Conceptual Issues for the Comparative Study of Agricultural Development

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This paper begins by addressing the central questions underlying the country-specific essays in this volume: what was the relationship between agricultural development and the development of other sectors? Did agricultural growth support or compete with industrial development? And, was an agricultural revolution a necessary condition for an industrial revolution? We also ask how the growth of the agricultural and non-agricultural sectors during the great transformation of the European economies compared with the relative growth of these two sectors in later developing Asian economies. We next draw on Theodore Schultz’s insights to help frame the comparative study of European development. In addition, we note the shortcomings of the “New Growth Theory” as a tool for historical analysis and explore some of the conceptual pitfalls associated with the use of induced innovation and threshold models—paradigms commonly employed to explain the diffusion of technologies and cropping systems. A better understanding of these models, and of the broader global experience, suggest a reassessment of important issues in European agricultural development.

Friend or Foe

A first step in assessing the relationship between agricultural and nonagricultural development is to delve into the fundamental nature of the linkages connecting the two sectors. To this end it would be useful to look at Europe through the American mirror. Early America provides a useful testing ground because both sectors essentially have to
develop *de novo*, that is, almost entirely from scratch in a new environment. Two of the
new nation’s founding fathers advanced fundamentally different positions on the
relationship between agriculture and manufacturing.¹

In the view of Benjamin Franklin the agricultural and nonagricultural sectors were
clearly competitive, whereas in Alexander Hamilton’s opinion, the two sectors were
complementary. According to Hamilton’s 1791 Report on Manufactures: “the aggregate
prosperity of manufactures, and the aggregate prosperity of Agriculture are intimately
connected.” A prosperous agricultural sector encouraged manufacturing by supplying
less expensive raw materials as well as food for workers and by providing larger markets
for industrial products. Local manufacturing development in turn created a larger and
more reliable market for agricultural products, one subject to fewer “injurious
interruptions” to demand. The possible competition for labor was less problematic in
Hamilton’s view because manufacturing could employ women and children who were
underutilized in farming and could attract new migrants from abroad.

Benjamin Franklin disagreed:

> Manufactures are founded in poverty. It is the number of poor without land in a country,
> and who must work for others at low wages or starve, that enables undertakers to carry on
> a manufacture…. But no man, who can have a piece of land of his own, sufficient by his
> labor to subsist his family in plenty, is poor enough to be a manufacturer, and work for a
> master. Hence while there is land enough in America for our people, there can never be
> manufactures to any amount or value.²

Franklin’s position is consistent with a standard neoclassical trade model where industry
and agriculture compete for a nation’s given endowment of labor and sell their products
in a large international market.

The main issues in this debate are whether the economy is open or closed to trade
and whether the supply of labor (and other factors of production) is fixed and fully
employed. If an economy is open to trade then the links between agricultural and
industrial development in that economy are weaker and more tenuous. An “agricultural
revolution” in an open economy characterized by comparative advantage in agriculture
can slow its industrial development. (The development of the American South following
the introduction of cotton and the invention of the cotton gin serves as an example.) In a
closed economy the situation is different. If food demand follows Engel’s Law—namely
that the share of income spent on food declines as income rises—then a revolution in
agricultural productivity can free up resources, raise income and non-food demand, and thereby promote industrialization.³

The relationships linking agriculture to other sectors have long been of interest to economists.⁴ We draw on the work of two eminent agricultural economists, John W. Mellor and Theodore W. Schultz, both of whom are “Hamiltonians” in that they see agricultural development as complementary to industrialization. Mellor and Schultz bring to bear a wealth of information from the less developed and developing countries of the past 60 years that provides a context for evaluating the nineteenth and early twentieth century European experience.

Mellor’s Law

In 1966 Mellor posited that “the faster agriculture grows, the faster its relative size declines.”⁵ Others have dubbed this “Mellor’s Law.” Mellor’s observation stems from the possibility that technological changes can overcome the effects of a growing population, and following Engel’s Law, as per capita income increases, the percentage of income spent on food will decline leading to a relative decline in the size of the agricultural sector. Where agriculture represents a large share of total output, structural transformation requires increases in agricultural productivity. In the process, agriculture becomes relatively less important while paving the way for the development of the nonagricultural sector. Nearly 40 years later, leaders in the international development community still hold that this notion “captures the essence of agricultural growth and its causal relationship to the structural transformation and aggregate growth of an economy.” (p.1) Mellor further notes that the relationship described in the above statement “can be illustrated by comparing the agricultural and nonagricultural growth rates of countries in each of the world’s three major geographical regions [meaning Asia, Africa, and Latin America].” (p. 1)

Figure 1 reproduces Mellor’s graph for Asia where the x-axis shows the percentage rate of growth of the agricultural sector for each country divided by each country’s percentage rate of growth of the total population. The y-axis shows the nonagricultural growth rate also divided by the growth rate of the total population. As
the note on the figure makes clear, Mellor estimated OLS fits for two sets of countries—the whole sample of 14 nations and a sub-sample omitting four outliers (Burma, Philippines, the Republic of Korea, and Singapore). The outliers are worth noting (beyond emphasizing the ad hoc analysis so common to comparative research).

Singapore is a city-state with almost no agricultural sector. The Republic of Korea represents a counter example to what Mellor sees as a general pattern for the region; its agricultural sector lagged relative to its industrial sector. Korea’s industrial sector in Mellor’s view, “pulled the lagging agricultural sector into more rapid growth.” (p. 2) The Korean case was made possible by a heavy reliance on export demand for its industrial output—a situation Mellor asserts is unusual. In Burma and the Philippines hostile (albeit different) policy environments prevented creditable agricultural performances from pulling along the rest of the economy.
For the remaining 11 countries Mellor’s data show that 91 percent of the growth in one sector was correlated with growth in the other. “The slope of the line of that relationship suggests that for each 1 percent of acceleration in per capita agricultural growth, there is about a 1.5 percentage point acceleration in per capital nonagricultural growth.” (p. 4) This finding leads Mellor to ask, what explains the differences in the impact of accelerated agricultural growth on nonagricultural growth, how might agricultural growth have been increased even more, and what policies might have increased the effectiveness of transmission of agricultural developments to the rest of the economy? A century (more or less) before the Asian Miracle, Europe underwent its own great transformation. How did the European experience compare to Asia’s later path? Figure 2 makes a preliminary attempt to answer this question using per capita income data for 11 European countries.
nations. Each data point represents the country for at least two decades. Seven countries have data going back to 1870/1874 and ending in 1935/1939. For these countries we offer three entries, each for a roughly 20-year sub-period. The data for Norway only start in 1890 and are broken into two sub-periods. The data for Austria, Hungary, and Czechoslovakia only cover one period, the years 1910/1914 to 1935/39. There is clearly a positive association between the per capita rate of growth of the agricultural and nonagricultural sectors, but it is neither as pronounced nor as statistically significant as that displayed in Figure 1.
Figure 2: Mellor’s Law and European Agriculture, 1870-1939

Key: X  1870/74-1890/94;  (X)  1890/94-1910/14;  <X>  1910/14 to 1935/39

COUNTRIES

AU  Austria     FR  France     NO  Norway
CZ  Czechoslovakia  GR  Germany  SW  Sweden
DN  Denmark     HU  Hungary     UK  United Kingdom
FI  Finland     IT  Italy

Several features of Figure 2 deserve comment. First, Austria (AU) appears to be an abnormality—maybe the result of political realignments in the period. (Dropping this one observation does improve the fit significantly.) Next, there is some tendency for the more industrialized economies to show negative agricultural per capita growth rates; the same is true for countries in later decades relative to earlier decades. This is to be expected. When agriculture represents a major part of all economic activity, its performance would likely be associated and even affect overall economic performance. But when agriculture represents a small part of all economic activity there is little reason to expect such an association. Mellor addressed this problem in his discussion of the reasons for a relatively poor fit for Latin America because the structural transformation in the high-income countries had already occurred. (p. 5)

This raises an intriguing question. Would the fit for Europe have been much stronger if we had had data for an earlier period? We suspect so. After all, the rapid growth of the nonagricultural sectors in many countries, and especially in the UK and Holland, was far along by 1870/1874. One useful task for future research would be to assemble the data, where possible, to provide a clearer picture for earlier years of the systematic relationship between the agriculture and nonagricultural sectors following Mellor’s conceptual framework. More closely linking Europe’s transformation with the paths of more recent developing countries might shed light on both experiences.

Was an Agricultural Revolution Necessary?

As just noted, we realize that there are many conceptual problems and ambiguities with the Mellor framework. To explore one such problem, we turn to an issue raised by Pedro Lains and Vicente Pinilla in their introduction to this volume. They delve into the relationships linking agricultural modernization and industrialization and note that, in the Rostowian framework, “an agrarian revolution was a prerequisite for the industrial revolution.” This view has been under scrutiny in the last decades. In fact, a revisionist literature has emerged questioning the contribution of the agrarian revolution to the industrialization of Great Britain and other European forerunners. Lains and Pinilla are raising the same issue that concerned Mellor and America’s founding fathers—were
advances in the agricultural sector a necessary precursor for more broadly based economic growth?

This is an issue that has long been debated and for good reason—the issue is both extremely important and decidedly more complicated than once thought. Posing functional relationships is relatively simple, but testing them in the context of varying institutional, cultural, and historical settings can be challenging. As we have noted, the importance of the task is amplified by the fact that in pre-modern times the agricultural sector, nearly everywhere, accounted for over 50 percent of employment and output and in some regions up to 90 percent of economic activity. Measuring the inputs and outputs of the agricultural sector and understanding the production processes, both within the sector and those linking the sector to the broader world, are crucial to our understanding of the role of agriculture in development. But in the pre-modern age the absence of data on even the most basic issues is a serious barrier.

The answer to the question, “can industrialization take place without an agricultural revolution” is Yes and No. The treatment of this issue has often suffered from a fallacy of composition. Someone, somewhere, needs to produce the food and fiber to feed and clothe the growing non-agricultural workforce—this is a necessary condition for industrialization. (It also helps to be able to transfer savings out of the agricultural sector, to earn foreign exchange via agricultural exports to help support industrialization, etc.) This implies that significant changes in agricultural production, and in the associated institutions and technologies that connect the agricultural and non-agricultural sectors, are necessary conditions for industrialization. However, these changes in the agricultural sector need not take place within each and every industrializing nation. Just as every industrializing nation need not mine its own iron ore, every country does not need to harvest its own grain, produce its own beef, or grow its own cotton as long as there is international trade.

Thus, as we noted above, the answer to the question of whether an agricultural revolution is a necessary condition for industrialization is both yes and no. A nation’s growing urban population must obtain supplies from someone, but not necessarily from its own countrymen. In this schema, the extent of agricultural development across nations will depend on a host of factors, including national comparative advantage, technological
change in the transport sector, and the political economy and policies of individual
nations. Just like no man is an island, few nations in the modernizing age ever truly
divorced themselves from the international economy. One nation’s opportunities and
policies, for better or worse, affected and were in turn affected by, the changing
international environment. Exogenous changes (at least exogenous for many smaller
nations) defined technological options, the cost and speed of transport, the access to
markets, and much more. These considerations point to the need for comparative country
studies, precisely of the type that Lains and Pinilla have encouraged in organizing this
scholarly collaboration. In this regard Lains and Pinilla note: “The fact that we are
putting the available quantitative information together will make it possible to answer
relevant questions regarding the contribution of agriculture to economic growth since
1870.” But take care. Our point is that it is not enough to simply study each country as a
separate entity and sum up the component parts, because with international trade all sorts
of efficiency enhancing substitutions, leading to different development paths, were
possible. A finding that a specific industrializing country experienced little productivity
growth in agriculture is not too meaningful when it had access to the bountiful surpluses
of North America, Australia, Argentina, and Russia.

The Reasons for Agricultural Success and Failure

In the 1960s, Theodore W. Schultz was concerned with understanding the nuts
and bolts of agricultural progress. He argued that to a significant extent agricultural
failure had much more to do with misguided government policies than to bad weather,
irrational farmers, and the like.

To the minds of many who shape agricultural policy...farmers are ever so perverse.
When a national economic plan calls for more agricultural production, farmers fail to
respond; when instructions are issued to shift from wheat to corn, they fail to produce
enough of either crop; when given the command to make a big leap forward, they step
backward; and when they are heavily subsidized to reduce the acreage of particular crops,
they proceed to increase the yield to produce more than offset the reduction in acreage.
Farmers, especially in poor countries, are then looked on as loafers who prefer leisure to
doing the extra work to increase production, as squanderers when it comes to savings for
investment to increase agricultural production, and as ever so inefficient in using the
resources at their disposal.
After criticizing both W. Arthur Lewis and Ester Boserup for overplaying the shortcomings of individual farmers, Schultz noted that “there is a long shelf of empirical evidence ... which shows that in Africa, when the export price of cocoa, cotton, peanuts, or palm fruit becomes profitable, the supply response of farmers is highly elastic.” (pp. 4-5) This is the fundamental insight of George Grantham’s important work on French historical development: “farmers responded to market opportunities...by working harder, investing more, and by shifting the balance of their crop mix towards more marketable productions.”

Schultz’s (and Grantham’s) observations lead us to two issues of historical concern worthy of more formal cross sectional study in the European context. The first deals with farmer rationality and their responsiveness to economic stimuli. Related to this is the question of how institutions affected farmer responses to changing stimuli. Schultz is of the opinion that farmers [in developing countries] “in general are shrewd, hardheaded, calculating people in their economic affairs. Whenever there is a real payoff they respond.” (p. 13) Government policies can, through research and extension services, help to develop and disseminate new technologies, but these must be conducted in a way that pays “sufficient attention to the profitability of such programs for farmers.” By 1900, most European nations established wheat breeding programs that created a succession of improved varieties. It would be useful to have a better comparative sense of how rapidly these varieties spread to farmers and of the role played by government extension services in the diffusion process.

The second issue Schultz raises deals explicitly with the role of government policy. Bad government policy is often the culprit when explaining bad agricultural performance. Looking at a broad cross section of nations as of the 1960s, Schultz identified the number one culprit responsible for failed agricultural economies as the absence of an efficient price system that in poor countries typically undervalued farm commodities and often over priced key farm inputs. The European experience offers a rich testing ground for examining the response of farmers to price rigging policies. In particular, the contrast between countries such as Great Britain and Denmark that lowered trade restrictions and those nations such as Germany and Italy that maintained or
raised trade barriers (and thus internal grain prices) shows that farmers shifted production accordingly.\textsuperscript{15}

A finding that significant agricultural change did or did not occur in conjunction with industrialization may say much more about government policy than anything inherent to the agricultural sector and its potential. More generally, it would be valuable to have a cross sectional comparison, using a common set of metrics, of government policies affecting agricultural prices, the extent of price distortions (including tariffs) and their impact on the farm sector, and its ability to provide positive linkages to the rest of the economy. Schultz raised a third related issue that is of importance to the study of historical development. Referring to the 1960s he noted that “We live in a period in which there is indeed an agricultural revolution. The scientific and technical knowledge in the West is so far ahead, in terms of what is theoretically possible, that what we see in more than half of the world is obsolete by a very wide margin.” (p. 13) Schultz goes on to note that “the new inputs to increase world food supplies must come from outside the agricultural sector.” (p. 14) Again, there are many issues here of historical importance. Nineteenth and early twentieth century farmers in Europe were also living in revolutionary times with the advent of new machinery and crop varieties, the opening of new markets, the growing exposure to competition from farmers in distant lands, the threats of new and devastating diseases and pests, and in some cases the advent of increasingly effective methods of combating diseases and pests.

What was the extent of the differences between advanced and backward agricultural sectors and nations within Europe (and between Europe and other areas such as North America)? Were these gaps closing or widening? What institutions arose to facilitate the transfer of knowledge? Finally, as Schultz highlighted for the 1960s, many of the sources of European agricultural development came from outside agriculture. Reapers, threshers, improved plows, tractors, drainage tiles, and pumps all were produced by industry. And, even the understanding of and the technologies developed for fighting crop and animal diseases and pests often depended on linkages to industry, the scientific community, and early government and private research and extension services. A comparative analysis of all of these issues, cataloging which policies were efficient and why, would be of great interest. In addition, we need a better accounting of the extent of....
the backward linkages that stimulated industrial output to deepen our understanding of the role of agriculture in the development process.

**Caveat Emptor: Modeling Agricultural Growth**

In this section we examine some of the models used to analyze economic and agricultural growth. We argue that recent advances in the “New Growth Theory” have great potential value for aiding our understanding of the place of agriculture in economic development, but its promise is currently limited by the failure to capture the diversity of agricultural conditions. One of the fundamental insights of modern economics has been to emphasize the importance of technological and institutional changes (along with human capital formation) in the growth process. The *induced innovation hypothesis* and the *threshold model* have been the dominant paradigms used for analyzing the invention and diffusion of new agricultural technologies (and in the case of the induced innovation model, the linkages between the agricultural and nonagricultural sectors). Our work on the United States demonstrates that these models (and many of the assumptions underlying their use) suffer from serious conceptual problems and that studies relying on these models have contributed to a serious and prolonged misunderstanding of American agricultural development. These analytical pitfalls are of a general nature and many have crept into the study of European agricultural development.

**The New Growth Theory**

Few economists are held in higher esteem than the macroeconomic theorist and Nobel laureate Robert Lucas, Jr. His work over the last two decades has helped revive research on macroeconomic growth under the label of the “New Growth Theory.” Adopting a dynamic optimization framework incorporating individual preferences, this literature initially focused on generating endogenous growth along the steady-state equilibrium path of aggregative or single-sector models. Agriculture fits uneasily into such models because it employs non-reproducible inputs, such as land, that are subject to diminishing marginal returns. The operation of Engel’s law, leading agriculture’s share of
consumption spending to fall as income rises, further undermines the standard application of steady-state analysis (where in equilibrium every per capita growth rate is equal). To better understand the classical issue of the role of agriculture in economic development, a small stream of the new growth literature has begun analyzing the asymptotic transition path of dual-sector models. Such an approach allows for structural shifts including the possibility that the share of the agricultural sector declines toward zero over the long run.

Yet the potential of the “New Growth Theory” to aid our understanding of the transition is hindered by a failure to come to grips with the diversity of agricultural environments and institutions. For example Lucas, in his Lectures on Economic Growth, argues that it is relatively simple to estimate the per capita incomes of pre-modern agrarian societies by simply examining a painting given to him by an ex-student. It depicts a Korean farmer plowing his field behind an ox, against the idyllic backdrop of some flowering fruit trees. According to Lucas,

> It is not difficult to estimate the income of this farmer, for we know about how much land one farmer and his ox can care for, about how much can be grown on this land, about how much fruit the little orchard will yield, and how much the production would be worth at 1985 U. S. dollar prices. This income is about $2000. Moreover, we know that up until recent decades, almost all of the Korean workforce (way over 90 percent) was engaged in traditional agriculture, so this figure of $2000—$500 per capita for the farmer, his wife, and his two children—must be pretty close to the per capita income for the country as a whole. Though we do not have sophisticated national income and product accounts for Korea 100 years ago, we do not need them to arrive at fairly good estimates of the living standards that prevailed back then. Traditional agricultural societies are very like one another, all over the world and over time, and the standard of living they yield is not hard to estimate reliably. Indeed, my Korean farm scene…could be drawn from any century in this millennium or the last one.16

For Lucas, a picture is worth far more than the proverbial thousand words—such is the power of theory! His notion appears to be that pre-modern agricultural societies were all in a steady state, undifferentiated, with zero per capita growth. Given that agricultural societies were all the same, searching for distinctive cross sectional differences between the agricultural sectors of various countries that might help explain different patterns of industrialization is folly.17 Fundamentally, the world of Lucas is constructed on the Malthusian scaffold because the benefit of any technological change that might occur will simply be devoured by a larger population.

Most economic historians would recoil from the notion that all agricultural societies were basically the same at any point in time, let alone across the millennium.
(although the Malthusians among us would subscribe to the notion that incomes were more or less constant). Nonetheless, any true insight as to the role of agriculture in development must take us beyond Lucas.

The New Growth literature is increasingly focusing on another relationship, long-understood by economic historians, showing the inverse correlation between the share of the national labor force in agriculture and its level of per capita income. This pattern, documented for recent years in Figure 3, strongly suggests that growth inherently involves structural change, specifically, a movement out of low-productivity agriculture into higher productivity sectors such as manufacturing and services. Studies of the contemporary cross-country growth experience, based on the Penn World data, confirm the standard Kuznets findings that labor productivity is higher outside than inside agriculture. But the studies go two steps further, showing that (1) labor productivity inside agriculture varies much more across developed and developing economics than labor productivity outside agriculture, and (2) the gap between agricultural and nonagricultural productivity closes at higher incomes/lower shares of the labor force in agriculture. By the end of the nineteenth century, productivity in the two sectors in the United States was virtually equal.
Caselli concludes that “there are three proximate reasons for poor countries’ poverty: their much lower labor productivity in agriculture; their somewhat lower labor productivity outside agriculture; and their larger share of employment in the (agricultural) sector that—on average—is less productive.”20 This analysis raised the question of whether the productivity differentials within each sector or the sectoral employment shares account for most of the variation in national productivity. In his decomposition, Caselli finds that the differentials rule and the sectoral shares are far less important.21 It would be of great interest to carry out such analysis for earlier periods. Van Zanden’s analysis of the relationship of agricultural productivity to the share of non-agricultural labor in the total labor force, as shown in Figure 4 below, provides a model and foundation for a very promising direction of inquiry.
Induced Innovation

The induced innovation hypothesis is essentially a long-run version of the factor substitution argument that treats the evolution of technology and institutions as endogenous responses to the forces of factor supply and product demand. In terms of its simplicity, intuitive appeal, and number of adherents, it has no close competitor. The model is most closely associated with the works of Yujiro Hayami and Vernon W. Ruttan. They and numerous other adherents have claimed success in “testing” the model using national data from Europe.

In the induced innovation literature the United States represents an example of a high-wage and resource-abundant economy and Asian nations (such as Japan and Korea) represent the opposite extreme of low-wage and resource-scarce economies, and European nations fall somewhere in between. We have shown that the stylized facts, as portrayed in the induced innovation literature, of America’s agricultural past were simply at odds with the actual historical record. The differences are significant. In brief, the actual changes in relative factor scarcities over the past one-and-one-half centuries generally ran precisely counter to what has been claimed in the induced innovation
rendition of American history. In addition we have shown that many of the widely accepted generalizations about the United States are, in fact, purely regional phenomena. Vast areas of the United States did not behave in accordance with the stylized account. As an example, the persistent claim that there was a substantial rise in the land-to-labor ratio in American agriculture during the century before 1940, in reality, only holds for the grain-growing regions of the Midwest and the Great Plains. For the remainder, roughly 50 percent, of the country the movement in this key ratio was on par with what took place in Japan. This and other findings point to the desirability of disaggregating national data even when drawing international and interregional comparisons. This problem is less severe in analyzing Western European nations because of their smaller size, but it still needs to be accounted for. National data that homogenizes the developments in the Po Valley with those in the mezzogiorno in Italy, or blends the large-scale agriculture of Prussia with the smaller scale producers found in the western regions of Germany can clearly lead to serious interpretative problems.

We have many other concerns with the application of the induced innovation model to the European case. The general tendency is to claim success when the model seems to fit, but when the data are at odds with the model’s predictions, ad hoc reasoning is presented to make things fit. Giovanni Federico dismisses some of our concerns with the observation: “Indeed, a quick perusal of the country of origin of innovations confirms the basic insight of the model. All major mechanical innovations (the reaper, the tractor, the cotton and corn pickers, and so on) were invented or developed in the United States, while Europe led in the development of fertilizers and chemical products as well as in new practices of cultivation.” We take Federico at his word; he indeed made a “quick perusal.” Even if he is correct that Europe on balance was more inclined to develop biological innovations and the United States (and the other land abundant nations) was more apt to create mechanical technologies, the number of exceptions on both sides of the Atlantic suggest that simple relative factor scarcities (or even changes in relative factor scarcities) do not explain the patterns of innovation.

In addition to the highly visible achievements of the legendary American plant scientists and innovators, George Washington Carver and Luther Burbank, there was a rich tradition of biological innovation in the United States. Through extensive breeding
efforts, Americans literally created the upland cotton varieties that would dominate international production and trade over the nineteenth and twentieth centuries. Try as they might, planters in other nations generally could not reproduce these results. In a similar fashion, nineteenth century Americans bred a succession of maize varieties that vastly increased the crop’s domain. Without these innovations corn would never have become America’s leading crop. The practical achievements of American, along with Canadian and Australian wheat breeders, equaled or surpassed the accomplishments of European breeders and made possible the expansion of production that would fuel the “Great European Grain Invasion.” It was not just in the three dominant staple crops that American innovators were at work. American scientists solved the problem of how to deal with phylloxera and America supplied the rootstock needed to replant the vineyards of Europe. By the early twentieth century American scientists were also on the cutting edge of achieving an understanding of animal diseases that would significantly increase productivity.

European innovators did lead in the development of agricultural chemicals and fertilizers. However, a disproportionate fraction of these innovations came out of Germany. Was that nation significantly more land scarce than France, Italy, the UK, etc.? Or was there a path dependency that had much to do with the independent development of German science and the needs of the German military? The most important innovation in the chemical-fertilizer arena was the Haber-Bosch process (1909) for manufacturing ammonia. This fundamental breakthrough would eventually lead to a significant decrease in the price of nitrogen fertilizers. But the quest to develop new sources of nitrogen appears to have been driven by a widely held concern about looming worldwide food shortages (with trade) rather than country-specific agendas driven by land scarcity.26

The other half of Federico’s claim asserts that “all” the major laborsaving mechanical innovations were “invented and developed in the United States.” Not true; not even nearly true. Jethro Tull of England invented the seed drill (in 1701), the horse-drawn hoe, and an improved plow. The threshing machine vies with the reaper as the most important of the grain harvesting innovations. The mechanical thresher was invented by Andrew Meikle of Scotland circa 1796. This laborsaving innovation gained
wide acceptance in Europe. It had the added anomaly (from the perspective of the induced innovation model) of not saving peak-load labor, but rather increasing the relative peak harvest demand for labor in small grain production. Laborsaving technological changes, including cream separators, mechanical churns, and milking machines transformed dairying in both the United States and Europe. In the United States the milking machine certainly rivaled the cotton picker in the amount of labor saved, and in both Europe and the United States mechanization of dairy operations significantly reduced the reliance on hired labor.27 Inventors were active in most European countries, with those in Scotland, England, Denmark, Germany, the Netherlands, and Sweden being particularly industrious. Prominent European inventors of dairy equipment include Gustav De Laval of Sweden who invented the continuous centrifugal cream separator in 1878 and introduced an improved the vacuum milker in 1913; the Scots, William Murchland (Marchand) who invented an improved vacuum milking machine in 1889, and Alexander Shields who “adopted the pulsator principle on the Thistle Mechanical Milker” in the mid 1890s.28

Few issues dealing with American and European agricultural development have been more misunderstood than the role of biological innovations—in this context “biological innovations” include most everything except mechanical innovations. Hence new seed varieties, better fertilizers and irrigation and drainage systems, and improved crop rotation schemes would qualify as “biological.” The induced innovation literature has maintained that biological investments primarily save land and mechanical investments primarily save labor. In the American context the literature argues that because land was relatively cheap, there was little incentive or interest among farmers to make biological (land-augmenting) investments. Western Europe was at an intermediate stage, less likely to introduce laborsaving mechanization than America, but more likely to do so than labor-abundant Asian economies. In keeping with this conceptualization, one of America’s most renowned agricultural economists has asserted that, in the United States, mechanization “was the principal, almost the exclusive, form of farm technological advance” between 1820 and 1920.29 As noted above, our work on American wheat, cotton, and corn production indicates that this widely held view is simply wrong. To add to the wheat story, over the nineteenth and early twentieth
centuries a succession of new varieties transformed the basic types of wheat grown in the United States which had an enormous impact on both labor and land productivity.\textsuperscript{30}

The European literature is far less tainted on this issue than American scholarship. In particular J. L. van Zanden’s classic on the “First European Green Revolution” offers a balanced assessment of mechanical and biological innovations (although a close reading suggests even he at times is misguided by the flawed logic of the induced innovation model).\textsuperscript{31} The same process was underway in Europe with new wheat varieties being tailored for the harsher conditions found on the eastern steppes of Russia, for the more arid conditions in the Mediterranean, and the more frigid and shorter growing seasons of northern Europe. In the latter half of the nineteenth century major advances in wheat research conducted in nearly every European country enhanced production. Among the leading innovators were Henri Vilmorin (France), Wilhelm Rimpau (Germany), Rowland H. Biffen (UK), and Nazareno Strampelli and Francisco Todaro (Italy). Important wheat breeding programs were also underway in the Austro-Hungarian and Russian Empires.\textsuperscript{32} A truly sophisticated comparative history of the impact of biological innovations in Europe (and elsewhere) would be a major accomplishment. Such a work would have to consider the next issue we address.

**Before and After vs. Cause and Effect**

One spin-off of our work on the biological sources of productivity growth deserves special mention. To illustrate this, it is useful to return to our discussion of wheat. It is well known that yields per acre for wheat and other major crops in the United States remained roughly constant before the 1930s or 1940s and only increased with the advent of hybrid seeds and new chemical fertilizers. Figure 5 shows the long run trend in U.S. wheat output per acre. This general picture has reinforced the view that increases in biological knowledge before the 1930s were of little significance in the United States, especially relative to mechanical innovations. However, to say anything meaningful about biological innovations one would need to ascertain what would have happened to output per acre in the absence of innovations. Specifically, how would diseases and pests
have limited production if left unchecked and how would the locus of production been constrained? We carried out just such an exercise in our published work on wheat. Our estimates suggest that without innovations national wheat yields would have been about 54 percent of those actually achieved in 1909 and about 67 percent of those prevailing in 1839. There is nothing unique about wheat to suggest that the yields of other crops and livestock would not have also fallen if farmers had not invested heavily in biological technologies.

Figure 3: U.S. Wheat Yields, 1866-1969
This finding serves to highlight an important distinction between measuring the agricultural and nonagricultural sectors. In most areas of economic activity technological solutions last forever. A new idea, method, or type of machinery only becomes obsolete when it is replaced through the competitive process by an even more productive innovation. But the old idea is neither destroyed nor lost; it is just no longer efficient. In many instances the new build on the old, giving rise to the cumulative nature of technological development. In addition, for most sectors, innovations tend to be highly portable—an idea or a machine developed in one country is apt to work equally well in a wide variety of environments. Agriculture is uniquely different. Human intervention into biological processes predictably produces natural reactions in the form of pests and pathogens that inevitably erode the innate productivity of past innovations. Farmers have long understood the Red Queen’s dictum: they have to run fast just to stay in one spot. Moreover, unlike many mechanical or organizational innovations, biological technologies must be fine-tuned and harmonized to the specific climatic and soil conditions of a given locale, and maybe even a given plot of land. These insights are extremely important for
the study of both European and American agricultural history given that a primary challenge for farmers in the nineteenth century was to enter into an increasingly globally integrated market where the prospect for the transmission of pests and pathogens was also increasing. Federico has touched on the Red Queen problem in the European context, but this issue still needs to be properly accounted for in the broader literature.\(^{33}\) Doing so has the potential for changing many notions about the dynamics of medieval and modern European agriculture because, almost surely, the importance of biological innovations has been vastly understated.

**Threshold Models**

While the induced innovation hypothesis is the leading model for explaining the creation of new technologies, the threshold model is the standard tool for analyzing the timing and extent of technological diffusion. Whereas induced innovation models grapple with the dynamics of long-run factor substitution, threshold models are more modest in concentrating on short-run cost calculations. These simple models generally depict individual farmers as choosing between a traditional method of production with high variable cost and new mechanical methods which are fixed cost intensive. On small farms the high fixed costs of machines cannot be spread over a large enough acreage, and thus mechanization is not profitable. Paul David’s contributions analyzing the mechanical reaper in the United States and England represent examples of a tradition dating back at least to Chayanov’s innovative studies of peasant farms in the 1920s.\(^{34}\)

In this section we build on some of our research on the history of mechanization in the United States to offer some general comments on the application and misapplication of threshold models. It turns out that, in the cases we have dealt with, the classic threshold approach makes a number of strong and questionable assumptions about the quality of different markets. As examples, it assumes that farmers are perfectly informed about the competing technologies, can buy and sell labor at the going wage rate, borrow and lend capital at the going interest rate, and can buy and sell equipment at going prices; but farmers cannot buy or sell custom machinery services, buy, sell or rent land (so as to alter the farm’s scale), or adjust the farm’s crop mix, or other activities.
This seems quite a peculiar list of “cans” and “cannots.” The differential treatment of closely related markets raises a number of questions. For example, under what set of institutions would one expect to find complete flexibility in the new equipment market and total inflexibility in the land market? Why is it that farmers can hire labor but not machine services, etc.? Our studies on the diffusion of the mechanical reaper, cotton harvesters, and the gasoline tractor suggest that a rigid adherence to the assumptions underlying the threshold model not only led researchers to misunderstand the diffusion process, but in many cases to fundamentally mis-specify the broader social and structural characteristics of rural society. As an example, in the cases of the reaper and the tractor the literature steadfastly held that equipment was not and could not be shared or jointly used beyond isolated cases. What started as a simplifying assumption evolved into an “historical fact” that had broad implications.35 The reality was that in the early decades of diffusion, joint ownership, sharing, and custom operations were the rule rather than the exception. In the case of the reaper, over 50 percent of all machines in some areas were used on more than one farm, and many were used on five or more farms in a given year. The implications of this and related findings suggest that, at least in the historical periods we are looking at, we must reconsider studies that treat individual farms as discrete, independent, self-contained units of analysis. Van Zanden’s treatment of mechanization illustrates our general point. In his introductory remarks he notes: “As costly machines could only be purchased by rich farmers, and as the use of them would have sharply increased the attractions large-scale production, a rapid mechanization of the production process would have given large farmers important cost advantages over smaller ones.” But in practice what happened? Van Zanden’s later analysis hints that sharing arrangements that practically mitigated scale effects may have been (as in the United States) fairly common. Most evident, small dairy farmers in many European countries improved their economic conditions by participating in cooperative factories that employed new technologies such as the mechanical cream separator.36 To what extent did markets adapt in a similar fashion in Europe for other forms of agricultural machinery, and how did the different national experiences differ?

We have a number of other criticisms of how threshold models have been used. Scholars looking at the displacement of horses by tractors in the United States and
Europe have long been baffled because they found very little cost difference between the two modes of production over a period of several decades.\textsuperscript{37} Our work suggests that the coexistence of the two modes was in large part a result of the fact that many of the key variables in the tractor adoption decision were endogenous. The old technique was embodied in the horse, a durable capital good with an inelastic short-run supply and a price that could adjust to keep the animal mode competitive. As an example, the real price of mature horses \textit{(age 2 and over)} declined by over one-half during the first wave of tractor diffusion between 1915 and 1925. Besides lowering horse prices through direct competition, advances in the mechanical technology increased agricultural productivity and shifted out the supply of agricultural goods. Given a downward sloping demand for agricultural products, this led to lower crop prices and reduced the major expense of the animal mode: feed. Thus, via its effects on both horse and feed prices, the tractor by its very nature made its major rival more competitive.

Rather than reflecting long-run conditions, the co-existence of tractors and horses may merely have represented a transitional phase in the adjustment process. As in the debate over the profitability and viability of American slavery, the real question answered by such static microeconomic comparisons is whether the market for durable capital goods \textit{(here, the horse)} was working properly. Apparently, it was.

\section*{Conclusion}

We have drawn on the works of a number of agricultural economists with the goal of illuminating historical studies. Many of the issues that concerned Mellor, Schultz, Hayami, and Ruttan have close parallels in the economic history literature. This should come as no surprise because the fundamental problem of economic modernization is a process that has been underway for centuries and is still far from complete. Perhaps by linking up with a literature studying a different set of countries and using different databases will provide insights and a firmer foundation for comparative analysis. There are a number of issues that deserve more attention. As an example, more work needs to explore how links between the inventors-manufacturers and the adopters effected the pace and pattern of technological change. The induced innovation model
focuses on the role of market price signals to the exclusion of supply-side forces. But there are also vast quantities of technical information and more qualitative insights about machine use which provide impetus to both inventors and adopters. In the United States, some regions were far more dynamic and innovative than others. Notably, pockets of New England, the upper Midwest, and California became centers of innovation. By contrast, the American South was long marked by little indigenous inventive activity and the absence of modern machinery on its farms. One of the essential characteristics of the inventive hothouse that developed in nineteenth century California was the close and regular interaction of inventors with local users. Men like Benjamin Holt and Daniel Best (both inventors of combined-harvesters and track-laying tractors) were in constant communication with farmers, and this feedback provided valuable information about how to perfect their machines. In a similar fashion, these interactions educated farmers about new machines and methods thereby speeding adoption. Such practices were common throughout the northern states, but rare in the American South (and we suspect in many parts of Europe and many developing countries) where social and class barriers stunted the important two-way flow of qualitative and technical information.

More generally, we would like to comment on the interplay of data and institutions on the one hand, and theory on the other. It goes without saying that economic theory is essential for our understanding of both contemporary and historical problems. But, in the case of the induced innovation and threshold literatures, some of the underlying assumptions took on a life of their own thereby creating research blinders. Assumptions made for simplifying purposes, along with preconceptions and tentative conclusions have been repeated enough to miraculously be metamorphosed into rock-solid “historical facts,” often with little or no regard for the actual data. In the case of the threshold literature, this led a generation of economists to define rural America in terms that were at odds with the data and that defied simple economic intuition about the persuasiveness of markets and the flexibility of production relationships.

Excessive commitment to the threshold model also led scholars to focus on a subset of questions, often ignoring more interesting and more fundamental issues that did not lend themselves to analysis with that model. This is particularly true of the work of economic historians dealing with the tractor, where almost all the emphasis was devoted
to trying to explain the pattern of diffusion and virtually no attention was given to the tractor’s enormous impact on the economy. In a similar fashion, for almost 30 years agricultural economists, relying on the induced innovation literature, had many of the stylized facts of America’s past wrong—often 180 degrees out of phase. Perhaps fresh investigations of other national experiences will raise similar concerns. We hope that our perspectives on the induced innovation hypothesis and threshold models will stimulate new research that will both help refine the models and illuminate the dynamics of technological change. We further hope that our findings might allow others to avoid some of the errors that befell a large body of the American literature.

2 Benjamin Franklin, The Interests of Great Britain Considered with Regard to her Colonies and the Acquisitions of Canada and Guadaloupe (London: T. Becket, 1760). In addition to the debate between Hamilton and Franklin about the “positive” aspects of this relationship, there was an even more famous “normative” or policy debate between Hamilton and Jefferson. This conflict raged over the inherent value of industrial/commercial/urban development and over the desirability of using government policies to promote this end. The positive and normative debates are linked if one adopts the Hamilton position that due to the complementary nature of industrial and agricultural development, government policies that promoted industry ultimately benefited agriculture as well.
3 These insights are supported in theoretical work by Kiminori Matsuyama, “Agricultural Productivity, Comparative Advantage, and Economic Growth,” Journal of Economic Theory 58 (1992): 317-34. Matsuyama uses a two-sector endogenous growth model where preferences are non-homothetic (i.e. the income elasticity of demand for food is less than unity) and productivity growth in manufacturing occurs through learning-by-doing. He finds agricultural productivity and aggregate growth are positively related in a closed economy setting and negatively related in a small open economy.
5 John W. Mellor, ed., Agriculture on the Road to Industrialization, (Baltimore: Published for the International Food Policy Research Institute, Johns Hopkins University Press, 1995).
6 Mellor also addresses the issue raised earlier of whether the agricultural sector competes with the industrial sector by drawing away resources that might promote industrialization. We have not presented Mellor’s results for Africa and Latin America. Neither region exhibited a close relationship between agricultural growth per capita and nonagricultural growth. This is not to say that agricultural growth was not a stimulant to general development, only that the situation is less clear due to a complex array of differing policy regimes and external shocks that have masked the relationships.
7 This allows for some ambiguity because of the creation of new nations and changes in the borders of others during the period of analysis. The data are preliminary and would benefit from refinement by national experts. The data were created by combining per capita income statistics from Angus Maddison, The World Economy: Historical Statistics (Paris: OECD, 2003) and statistics on the “Agricultural Share of Income” from B. R. Mitchell, International Historical Statistics Europe 1750-2000, 5th ed. (New York: Palgrave Macmillan, 2003), 929-36.
Most obvious is the question of the direction of causality. The causal link between agriculture and industrialization (and commercial growth) runs in both directions. A growing industrial sector will, all else equal, eventually affect agricultural wages, prices, land values, and the like, thereby creating pressures to mechanize or otherwise modernize the agricultural sector.


An alternative is constant agricultural productivity, a significant deterioration in agricultural incomes, coupled with a transfer of resources to the industrial sector.

This essential point underlies much work in economic history, including in recent years, research by Nick Harley, Kevin O’Rourke, Gunner Pearson, and others for Northern Europe; and work by Morilla, Olmstead and Rhode, and Pinilla and Ayuda, and others for Southern Europe. Europe’s reliance on food imports increased in the nineteenth century, but some regions had long been heavily dependent on food imports from the Baltic region.


The modern growth literature rests on many other highly dubious assumptions. In a 2004 article, Lucas turns to analyzing the forces shaping rural-urban migration. In particular, he investigates the intriguing question of why, given sectoral productivity differences, the shifts do not occur all at once and instead involve a lengthy process of adjustment. To explain this process as part of an equilibrium in a dynamic growth model, Lucas emphasizes agglomeration economics in urban areas for investing in human capital. That is, the model assumes it is cheaper in cities to enjoy continuing learning spillovers from more educated (in the most elaborated version, from the most educated). As another leap at heroic simplification, presumably to make the model tractable, Lucas assumes education confers no advantage in rural production; the elasticity of rural output with respect to human capital is zero. Robert Lucas, Robert E. Lucas, “Life Earnings and Rural-Urban Migration,” *Journal of Political Economy* 112, no. 1 (Feb. 2004): S29-S59.

For a recent summary of some of the literature on this issue see van Zanden, “Cobb-Douglas.” The idea that all pre-modern economies were the same is not consistent with the data. Crude estimates for pre-industrial Europe suggest that income per capita levels may have varied by more than a factor of four. The relationship between agricultural structure and demographic behavior (fertility, migration, and mortality) also bears careful attention.


In his counterfactual analysis, Caselli, pp. 723-24, uses the United States as the base case to compare effects of world income inequality of alternatively replacing each nation’s (a) agricultural labor productivity; (b) nonagricultural labor productivity; and (c) labor force share with the corresponding US values. He observes the “results are stunning… if poor countries achieved the same level of agricultural labor productivity as the U.S., world income inequality would virtually disappear!” The decomposition
results of this comparison are problematic because, in the U.S., agricultural productivity is the same or higher than nonagricultural productivity. Choosing a different base country would likely yield different results.


27 Federico is correct that the mechanical cotton harvester was an American invention, but so were the cotton varieties that could be hand picked three to four times faster than older varieties. Given little cotton was grown in Europe it is not surprising that Continental inventors turned their attentions elsewhere.


33 Federico, pp. 9-10.


36 van Zanden, “First Green,” p. 216, 233. Relevant to our discussion of the induced innovation model, van Zanden also emphasizes that in a period of rising wage to land prices farmers in many countries opted for significant investment biological investments, pp. 216-17.


38 Olmstead and Rhode, “Tractor.”