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Agricultural Productivity, Technological Change, and Deforestation: A Global Analysis

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This study takes advantages of recent developments in measuring total factor productivity in output specific directions to examine the influence of technological change in different agricultural sectors on land-use decisions in a cross-section of countries from 1969 to 2001. Results demonstrate a positive relationship between productivity and land in agriculture in most cases. The ruminant sector is an exception where an increase in productivity was negatively associated with amount of pastureland. The analysis also includes variables that have been found to be important determinants in other studies of land-use change. Population is clearly the dominant factor over the time period analyzed, although it is argued that other factors are likely to become more important in upcoming years since population growth has slowed significantly in many countries.

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Orlando, FL, July 27-29, 2008.

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In this study we examine the relationship between land-use change and agricultural productivity in a large cross-section of countries over 4 decades to estimate the relationship between technological change in agriculture and deforestation. The demand for agricultural production is going to continue to increase as the population approaches 9 billion at mid-century, per capita incomes continue to rise, and the biofuels sector grows. Whether this can be achieved without a significant expansion of agricultural land depends largely on the pace of technological change. This has critical implications for many environmental issues, particularly with respect to climate change (Searchinger et al., 2007; Feddema et al., 2005; Tavoni, Sohngen, and Bosetti).

The goal of this paper is not to provide a forecast of global land use change a number of years forward. That is better done by any number of computable partial and general equilibrium models. Instead, our contribution is to examine the relationship between rates of productivity growth across agricultural sectors and land-use change in the recent past to help understand what may happen in the future. We improve on previous studies by using output specific measures of total factor productivity (TFP) that disaggregate crops, ruminants, and non-ruminant livestock. Using output specific measures is important because technological change occurs independently between sectors, and changes in one sector can affect another. For instance, an improvement in poultry productivity may increase the demand for cropland to grow feed grain. Research that has separated sectors have relied on less accurate partial factor productivity (PFP) measures.

The rapid growth in agricultural productivity beginning in the mid 1960's was primarily a result of 4 types of technological advancements; improved germplasm, increased

fertilizer use, double cropping, and irrigation (Cassman, 1999). In many industrialized countries crop yield growth outpaced demand growth resulting in lower prices, a reduction in agricultural land, and afforestation. At the same time, many developing countries experienced accelerating deforestation rates largely as a result of agricultural expansion. This led to concerns about carbon loss and climate change, biodiversity loss, and top soil loss, to name a few. A number of studies have empirically estimated which factors are the most important in either decreasing or increasing the expansion of agricultural land. Barbier and Burgess (1997) and Ehui and Hertel (1989) found that a reduction in forest cover was associated with increasing population density, while rising income per capita and increasing agricultural yields led to an increase in forest cover. Another set of papers looking at household decision-making concluded that increasing agricultural output prices accelerates the conversion of forest to agriculture, while rural wage rates are positively related to forest cover (eg. Barbier (2000), Barbier and Burgess (1996), and Lopez (1997)).

We build on these studies by focusing on the relationship between productivity and land-use between agricultural sectors. The extent to which repercussions of a change in either the crop or livestock sector are felt in the other have been amplified through the spread of confined livestock facilities (CAFOs) that use feedgrain to raise animals rather than pasture grazing. Soybeans, which are a major feed source for pig and poultry production, were grown minimally relative to rice, wheat, and maize 40 years ago. Today soybeans cover a significant portion of some of the most productive farmland in the U.S., Brazil, and Argentina. Nearly all soybean meal is used to make feed for livestock (ERS). Livestock productivity in the non-ruminants sector (primarily pigs and poultry) is expected

to grow faster than any other agricultural sector in many parts of the world as the use of CAFOs spread, particularly in China (Ludena et al., 2006).

Meat consumption is also expected to increase significantly for a significant portion of the world population due to economic growth in countries like China and India. The average consumption of meat per person in China rose from 20 kg/person/year in 1985 to 50 kg/person/year in 2000 (FAOSTAT). This an important step towards improving living standards for the world's poorest people. At the same time, each calorie of meat requires 5 to 10 times as many calories of grain for feed. This raises questions as to whether productivity growth for crops will be sufficient to prevent a significant expansion of cropland.

1 Agriculture: The Big Picture

1.1 Production

From the beginning of agriculture in the Neolithic period 12,000 years ago until well into the 20th century labor was the limiting factor of production in most societies. As a result, innovation was induced towards creating labor augmenting technologies (Hayami and Ruttan), which accelerated rapidly after the Industrial Revolution. The ability of each farmer to tend to greater tracts of land through the use of various tools, culminating with mechanized tractors, had . First, each farmer produced an increasing amount of excess food allowing more people to engage in non-farm labor, which in turn led to a rapid increase in forest clearing for agriculture. As a result, land rather than labor became the scarcer factor

reorienting research, particularly in developed countries where most research money is spent, towards land intensifying technologies throughout the 20th century¹.

Figure 1 shows the total production of each of the world's four crops in 1961 and 2006. All increased significantly, although on a percentage basis the growth in soybeans is the most dramatic. Figures 2 through 5 track total production, separating out the largest producers, along with total area. To provide some perspective, about 38% of the total global land base (13 billion ha) is used for agriculture in some way (FAO, 2007). Arable land constitutes 11%, 5% contains permanent crops, and 26% is pasture. Figure 6 is an abstract representation of global land use that provides some perspective of these allocations relative to other land types.

Soybean production is unique in a number of ways (Figure 2). Maize, rice, and wheat all show increasing productivity. Total production increased faster than area. While this was the case for soybeans in the 1990's the increase in production since has largely been the result of extensification. Soybean production is also more geographically concentrated than the other crops. The U.S., Brazil, and Argentina account for nearly all of global soybean production. Neither South American country produced a significant amount of soybeans before 1970. Production started to take off in Brazil in the early 1970's and in Argentina 10 years later. China is a distant fourth and total production has changed very little there. This is striking example of the implications that livestock has had on cropland. Total production of maize continued to increase significantly. Wheat and rice production

¹An endogenous factor was the growth in off-farm income which resulted from technological improvements that increase labor productivity.

and productivity have slowed. Figures 2 to 5 also show that the amount of land used for rice and wheat production has flattened while land in maize and soybeans continues to expand.

While yield provides a useful measure of the intensity of production it does not account for factor substitution. Figure 7 compares trends in world TFP for crops and PFP for maize, wheat, and rice separately. TFP for crops is lower than each PFP measure because it accounts for increased use of non-land inputs. Figure 7 also shows why it is important to delineate between agricultural sectors even within livestock. Growth in non-ruminant TFP was larger than that for ruminants. There is significant variation across regions as well. Industrialized countries made their biggest gains in crops and ruminants while China dominated growth in non-ruminant productivity. Regions like Sub-Saharan Africa and the Middle East made little improvement in productivity in any sector, which was likely both a cause and effect of stagnating living standards in those areas.

1.2 Consumption

For the next few decades increasing demand will come from growth in population and income. Higher income increases overall food consumption, but also increases the prevalence of meat in diets. Approximately 16% of income in rich countries is spent on food compared to 55% in poor countries (ERS, 1997). In 2002, the highest consumption in countries including the United States was approximately 124 kg/person/year, which was up 85% from 1970. Bangladesh consumes the least meat at 3.1 kg/person/year. About 30% of total dietary energy consumption for people in the U.S. is from animal products compared to 3% for Bangladesh. Projections assert that 85% of the growth in food demand to 2020 will come from developing countries where the demand for meat could double over this time period (Andersen, Pandya-Lorch, and Rosegrant, 1999 via ERS WRS-011-1).

A scatterplot of meat consumption (kg/person/year) and GDP per capita (current US dollars) for most countries in the world in 2002 (Figure 6.1) shows the positive correlation between income and meat consumption (FAOSTAT). The size of the bubbles reflects the population of the country. A simple regression analysis shows that a 1% increase in GDP per capita leads to a 0.48% increase in meat consumption. The relationship is concave² so meat consumption can be expected to increase as incomes grow from low levels but from medium to high income the relationship decelerates. Both graphs in Figure 6.1 show that increased demand for meat could have huge land use implications in the near future because the majority of the global population resides in the region where meat consumption increases significantly with income growth.

1.3 Trade

Currently, 10% of global agricultural production is traded internationally in terms of quantity (Tubiello, Soussana, and Howden, 2007). The effect of increased demand from China for animal feed on cropland demand in South America is likely to be the most important factor affecting global land use change in the near future. Countries have also started trading more processed meats, although countries with increasing meat consumption have not increased meat imports. Domestic production has met increased demand in most cases. Trade in feed grains has shifted from developed to developing countries, particularly soybean meal, explaining why soybeans have passed wheat as the most traded cereal grain. Coyle, et al. (1998) found income change to be the most important variable in explaining changes in trade patterns.

² Based on the coefficient estimates for GDP per capita and its square.

2 Variable Description

This analysis is modest in terms of the structure it imposes on the dynamics of land use change. Using a large sample of countries over 30 years provides an amount of variation needed to assess land use change that can be relatively slow. At the same time, it presents difficulties in formulating an applicable set of assumptions on the nature of land use change across the sample. Angelsen's (1999) summary of land use models shows how the dynamics of land use change depend on assumptions about household objective functions, trade policy, farm and off-farm labor markets³, and property rights⁴. Our approach then is to investigate within a simple framework i) what relationships predominate between sub-sector productivity change and agricultural land use change, and ii) how strong the relationship between productivity and land use change is relative to other factors. These include population, population density, income, property rights institutions, and agricultural productivity.

Using output specific TFP measures for 127 countries from Ludena et al. (2007), a set of panel data specifications are used covering the years from 1968 to 2000. The dependent variables are two categories of agricultural land-use from the FAO; arable land and permanent crops (ALPC), and pasture and rangeland (PAST). The explanatory

³Household preferences focus primarily on the labor/leisure tradeoff. 'Traditional' societies display lexicographic preferences where they are not willing to trade leisure for labor once subsistence consumption requirements are met. This is largely a result of not being integrated into a larger economy. Models also vary the level of market integration primarily with respect to labor, which is critical in determining the relationship between productivity and land-use. Labor markets are assumed to take one of three forms. First, no off-farm employment options exist. Second, imperfect labor markets are present, but the household is quantity constrained. Third, labor markets are perfect for both buying and selling labor time.

⁴ Assumptions about property rights regimes are categorized as being a system of complete private or communal rights for both forest and cultivated land, pure open access, or partial open access. The last category applies to countries with land tenure laws where forests have no de facto ownership, but clearing and using land for agricultural production can lead to ownership. This is also referred to as homesteading, or ax rights.

variables include lagged values for population, population density, property rights institutions, and TFP measures for crops and livestock.

2.1 Land Use

The two agricultural land categories, ALPC and PAST, are from FAOSTAT (2004). ALPC is land under temporary crops, temporary meadows for mowing or pasture, land under market or kitchen gardens, land temporarily fallow (less than 5 years), and land cultivated with permanent crops. PAST is hectares of land used permanently (more than 5 years) for herbaceous forage crops, either cultivated or growing wild. All summaries of ALPC and PAST are limited to countries that are included in the productivity data set. The abstract representation of the global land supply in Figure 6 provides a useful framework for understanding the relative changes in the land use variables in recent years. From 1980 to 2006, ALPC increased by about 44 million hectares, which is equivalent to just under 40% of one of the squares. PAST has increased by about a square and a half over the same time period, or 197 million ha.

Industrialized countries of North America and Western Europe have decreased ALPC over the last forty years in most cases. The largest increases were in China, South America, and Western Africa. Pasture decreased in India, Western Europe, and to a lesser extent in Australia and the USA. The greatest expansion in PAST was in South America, Central America, and Asia. Australia, USA, China, Mongolia, and Brazil were among the countries with the most land in PAST in both 1961 and 2001. USA, India, Canada, Australia, and Nigeria had the most land in ALPC, which continued to 2001 with the exception of Nigeria.

2.2 Productivity

The total factor productivity (TFP) measure is based on a directional distance function (DDF) approach (Chambers, et al. 1996). Details on how TFP is measured using a DDF approach can be found in Nin et al. (2003) and Ludena et al. (2007). Input and output variables are from FAOSTAT (2004), the database from the Food and Agriculture Organization of the United Nations. Inputs are feed, animal stock, pasture, land under crops, fertilizer, tractors, and labor. Outputs are crops, ruminants, and non-ruminants livestock.

A significant drawback with directional measures is that there is sometimes no solution to the linear programming problem when measuring productivity in an output specific direction. This tends to occur when a production unit is near the efficient frontier. We attempt to “smooth” over the some of the missing observations by transforming the productivity number into a lagged mean. This also smooths over year to year fluctuations in productivity from weather. We only include a country in the sample if it has at least half of the observations for the years from 1961 to 2001.

The average annual percentage change for crops and livestock by country from 1961 to 2001 is shown in Figures 8 and 9. Extreme values are partially a result of some countries having very few observations due to the solution problem described above. These are not included in the sample for statistical analysis. World agriculture TFP has grown at just under 1% per year over this time. As expected, countries in North America and Western Europe increased productivity in agriculture significantly relative to the rest of the world. That said, there were a number of less developed countries in South America, parts of Africa, and Southeast Asia that experienced significant gains in productivity. Many countries that have been associated with rapid deforestation and loss of natural habitat

achieved more modest productivity increases, such as Brazil, countries in Western Africa, and India.

Growth in non-ruminants productivity has been the largest among the agricultural sectors. Average annual percentage growth rates are estimated at 2.6% compared to 0.62% for ruminants. The performance in the non-ruminant sector has largely resulted from improved feed and controlled industrial facilities. There is trend across developed industrialized countries for greater productivity gains in crops than for livestock. For example, Western Europe collectively achieved an annual percentage growth rate for crops of 2.5% compared to 1.19% for livestock.

2.3 Other Determinants of Land-Use

Other variables that have been shown to influence land-use change are GDP per capita as a measure of income, population, population density, and political institutions. Data for GDP per capita is from The World Bank national accounts data and is measured in constant 2000 \$US. The wealthiest countries in 1965 not only remained the wealthiest in 2001 but also became relatively more wealthy. GDP per capita increased on average at 2.4% per year for the wealthiest countries. Living standards in the former Soviet block countries and the Middle East and North Africa were stagnant. The largest rate of improvement was in Asia where many of the 'Asian Tigers' achieved rapid economic growth. Income improved slightly in Latin America. The poorest countries in both 1965 and 2001 were primarily in Sub-Saharan Africa.

We include both population and population density. Countries with a large land mass may be able to accommodate a rapidly growing population without people being

driven out in the countryside if levels remain below a threshold, such as is the case in the U.S. and Canada.

A number of studies have empirically estimated a statistically significant relationship between land-use change and the political and institutional makeup of countries. The general hypothesis is that poor institutions lead to a weak system of property rights which is necessary to avoid problems associated with the overuse of open access resources. The primary difficulty in this line of analysis is creating a representative variable or set of variables that adequately capture the strength of political and economic institutions. We use indexes for property rights is produced by Freedom House and is used here. It ranks countries on a 5 point scale where 1 is strong property rights and 5 is weak. The drawback is that it is not until the year 2000 that observations are available for nearly all the countries in the productivity sample. Therefore, analysis including the property rights variable will be limited to years after 1990. Going further back would make it more likely that significant institutional change has taken place. Using only a single observation for each country requires using a random effects model instead of fixed effects, which does improve efficiency of estimation but introduces greater risk for bias.

3 Regression Analysis

While lagged observations are used for all independent variables productivity differs slightly. As mentioned earlier, the average of the previous four years of annual productivity change observations is used to reduce loss of observations from missing data, and to smooth out weather shocks. Since the variable is a percentage change the geometric mean is used. The other variables are simply a one period lag.

This design has two motivations. First, planting decisions in agriculture are discrete in that they are made at the beginning of the year and can rarely be changed until the following year. For productivity four years is used because it is long enough to smooth out year to year fluctuations, but is also short enough to capture changes in values of variables over time. Results did not change significantly using 3 or 5 year lags. This general length of time has also been used in other studies. Deacon (1994) used 5 year non-overlapping blocks.

The primary regression framework used is a fixed effects panel model. This has the advantage of avoiding bias resulting from correlation between unobserved country characteristics that do not change over time, such as whether it is landlocked, and the included regressors. The model follows the general fixed effects transformation of differencing by the group mean

$$y_{it} - \bar{y}_i = \beta_1(x_{it} - \bar{x}_i) + u_{it} - \bar{u}_i, t = 1, 2, \dots, T$$

which is estimated using OLS with a constant β_0 . This assumes the demeaned errors are homoskedastic and serially uncorrelated. To partially guard against bias resulting from the violation of these assumptions robust standard errors are used throughout.

3.1 Aggregate Agriculture

Table 1 shows results for the the dependent variable that is the sum of PAST and ALPC. Explanatory variables include TFP for agriculture, not output specific, GDP per capita, population, and population density as the set of explanatory variables from 1969 to 2001. While some of the data is available back to 1961 the panel does not start until 1969 because it reduces missing observations for GDP per capita in the mid 1960's, and the four

period lagged mean for productivity means that the first land-use observation that can be used is 1966. Using agricultural land variables and TFP for agriculture is a less precise analysis than what follows, but it provides a useful general overview of the relationships among the variables. It also avoids the missing data problem for productivity since it is not an output specific measure.

The p-value for all coefficients is less than 0.05. The relationship between productivity and land is positive. The coefficient estimate implies that an average increase in productivity of 1% over the previous four years is associated with an increase of 62,000 ha of land in agriculture. Put into perspective, Japan has approximately 5,000,000 ha of arable and pastureland combined, which constitutes about 1/7th of the total land mass. An increase in GDP per capita was inversely related to agricultural land. A significant number of countries did not have observations for GDP per capita in 1965, although the number decreases quickly moving into the 1970's and 80's. For obvious reasons related to reporting and monitoring poorer countries were more likely to be missing observations early on. The average value for 2001 GDP per capita for a country with an observation for 1965 was \$7000, while it was \$2500 for those without. So, a \$1000 increase in GDP per capita leads to a decrease in agricultural land of 100,000 ha. Some countries achieved an increase much greater than \$1000 over the time period while others do not come close. Bangladesh only increased GDP per capita from \$103 to \$353 over the 30 year period. Australia on the other hand managed to grow from about \$2000 to \$20,000.

The sign of the coefficient is negative for population density and positive for raw population, but this is likely due to collinearity between the two variables. Population appears to be the more significant measure. Running the same regression without

population density changes the coefficient on population very little. If population is dropped the coefficient on density is positive and significant. Population is measured in millions, so an increase in population of 1 million people corresponds with an increase in agricultural land of 178,000 ha. For an average country in the sample this is about a 3% increase. Even though the coefficients for all the explanatory variables were significant a comparison of the values for overall R-square demonstrates that population has the most power in explaining variation in the dependent variable. The right column in Table 1 shows the R-square for the model when dropping the variable on that line. The value changes very little when productivity and GDP per capita are not included. When population is dropped the value decreases by a factor of 10 from about 0.3 to 0.02.

3.2 Sector Specific Regressions

Table 2 displays results from a model that takes advantage of the ability to measure productivity change with respect to specific sub-sectors of outputs within agriculture. This also motivates separating land into ALPC and PAST to isolate the effect of each explanatory variable on land allocated towards growing crops versus livestock. The productivity measures for crops, ruminants, and non-ruminants are all included for regressions for both ALPC and PAST because productivity change in each sector can have an influence on each type of land-use. The sample consists of only countries that had more than half of the productivity observations for all three of the sub-sectors.

The relationship between crop productivity and ALPC and PAST displays what has been generally found in developed industrialized countries over the last few decades where there has been a net loss in agricultural land. This may be partially a result of increasing crop productivity, which was much higher in wealthier countries where some pastureland

was converted to grow crops or was taken out of production. This also comes through in the fact that the coefficient on crop productivity in the PAST regression is about 4 times as large as that for the ALPC regression. To reiterate, all coefficients on productivity variables range between 10 and 50 meaning a 1% increase in productivity leads to an expansion or contraction, depending on the sign, of 10,000 ha to 50,000 ha.

This relationship between crop productivity and the change in allocation of land has interesting environmental implications. Countries like the U.S. have managed to increase forested land because the decrease in pasture has been larger than the increase in cropland. Therefore, there is a positive effect on decreasing deforestation. At the same time, crop production generally carries with it an increase in the use of chemical additives, which have significant environmental impacts, particularly on water related resources.

Increasing productivity in the non-ruminant sector was associated with an increase in both ALPC and PAST significant at a confidence level greater than 99% in both cases. A significant cause of productivity gains in developed countries in the pig and poultry sectors has been related to the science of feed (Nin et al. 2003). It is possible that this increased demand for crops that produce grains for animal feed. In the case of China Ludena et al. attribute the rapid increase in non-ruminant productivity to a process of 'catching-up' to methods already existing in developed countries that were adopted quickly once some element of private ownership was introduced into the agriculture sector around 1980. This mainly had to do with increased use of confined production systems.

Productivity gains in the ruminant sector have been more modest in general. Only China stands out as having achieved particularly strong improvements. Ruminant productivity is not significantly related to ALPC, but does show a positive and significant

relationship with PAST. This makes intuitive sense given that non-ruminant livestock rely primarily on pasture grazing. Although, corn has become an important feed stock for cattle in the U.S. and some other countries. It is interesting to view these results in the context of which shows that countries with the largest increases in PAST include Brazil and China. Latin America has achieved greater increases in ruminant productivity from 1980 to 2000 than industrialized countries after having made no gains at all in the previous 20 years. It is over this time period of realizing productivity gains that the rate of reduction of the rainforest has quickened. These results provide some evidence that increased productivity in ruminants has not slowed the rate of clearing.

Turning to the non-productivity related explanatory variables reveals that GDP per capita is not significantly related to either land variable in isolation. Population remains highly significant and positive for both ALPC and PAST. For ALPC, population density is significant even when population is included. As was true for the agriculture regression in Table 1, population density becomes positive and significant when population is dropped. Another interesting difference between the ALPC and PAST regressions is the difference in the overall R-square. Compared to other regressions in this study the R-square for PAST is very high considering the included regressors explain about 70% of the overall variation in permanent pasture and meadows. Alternatively, R-square for ALPC is more than a factor of 10 smaller at 0.02. This could mean that population change has very significant effects on pasture, but much less so on cropland. In terms of ALPC there is likely additional factors that influence cropland decisions which should be investigated in future research. A likely candidate is output prices for agricultural goods. As mentioned earlier, it is additionally

important given the confluence of predictions provided by increasing productivity and prices.

3.3 Property Rights

Table 3 shows results from a random effects regression that includes dummy variables for strength of property rights institutions from Freedom House. A random effects model is necessary because only one observation is available for each country, which applies to the year 2000. The sample is limited to the period from 1990 to 2001 to increase the relevance of the 2000 observation to each year in the sample. Again, the property rights variable is reported on a scale of 1 to 5 increasing inversely with strength of property rights. To discern between different levels of strength the ordinal variable is converted to a set of dummies. Category 1 is dropped. Most Western European and North American countries have a score of 1. Brazil has a score of 3, while countries such as the Congo and Haiti are rated at 5.

Results show that weaker property rights are associated with increasing land in agriculture to a point. The trend does not hold over the entire range of the variable. Compared to countries with full and complete property rights institutions those with scores of 2 and 3 have greater land in ALPC, but this is not so for countries with scores of 4 and 5. For PAST there is no difference between 1 and 2, but countries with scores of 3 and 4 have more land in PAST. While there could be signs of an interesting difference between PAST and ALPC being demonstrated here the lack of precision of the property rights variable given the time displacement issue make it unwise to draw overly strong conclusions.

This regression also provides an interesting comparison for different time periods by focusing on the later years in the sample. Estimates are insignificant for both crops and

ruminants, but remain moderately significant and positive for non-ruminants in terms of both dependent variables. The most difference is for population. Comparing coefficients for the two dependent variables show that they are similar in magnitude, which is surprising since that for PAST tended to be larger when considering the full time period. The coefficient is also significant at a much higher confidence level for ALPC compared to PAST.

4 Conclusions

This study analyzed the determinants of land-use change in agriculture building on previous studies by incorporating total factor productivity measures that isolate technological change in different agricultural sectors. This is important for a number of reasons. The production of crops and different types of livestock experience technological change at varying times and rates. This is a fact that would not be captured with a general measure of agricultural productivity. Different sectors of agriculture also have unique environmental repercussions. Lastly, mechanisms exist that allow productivity change in one sector to influence land-use change in another. For example, the demand for grain for livestock feed has dramatic implications in terms of allocating land to crop production.

Results showed that increased productivity in different sectors of agriculture was most often associated with agricultural expansion, although this is by no means the entire story. Countries with increased crop productivity decreased land in pasture. This relationship was common in industrialized nations. Increased productivity in the non-ruminants sector was associated with increases in both ALPC and PAST. It is understandable how the association would exist for ALPC from increased demand for feed

grain. It is less obvious how non-ruminants could be connected to changes in PAST since they are not grazed. Weaker property rights were associated with an more land in agriculture, although this result primarily existed for countries in the middle of the scale relative to countries with the strongest institutions defining ownership. While all the included variables demonstrated some relationship with land-use change population was clearly the most important in terms of explaining the variation in land-use.

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Tables

Dependent Variable = ALPC + PAST (1000 ha)		
	Estimate	Overall R-square without
Constant	33189*** (828)	
TFP Agriculture	62** (20)	0.341
GDP per capita	-0.1*** (0.023)	0.343
Population (millions)	178*** (26)	0.021
Population Density (people per sq. km)	-34*** (4.9)	0.306
Overall R-square	0.342	
N	102	
Average T out of 32	29.6	
Notes: Robust standard errors are in parentheses. ***, **, and * denote significant at 99%, 95%, and 90% confidence levels. The R-square without column provides the percent of overall variation in the dependent variable explained by all the listed regressors except the one on that row.		

Table 1. Fixed Effects Regression on Determinants of Land Under Crops and Pasture from 1969 to 2001.

	Dependent Variable (1000 ha)	
	ALPC	PAST
Constant	5728*** (206)	19814*** (746)
TFP Crops	12.6* (7)	-49.7*** (14.2)
TFP Non-Ruminants	25.8*** (8)	59.5*** (12.7)
TFP Ruminants	-9.4 (6.8)	74.9*** (24)
GDP per capita	-0.013 (0.014)	-0.018 (0.013)
Population (millions)	31.4*** (3.7)	315*** (15)
Population Density (people per sq. km)	12.3*** (2.9)	-66.9*** (9.6)
Overall R-square	0.022	0.794
N	55	59
Average T out of 32	19.9	21.6

Notes: Robust standard errors are in parentheses. ***, **, and * denote significant at 99%, 95%, and 90% confidence levels.

Table 2. Fixed Effects Regression on Determinants of Land in ALPC and PAST from 1969 to 2001.

	Dependent Variable (1000 ha)	
	ALPC	PAST
Constant	1514 (1497)	7134** (3240)
TFP Crops	10.3 (7.7)	67.1 (8.2)
TFP Non-Ruminants	10.6* (5)	12.1* (7)
TFP Ruminants	-5.8 (7.1)	-8.5 (7.8)
GDP per capita	-0.003 (0.04)	0.074* (0.043)
Population (millions)	41.7*** (8.7)	34* (18.7)
Population Density (people per sq. km)	4.8 (3.7)	-6 (4.3)
Property Rights 2 Dummy	9089*** (3192)	-1598 (3902)
Property Rights 3 Dummy	6642** (3133)	19109*** (6941)
Property Rights 4 Dummy	356 (2465)	42986*** (10601)
Property Rights 5 Dummy	3633 (3941)	3742 (5328)
Overall R-square	0.091	0.31
N	52	56
Average T out of 12	9.2	9.7

Notes: Robust standard errors are in parentheses. ***, **, and * denote significant at 99%, 95%, and 90% confidence levels. The property rights variable is on an ordinal scale from 1 to 5 where 1 represents strongest property rights, which is the dropped category.

Table 3. Random Effects Regression for Determinants of Land-Use from 1990 to 2001.

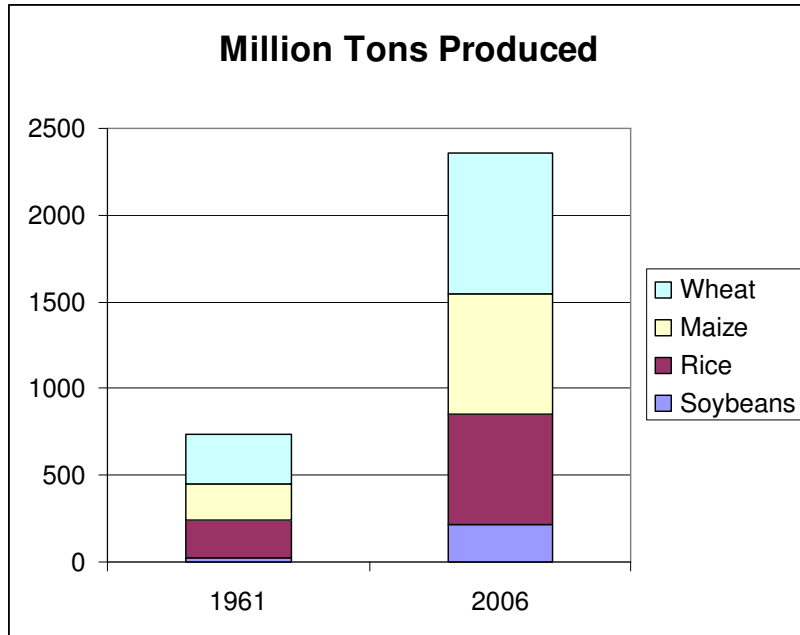


Figure 5. Total Global Production of the 4 Major Crops.

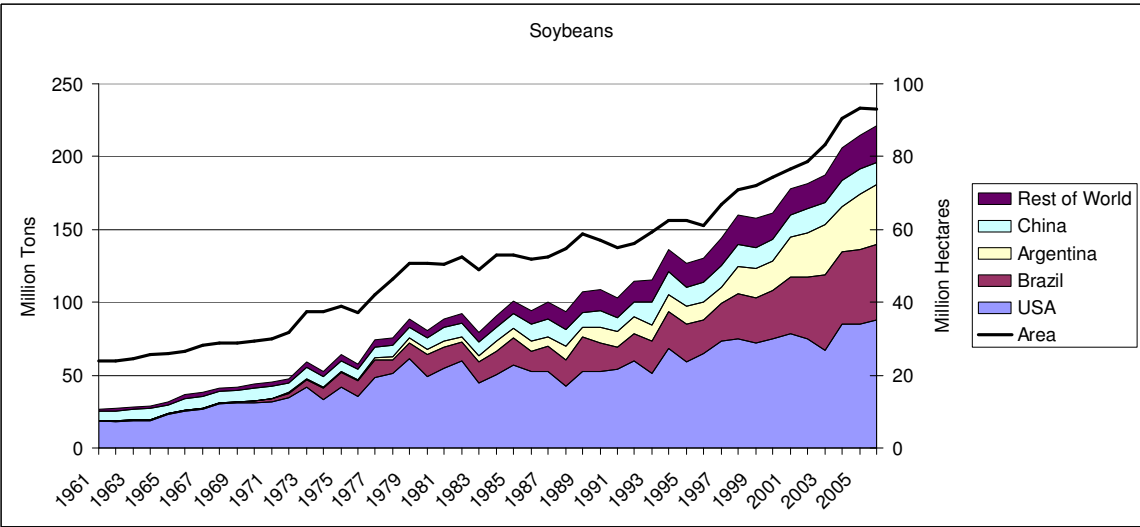


Figure 2. Soybean Production and Area.

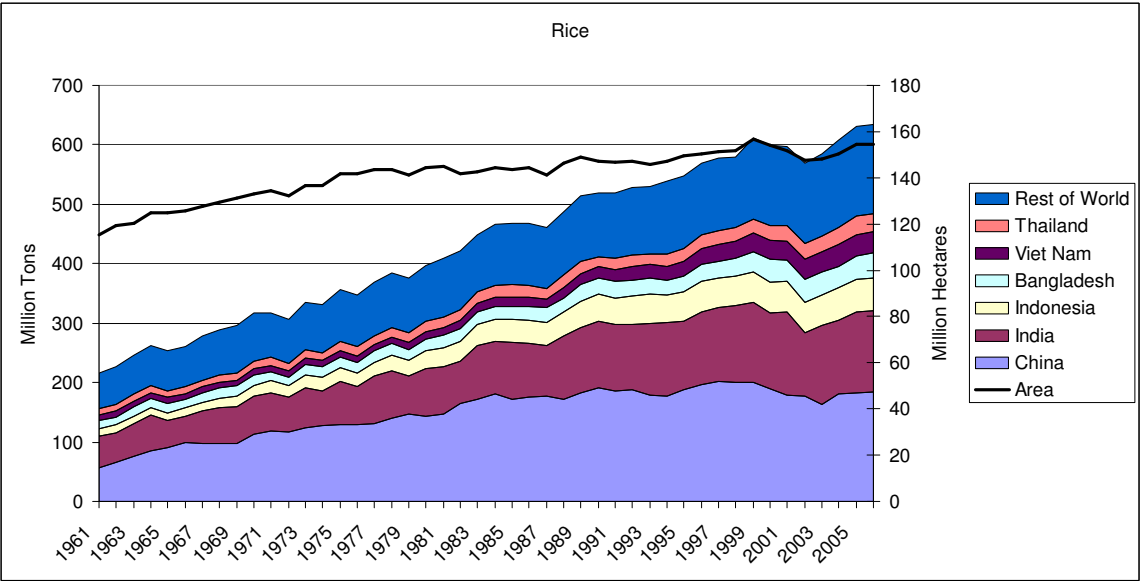


Figure 3. Rice Production and Area.

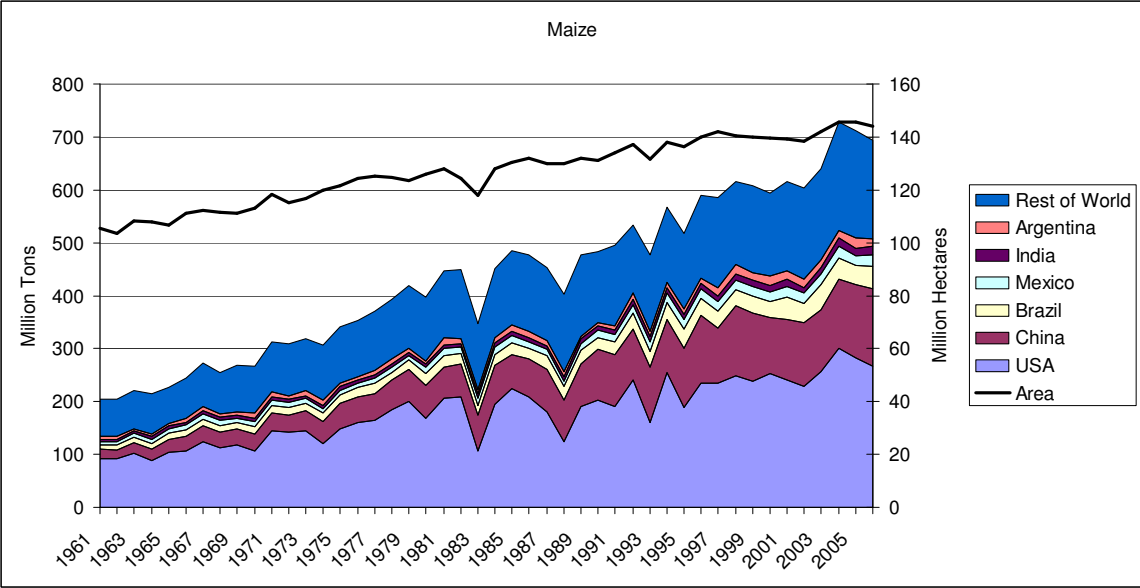


Figure 4. Maize Production and Area.

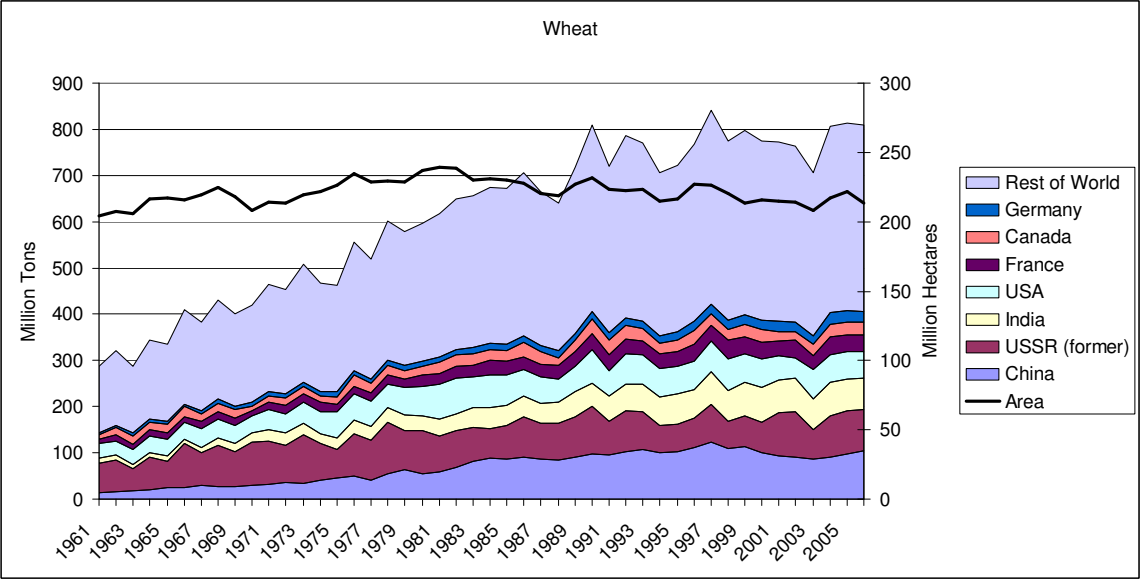
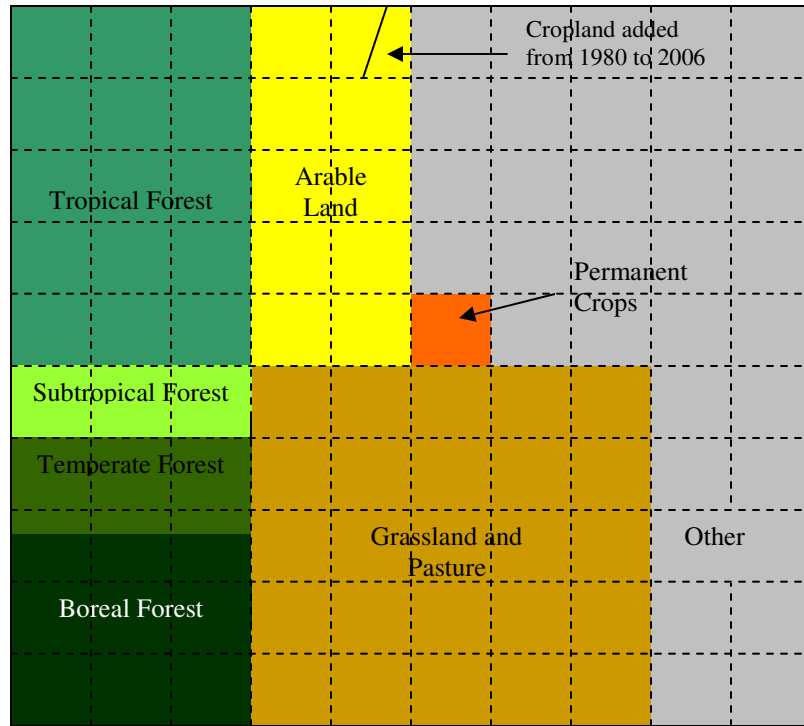


Figure 5. Wheat Production and Area.

**Global Land Base Allocation in 2006
(13 Billion Hectares)**



Note: One square is equal to approximately 130 million hectares.

Figure 6. An Abstract Representation of the Allocation of the Global Land Base.

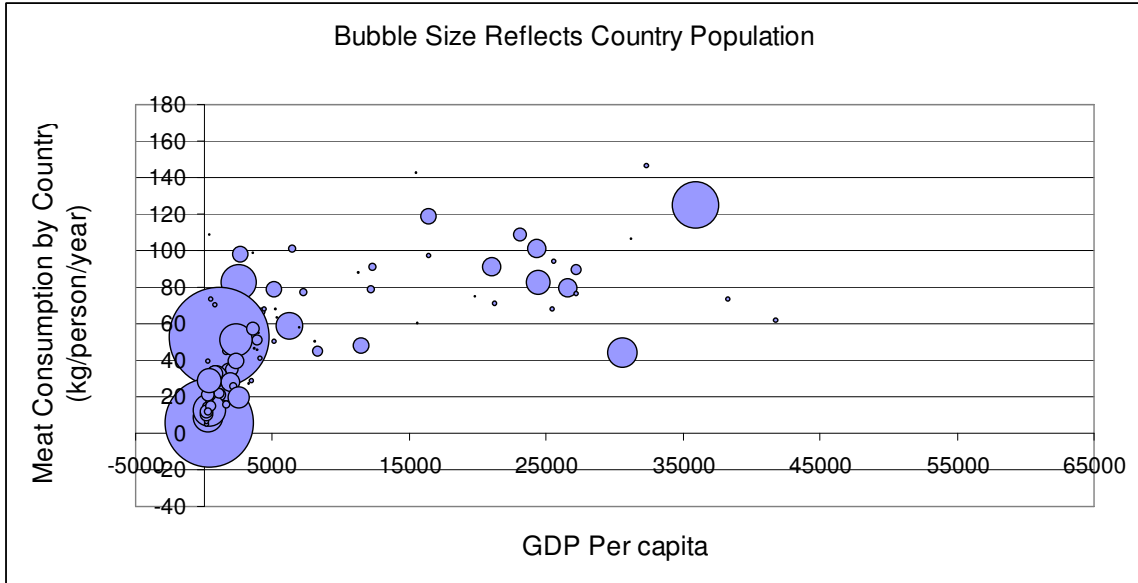


Figure 6.1. GDP per capita and Meat Consumption per capita in 2002.

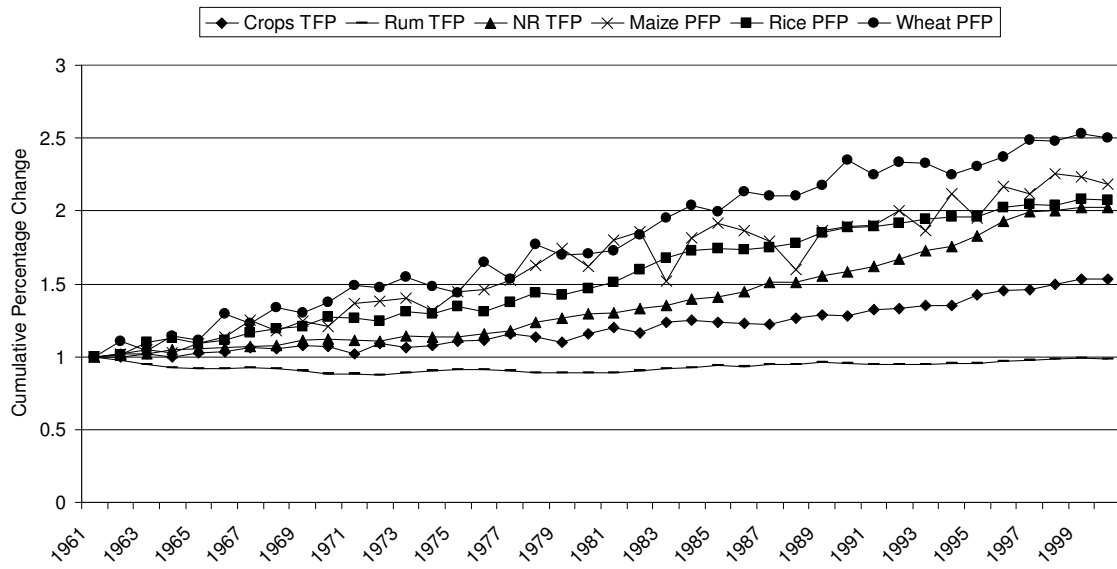


Figure 7. World Crop TFP and Commodity Specific PFP Cumulative Percentage Change.

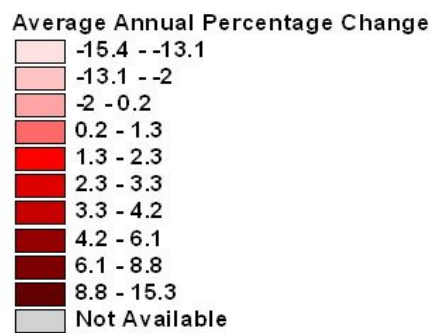
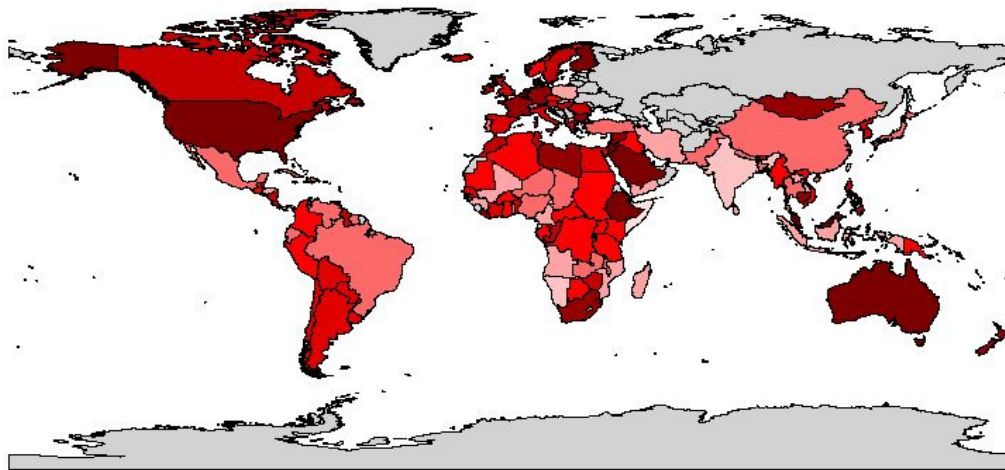


Figure 8. Average Annual Change in Crop Total Factor Productivity from 1961 to 2001.

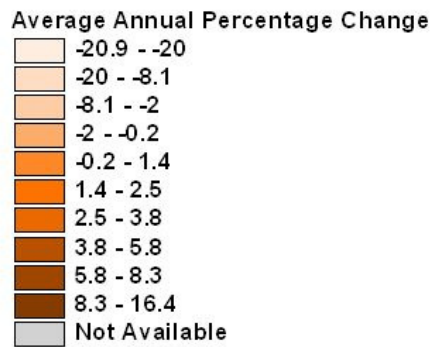
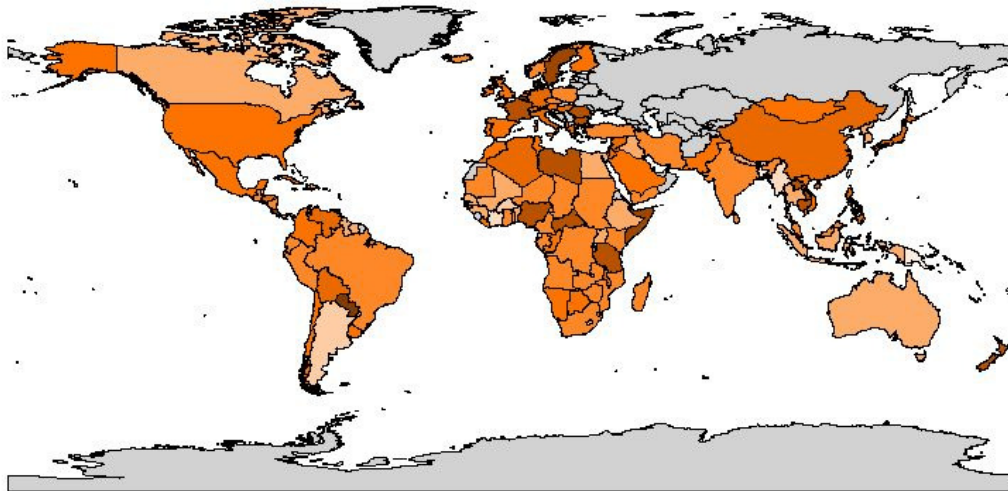


Figure 9. Average Annual Change in Livestock Total Factor Productivity from 1961 to 2001.