Hindsight and foresight about potato production and consumption

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Comments are invited.

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Hindsight and foresight about potato production and consumption

INTRODUCTION

Since its diffusion from the Andes in the 16th Century, the potato has been characterized by dynamism over space and time that has translated into widespread social change and economic impact (Salaman, 1985). The destruction of most of the potato crop by blight in Ireland in 1845 and the famine and social upheaval it contributed to is the best known example of abrupt change. Other instances of extreme dynamism have largely escaped public attention. For example, at one time in the late 19th Century, the mid-west State of Illinois was the largest producer of potatoes in the United States. Today less than 3,000 hectares of potatoes are planted in the State as the crop migrated from where consumers lived to specialized, compact regions of high production potential in the northern and western United States. More recently, potato production in Poland has fallen from about 1500 kgs per capita in the early 1970s to about 200 kgs per capita in the early 2000s in what is arguably the sharpest decline in the production of a major field crop in a country unaffected by war. Other less abrupt changes have also gone unnoticed. The slow but steady transition of the potato from a developed country crop overwhelmingly produced in the developed countries to a developing country commodity is a trend that has yet to capture the public's attention.

In this paper, we take a new look at the potato's dynamism over space and time. We update several of the trends and empirical facts that were analytically described in Horton (1987), Zaag (1991), CIP/FAO (1995), and Walker et al. (1999) in the first section of the paper. This rendering of relevant 'key' facts sets the stage for the second section: determining the correspondence between predictions and results from commodity projections that are presented in Scott et al. (2000). The analysis of trends and the validation of predictions leads to the confirmation of conventional wisdom in some cases, the identification of several important surprises, and the emergence of some new facts. The implications of these findings are discussed in a concluding section.

Two aspects of this report warrant more comment. Firstly, the analytically descriptive section on the documentation of key empiricisms and the normative part on the validation of predictions are mutually reinforcing often pointing to the same conclusions. Secondly, the key facts vary in their external validity as some apply to potato production and consumption globally and others are more location specific and conjectural for the lack of comparable experience or of country-specific data.

UPDATING KEY FACTS ABOUT POTATO PRODUCTION AND CONSUMPTION

In this section, we present and update several key facts (KFs) about potato production and consumption with the benefit of hindsight from 2008, the International Year of the Potato. The key facts are all derived from the temporal analysis of time-series data and are presented in a numerical format that is designed to tell a thematic story.

KF1. Since the second half of the 20th Century the relative importance of potato has slowly but surely shifted from developed countries to developing countries. The continuation of this trend means that a tipping point has been reached where more potatoes are produced in developing countries than in developed countries.

The secular shift in the relative importance of potatoes from developed to developing countries may not seem that surprising today, but this trend was not anticipated at the founding of the International Potato Center (CIP) in 1971 when the bulk of potato production took place during the long day-length summer months in the temperate countries of the North. Potato is characterized by a binding physiological constraint: a minimum daily temperature of 21 degrees C for bulking which limits its production to the cool season in the sub-tropics and to higher altitude locations in the tropics. That potato production would expand markedly in developing countries was not a certainty in the 1960s.

The salience of this trend in relative importance is not transparent in the FAOSTAT data if one relies on FAO's classification of developed and developing countries. Prior to Glasnost, the USSR was designated as a developing country according to the current FAOSTAT data. After the collapse of the Soviet Union in 1991, FAO reclassified most of the countries that comprised the erstwhile USSR as developed. The effect of this reclassification is evident in Figure 1.

Between 1992 and 1993, production in developed countries increased by about 70 million metric tonnes and production in developing countries declined by 50 million. This definitional change and the inclusion of the erstwhile USSR as a developing country masks the relevance of the trend in relative importance of global potato production between developed and developing countries. According to FAO's changing classification of the USSR and its resulting countries, potato output first crossed over—production in developing countries exceeded that in developed countries—in 1973.

Moreover, a false impression is given by Figure 1 that the upward trend in developing country production is a relatively recent phenomenon.

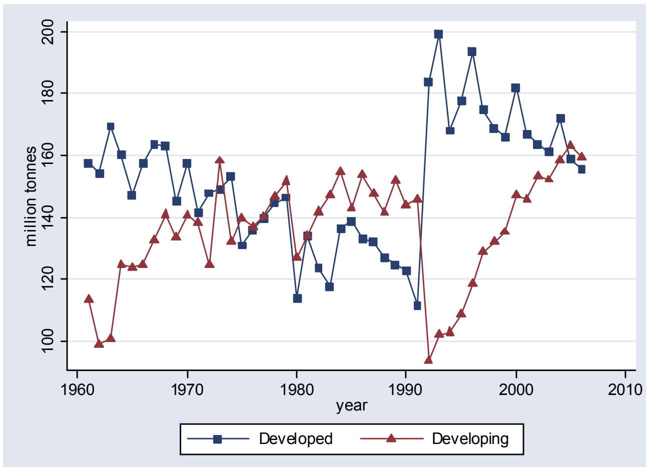


Figure 1.
Potato production from 1961-2006 by region based on FAO's classification of developed and developing countries in the current FAOSTAT data set.

The CGIAR in general and CIP in particular never viewed the temperate USSR as a developing country in its mandate. We classify the USSR as developed, which is consistent with the CGIAR's priority to focus improving agricultural productivity in tropical and sub-tropical low-income countries. This classification shows that potato was primarily a developed country commodity prior to CIP's founding in 1971 (Figure 2). Although developing country production increased by 50% from 1961 to 1970 and the initial indications of an embryonic trend were visible, Figure 2 suggests that potato was very much a developed country crop in 1970. The signs of a trend in shifting importance were not clear in the 1960s mainly because the developing country production base was small, and there was no general tendency for production to decline across developed countries as an aggregate as increases in productivity more than compensated for falling area.

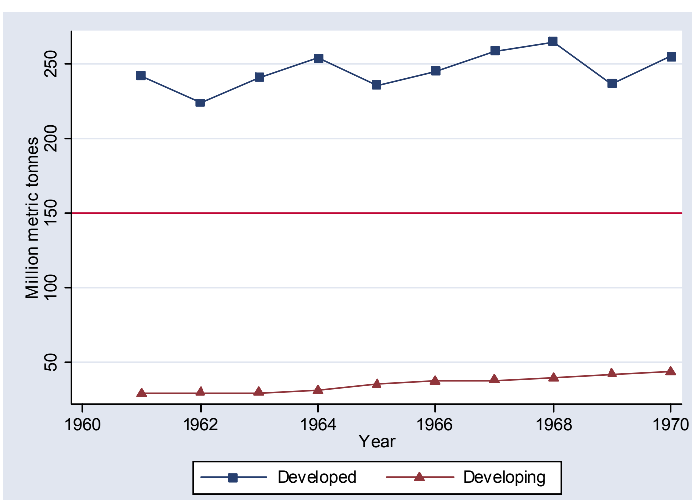
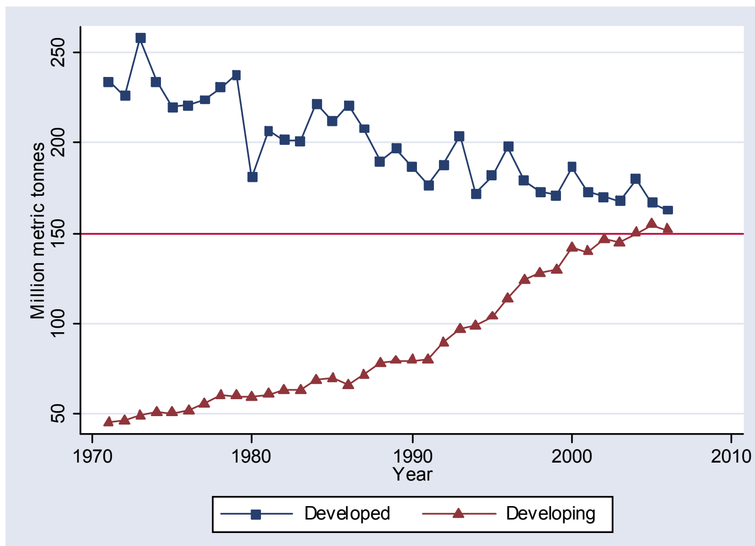


Figure 2.
Potato production from 1961-1970 by region based on the classification of developed and developing countries at the time of the founding of the International Potato Centre in 1971.

Although the dream of lowland potato production in the humid tropics has not materialized, potato has increasingly become a developing-country commodity capable of leveraging improved outcomes in well being for poor people in the tropics and sub-tropics (Figure 3). Seasonally cool production environments in the sub-tropics and higher altitude ecologies in the tropics have been exploited to accommodate rising demand for potato as an affordable vegetable. Recently, developing country production has broken through the 150 million ton level and is now at parity with developed country production. Since 2004 potato-growing acreage in developing countries has exceeded developed-country area (Figure 4).

Figure 3. Potato production from 1971-2006 by region based on the classification of developed and developing countries at the time of CIP's founding in the current FAOSTAT data set.



This gradual but steady transition in relative importance fully justifies the donor vision for CIP which was a risky institutional proposition at the time of its founding. Although the economic prospects were bright, there was no guarantee that potato would fulfill its destiny as an important cash crop in many low-income regions in developing countries. The rising relative importance of potato in developing countries is attributed to both the expansion of production in developing countries and the contraction of production in developed countries. The decline in developed country area has been steeper than the rise in developing country area in Figure 4.

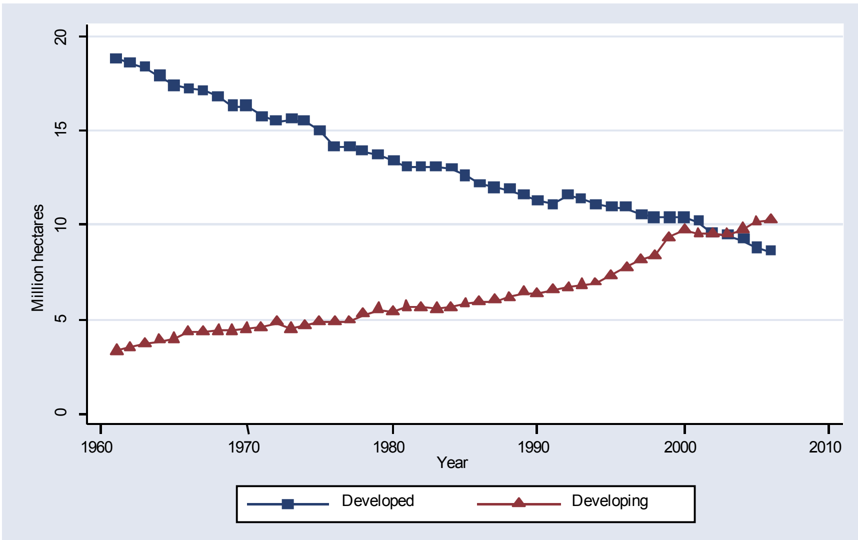


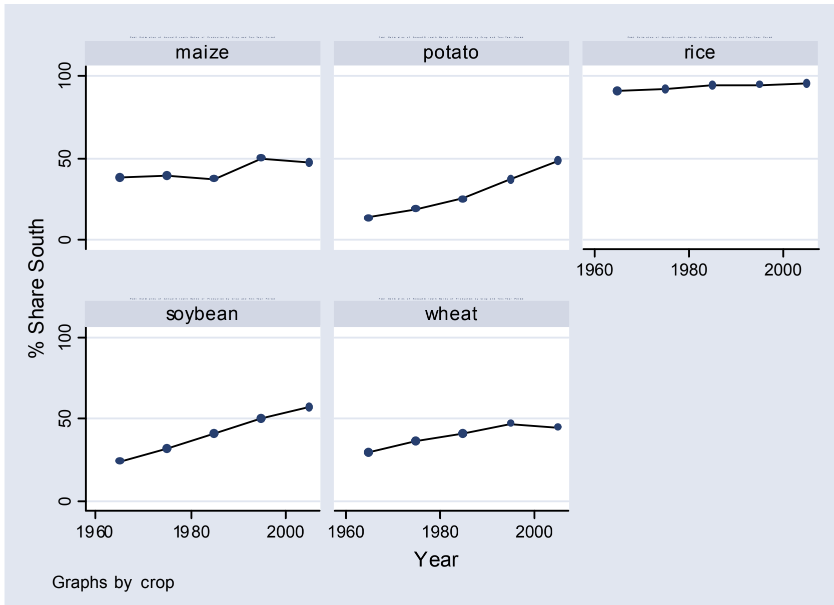
Figure 4.
Potato area from 1961-2006 by region based on the classification of developed and developing countries at the time of the founding of the International Potato Centre in 1971.

This trend in relative importance should continue, most likely at a diminishing rate, well into the 21st Century. For example, preliminary results from IFPRI's IMPACT model that is described in Section 2 suggests that by 2050 developing countries will lay claim to about 56% of global production (M. Rosegrant, 2008, personal communication). Growth is projected to be especially strong in Sub-Saharan Africa with a rise in relative global importance from 2.7% in the 2000 base period to 5.4% in 2050. This doubling in relative importance is driven by a projected annual growth rate of about 2.0%, the highest of any region in these preliminary results of the updated IMPACT Model. Among developing countries, South Asia is the other region projected for high growth; its share increases by about 50% from about 10% to 15% of global production. These results are being fine tuned in subsequent runs of the IMPACT model. The size of these preliminary estimates may change, but their direction, signaling the rising dominance of developing countries in global potato production, is irreversible.

KF2. Among major field crops, potatoes are not unique in attaining a tipping point of a greater than 50% share of global production in developing countries.

In the mid-20th Century, potato may have been the prime example of a major field crop where production became increasingly concentrated in developed countries, but its trend towards the rising importance of developing country output was not unprecedented. Four of five major field crops in Figure 5 fit the pattern of increasing relative importance of output from developing vis-a-vis developed countries. Rice which is mainly produced in warmer climates is the exception. Of these five major field crops with global production exceeding 100 million tonnes, the tendency for developing countries to make a larger contribution to production over time is moderate in maize and wheat and seems to have stabilized in the recent past. In contrast, a more marked tendency towards developing country production is noted in soybean and potato.

Figure 5. Shares of developing country output in global production for five major field crops in 1965, 1975, 1985, 1995, and 2005.



KF3. Among major field crops, shrinking production in developed countries is the aspect of the trend of rising relative importance of developing country production that is unique to potatoes.

Estimated annual growth rates calculated across four 10-year periods from 1965-75, 1975-85, 1985-95, and 1995-2005 for developed country production suggest that potato is the negative outlier in Figure 6. Only for potato was the growth rate consistently negative. Poor production conditions in several large producing countries in 1995 resulted in negative or sharply reduced growth for the period 1985-95 but that fluctuation is only an aberration in the strong productivity performance of maize, wheat, and soybean. Rice production in developed countries, mainly Japan, has stagnated, but even rice registered one decade of strong growth in production. As observed earlier, developed country production has never loomed that large in global rice output.

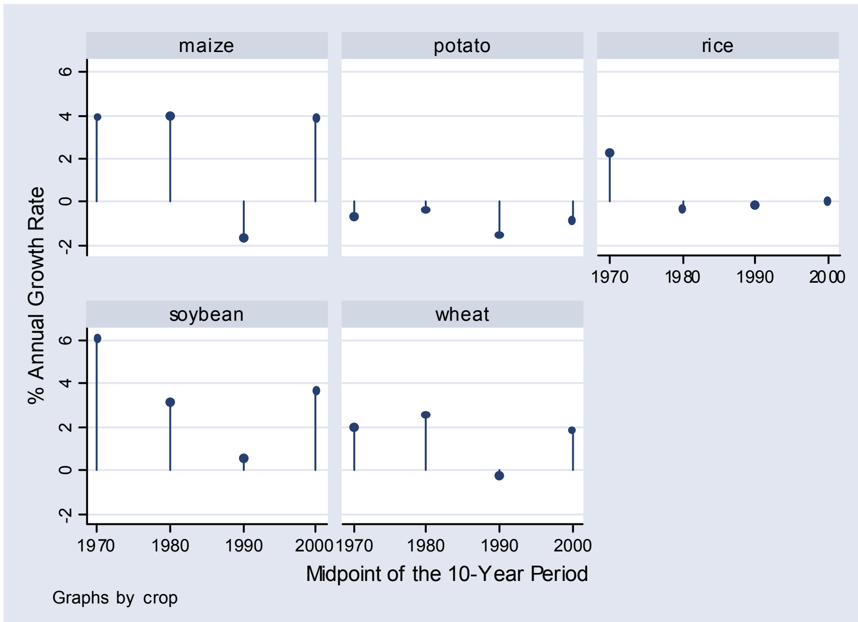
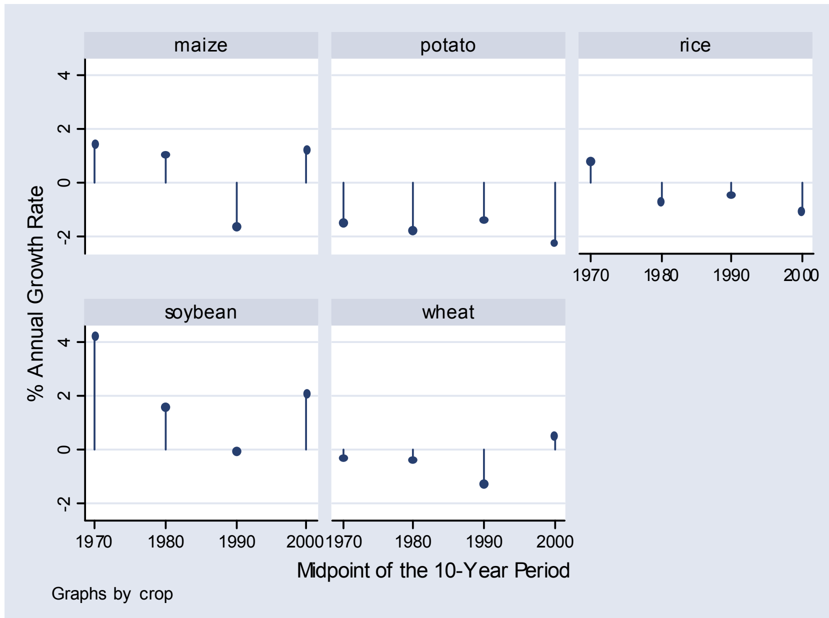


Figure 6.
Estimated growth in developed country production by major field crop from 1965-75, 1975-85, 1985-95, and 1995-2005.

As strongly suggested by Figure 4, the decline in developed-country potato production has been manifested in steadily declining harvested area. Over the four 10-year periods, this decline has consistently approached 2% per annum (Figure 7). In contrast, maize and soybean—two crops with diverse and versatile end uses—have enjoyed several periods of area expansion in developed countries. Estimated production growth approached or exceeded 4% per annum in three of the four periods (Figure 6). Protective policies have also contributed to the expansion of both crops, but it is unlikely that the elimination of such policies would have reversed the decline of potatoes in table and animal feed uses.

Figure 7. Estimated growth in developed country area by major field crop from 1965-75, 1975-85, 1985-95, and 1995-2005.



KF4. A sustained decline in potato production in developed countries results from the modernization of the animal feed sector, the rapid diet diversification away from a starchy staple with rising income, and the limited prospects for international trade in fresh table potatoes which is the dominant use globally.

Where potato has been a food staple in developed countries with intensities of production that exceed 100 kgs per capita, economic growth and modernization result in a long-term decline—usually across several decades—in the intensity of direct consumption and in potato's use as a feed source (Horton 1987 and Walker et al. 1999). The decline in fresh table consumption responds to Bennett's observations in 1936 that describe the transition from a potato economy to a wheat economy to a modern mixed economy. Completing this transition can be telescoped into a few years—e.g., East Germany during Reunification in the early and mid-1990s—but usually occurs over several decades. The contribution the staple food crop makes to energy availability falls steeply from about 80% at low income levels to about 25% at high income levels in northern Europe (Walker et al. 1999).

The use of potatoes as livestock feed is vulnerable to the forces of economic development and modernization. Economic development results in the demise of small mixed crop-livestock farms as the opportunity cost of labor and time steadily rise. Potatoes are normally steamed and sometimes made into silage before they are fed to pigs. Both practices are time consuming. As the economy develops, the incidence of price risk and fluctuations in production also decrease. Increased price and production risk made feeding potatoes to livestock in times of glut an attractive option.

Unlike other major field crops, international trade does not offer an opportunity to accommodate the steady decline in use intensity of potatoes for fresh consumption and for feed. Phyto-sanitary regulations restrict international trade in fresh potatoes particularly among developed countries, and fresh potatoes are characterized by high transport costs that restrict trading opportunities between developed and developing countries. In other words, the production potential of long-day summer growing conditions in temperate climates does not translate into a comparative advantage that can be used to export accumulating 'excess' production.

The decline in production intensity of potato in developed countries where it attained the status of a staple food crop would not be a self-fulfilling prophecy if the commodity were less bulky and if vegetative propagation was not the dominant form of multiplication. Only the Netherlands, the United States, and Canada have been able to partially offset the secular decline in domestic demand with exports mainly in the form of frozen french fries that dominate international trade in potatoes. These three countries have large trade volumes and slightly positive balances based on flows into their processing plants.

Although demand for frozen french fries is robust in many countries and international trade may be the only economic means to satisfy this demand, production in this high quality use is limited by severe economies of scale; therefore, export of frozen french fries is not in general a viable means to compensate for declining demand in table and animal feed end uses. Developed countries have no option but to 'wring out' hundreds of thousands, and in some cases millions, of tonnes of potatoes from their growing economies.

During the past 50 years, Poland and Germany are the extreme cases that best illustrate the secular decline in production intensity (Figure 8). Since the mid-1970s, production per capita in Poland dropped in truly dramatic fashion by about 30 kgs annually. The decline in Germany was not as sharp because the fall in production intensity started earlier in West Germany, but potato production per capita still diminished at an appreciable rate of 8 kgs per capita from 1961 to 2006. Annual potato production was about 65 million tonnes higher in the early 1960s than today. This reduction in production is equivalent to about 20% of current global production.

Moreover, Figure 8 does not do justice to the steep decline in production in East Germany following reunification. West German production declined markedly in the 1960s and 1970s.

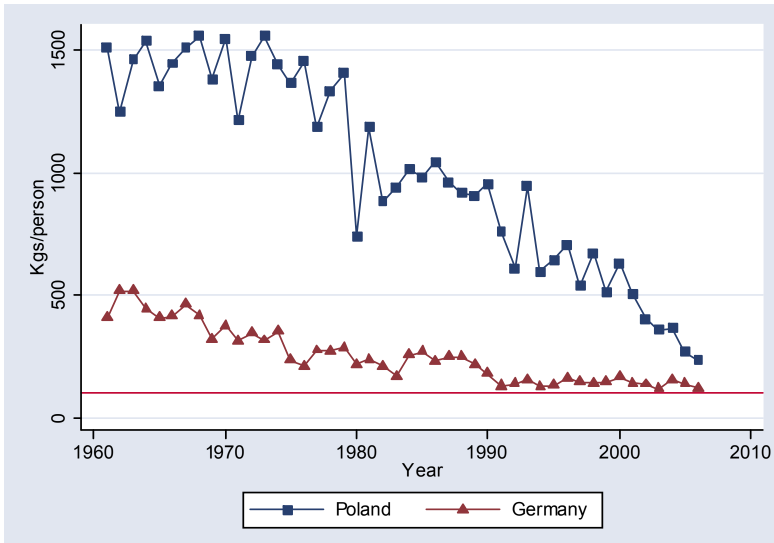


Figure 8. The decline in the intensity of potato production in Poland and Germany from 1961-2006.

Both Germany and Poland have experienced robust, verging on spectacular, rates of increase in maize production for animal feed in the recent past. For example, the growth rate of maize production in Poland from 1995-2005 exceeded 20% annually. Maize and other crops are replacing potato at a rapid pace. Concentrated small grains trump bulky roots and tubers as raw materials for livestock feed in a growing, modern economy.

Germany has finally arrived at a level of production intensity (about 100 kgs per capita) that approaches several other western European countries such as France where the transition of potato from a food staple and from a source of livestock feed to an affordable vegetable is further along the road to completion. In Poland, per capita production is still at a high level exceeding 200 kgs per person, suggesting considerable scope for squeezing out low quality potato production from the rapidly growing Polish economy.

Livestock feed as a use fell by about 80 million tonnes in 1971 to about 65 million tonnes in 1989 to about 40 million tonnes in 2003 (FAOSTAT 1971, 1989, and 2003). Poland is not the only country where the decline in potato production intensity is still expected with rising income. Belarus, Romania, the Russian Federation, and the Ukraine are all characterized by both high production intensities and allocations to animal feed that approach or exceed 20%. Sustained economic growth in these countries will set the stage for the rapid decline in potato production that East Germany and Poland experienced in the recent past.

Developing countries seem to be insulated from the economic forces that result in a declining use intensity of potatoes for animal feed and for table consumption in developed countries where potatoes are or were a staple. With the exception of the Central and southern Andes, small parts of the East African highlands, particularly Rwanda, and areas of northern and western China, potatoes almost never figure as a primary source of calories in developing country agriculture and their value as a vegetable crop is too great to destine appreciable quantities for animal feed even in times of surplus (with the apparent exception of China). The global population-weighted mean level of production intensity is about 60 kg per capita averaged across 114 countries with production per capita levels exceeding 5 kgs per capita. The ratio of mean weighted production intensities in developed to developing countries is 3.5:1.0. Fifteen developed countries have higher levels of production intensity than Rwanda which tops developing countries at about 150 kgs per capita. Of all developing country regions, northern China is probably most susceptible to stagnating demand, especially if regional inequality in economic growth diminishes. According to FAOSTAT (2005), about nine million tonnes of potatoes are fed to livestock, mainly pigs, in China.

KF5. Globalization of processed potato products, especially frozen french fries, has increased and stands in marked contrast to international commerce in fresh table potatoes that are mostly nontradeable because of high transport costs and effective non-tariff barriers such as phyto-sanitary regulations when developed countries participate in trade.

Specific hotspots of international trade in fresh potatoes are well known. The seasonal export of winter and spring potatoes from the WANA region, mainly Egypt, to Europe is a robust trade that has fueled the growth of potato production in North Africa and West Asia. By far, the largest trade in fresh potatoes in North America occurs between the United States and Canada. With the exception of occasional hiccups that are manifested in the so-called "potato wars", each year about 250 thousand metric tonnes of fresh potatoes are exported by each country to the other. A significant percentage of this trade comes from an economic hinterland to a processing plant located across the border. Fresh potatoes flow south from Canada to the United States in the East and the opposite occurs in the West.

Countries such as Malaysia and Cambodia in Southeast Asia, and small countries in Sub-Saharan Africa in the humid tropics are not favorably endowed with areas for production and have to import all of their consumption requirements that are often oriented to the lucrative tourist and hotel trade.

International trade in fresh potatoes is also likely to be underestimated in global trade statistics. For example, the bulk of potato production in Mozambique flows across the border to Malawi. In other developing country cases, the cross-border flows in fresh potatoes are two-way in response to price differentials. Notable instances include Colombia-Ecuador, Colombia-Venezuela, Uganda-Kenya, and Uganda-Rwanda. A large share of Pakistan's potato harvest is destined for richer countries in the Middle East; this sizeable export does not appear in FAOSTAT trade statistics.

In spite of such underreported local trade in fresh table potatoes between neighboring countries, international trade in the commodity is severely constrained by high transport costs and non-tariff barriers in the exchange of fresh potatoes. Non-tariff barriers mainly take the form of phyto-sanitary restrictions particularly when a developed country is involved as the importing country. Prior to the enactment and enforcement of NAFTA, fresh produce could not be exported from the United States to Mexico ostensibly because of concerns of contamination from the import of well-defined nematode species. Trade between Canada and the United States requires a great deal of coordination to deal with specific disease concerns such as potato wart. All it takes to stymie trade is to establish one disease risk (not found in the importing country) that is present in the prospective exporting country.

In contrast to the sluggish performance of and dim prospects for international trade in the commericalization of fresh potatoes, frozen french fries are the stellar source of international potato trade. The dramatic rise in importance in frozen french fries in receipts from international trade is illustrated in Figure 9 for Canada, a country that is recognized for the global trade of its potato products. The immediate cause of the strong trade in frozen french fries is also well-recognized: graphs showing the strong association of hundreds of millions of pounds of product consumed with the expansion in tens of thousands of fast food restaurants throughout the world are highly publicized. International trade in frozen french fries is dominated by the United States, Canada, and the Netherlands. The United States has the unique position of being the world's largest producer of the product and is also a net importer.

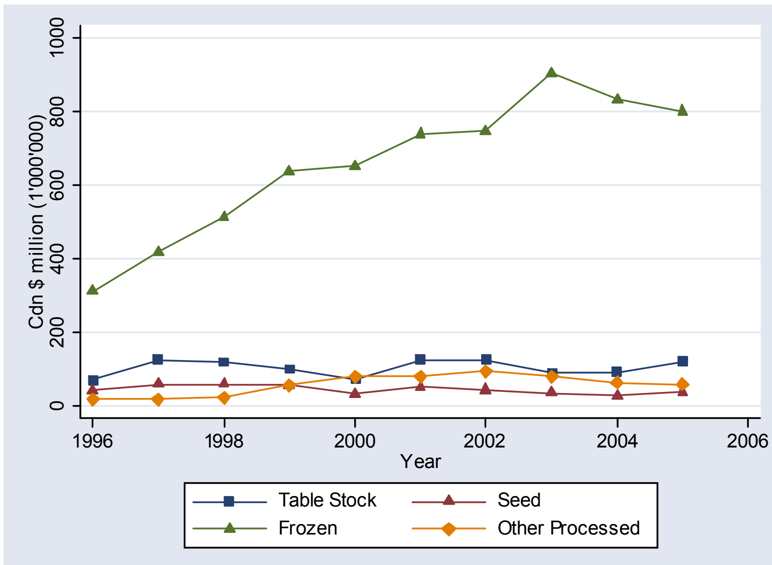


Figure 9.
The value of potato exports by Canada from 1996-2005 by product type (Source: Agriculture and Agri-Food Canada, 2007).

Two major implications, pertaining to developing country potato production, flow from KF5. The first is a major positive, and the second is a decided negative about the prospects for domestic production. International trade in potatoes is highly segmented into two components, fresh table stock and frozen french fries. Barriers to trade and high transport costs in the former mean that sustained demand for potatoes as an affordable vegetable will have to be met largely from domestic production. Economies of size and scale in the production of the latter mean that domestic production finds it hard to substitute for and satisfy the increasing demand for frozen french fries. This negative implication may seem like an over-generalization, but attempts by processors to penetrate the dynamic global frozen french fry market with production from developing countries such as China has thus far met with limited success. Prospects are brighter that domestic production could satisfy emerging and increasing demand in other processed potato production on a case-by-case basis, but frozen potatoes dominate the global trade of processed potato products.

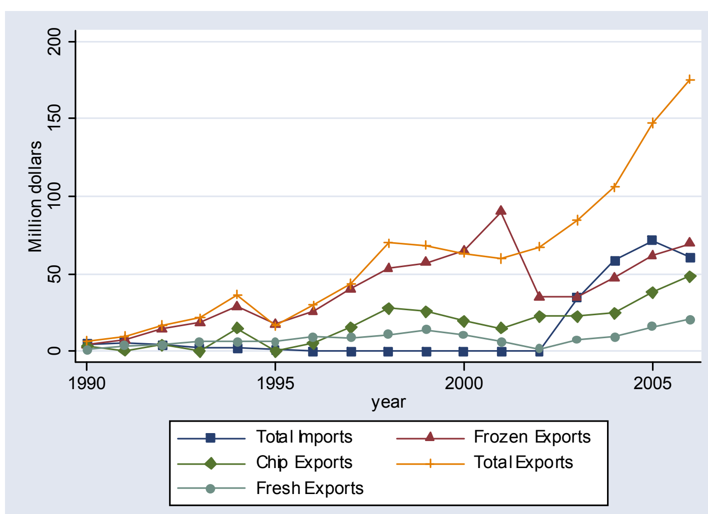
KF6. International and regional trade agreements have potential to enhance trade in potatoes, especially in end uses other than frozen french fries.

Having said that the international commerce in fresh potatoes is restricted does not mean that nothing can be done to expand global and regional trade. By the same token, the mere existence of international and regional trade agreements does not automatically imply that proposed reductions in tariff and non-tariff barriers will translate into augmented trade. The agreements have to be enforced, and the obstacles to enforcement are likely to be larger in potatoes than in other commodity areas because of the ease with which non-tariff barriers can be erected to block trade.

Empirical results from NAFTA suggest that regional agreements can eventually be effective in increasing trade. Because of NAFTA, the last protective barriers on trade in potatoes in North America expired on Jan 1, 2008. Compared to Mexico, Canada and the United States enjoy an overwhelming comparative advantage in the production of potatoes. But that economic edge does not extend to all production seasons and all potato products.

Between the mid-1990s when NAFTA was established and 2002, the trade trends in Figure 10 did not show much change from their earlier values. Trade in frozen french fries from the United States to Mexico dominated the picture. From 2002 onwards, trade between the United States and Mexico has taken off. This spurt in trade depicted in Figure 10 is characterized mainly by rising exports from the United States but also from increasing imports to the United States from Mexico. Both fresh potatoes and potato chips have contributed to increasing exports from the United States. Exports from Mexico are focused on potato chips as one or more U.S. manufacturers have established processing plants in Mexico in response to NAFTA. Domestic producers in Mexico gain as long as imported table stock is not destined for chip production. Figure 10 is consistent with the conclusion that, after some time, NAFTA has benefited potato consumers in both countries and has likely benefited potato producers as well.

Figure 10.
International trade in potatoes between the United States and Mexico from 1990 to 2006 from the perspective of the United States.



With or without NAFTA, trade in frozen french fries would most likely have continued on its same trajectory. Proportionally, NAFTA appears to have stimulated growing trade in fresh potatoes from the United States to Mexico and two-way trade in potato chips. Without NAFTA, it is unlikely that Mexico would have emerged as the U.S.'s second most important trading partner after Canada.

The import of seasonally fresh potatoes from Mexico is conspicuously absent in Figure 10. Comparable to the earlier noted winter and spring production of potato in North Africa and the Middle East for export to Europe, one would have posited that NAFTA would give rise to emerging imports of seasonal potatoes from Mexico to the United States and even to Canada. The non-existence of any trade in fresh potatoes from Mexico to the United States is surprising. It could arise from non-tariff barriers still in force or from Mexico's inferior competitive status in potato production relative to its partners. Historically, spring and even summer production of potatoes in the United States has receded in importance relative to production in the increasingly dominant fall season. Nowadays, production of potatoes in the South of the United States is only a shadow of its former self. Whatever the reason, the absence of two-way trade in fresh potatoes is surprising.

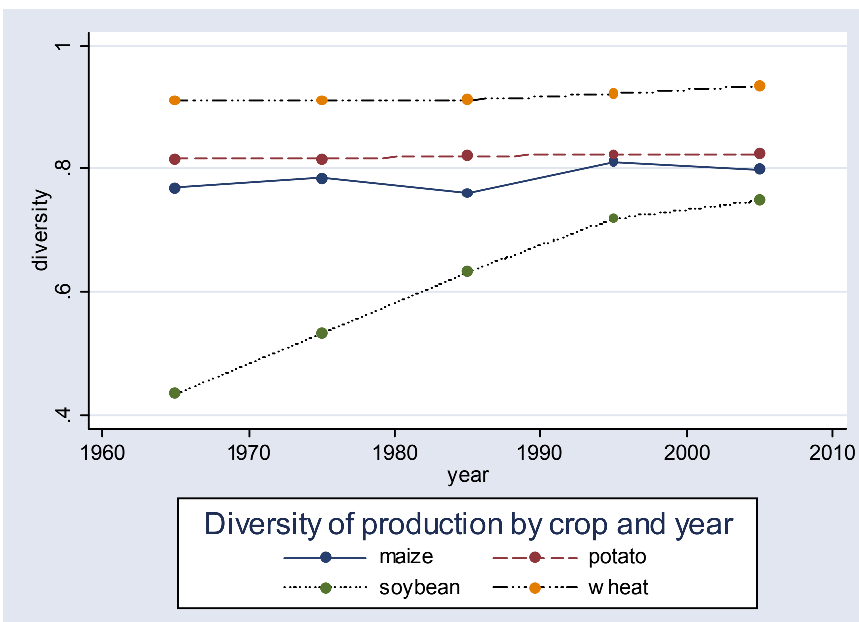
KF7. Similar to most other major field crops, the concentration of potato production across producing countries has not changed appreciably since 1965.

With increasing globalization and international trade, it is logical to expect increasing specialization in production as manifested in comparative advantage. Accordingly, one would hypothesize that production would become increasingly concentrated over time across countries. However, increasing concentration does not appear to be the case for any of the major field crops graphed in Figure 11 that presents estimates of a concentration index (the Simpson Index of Diversity) for five points in time. The index varies from 0 when production comes from only one country and approaches 1.00 when production is equally shared across numerous countries.

As displayed in Figure 11, maize is the least concentrated of the major field crops as maize can be and is produced in almost all countries. Potatoes and rice are also characterized by diverse production across countries. (Estimates for rice are not shown in Figure 11 because the levels of diversity are almost identical for potatoes). For soybeans, spatial diversity of production has been steadily increasing over time reflecting soybeans' status as the most rapidly expanding crop in the 20th century. In 1965, the United States accounted for over 70% of global soybean production.

For the other crops, the concentration of production has surprisingly not changed much in the past half century. The collapse of the Soviet Union imparted diversity to wheat and potatoes as what was a large aggregate production was divided across more than 20 republics. But, more importantly, increasing production in several large potato producers, such as China and India, compensated for declining production in other large producers, such as Poland and Germany. The country composition of production changed, but its distribution across countries did not. The prospects are bleak that globalization and gradually expanding trade will result in significantly more concentrated production across countries. (Globalization is hard to maintain over a long period as spikes in food prices are often marked by a return to policies oriented toward self-sufficiency). With the decline in production in several large producers in the northern hemisphere and the expansion of output in selected countries in South Asia and in Sub-Saharan Africa, the opposite would appear to be the case: concentration in global potato production will remain unchanged or could even decline. KF5 also implies that the forces for concentration in production from exploiting comparative advantage in international trade are weaker for potatoes than for other major field crops.

Figure 11. Estimated indices of diversity by major field crop for 1965, 1975, 1985, 1995, and 2005.



KF8. The production growth achieved in potatoes in developing countries has been strong in most regions and compares favorably to other major field crops.

Among the major field crops, three production-related observations stand out in Figure 12. First, both maize and potatoes have consistently registered solid growth rates in production over time. Secondly, growth in both rice and wheat production has tapered off over time. Thirdly, robust growth in soybean production exemplifies its transition from a secondary food and feed commodity to a major field crop.

Area expansion has fueled increased production in potatoes more than in any other major field crop with the exception of soybeans. The estimated annual rate of area expansion has approached or exceeded two percent in each of the four ten-year periods in Figure 13. Since 1975 the rate of area expansion in rice has been negligible. At the opposite extreme, soybean was characterized by annual rates of area expansion that exceeded 5% in two of the four ten-year periods. For both potatoes and soybeans, robust growth rates in area expansion are synonymous with small starting bases.

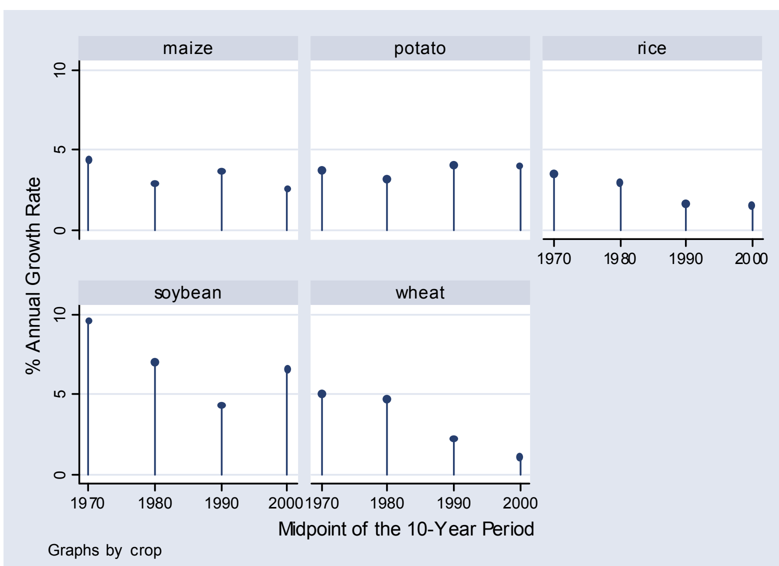


Figure 12. Estimated growth in developing country production by major field crop from 1965-75, 1975-85, 1985-95, and 1995-2005.

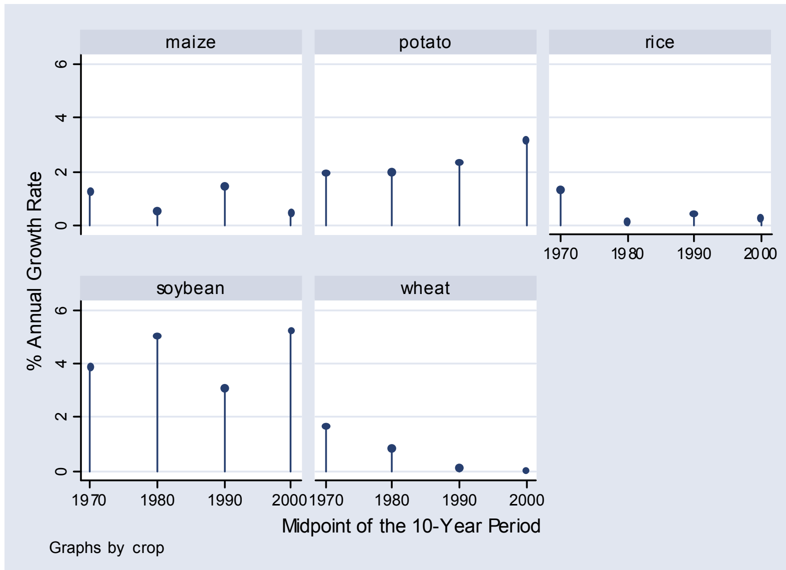


Figure 13. Estimated growth in developing area by mayor field crop from 1965-75, 1975-85, 1985-95, and 1995-2005.

Potato has chalked up solid rates of productivity growth in developing countries, but its performance in yield growth has not been as good maize, wheat, and rice (Figure 14). Growth in potato yield approached but never surpassed 2% in any of the periods in Figure 14. Although yield gains have contributed heavily to production growth, area expansion has played a relatively more important role in potato than in the major cereals.

Potatoes are highly responsive to inputs, and several sources of productivity growth such as seed quality and yield potential are qualitatively different in potatoes than in cereals. Seed quality looms larger in potatoes while higher-yielding varietal change figures more prominently as a source of yield growth in cereals.

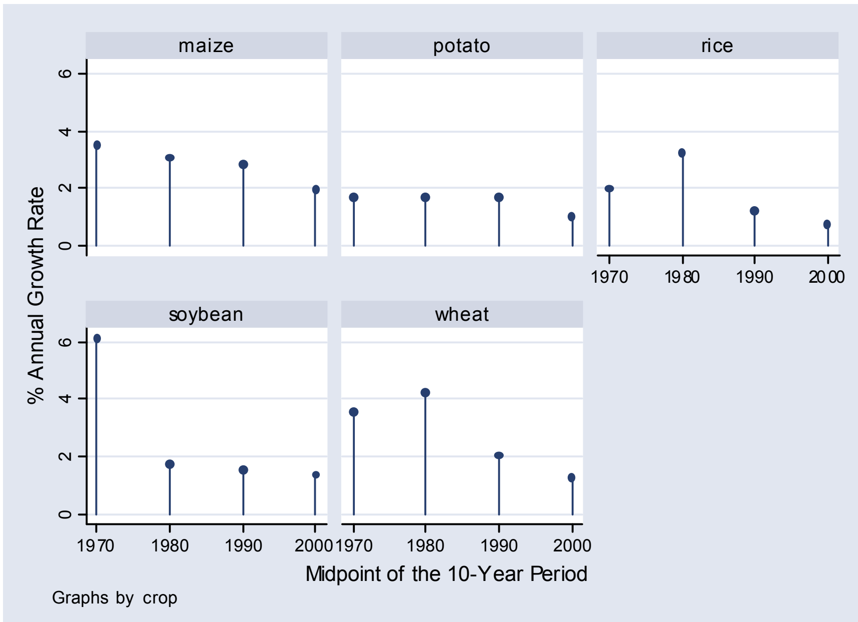


Figure 14. Estimated growth in developing country yield by major field crop from 1965-75, 1975-85, 1985-95, and 1995-2005.

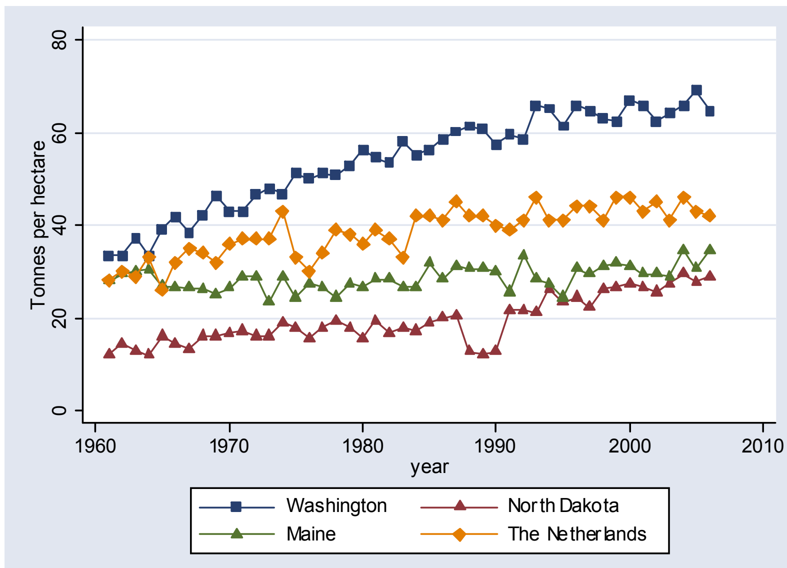
KF9. Stagnant potato productivity levels and yield plateaus seem to be an increasing problem in several specialized, compact potato-growing regions.

The 1930s, 1940s, and 1950s were the heyday of unprecedented growth of potato productivity in Western Europe and North America. Innovations in seed systems, pesticides, inorganic fertilizer, and irrigation resulted in marked growth in productivity. This pace of growth has been difficult to maintain in subsequent decades, and, nowadays, growth appears to be slowing down in several well-defined and highly productive potato-growing regions.

KF9 appears to apply to two of the four areas that are well-known for potato production and that are charted in Figure 15. The Columbia River Basin in Washington is one region where upward trending productivity is visible throughout the period from 1961-2006. Arguably, this high desert, irrigated region, characterized by fall production under long-day conditions, is endowed with higher yield potential than any other potato-growing area in the world. Since 1960 potato yields have doubled although the most widely grown cultivar, Russet Burbank, has stayed the same. But the data in Figure 15 hint at a slowing down in growth beginning in the early 1990s even in this most productive of potato-growing environments.

The Netherlands is a world-renown producer known for a dominant commerce in potato products and is home to a dynamic crop improvement program that relies heavily on private breeders. Since the mid-1980s, potato productivity in the Netherlands appears to have slowed and to have hit a yield plateau. A similar trend applies to other major potato producers in Western Europe, such as Belgium, France, and the United Kingdom.

Figure 15. Historical yield performance of potatoes in selected production regions of the United States and in the Netherlands from 1961-2006.



Since the 1890s, the Aroostook Valley in Maine epitomized high potato productivity with yield levels that rivaled any other potato-growing region in the world in the first half of the 20th Century. Although grown in a rain-fed production environment, conditions are highly favorable for production. Indeed, plotting yield over time in Figure 20 for the State of Maine conveys the high level of stability in production in an 'assured' rainfed environment but it also displays the absence of productivity growth during the past half century as yields fluctuate slightly around a constant level of about 30 tonnes per hectare.

Assured rainfall is not an attribute that would be associated with production in North Dakota's Red River Valley. Variability in production is manifested by the dip in productivity during the three-year drought of the late 1980s and early 1990s. In spite of rainfall uncertainty, yields have slowly but steadily increased in the Red River Valley of North Dakota. Two factors appear to be responsible for the modest but sustained upward trend in yields: a dynamic potato breeding program at North Dakota State University and an increase in irrigated area from less than 1% in

1974 to 26% in 2002. Yields in the Red River Valley in North Dakota are now on a par with those in the Aroostook Valley in Maine.

Potatoes are characterized by a very high harvest index and a yield potential that has not changed significantly in 100 years (Douches et al., 1996). Although the crop is highly responsive to input use, stagnating yield potential will eventually become an effective constraint to productivity growth in specialized potato-growing environments in developed countries especially in North America and northern Europe. In general, because of the notable disparity between potential yield and productivity in farmers' fields, a ceiling on yield potential should not pose an effective constraint for many years in developing countries.

But certain specialized production areas in developing countries may also not be immune to yield plateaus. Stagnating yields seem to have beset several of the dominant potato-producing districts on India's Indo-Gangetic Plain (Figure 16). Each one of the four districts graphed in Figure 16 produces more than one million metric tonnes of potatoes annually or did (prior to the bifurcation of Farrukhabad District in Uttar Pradesh in 1997). Presently, the three largest producing districts, Hooghly, Burdwan, and Midnapore (West) are all located in West Bengal. If any of these four districts were a country, they would rank in the top 50 potato-producing countries in the world. Hooghly would figure in the top 25. Production takes place in an intensive rice-based cropping system that features short-duration potato varieties planted in the cool summer season characterized by short-day growing conditions. This 'short' production ecology has been identified as one whose productivity is threatened by global warming (Hijmans, 2003).

Although data during the 1990s are missing in Figure 16, the remaining data tell a vivid story about productivity growth that reaches about 30 t/ha but which cannot be maintained. Whether or not sustainability is an issue depends on additional information that reflects factor productivity over time. In any case, it is transparent that a yield plateau has set in and that prospects for further productivity growth hinge on strategic research that addresses physiological constraints, water response, and component productivity in rice-potato sequential cropping systems (Bardhan Roy *et al.*, 1999).

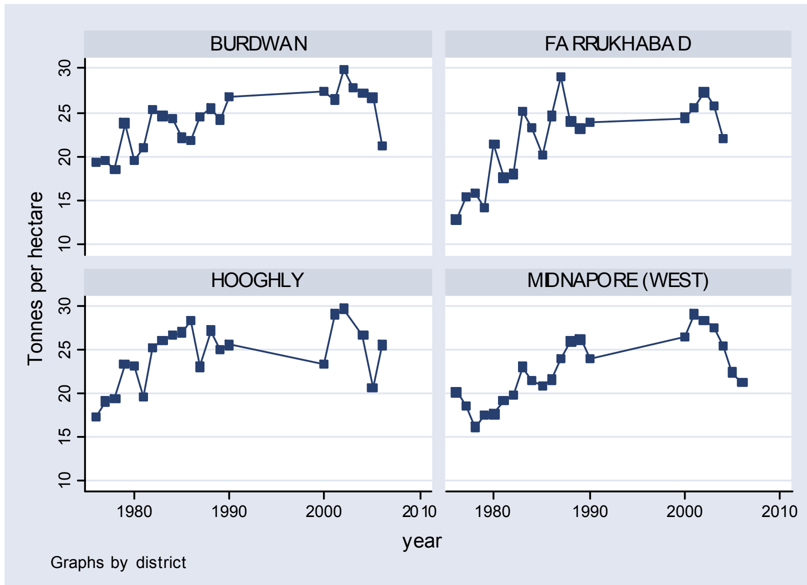


Figure 16. Historical yield performance in major potato-growing districts of India. Source: Agricultural Situation in India (various issues).

KF10. Shifts to irrigated regions and increases in irrigation within a region have conditioned (and will continue to influence) productivity performance in both developed and developing countries.

The determinants of productivity growth are often conceptualized in the narrow sense of a well-defined production ecology over time. At a national level, increased productivity can stem from three sources: (1) technological change within a region where the resource endowment for production is constant, (2) an increase in the resource endowment within a region, and (3) a secular shift in cultivation away from regions of lower resource endowment to regions of higher production potential. The first factor is more transparent than the second and third determinants which are often overlooked in any discussion of technological change. In the United States, all three determinants have contributed to national yield growth in potatoes that has bordered on spectacular, approaching 6.0% per annum from 1949-2007 (Figure 17). Over this period, annual productivity increments were equivalent to about 0.2 metric tonnes.

A large share of this productivity increase is attributed to technological change within a state—particularly Idaho and Washington—that was graphed in Figure 15. Irrigation, the main driver of a changing resource endowment, also expanded in all producing states. The simple average of the incidence of irrigation across all producing states increased from about 40% in

1974 to about 60% in 2002. Lastly, and more subtly, potato cultivation steadily shifted to compact production zones more favorably endowed with production potential.

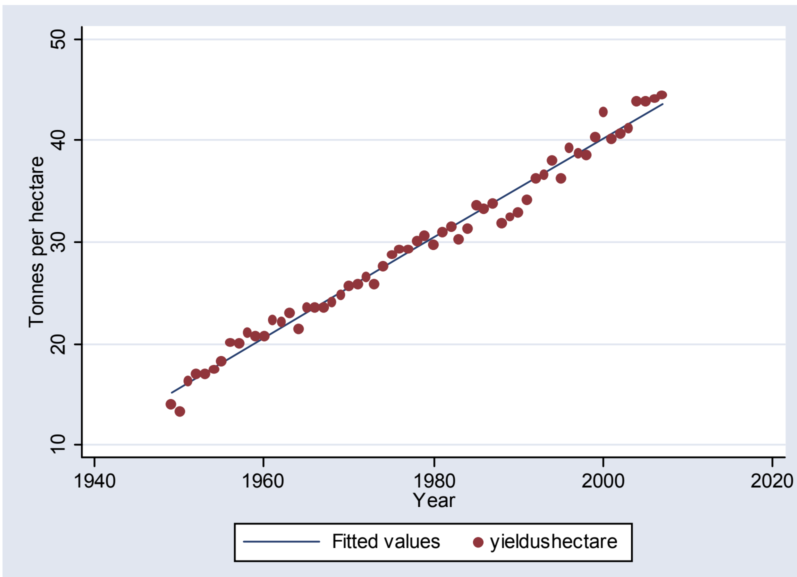


Figure 17. Historical yield performance of potato in the United States from 1949-2007.

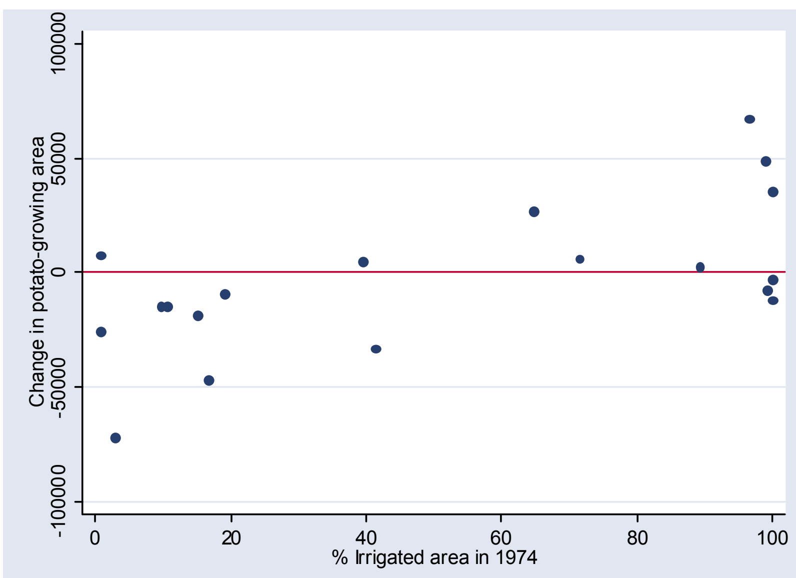
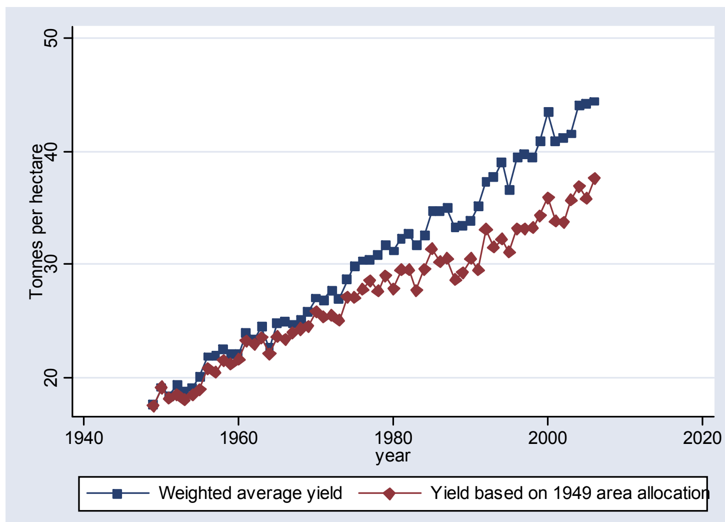


Figure 18. Change in growing potato-growing area between 1974 and 2002 by % irrigated area in 1974 for major potato-producing states in the United States.

Favorable production potential is synonymous with irrigation. As shown in Figure 18, the change in state growing area between 1974 and 2002 was positively associated with the level of irrigation in 1974. Many of the dryland states lost area; and several of the irrigated states gained area.

An illustration of the consequences of the geographic mobility of the crop is presented in Figure 19 where the estimated weighted average yield is compared to a fixed area allocation in 1949, which is tantamount to assuming geographic immobility. The growing gap between the two yield estimates over time reflects differences in production potential. By the early 2000s, the mean difference between the two productivity series was about 17%. In other words, mean national yield would have been 17% less had differential supply response not occurred. The 'migration' of potatoes to more favorable regions was accompanied by an increase in the concentration of production as the Simpson Index of Diversity declined from about 0.92 in 1949 to about 0.85 in 2006.

Figure 19.
Comparing weighted average estimated yield from 1949-2007 to a yield estimate based on a fixed allocation of area in 1949 across 18 major potato-producing U.S. states.



How well the U.S. experience in the specialization of production applies to other developed and developing countries hinges on several factors. The size of the country and the range of agro-ecologies for production are two key considerations. India is a country where specialization in production has increased as area shifted following Independence from cultivation in the rainy season in the hills to planting on the Plains in the cool dry season. Similar to soybeans, potatoes "descended" from the Hills to the Plains. Finding areas that escaped aphid infestation on the western Plains of Punjab and Haryana for seed production in the 1950s was the key piece of technological change that precipitated this geographic transition. One indication of specialization in production is the strong correlation between area and yield that is conveyed in Figure 20 for all districts that grew potato in India in 1990. Higher yielding districts are associated with more cultivated area.

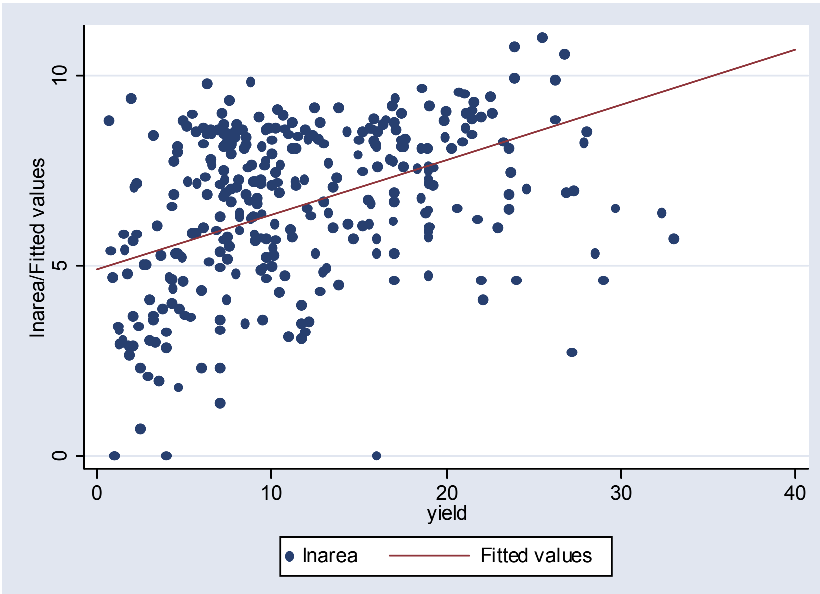


Figure 20.
The association between yield in tonnes per hectare and area across districts where potatoes were produced in India in 1990.

Surprisingly, the recent strong growth of potato production in China appears to exhibit none of the hallmarks of increasing specialization in production according to differentials in production potential. Indeed, the correlation between yield and area was decidedly negative in 2003, the only year for which we have assembled provincial data (Figure 21). More area is cultivated in lower yielding provinces.

Comparing provincial changes in cultivated area between 1991 and 2003 reinforces the same message: production is undifferentiated and specialization is not evident (Figure 22). The main 'gainers' of cultivated area are poor and low-yielding Gansu and Inner Mongolia provinces. The main 'loser' was erstwhile Sichuan Province, which was split into present-day Sichuan and Chonqing in the 1990s.

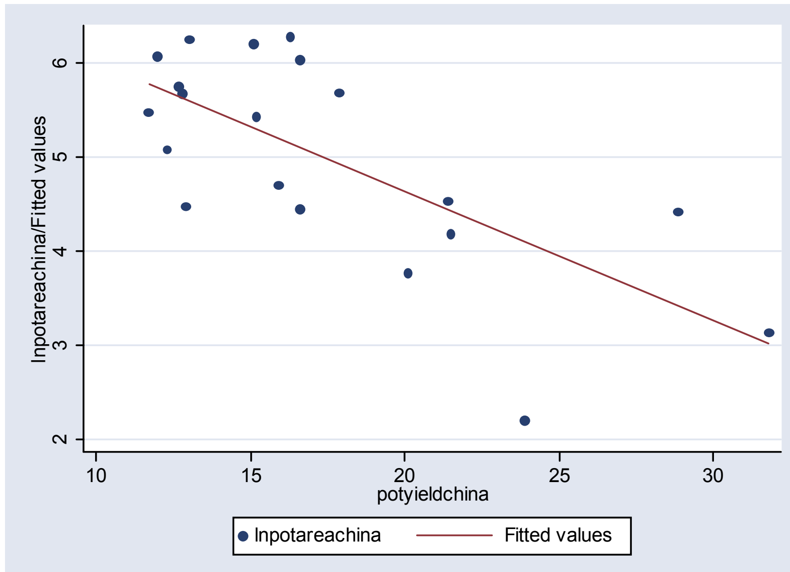


Figure 21. The association between yield in tonnes per hectare and area across provinces where potatoes were produced in China in 2003.

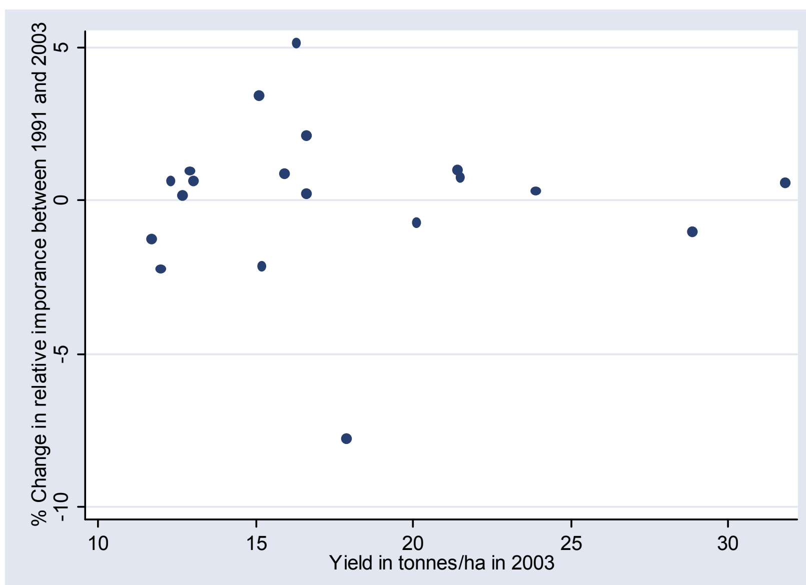


Figure 22. Change in the relative importance of potato production in China across provinces between 1991 and 2003 by yield.

Mapping potato cultivation in China reinforces this message as production appears to be scattered throughout a wide arc in the western and northern part of the country. Perhaps the transport system is not sufficiently developed in western and northern China to facilitate emerging specialization. Whatever the case, the seeming absence of differentiation in the presence of robust production growth in China is perhaps the most puzzling surprise identified in this report. Differentiation may yet appear as targeted geographic and commodity policies provide technology and infrastructure and as government investment stimulates the private-sector development of wholesale markets, processing plants, and seed systems.

KF11. If the United States and Canada are any indication, varietal change in potatoes still remains sluggish in developed countries.

One unique aspect of potato cultivation as a major field crop is the slowness of varietal change especially in developed market economies. This observation was duly noted by D.E. van der Zaag in 1991 in the context of the dominance of Bintje, a variety selected in the early 1900s by a Dutch hobby breeder and named for one of his students. Bintje was (and still is) widely grown in several important potato-producing countries in Western Europe. Bintje's equivalent in North America was the Burbank variety, which Luther Burbank selected from a seed ball in his mother's garden in 1872. A somatic variation of Burbank was reported found in Colorado in 1914 with a desirable russet skin covering. The diffusion of Russet Burbank took off in the West in the early 1930s and gradually spread eastward to lesser endowed, production environments as the cultivar is difficult to grow.

Economic impact from a plant breeding program is mainly a function of two variables: the per unit increase in net economic benefits of adopted varieties relative to the cultivars they replace and the velocity of varietal change. For maize hybrids in the corn belt of the United States and high-yielding, rust resistant wheat varieties in irrigation districts in Mexico, varietal turnover can be as rapid as three years. However, in potatoes, varietal change is slow in a mature economy for reasons outlined in Walker (1994). He hypothesized that varietal turnover should be more rapid in developing countries because of an effective demand for disease resistance because chemical control may not be effective and institutionally efficient seed propagation schemes may not be in place and because a premium is less likely to be attached to multiple market quality characteristics.

Because they are 'usually' sown from certified seed and area in certified seed is listed by variety by state in the U.S. and by province in Canada, reliable data are available to estimate varietal change.

In contrast, other major field crops rely on sexual propagation, and nationally representative varietal surveys are no longer conducted.

In estimating varietal change from the release of the first USDA-bred cultivars in the 1930s to the early 1990s, Walker (1994) underscores several interesting and important facets of the varietal change story for potatoes in North America. First, varietal turnover was slow as mean varietal age from the date of release to the annual average ranged from about 30 to 55 years for selected years between 1937 and 1992. Secondly, varietal age fell dramatically from the late 1930s to the early 1960s as widely adapted USDA-bred varieties such as Kathadin, Sebago, and Kennebec replaced widely grown 19th century varieties selected by hobby breeders. Thirdly, varietal age rose rapidly from the early 1960s to the mid-1980s. The pace of varietal change could not be maintained largely because of the increasing popularity of Russet Burbank. The mid-1980s to the early 1990s saw a quickening of varietal change. State programs in the United States and programs related to Agriculture Canada were delivering practical results as varieties bred in these programs were finding a home in farmers' fields (Agriculture and Agri-Food Canada**,** 2007). The stellar performer during the second half of the 20th century that was most responsible for reversing the trend of rising varietal age was Robert Johansen's potato breeding program at North Dakota State University. So the relevant question is: Has varietal age continued downward since the early 1990s or has this desirable trend in varietal turnover showed signs of reversal?

The answer to this question appears to be the latter. The recent data on certified seed area are consistent with a rise in varietal age (Figure 23).

There are several reasons for the upturn in varietal age that is tantamount to saying that the productivity of plant breeding has declined over this period. Russet Burbank is still the leading cultivar in six of the seven heaviest producing states. Several of the outstanding varieties, such as Russet Norkotah, that were released in the 1980s and early 1990s have turned out to be shorter lived than expected as their rates of disadoption have been higher than for the original set of USDA-bred varieties. Moreover, the window of opportunity for transgenic varietal change has thus far been closed to plant breeders in response to the concerns of the fast food industry about GMOs. On a more positive note, some breeding programs in the Pacific Northwest have made substantial progress in diminishing the dominance of Russet Burbank. Dutch varieties are now penetrating into the market in North America where growers have more varietal diversity to choose from than they have had in the past. But, in general, the recent estimates in Figure 23 for

2001 and 2007 lead to the conclusion that the incorporation of biotechnology into plant breeding programs has yet to translate into practical impact as it is still 'business as usual.'

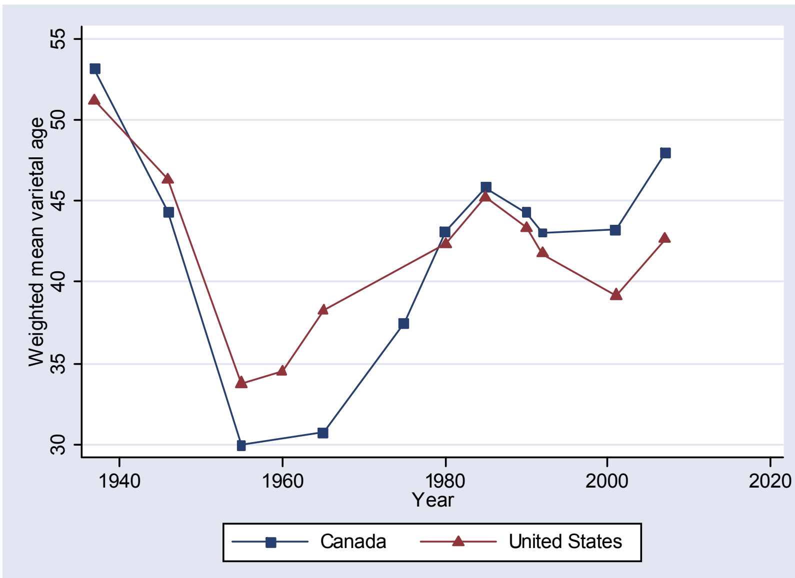


Figure 23. Estimated varietal age of potatoes cultivated in Canada and the United States for selected years from 1937 to 2007.

Comparing trends in potato production with projections in the IMPACT Model

An informative way to discuss trends in global, regional, and national potato production is to compare past projections with emerging reality. Such a comparison helps in the identification of conventional wisdom when projections predicted the future well and of surprises when projections deviated markedly from reality. Validating projections also contributes to more knowledgeable predictions from future modeling exercises. Armed with the descriptive information on key facts (KFS) from the previous section, these validations have an analytical base to draw on.

Comparing trends and projections generates valuable information when the model is rigorous in terms of its assumptions and is specific with regard to disaggregation so that a coherent story can be told to begin to explain matches to and departures from reality. In the 1990s, investment in multi-commodity global modeling increased, but some of these efforts did not result in reliable projections for potatoes because of the prevailing wisdom that roots and tubers were inferior goods compared to superior cereals such as wheat. Projections from such models led to severe underestimates of reality so much so that within a few years growth in production had exceeded the levels projected for 2000, 2020, or 2025.

One modeling effort that satisfied the requirements of rigor and specificity for our purposes of providing a valuable point of reference for documenting trends in potato production was the IFPRI IMPACT model. This general equilibrium model combined commodity expertise with a tested global commodity modeling framework with a focus on the production and use of four root and tuber crops in eight developing country regions and in developed countries as a whole (Scott *et al,.* 2000).

The period 1992-1994 was used as a baseline and projections were made on production and use to 2020 for both base and high demand scenarios. For comparative purposes, we draw mainly on the period from 1988-1990 to 2003-2005 for estimating trends. Specifically, we juxtapose projections for 2004 from the IMPACT Model with estimated production in 2004 from the FAOSTAT data, which are also the primary data source for the IMPACT model. For potatoes, the period 1988-1990 to 2003-05 is of particular interest because it includes the years immediately prior to glasnost and the post-glasnost period.

Projected and estimated levels of production are compared in Table 1. Projected and estimated growth rates are analyzed in Tables 2, 3, and 4. Overall, the IMPACT model did a very good job in predicting global potato production in 2004. The mean absolute percent error (MAPE) was only 1.2% in the base projection (Table 1). The high growth projection was also accurate with a MAPE of 2.4%.

The model's predictions were not as precise in forecasting regional production or for developing and developed countries. IMPACT generated predictions that underestimated developing country production about 20-30% with the high growth scenario being a more reliable forecast than the base projection (Table 1). In contrast, developed country production was 15% lower than predicted. Underestimates in developing countries production just compensated for overestimates in developed countries resulting in predictive accuracy for global production. In the sub-sections that follow, we discuss the predictive performance of the IMPACT model for developing and developed countries.

Table 1. Comparing projected to actual levels of production for potato in 2004.

	Production (million mt)				Difference (%)	
Country/ region	**1993 baseline**	**2004 base projection**	**2004 high growth projection**	**2004 actual**	**With base projection**	**With high growth projection**
Developing	94.3	117.5	126.5	152.5	+29.8	+20.6
China	42.5	50.0	57.1	71.3	+42.6	+24.9
Other East Asia	2.4	2.7	2.7	5.7	+111.1	+111.1
India	16.3	22.8	24.2	23.3	+2.2	-3.7
Other South Asia	3.5	4.8	4.8	8.8	+83.3	+83.3
Southeast Asia	1.3	1.6	1.6	1.25	-21.9	-21.9
Latin America	12.6	15.2	15.3	15.8	+3.9	+3.3
WANA	13.0	16.2	16.5	18.6	+14.8	+12.7
Sub-Saharan Africa	2.6	3.6	3.7	8.3	+138.8	+124.3
Developed	191.0	197.6	198.3	168.1	-14.9	-15.2
World	285.3	316.9	328.5	320.6	+1.2	-2.4

Source. Constructed from Scott, et al., 2000, and FAOSTAT data.

Developing countries

Production was underestimated in the IMPACT Model for six of the eight developing country regions in Table 1. Reasons for the strong growth of potatoes in developing countries were highlighted in the discussion of KF1 and KF8.

Regions where IMPACT underestimated growth in production. Although the IMPACT Model underestimated production in six developing country regions, much of the predictive error is attributed to not fully accounting for the robust growth of potato production in China in the 1990s and early 2000s. Between 1983 and 1996, potato production increased in China at a rate of 4.6% per annum. Between 1989 and 2004, the annual growth rate of potato production in China climbed to 5.4% per annum. China was the major beneficiary of the high growth scenario as the assumed rate of growth increased from 1.49% in the base scenario to 2.71% (Table 2). The high growth scenario was tailored to the bright potential for growth in production primarily in China and secondarily in India. However, production performance in China easily surpassed the prediction generated in the high growth scenario by 25%. Hence, the high growth scenario proved too conservative in predicting production performance in China.

Among Asian countries where production data for major field crops are generally reliable, the FAO production yearbooks convey an aura of uncertainty about levels of potato production in

China. For example, in 1978 at the return to private sector production in the form of the household responsibility system, the 1980 FA0 production yearbook showed 14.2 million metric tons less than the estimate in the current FAOSTAT database. In other words, the revised estimate for the 1978-1980 period was 26.7 million metric tonnes which was more than double of the erstwhile estimate in 1980 FAO Production Yearbook of 12.5 million metric tonnes. The magnitude of the FAO revision suggests that there were considerably more potatoes in China than conventionally thought in the 1960s and 1970s. At the time, the volume of this revision was equivalent to about 25% of developing country potato production.

Table 2. Comparing growth rates for potato production by region.

	Growth rates in % per annum		
Country/region	**Base projection**	**High growth projection**	**Actual (1988-1990 to 2003-2005)**
Developing	2.02	2.71	4.08
China	1.49	2.72	5.42
Other East Asia	1.13	1.18	0.80
India	3.10	3.67	3.14
Other South Asia	2.90	2.98	6.65
Southeast Asia	2.06	2.08	4.46
Latin America	1.72	1.76	1.37
WANA	2.02	2.21	3.32
Sub-Saharan Africa	3.01	3.06	5.02
Developed	0.31	0.34	-0.73
Eastern Europe	na	na	-5.14
CIS	na	na	0.08
Western Europe	na	na	-1.17
Canada and USA	na	na	1.55
Australia & New Zealand	na	na	1.75
World	0.96	1.29	1.14

Source: Constructed from Scott, et al., 2000 and FAOSTAT data.

Given the high rate of economic growth in China since the late 1970s, a low average per capita direct consumption barely exceeding 10 kgs in the early 1990s, and yield levels substantially below potential, a 5% rate of growth in production is credible. Increasing demand for processed potato products is one of the main drivers of expanding production (KF5). Although data are sketchy for processing as a use in many countries, China (most likely) accounts for more than 90%

of potatoes processed in developing countries especially if starch production is included in the calculation.

As treated in KF11 on its apparent absence of geographic specialization in potato production, China is unique among developing countries in destining an appreciable proportion (more than 30% in the early 1990s) of potatoes for livestock feed. Surprisingly, potatoes for pig feed seems to have grown as fast as other uses for potatoes in China. With specialization in production and globalization, one would have thought that potatoes for livestock use would contract similar to sweetpotatoes for pig feed in China and potatoes for pig feed in Western and Eastern Europe (KF3).

China is the largest potato-producing country in the world, and it also figures as the greatest source of uncertainty in predicting future performance in potato production among developing countries. Cultivable land is extremely scarce in China; it is unlikely that a 3.4% growth rate in area can be maintained (Table 3). On the other hand, sustaining a growth rate in productivity of 2.0% (Table 4) should be an attainable target particularly if increasing specialization in production takes place over time. Arriving at a better understanding of the spatial distribution of production over time is a priority for more informative projections. The unique (among developing countries) use of potatoes for livestock feed also warrants more research to determine if it is a sustainable proposition, a transitory phenomenon based on distorted policies, or a regional consequence of highly specific mixed ecological and economic conditions.

Among the other five regions for which actual production exceeded its predicted level in the IMPACT model, Other East Asia (OEA) and Sub-Saharan Africa (SSA) were characterized by MAPEs that exceeded 100% in Table 1 even in the high growth scenario. Both South and North Korea contributed heavily to the growth in potato production in the OEA. Largely in response to relief measures and food security concerns, potato-growing area in North Korea expanded by 7.6% annually between 1989 and 2004. Within a few years, North Korea should be a larger producer of potatoes than Japan where area is contracting and which has been an outlier in terms of unusually low per capita consumption given its high income level (Walker *et al.*, 1999).

Table 3. Comparing growth rates for potato area by region.

	Growth rates in % per annum		
Country/ region	**Base projection**	**High growth projection**	**Actual (1988-1990 to 2003-2005)**
Developing	0.51	0.84	2.72
China	0.17	0.67	3.40
Other East Asia	-0.41	-0.39	2.42
India	1.19	1.71	2.40
Other South Asia	0.89	0.92	4.12
Southeast Asia	0.59	0.58	3.17
Latin America	0.41	0.43	-0.34
WANA	0.55	0.67	1.30
Sub-Saharan Africa	1.25	1.27	4.72
Developed	-0.19	-0.18	-1.56
Eastern Europe	na	na	-5.05
CIS	na	na	-0.02
Western Europe	na	na	-3.14
Canada and USA	na	na	0.00
Australia & New Zealand	na	na	-0.01
World	0.09	0.23	0.30

Source: Constructed from Scott, et al., 2000 and FAOSTAT data.

The poor predictive performance of the IMPACT model in SSA is partially an artifact of including South Africa as a producer but is mainly related to conservative estimates on the scope for area expansion of about 1.25% when the estimated rate of area growth exceeded 4.0% (Table 3) (See KF8). Area expansion was most pronounced at a spectacular annual growth rate of 16.9% in Angola which recovered from civil war. Cameroon, Malawi, Rwanda, Sudan, Uganda, and Zaire were all characterized by growth rates of area greater than 5%.

Table 4. Comparing growth rates for potato productivity (yield) by region.

	Growth rates in % per annum		
Country/ region	**Base projection**	**High growth projection**	**Actual (1988-1990 to 2003-2005)**
Developing	1.50	1.85	1.36
China	1.32	2.04	2.02
Other East Asia	1.55	1.57	-1.62
India	1.89	1.94	0.07
Other South Asia	1.99	2.05	2.53
Southeast Asia	1.46	1.49	1.29
Latin America	1.30	1.33	1.71
WANA	1.46	1.53	2.03
Sub-Saharan Africa	1.74	1.77	0.29
Developed	0.50	0.52	0.83
Eastern Europe	Na	na	0.00
CIS	Na	na	0.10
Western Europe	Na	na	1.98
Canada and USA	Na	na	1.57
Australia & New Zealand	Na	na	1.89
World	0.87	1.06	0.84

Source: Constructed from Scott, et al., 2000 and FAOSTAT data.

Contrary to its performance in area, SSA did not appear to live up to the expectations of about 1.75% rate of yield growth assumed in the IMPACT model (Table 4). However, statistical agencies in most countries do not carry out crop cuts on potatoes combined with estimates of plant populations in an area sampling frame; hence, productivity data on root and tuber commodities in SSA are notoriously unreliable. For example, clean tuber seed and higher-yielding varieties were rapidly adopted by potato farmers in Rwanda in the 1980s, but yields remained stagnant according to data collected by the Ministry of Agriculture. There is substantial potential for augmenting productivity in SSA; however, availability to inorganic fertilizer is a prerequisite for heavier potato yields.

Other South Asia (OSA) was another region where the IMPACT model's projections were significantly lower than actual production levels. Several countries substantially exceeded the reasonably optimistic growth rate that approached 3.0% in the IMPACT Model. In particular, Bangladesh, Nepal, and Pakistan experienced robust growth in both area and yield. Growth in the 1990s and early 2000s was a continuation of impressive growth in production registered in the 1970s and 1980s in the Subcontinent.

The IMPACT model did a reasonably good job of predicting production in West Asia and North Africa (WANA) and in Latin America although the projections resulted in lower estimates of production than what occurred. Optimistic rates of production growth exceeding 2.0% were well founded on production performance in the 1970s and 1980s for the WANA region where many countries export a part of winter and spring production to Europe. Several countries exceeded projected production. Algeria, Iran, Iraq, Jordan, Lebanon, and Saudi Arabia all experienced rates of production growth that exceeded 5% and Libya, Egypt, Morocco, and Tunisia approached or exceeded the projected growth rates for the region. Only Turkey was characterized by stagnating production from 1989 to 2004.

The IMPACT Model accurately predicted moderate growth in potato production for Latin America. Peru was the stellar performer among larger producing countries in the 1990s recovering from difficult times in the 1980s. Potato production also increased rapidly in Brazil exceeding a 2.0% growth rate in response to rising income during the 1990s and early 2000s. Several Latin American countries, especially those where potatoes figured as a staple food crop for one or more regions, did not meet the expectation of a moderate rate of growth.

Regions where IMPACT overestimated growth in production. In contrast to the six previous groups of developing countries, projected output was greater than realized production in two regions, Southeast Asia and India. In the former, the shortfall in production was most likely due to a mis-classification of countries such as Myanmar in other regions and is less a reflection of the absence of potato growth in Southeast Asia. Both Indonesia and Thailand substantially exceeded the IMPACT expectations on production growth.

In India, IMPACT slightly underestimated productivity growth in the base scenario and overestimated productivity growth in the high demand scenario. According to the IMPACT Model, yields were forecast to increase at about 1.90% per annum (Table 4), but the actual rate of yield increase was not statistically significant from zero. This shortfall between actual and expected yields is surprising but it reinforces the discussion in KF9 as summarized in Figure 16. As hypothesized in the previous section, this shortfall may reflect that on-farm potato productivity is bumping up against yield potential when grown in rice-based cropping systems on the Indo-Gangetic Plain in short-day, cool-season conditions. Concerns, expressed in the 1990s, about stagnating productivity in the widely cultivated rice-wheat cropping system may also apply to potato productivity in these intensive multiple-cropping sequences. On-farm trial data patterned along the lines of yield-gap experiments in the major growing districts need to be analyzed over time to determine the size of the problem of stagnating productivity suggested by the FAOSTAT data.

Developed countries

Estimates for regional aggregates of developed countries were not presented in Scott et al. (2000) which focused on developing country prospects. In general, the modelers were less sanguine about the prospects for potato production in developed countries. Productivity growth was projected at 0.31-0.34 per annum as projected growth in yield of about 0.5% more than compensated for a projected decline in area of –0.18% (Tables 2, 3, and 4). With hindsight, the authors were overly optimistic about the growth prospects for potato production: the actual growth rate was negative at –0.73% and about twice the size of the absolute value of the projected rate. Yield growth at 0.83% per annum exceeded expectations, but a steady contraction in area in a few prominent producers translated into substantial negative growth for developed countries as a whole (KF5 and Figure 7).

Five developed country groups with widely varying potato prospects are described in Tables 2, 3, and 4. Both Eastern and Western Europe were characterized by negative growth rates. As presented in KF4 and Figure 8, the estimated production trend in Eastern Europe was dominated by events in Poland where the use of potatoes as livestock feed became decidedly uneconomic following glasnost and where income gains spurred diet diversification away from potatoes as the staple food crop. Potato production declined sharply at 6.8% per annum in Poland from 1989 to 2004.

With hindsight, the steep decline of potato production in Poland was predictable and merely represented an acceleration of an ongoing trend. Perhaps the surprising element of the Polish case was the apparent absence of a growth in yields as one would expect areas of lower production potential to be more vulnerable to more market-based supply and demand. Albania was the only Eastern European country to experience a marked increase in potato production in the recent past.

Likewise, the trends in Western Europe were dominated to a lesser extent by what happened in one country, reunified Germany (Figure 8). Production fell off sharply in the provinces of erstwhile

East Germany as the growth rate in area declined by more than 5% per annum for the country as a whole. But an increase in productivity of 2.5% did cushion the fall in area such that production only fell by 2.5% per year in the largest producer in Western Europe. Spain and Portugal also experienced a steady decline in potato area; gains in productivity helped to offset some of the setbacks in area but production still declined in a marked manner. Competition from the WANA region in supplying winter and spring potatoes to Western Europe may contribute to the decline in potato production in the Iberian Peninsula. No Western European country was characterized by a statistically positive trend in area and, for most, gains in productivity did not compensate for declining area as production also fell.

In contrast to Europe, production increased moderately in both Canada and the United States and in Australia and New Zealand (Table 2). All of the growth in production is attributed to a growth in yield (Table 4). These growth rates are not significantly different from those estimated for the same sets of countries in the 1980s. Consumption of processed potato products has fueled growth in potato production in these countries particularly in the United States (KF5). Use of potatoes for livestock feed never played a large role in these land abundant economies, and the limited quantities of potatoes fed to livestock declined to negligible levels many years ago. Hence, these countries do not face the threat of sharply declining area from an increasingly uneconomic end use that was extensively discussed in KF3.

Several countries from the erstwhile Soviet Union do face this prospect, and we would have expected that production in the Russian Federation, Belarus, and the Ukraine would have declined following the downward production trajectory of Poland and Germany. But total production for the new Independent States in 2004 was the same as for the USSR in the late 1980s. The absence of change in production testifies to the limited economic growth that has taken place in these countries since glasnost. In future projections, what happens in the CIS is the biggest source of uncertainty pertaining to potato prospects in developed countries.

CONCLUSIONS

This report has aimed to provide hindsight about the recent past with an eye towards making more informative assessments about potato production, consumption, and trade. Revisiting trends has not only confirmed conventional wisdom, but has also generated surprises. The shift in relative importance in potato production and consumption from developed to developing countries is the trend that received the most attention. The direction of this transition in geographic relative importance has been widely documented, but its pace has escaped the notice of several audiences such as modelers and the general public.

Two aspects of potatoes' becoming a crop that is more produced and consumed in the South than in the North are surprising. The first pertains to the steady contraction of potatoes in some developed countries in continental Europe where the crop is a food staple. In our analysis of growth of area and yield in five major field crops in developed and developing countries, two of the 20 estimates statistically stand out: the decline in area in potatoes in developed countries and the expansion of soybeans in developing countries. In particular, modelers and analysts have a hard time coming to grips with the rapidity with which economic growth in a lower income developed country, such as Poland, can result in declining production and consumption.

The second aspect of potatoes faster than anticipated rise in relative importance in developing country agriculture has been the surging growth in production in China in the recent past. With hindsight, such growth could have been anticipated as cultivated area in China was underestimated by 30%, and more precise statistical data should have resulted in estimates of increased production across several crops but that does not appear to be the case as the production of some crops such as rice has stagnated in China. What is most surprising about China's 'surging' potato output is the undifferentiated nature of production across the leading agro-ecologies. Agro-ecological differentiation among the potato production systems in China is not yet conducive to geographic specialization. As yet, production shows no signs of specialization in smaller compact areas of higher yield potential. Potatoes as pig feed is reportedly an important use across several provinces in China. The distribution of potato production in western and northern China in the early 21st Century seems to be as undifferentiated as the distribution of production was in Europe and North America at the end of the 19th Century.

Foresight also suggests some surprising characteristics of the steady trend in relative importance towards greater developing country production and consumption of potatoes. Preliminary estimates from IFPRI's IMPACT model show rising importance of potato in selected countries in Sub-Saharan Africa, so much so, that by 2050 about 5% of global potato production is predicted to come from SSA. Both hindsight and foresight point to the increasing potential of potato to be an engine for poverty reduction in agricultural-based developing economies and regions.

Like the trend in relative geographic importance that occupied center stage in our analysis, several surprises or re-confirmations of conventional wisdom were about the quantitative pace of change. For example, the rapid globalization of processed potato products, particularly frozen french fries, the very slow expansion in the international trade of fresh table potatoes, and the slow rate of varietal turnover of released potato cultivars in developed countries were all anticipated.

Some documented outcomes, particularly surprises, were qualitative in nature. We did not anticipate that NAFTA would show signs of stimulating two-way trade in potatoes between the United States and Mexico, that the emerging upward trend, documented in the early1990s, in the pace of varietal change would be reversed, that specialization in production would still loom so large in determining potato yield growth in the United States, that potato productivity on the Indo-Gangetic Plain in India could hit a yield plateau, and that increasing commodity concentration across producing countries would not occur for major field crops in an era of globalization.

This trip through the recent past with an eye towards the future has generated several insights for potato research and also for modeling potato supply and demand. For example, the strong showing of potatoes in South Asia, particularly India, during the second half of the 20th Century could be compromised by stagnating productivity as manifested by yield plateaus in farmers' fields in the Indo-Gangetic Plain. Unless strategic research on heat tolerance and improved yield potential under short-day, short-duration conditions translates into practical impact, the only way to increase potato production in this land-scarce region of the world would be through crop substitution. Temporal research on total and partial-factor productivity is warranted to assess the sustainability of these intensive rice-based systems that feature potatoes as the cool season crop.

With regard to modeling, our results illustrate the differential prospects in international trade for processed potato products vis-a-vis fresh table stock. Demand projections that do not account for these heterogeneous prospects are likely to overestimate the extent of trade in the future because the bulk of production in fresh potatoes is unlikely to be traded in response to price differentials among developed countries and between developed and developing countries. Understanding the irrigation dynamics of the crop is also important in modeling potato supply. Increasing irrigation in a region and shifting of growing-area to regions of greater production potential can figure prominently as sources of productivity growth especially when potatoes are produced as a vegetable crop.

The hindsight presented in this report is not perfect. It is beset by data limitations and incomplete coverage. An over-emphasis on the United States in this report is attributed to the adequacy of its data on multiple aspects of potato production and consumption. Potatoes were the first crop on which the USDA began collecting data in the early 1860s. The United States also epitomizes the geographic specialization in potato production that is an expected trend in major potato-growing countries in this century. But better balance could have been achieved if information from several of the largest European producing- and consuming-nations, such as the Netherlands, France, and Belgium, could have been brought into the mix of key facts. The Andes is another region that has not been probed to any extent in this report.

Data limitations are more difficult to address than problems of incomplete coverage. Potato production data in general and yield estimates in particular are notoriously unreliable in Sub-Saharan Africa (Low *et al.*, 2007). Potato area in Nigeria is grossly overestimated, but area in Ethiopia is severely underestimated in FAOSTAT. In Malawi, much of what passes for potatoes in FAOSTAT is really sweetpotato. Crop-cut experiments show significantly heavier yields than national level estimates reported in FAOSTAT. With the exception of South Africa, the analysis of trends in potato productivity in SSA is a waste of time.

Data on potato production and consumption are substantially more reliable in other regions of the world than in SSA. But the seeming absence of reliable disaggregated production data in China at the prefecture or county level is a key weakness in telling a persuasive story about the burgeoning growth in potato production in China in the recent past. The existing data need to be assembled and subjected to time series analysis similar to the in-depth exercise that was carried out by Gitomer in the early 1990s (Gitomer, 1996).

The major source of global uncertainty in potato production and consumption is the same today as it was ten years ago (Walker et al. 1999): the fate of potatoes in light-yielding but high-consuming countries of Belarus, the Russian Federation, and the Ukraine where production intensity still exceeds hundreds of kgs/capita. The social influence and economic impact of potato has also not diminished during the recent past. Potato is as relevant as ever to the welfare of the poor (Thiele et al., 2010).

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