuglie, (2000)	1998
Veterinarians per population	Number of veterinarians/ national population	FAO Animal Health	1961-1996
Franchises	Number of companies with franchises in a specific country for a given year	Narrod and Fuglie (2000)	1961-1996
Patent protection	Index	Ginarte and Park (1997)	1995
Grandparent stock vs parent stock	Dummy variable	Interviews with companies	1996

Table 9: Countries used in the model

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

* Dropped when percent using foreign technology used. Data was not available on that variable for Spain.

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

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

Table 10: Broiler response results using shorter time series

	Specification 1	Specification 2	Specification 3	Specification 4
Intercept	9.75 (40.47)	9.56 (40.35)	9.63 (43.83)	9.83 (39.69)
Price of broiler meat to price of corn	0.0032 (0.15)	-0.0056 (-0.25)	0.0016 (0.08)	0.006 (0.80)
Price of pig meat to price of corn	-0.0087 (-2.34)	-0.0057 (-1.56)	-0.011 (-3.29)	-0.009 (-2.57)
Percent Foreign breeds	0.068 (3.27)	0.053 (2.63)	0.078 (4.14)	0.07 (3.15)
Improved broiler feed	-0.047 (-1.11)	0.014 (0.40)	-0.03 (-0.78)	-0.04 (-1.01)
Veterinarians per population	0.063 (2.45)	0.060 (2.26)	0.066 (2.80)	0.06 (2.37)
Public research	-0.022 (-1.69)	-0.014 (-1.09)	-0.027 (-2.27)	-0.02 (-1.75)
Private breeding research	0.013 (3.52)	0.011 (2.97)	-0.017 (-2.50)	0.01 (3.66)
Franchises	-0.033 (-1.08)	-0.011 (-0.38)	0.007 (0.25)	-0.13 (-1.60)
Patent index	0.057 (2.63)		0.07 (3.54)	0.02 (0.66)
Interaction terms				
Private research and franchises			0.27 (4.95)	
Patent protection and franchises				0.03 (1.28)
R-sq	0.40	0.35	0.51	0.40
# countries	24	24	24	24
# years	8	8	8	8

Note: t-statistics in parentheses; Time dummies are not reported.

Table 11: Broiler response results using longer time series

	Spec. 1	Spec. 2	Spec. 3	Spec. 4
Intercept	9.59 (75.66)	9.57 (75.18)	9.54 (74.12)	9.66 (72.60)
Price of broiler meat to price of corn	0.01 (1.06)	0.008 (0.69)	0.009 (0.72)	0.01 (1.13)
Price of pig meat to price of corn	-0.006 (-2.50)	-0.004 (-1.59)	-0.006 (-2.51)	-0.006 (-2.65)
Number Foreign breeds	0.06 (2.49)	0.05 (2.06)	0.06 (2.21)	0.07 (2.62)
Improved broiler feed	0.01 (0.71)	0.03 (1.81)	0.02 (1.21)	0.01 (0.79)
Veterinarians per population	0.07 (7.24)	0.08 (7.58)	0.07 (7.04)	0.07 (7.18)
Public research*	-0.01 (-3.17)	-0.01 (-2.77)	-0.01 (-3.51)	-0.01 (-3.13)
Private breeding research	0.006 (3.74)	0.006 (3.73)	0.00005 (0.01)	0.006 (3.74)
Franchises	0.02 (1.36)	0.02 (1.26)	0.03 (2.04)	-0.05 (-1.16)
Patent index	0.03 (2.69)		0.02 (2.38)	0.002 (0.12)
Interaction terms				
Private research and franchises			0.006 (1.95)	
Patent protection and franchises				0.02 (1.76)
R-sq	0.38	0.37	0.39	0.39
# countries	25	25	25	25
# years	31	31	31	31

Moving research variable.

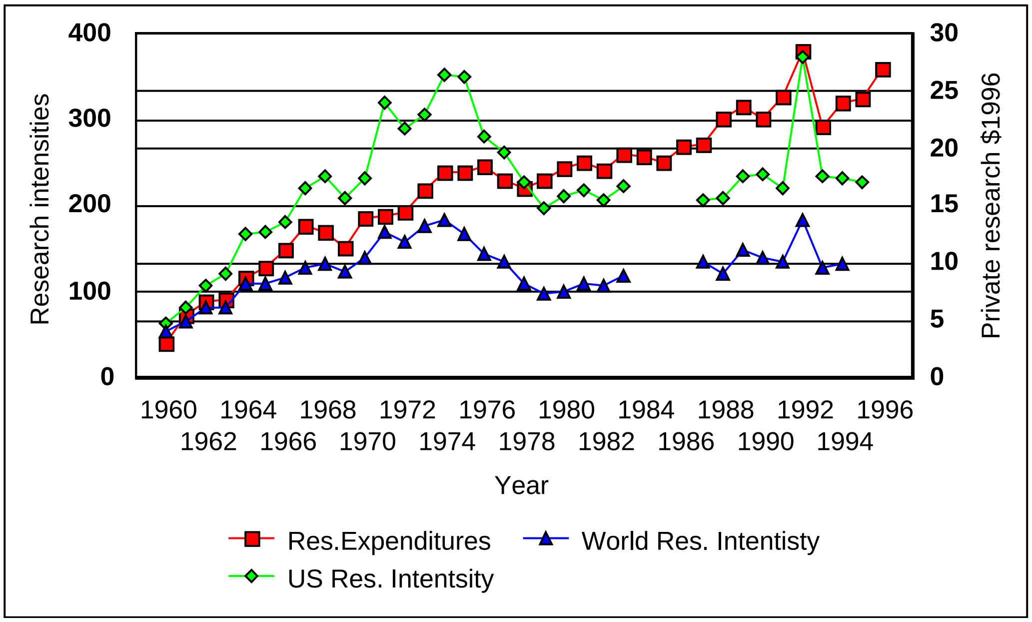
Note: t-statistics in parentheses; Time dummies are not reported.

Table 12: Broiler response results using longer time series and lagged research variable

Intercept	9.66 (72.56)	9.63 (71.95)	9.6 (71.59)	9.7 (69.93)
Price of broiler meat to price of corn	0.01 (1.05)	0.008 (0.60)	0.008 (0.60)	0.01 (1.09)
Price of pig meat to price of corn	-0.007 (-2.74)	-0.004 (-1.81)	-0.007 (-2.79)	-0.007 (-2.93)
Number Foreign breeds	0.08 (3.14)	0.07 (2.68)	0.08 (2.86)	0.09 (3.29)
Improved broiler feed	0.007 (0.47)	0.02 (1.69)	0.02 (1.07)	0.009 (0.54)
Veterinarians per population	0.08 (7.04)	0.08 (7.22)	0.08 (6.78)	0.08 (6.93)
Public research	-0.01 (-1.80)	-0.007 (-1.19)	-0.01 (-2.15)	-0.009 (-1.71)
Private research	0.006 (3.28)	0.005 (3.12)	-0.001 (-0.47)	0.006 (3.30)
Franchises	0.02 (1.32)	0.02 (1.12)	0.04 (2.15)	-0.05 (-1.30)
Patent index	0.03 (2.96)		0.03 (2.67)	0.003 (0.19)
Interaction terms				
Private research and franchises			0.007 (2.34)	
Patent protection and franchises				0.02 (1.92)
R-sq	0.39	0.37	0.39	0.39
# countries	25	25	25	25
# years	26	26	26	26

Research lagged
Note: t-statistics in parentheses; Time dummies are not reported.

Figure A: Private research on veterinary pharmaceuticals



Data from: PhRMA. 1998. Internet homepage www.phrma.org. Pharmaceutical Research and Manufacturers of America.