Green Revolution Counterfactuals

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Abstract

In this paper, we conduct two “counterfactual simulations for the 30-year period 1970-2000 – the first holding 1970 crop genetic improvements (CGI) constant and the second presuming the International Agricultural Research Center (IARC) system had not been built. Both these counterfactuals apply to developing countries only.The core estimates on which the counterfactuals are based include country fixed effects , and the key estimates are for the Dietary Energy Sufficiency (DES) equation. DES affects birth rates, death rates, child mortality rates and malnutrition rates, making it possible to “endogenize” population growth in developing countries, in the counterfactuals. Reduced DES levels (from reduced CGI contributions) will lead to more births, more deaths and more child deaths and higher levels of malnutrition. The key technology variables that determine DES are the number of agricultural scientists per million hectares of cropland, the average years of schooling of adult males (over 25), and the level of Green Revolution Modern Varieties (GRMV) adoption.

Our results show striking contrasts between the historical record and the alternative counterfactuals. The worst outcome is that without any Green Revolution Technologies or an IARC system to support it, which results in holding technological advancements constant at the 1970 level is a marginal improvement, leading to much higher prices over time, as agricultural production struggles to keep up with food demand in those countries. The endogenous feedback effects of population show the importance of nutrition and education, and argue strongly in favor of those factors playing a significant role in the improvement of human well-being that has been observed since the start of the Green Revolution to present.

INTRODUCTION

Agricultural productivity has experienced considerable levels of growth over the past few decades around the world, much of which can be attributed to agricultural research, particularly that during the Green Revolution period. Although the growth of public funding for agricultural research in OECD countries, like the United States, has slowed down in recent years, it has been a significant source of support for many decades. This was particularly true during the 1960s, when more public agricultural research funds were available than private (Alston and Pardey, 1996).

Even prior to the Green Revolution, an assessment was made of the National Agricultural Research Systems (NARS) in various countries around the world, in order to determine whether there was a demonstrated need for them to be supported by a system of International Agricultural Research Centers (IARCs). These IARCs were to provide the technical expertise and knowledge that would help to overcome local barriers to effective promulgation of best-agricultural-practices and productivity enhancements at the country level, and to support the struggling agricultural economies of those regions most in need of development. Even without the introduction of radical improvement in crop genetic traits, a successful argument for the positive impacts of IARCs could be made in many countries.

Numerous studies have found that public agricultural research has had a positive impact on agricultural productivity, and that the impact of IARCs on agricultural development has been positive in many countries. While some studies have looked at the impacts of public research funding on state agricultural productivity, few have looked closely at the plausible impacts if there had been a stagnant level or complete absence of crop productivity-enhancing research on international agricultural production. In this paper, we use IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) to construct alternative counterfactuals that can help to identify the effect that agricultural research has had on international commodity production, demand and world trade prices. By constructing scenarios in which these innovations are stagnant or absent, we are able to gauge the impact that both the Green Revolution and that the wide spread dissemination of knowledge generated by IARCs has had on agricultural productivity and the livelihoods that depend on it.

By endogenizing some of the key variables that underlie the projections of agricultural production growth made by the IMPACT model, we are able to examine the influence of a much wider range of socio-economic determinants and feedback effects than was previously possible within a framework of strictly exogenously-specified demographic growth parameters. By simulating the IMPACT model with an endogenously-determined system of demographic growth parameters and under the alternative counterfactuals, we can project an alternative path of agricultural growth from 1970 through to the 1990s, and compare them with the previous baseline results of IMPACT. The comparison of model results, under the counterfactuals, and the past trends are compared, in order to gauge the impact that the Green Revolution and the supporting system of International Agricultural Research Centers has had on the world's food situation, in terms of both agricultural productivity and production, as well as attendant impacts on hunger and malnutrition.

DEFINING TECHNOLOGICAL CAPITAL

Two forms of Technological Capital were defined. Invention/Innovation (II) capital was one form. Technology Mastery (TM) was the second.

The invention-Innovation (II) index is based on two indicators, agricultural scientists per million hectares of cropland and the UNESCO indicator of R&D/GDP. The UNESCO indicator is primarily an indicator of industrial R&D.

Countries are given II values of 1, 2, or 3 based on the following:

Agricultural Scientists per million hectares of cropland (ISNAR)

II = 1	if value is .02 or lower
II = 2	if value is .021 to .06
II = 3	if value is greater than .06

R&D/GDP (UNESCO)

II = 1	if value is .002 or lower
II = 2	if value is .0021 to .006
II = 3	If value is greater than .006

The sun of the two indicators is the II index. Thus the minimum II index is 2, the maximum is 6.

The Technology Mastery (TM) index is also based on two indicators, extension workers per million hectares of cropland and the average schooling of males over 25.

Countries are given TM value of 1, 2, or 3 based on the following:

Extension workers per million hectares of cropland.

TM = 1 if value is .2 or lower

TM = 2 if value is .21 to .6

TM = 3 if value is higher than .6

Average schooling of males over 25.

TM = 1 if value is less than 4 years.

TM = 2 if value is 4 to 6 years.

TM = 3 if value is greater than 6 years.

The sum of the two indicators is the TM index. The minimum TM index is 2, the maximum is 6.

Figure 1 reports II indexes for three periods – 1950-55, 1970-75, and 1990-95 (TM indexes are in parentheses). This figure indicates that 62 of the 86 countries were in II Class 2 in 1950-55. Twenty countries were in II Class 3 in 1950-55 and four were in Class 4 in 1950-55. On the strength of these comparisons, the IARC system was built.

ESTIMATING A SYSTEM OF NUTRITION-GROWTH FEEDBACKS

Table 1 below reports estimates for a six equation system of equations. Specifically, there are six endogenous variables in the system ranging from Dietary Energy Sufficiency (DES), a measure of calories consumed per capita to malnutrition based on height scores. Ten variables that may be considered exogenous variables are also considered in Table 1. For endogenous and exogenous variables, means for 1970 and 2000 are reported.

Table 2 reports estimates for the six equation system. A six equation system is estimated using 3SLS techniques. All equations are estimated in the presence of "country fixed effects."

The most important equation is the DES equation. DES is measured as calories consumed per capita. The exogenous variables determine DES and GDP per capita, average years of schooling of adult males (over 25 years of age), agricultural scientists per million hectares of cropland, Green Revolution Modern Variety (GRMV) adoption, the "real export price" of rice, wheat and maize in world markets, and the share of agriculture in GDP. The coefficient on GDP per capita is expected to be positive. Similarly, the coefficients for average years of schooling of adult males and GRMV adoption are expected to be positive. In contrast, the coefficients on the real export price of food grains is expected to be negative because this is, in effect, an "own" price elasticity. Similarly, the coefficients on the share of agriculture in GDP is expected to be negative because of "Engle's Law" (i.e., that higher shares of agriculture in GDP means that less food is consumed). Thus, the DES equation is consistent with expectations.

Next, consider the birth rate equation. This equation includes three variables: the average years of schooling of adult females (over 25), hospital beds per million population and the DES variable. We know from many studies that the schooling of adult females matters more than the schooling of adult males in contraception decisions. The coefficient on hospital beds is expected to be positive and it is, but it is not statistically significant. The coefficient on the DES variable is expected to be negative, because as DES goes up, contraception increases.

Next, consider the death rate equation. Since the birth rate and the death rate are denominated in population units, the difference in birth and death rates allow us to "endogenize" population. The exogenous variables for the death rate are the average schooling of both adult males and adult females (expected to be negative), physicians per million population (expected to be negative), rural population density (expected to be negative because urban areas have more services, and the endogenous DES variable (expected to be negative). We note that the DES coefficient reduces both birth and death rates.

Next consider the child mortality rate equation. The exogenous variables included are the average years of schooling of adult females (expected to be negative because mothers specialize in child care and care for sick children), physicians per million population (expected to be negative because more doctors can cure far more children), rural population density (expected to be negative because urban areas have better health services), and the endogenous DES variable (expected to be negative because better fed children live longer).

The two malnutrition equations (the first based on weight, the second on height) include four exogenous variables, GDP per capita (not significant), schooling of adult females (expected to be negative), rural population density (expected to be negative), and the endogenous DES variable (expected to be negative). These expectations (except for GDP per capita) are borne out in the estimate.

The equations that embody this simultaneous system of endogenized growth are given below

Birth Rate Equation:

$$6.154 - .4388 AVYSCF + .0137 HospBeds / Pop - .000535 DES$$

Death Rate Equation:

$$2.706 - .1194 AVYSCFM - .0277 Phys / Pop - .1097 RurPop\ Density - .000449 DES$$

Child Mortality Equation:

$$(.0482 - .001528 AVYSCM - .00105 Physician / Pop - .001515 RurPop\ Density - .0000117 DES) / Births$$

Malnutrition (W)

$$63.76 - .0002 GDP / Per\ capita - 1.499 AVYSCF - 1.314 RurPop\ Density - .0177 DES$$

Malnutrition (H)

$$77.83 - .005 GDP / Per\ Capita - .7757 AVYSCF - .1677 RurPop\ Density - .0240 DES$$

ENDOGENIZING POPULATION GROWTH

There are two ways to endogenize population growth. The first is to note the birth rates and death rates are denominated per 1000 population. Thus, the difference between birth rates and death rates is the rate of growth of population. Table 1 shows that mean birth rates declined from 43.5 in 1970 to 31.2 in 2000, and that death rates declined from 17 to 11.3. This is consistent with the demographic transition model where when both birth and death rates are high, population growth is low. Typically, death rates (particularly infant and child death rates) decline before birth rates decline. Since most (all?) developing countries are in demographic transitions that are quite rapid (and driven by the DES variable), the mean data for 1970 and 2000 are consistent with this.

The second method for endogenizing population growth is to note that the child mortality measures child deaths before age 5. But child mortality is demoninated in terms of births, not as for birth rates and death rates, in terms of population. However, we do have data on numbers of births per year for all major developing countries, and we can calculate child mortality rates directly.

Note that the DES effects on child mortality is very strong. In almost all countries when children survive to age 5, they typically survive for many more years.

The actual counterfactual experiment entailed here is to reduce the crop genetic improvement (CGI) component associated with the Green Revolution. Since some countries in Sub-Saharan Africa either did not have a Green Revolution or had a modest level of GRMV adoption, the subtraction of CGI gains will have little impact on these countries. But the main force of the Green Revolution was to propel successful Green Revolution countries onto a sustained path of economic growth.

THE IMPACT MODEL

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) was developed at the International Food Policy Research Institute (IFPRI) in the early 1990s. Since the development of the model, many publications have been produced that present results examining the future of global food supply, demand and trade (See, for example, Rosegrant et al., 2001; Scott, Rosegrant and Ringler, 2000; Delgado et al., 1999; Delgado et al., 2003). Although the model has been expanded several times in recent years to include additional commodities and different regional/country groupings, in this analysis we use the structure of the original IMPACT model. The primary differences between IMPACT70 and the original IMPACT are the replacement of the 1997 base year data with 1970 base year data (3-year average centered on 1970) and the calibration of the model to represent the historical trends in yield, area and livestock numbers growth from 1970-1997. A basic description of the IMPACT model is presented below.

The original IMPACT model covers 36 countries or country groups and 16 commodities, including all cereals, soybeans, roots and tubers, meats, and dairy products (accounting for virtually all of the world's food and feed production and consumption). The model is specified as a set of country-level demand and supply equations linked to the rest of the world through trade. Food demand, including fresh and processed food, is a function of commodity prices, per capita income, and population growth. Feed demand is a function of livestock production, feed prices, and feeding efficiency. Crop production is determined by the area and yield response functions; area is projected as a function of crop price, irrigation investment, and estimated rates of loss of land to urbanization and land degradation. Crop yield is a function of crop price, input prices, investments in irrigation, and yield growth due to technological change. Growth in productivity due to technological change is in turn estimated by its component sources including advances in management research and, in the case of food crops, plant-breeding research. Other sources of growth considered in the model include private sector investments in agricultural research and development, agricultural extension and education, markets, infrastructure, and irrigation (see Rosegrant, Meijer, and Cline, 2002 for additional details on the methodology).

COUNTERFACTUAL SIMULATION RESULTS

Table 3 reports estimates of yield changes and area changes for two counterfactual cases. The first case is the No Green Revolution case. The second is the No IARC case. The units are in percentage points per year. From this table it is clear that the yield increases realized under the Green Revolution have been greater than those attributed to the presence of IARCs, across the major grain categories shown. As a reflection of this, the area increases that would happen under lower productivity levels in the counterfactuals (as an alternative way of boosting production), are larger in the no-IARC case than in the case without the Green Revolution. So we can view the absence of crop technology innovation, in either of the counterfactual cases, as being a missed opportunity for productivity enhancement and savings in cultivated area – with the absence of Green Revolution-induced advances as representing the greater loss of the two.

The absence of results in Table 3 for developed countries, results from the design of the counterfactual experiments, which do not allow for changes in these regions. Thus, in our simulation experiments, all developed countries realize the actual productivity gains that were observed in this period. The intent of our analysis for developing country regions was to reduce the crop genetic improvement component of crop yields, so as to observe the impacts on overall productivity and crop production, resulting from a global equilibrium in all agricultural markets.

The resulting impacts from the changes in crop productivity that are reflected in Table 3, have consequent effects on the global agricultural market equilibrium, that are reflected in Table 3, for the major crops modeled in IMPACT. The decreases in crop production that are shown are reflective of the decreases in productivity that were shown previously, and also convey the relative importance of Green Revolution productivity gains, relative to the presence of IARCs. The price increases that result from these lower levels of production are also shown, as well as the attendant increases in cropped area, and overall trade impacts.

All of these results point to the fact that the innovations introduced by crop genetic improvements in the 1970s are a key factor that gave rise to the increases in agricultural productivity and production observed during that period. The land that was “saved” by higher crop productivity levels, is also reflected here, although other impacts such as the effect on land prices or the substitution for other possible land uses is not shown in our results – as it lies beyond the scope of our modeling framework. But there is no doubt that the labor that would have been locked up in more extensive and less productive agricultural activities would have resulted in decreased earnings from off-farm activities or higher paying non-agricultural sector employment opportunities. This, combined with the higher prices for agricultural produce, would undoubtedly lead to poorer welfare outcomes, that would be felt within the wider economy, but which cannot be captured within our partial equilibrium agricultural sector model.

Among the key welfare indicators that can be captured by our modeling framework, however, is that of malnutrition, which is explicitly treated within the DES simultaneous equation system. Because productivity gains are lower, in these counterfactual simulations, the realized DES levels will also be lower in developing countries – which has implications on growth and well-being that are reflected in the coefficient values reported in Table 2. Table 5 shows the resulting malnutrition-related impacts that are implied by the agricultural production (and consumption) equilibrium results generated from our counterfactual analysis. As would be expected, from the results shown in Tables 3 and 4, the malnutrition outcomes are much worse in the case where no Green Revolution innovations occur, compared to those outcomes realized in the absence of IARCs. The contrast is particularly sharp for South Asia and Southeast Asia regions, which attests to the importance of the Green Revolution in those countries.

While there is also a greater incidence of malnutrition in Africa, in the absence of Green Revolution innovations, as compared to the case without IARCs, the results in Table 5 show a lesser impact in Africa than for the Asia region. This is largely reflective of the fact that many of the crop genetic improvements realized in the course of the Green Revolution were not directly internalized within the agricultural production systems of Africa, and that most of its effects were trade-related, and tied more directly to the increased availability of food staples on world markets, and lower prices for consumers. The increase in calorie availability, through these marketed channels, then feed back through the DES system, and give rise to changes in malnutrition and other indicators of well-being, and are reflected in the results shown in Table 5.

CONCLUSIONS

The counterfactual analysis that we have shown in this paper, demonstrates the relative importance of the Green Revolution in generating sustained improvements in crop productivity growth through the 1970s and 80s, compared to the improvements that can be attributed to the presence of International Agricultural Research Centers. The attendant effects on the dynamics of global agricultural markets has also been shown, in terms of production, price and trade impacts, which is linked to the available calories for consumers and, consequently, to malnutrition, through the feedbacks embodied in the endogenous Dietary Energy Sufficiency relationships.

The regional differentiation of the impacts demonstrated in the counterfactual analyses shown, are both reflective of the degree to which crop genetic improvements have actually been embedded in the productivity growth dynamics in those regions, as well as of the nature of the relationships shown by the DES system of growth feedbacks that were estimated across them. While Latin America and Africa have less demonstrable effects, in terms of productivity growth levels of malnutrition incidence, within these counterfactual experiments, it should not be taken as a dismissal of the importance of the Green Revolution advances in those countries. Rather, it should underscore the urgency that should be placed on further embedding the crop genetic improvements that were realized through Green Revolution innovations into the agricultural production systems of those countries, and the missed opportunities that have resulted from not doing so, when compared with the South and Southeast Asia region.

Furthermore, the results of our counterfactual experiments should not cause the reader to think that the improvements attributed to the presence of the International Agricultural Research Centers are insignificant, either. The results reflected in this paper are driven largely by the attribution of productivity gains to either the presence of IARCs or Green Revolution innovation, but do not fully embody the wider benefits that the system of International Agricultural Research Centers has brought to agricultural research and innovation systems in the client countries that they have served. It is difficult to capture the strengthening of capacity that has taken place over the years, as a result of IARC presence in developing countries, in terms of improvement in research capacity as well as in the efficiency and operation of innovation systems and their integration with national policy and development strategies.

As a concluding thought, it should be noted that both the crop genetic improvements realized from Green Revolution-induced technologies and the presence of the International Agricultural Research Centers are key factors in the growth of agriculture in the past decades. No implied choice of one-over-the-other is intended in our analysis – except to point out that innovations in crop technologies remains the key to sustained productivity growth in those countries most in need of renewal of their food systems. Furthermore, the concurrent improvements in the functioning of crop research and innovation systems can only help this process – but cannot serve as a wholesale substitute to basic crop-level trait advancements. Our conclusions also speak to the 'nay-sayers' of the Green Revolution, who sometimes cite environmental impacts of bio-diversity losses as qualifiers to the successes realized in raising basic agricultural productivity levels. From our analysis, as well as from the testimony of many, there is little doubt that the improvements in human well-being that have been realized through the disseminations of Green Technologies would be unattainable by other means. The imperative suggested by our analysis is to further embed these innovations into the agricultural systems of other countries, that have yet to fully benefit from the advances observed in South and Southeast Asia. Towards that end, the presence and continued efforts of International Agricultural Research Centers to strengthen capacity and solidify these improvements within national innovation systems, will only help and serve as a vehicle for further dissemination and adoption within those regions that are in most need of improvements in agricultural productivity and rural livelihoods.

REFERENCES

Alston, J. and P. Pardey. 1996. *Making Science Pay*. Washington, DC: The AEI Press.

Brown, Lester R. and Hal Kane. 1994. *Full house: Reassessing the earth's population carrying capacity*. New York: W. W. Norton.

Delgado, C.L., N. Wada, M.W. Rosegrant, S. Meijer, and M. Ahmed. 2003. *Fish to 2020: Supply and Demand in Changing Global Markets*. Washington, DC: International Food Policy Research Institute.

Delgado, C. L., M.W. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. Livestock to 2020. The Next Food Revolution. 2020 Vision Discussion Paper 28. Washington, D.C.: International Food Policy Research Institute.

Huffman, Wallace, E. and Robert E. Evenson. 2003. New Econometric Evidence on Agricultural Total Factor Productivity Determinants: Impact of Funding Sources. Mimeo.

Huffman, Wallace E. and Robert Evenson. 2002. Determinants of State Agricultural Experiment Station Funding Shares. Mimeo.

Mitchell, Donald O., and Merlinda D. Ingco. 1993. *The World Food Outlook*. International Economics Department, Washington, D.C.: The World Bank.

Rosegrant, M. W., S. Meijer, and S. A. Cline. 2002. International model for policy analysis of agricultural commodities and trade (IMPACT): Model description. Washington, D.C.: International Food Policy Research Institute. <Http://www.ifpri.org/themes/impact/impactmodel.pdf>.

Rosegrant, M.W., M.S.Paisner, S. Meijer and J. Witcover. 2001. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. Washington D.C.: International Food Policy Research Institute.

Rosegrant, Mark W. and Prabhu L. Pingali. 1994. Policy and technology for rice productivity growth in Asia. *Journal of International Development*, 6: 665-688.

Rosegrant, Mark W. and Mark Svendsen. 1993. Asian food production in the 1990s: Irrigation investment and management policy. *Food Policy*, 18 (2): 13–32.

Scott, G., M.W. Rosegrant, and C. Ringler 2000. Roots and Tubers for the 21st Century: Trends, Projections, and Policy Options. 2020 Vision Discussion Paper 31. Washington, D.C.: International Food Policy Research Institute.

Figure 1: II indexes for 1950-55, 1970-75 and 1990-95. TM indexes are in Parentheses.

222 - 10 Countries	**224 – 7 Countries**	**233 – 10 Countries**
Afghanistan (222)	Dominican Republic (224)	Chad (222)
Angola (222)	Ecuador (333)	Gabon (232)
Cambodia (222)	Guinea (233)	Haiti (233)
Congo (Zaire) (223)	Mali (234)	Laos (233)
Ethiopia (223)	Nicaragua (234)	Madagascar (222)
Mongolia (244)	Togo (234)	Mauritania (233)
Mozambique (222)	Tunisia (224)	Morocco (333)
Niger (222)		Myanmar (333)
Congo (Brazzaville) (222)		Paraguay (324)
		Zambia (334)
223 – 7 countries	**232 – 3 Countries**	
Benin (234)	Guinea Bissau (222)	
Burkina Faso(243)	Sudan (222)	
Burundi (222)	Honduras (234)	
Central African Rep (233)		
Morocco (344)		
Rwanda (244)		
Somalia (222)		
234 – 12 Countries	**235 – 3 Countries**	**244 – 9 Countries**
Algeria (234)	Malawi (244) TM	Bangladesh (333)
Cameroon (234)	Panama (356)	Bolivia (333)
Indonesia (325)	Venezuela (333)	Cote d'Ivoire (223)
Iran (323)		Gambia (222)
Libya (233)		Ghana (334)
Nepal (234)		Honduras (224)
Nigeria (334)		Jordan (345)
Senegal (233)		Sierra Leone (244)
Tanzania (334)		Suriname ` (222)
Uganda (234)		
Uruguay (334)		
Yemen (223)		
245 – 4 Countries	**343 – 2 Countries**	**346 – 3 Countries**
Botswana (245)	Saudia Arabia (223)	India (224)
Iraq (222)	Zimbabwe (345)	Turkey (325)
Mauritus (256)		Pakistan (224)
Sri Lanka (356)		
334 – 2 Countries	**344 – 2 Countries**	**355 - 2 Countries**
Guyana (344)	Colombia (344)	Philippines (446)
Syria (238)	Jamaica (345)	El Salvador (225)
335 – 3 Countries	**345 – 3 Countries**	**356 – 3 Countries**
Guatemala (344)	Malaysia (435)	Brazil (346)
Kenya (345)	Mexico (335)	Chile (335)
Peru (445)	Thailand (345)	China (456)
445 – 2 Countries		
Argentina (444)		

Egypt (335)		
<u>455</u> – 2 Countries		
Costa Rica (344)		

Table 1. Variables International Data Set

I. Endogenous Variables	Means	
	1970	**2000**
Dietary Energy Sufficiency (Calories consumed per capita)	2218	2460
Birth Rate	43.47	31.22
Death Rate	17.04	11.31
Child Mortality Rate	190.1	101.1
Malnutrition (weight "z" scores) Percent of children 0–6 malnourished	30.0	10.2
Malnutrition (height "z" scores) Percent of children 0 – 6 malnourished	32.0	27.8
II. Exogenous Variables		
GDP per capita	1024	1458
Real export price in U.S. dollars per tonne	0.92	0.52
Agricultural Scientists/Million hectares of cropland	0.06	0.11
Share of Agriculture in Value Added (percent)	29.6	22.7
Green Revolution Modern Variety adoption (percent)	3	26
Average Schooling Adult males (over 25)	2.89	5.13
Average Schooling Adult Females (over 25)	1.95	4.11
Rural Population Density	2.14	2.42
Hospital Beds per million population	2.15	1.78
Physicians per million population	0.26	0.70

Table 2. Six Equation System: Estimated by 3SLS Techniques with Country Fixed Effects

	Dependent Variables (t Ratios in Parenthesis)					
Independent Variables	**DES**	**Birth Rate**	**Death Rate**	**Child Mortality**	**Malnutrition (W)**	**Malnutrition (H)**
Constant	2293.4 (25.92)		27.06 (9.07)	0.482 (14.25)	63.76 (9.56)	77.83 (9.66)
GDP/Capita	0.0604 (2.72)				-0.0002 (0.28)	0.0005 (0.63)
AYSCM	51.34 (4.47)					
AGSC/MHA	190.63 (2.24)					
GRMV Adoption	2.71 (3.18)					
Real Export Price	-33.98 (2.07)					
ShAgr in GDP	-3.078 (2.30)					
AVYSCF		-4.388 (19.57)		-0.01528 (7.49)	-1.499 (4.18)	-0.7757 (1.80)
AVYSCF&M			-1.194 (6.22)			
Hosp Beds/Million Population		0.137 (0.48)				
Physicians/Million Pop			-0.277 (0.77)	-0.0105 (2.42)		
Rural Population Density			-1.097 (4.56)	-0.01515 (5.44)	-1.314 (2.40)	-0.1677 (0.26)
DES		-0.00535 (3.41)	-0.00449 (3.56)	-0.000117 (8.67)	-0.0177 (6.32)	-0.0240 (7.15)
R^2	0.823	0.935	0.901	0.906	0.931	0.862
Chi^2	1830	5648	3499	4011	5507	3106
P	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 3. Changes in Productivity under the Counterfactual Cases

	The No Green Revolution Case				The No IARC Case		
	1970s	**1980s**	**1990s**		**1970s**	**1980s**	**1990s**
Wheat Yield Changes							
LA	-1.32	-1.56	-.77		-.63	-.75	-.37
Asia	-1.12	-1.17	-.85		-.47	-.49	-.36
WANA	-.53	-.86	-1.39		-.25	-.41	-.66
SSAfrica	-.84	-1.09	-.85		-.40	-.52	-.41
Wheat Area Changes							
LA	1.2	-.2	-.5		.55	-.1	-.12
Asia	.51	.1	.02		.23	.05	.01
WANA	.95	.61	.60		.44	.28	.28
SSAfrica	.52	2.0	2.5		.24	.92	1.15
Rice Yield Changes							
LA	-.78	-1.31	-.88		-.31	-.52	-.35
Asia	-.99	-.97	-.71		-.36	-.35	-.27
WANA	-1.2	-1.2	-1.2		-.3	-.3	-.3
SSAfrica	-.08	-.57	-1.22		-.02	-.16	-.35
Rice Area Changes							
LA	-.05	-.05	-.05		.02	-.01	-.01
Asia	.5	.1	.02		.16	.03	.01
WANA	.9	.6	.6		.30	.20	.20
SSAfrica	.5	2.0	2.5		.16	.65	.82
Maize Yield Changes							
LA	-.47	-.55	-.86		-.14	-.17	-.26
Asia	-.69	-1.02	-1.37		-.29	-.40	-.55
WANA	-.4	-.5	-.8		-.1	-1.5	-.2
SSAfrica	-.13	-.48	-.20		-.07	-.24	-.10
Maize Area Changes							
LA	1.2	-.2	-.5		-.45	-.07	-.18
Asia	.5	.1	.02		.19	.03	.01
WANA	.9	.6	.6		.34	.22	.22
SSAfrica	.5	2.0	2.5		.19	.75	.94

Table 4. Counterfactual-based Effects on Crop Price, Production, Area and Trade

	Wheat	Rice	Maize	Other Grains	Potatoes	Other Root Crops	All Food Crops
Price Effects (Percent Increase)							
1970 CGI	29-61	80-124	23-45	21-50	13-31	283-52	35-66
No IARCs	19-22	30-35	13-15	14-16	2-3	15-32	18-21
Production Effects (Percent Decrease)							
1970 CGI	9-14	11-14	9-12	5-9	12-18	2-3	8-12
No IARCs	5-6	4-5	4-5	3-4	3-4	1-2	
Area Effects (Percent Increase)							
1970 CGI	3.2-5.6	7.5-9.4	1.1-1.9	.4-2.2	1.1-2.2	2.2-3.2	2.8-4.6
No IARCs	2.1-2.2	2.9-3.3	.5-.6	.5-.6	1.1-2.2	1.4-3.2	1.5-2.7
Trade Effects (Percent Increase)							
1970 CGI	31-19	0-2	45-46	25-19	100-120	21-65	27-30
No IARCs	7-6	0-2	16-18	1-2	16-33	11-12	6-9

Table 5. Impacts on Malnutrition

Malnutrition Effects	(Percent Increase)
No Green Revolution	
Latin America	1.8-2.3
Sub-Saharan Africa	2.5-3.3
Middle East-North Africa	1.8-2.3
South Asia	11-2-14.6
Southeast Asia	6.3-7.9
All Developed Regions	6.1-7.9
Millions of Children Affected	32-42
No IARCs	
Latin America	.6-.7
Sub-Saharan Africa	.9-1.0
Middle East-North Africa	.6-.7
South Asia	3.7-4.1
Southeast Asia	2.1-2.3
All Developed Regions	2.0-2.2
Millions of Children Affected	13-15