The Road from Agriculture

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The great economist Arthur Lewis emphasized the distinction between traditional agriculture and urban industries. In his view, savings and investment originate solely in the latter, while vast pools of underutilized labor can be found in the traditional sector (Lewis, 1954). In this paper, we aim at filling a gap in his analysis by constructing a model of rational behavior in the traditional sector. We want to think of farmers as rational agents and thus attempt to explain economic backwardness not in terms of history or mentality but rather in terms of a model with maximizing behavior. The main contribution of our model is to show that the level of technology in agriculture in each country will not, in general, coincide with the "frontier" technology of the most advanced economy. In particular, each country has an optimal "technology gap" that separates it from the frontier. In our analysis, the size of this gap turns out to depend on factors exogenous to most economic models and seldom subject to change, such as farm size reflecting geography, the fertility of the land, the ability of farmers to digest and adopt new technologies and the rate of time preference. Most surprisingly, perhaps, the distance from the technology frontier turns out to depend on the position of the frontier itself; the more advanced is frontier technology, the larger is the optimal distance that maximizes the value of land from the frontier.

The share of agriculture in employment and value added has fallen relentlessly around the world over the past one hundred years. Until the end of the 19th century, an overwhelming part of the work force was engaged in agriculture everywhere. In 1960, almost half the labor force in low-income countries was still employed in agriculture, but this ratio continues to fall: today almost a fourth of the labor force in low-income countries works on the land, less than ten percent in middle-income countries, and less than two percent in high-income countries. To illustrate the relationship that motivates this study, we show in Figure 1 data from 86 countries, some rich and some poor, in the period from 1965 to 1998.[1]

Figure 1. Structural Change and Growth 1965-1998
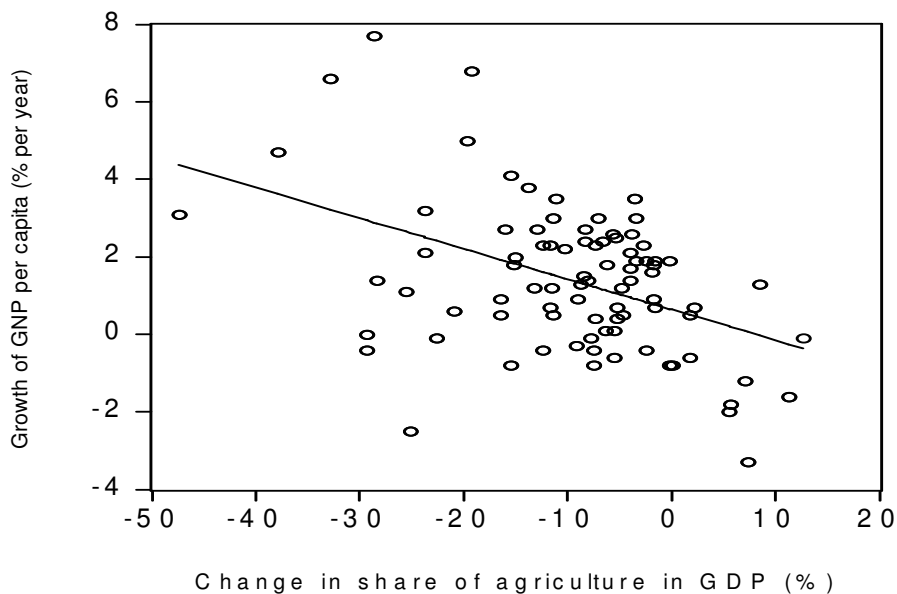
The figure shows the relationship between per capita economic growth along the vertical axis and structural change as measured from right to left along the horizontal axis by the decrease in the share of agriculture in value added from 1965 to 1998. Each country is represented by a single dot in the figure: the average growth rate over the sample period and the structural change from the beginning to the end of the period. The figure shows that a decrease in the share of agriculture

by thirteen percentage points from one country to another is, on the average, associated with an increase in annual per capita growth by one percentage point.[2]

In a recent study, Temin (2002) argues that a relationship similar to that shown in Figure 1 can account for the growth performance of fifteen European countries over the period 1955-1995. In particular, he argues that the migration of labor from rural to urban areas helps explain the post-war "Golden Age" of European economic growth, including the differences in growth rates during this period and the end of the high-growth era in the early 1970s.[3] Not all countries have handled this dramatic transformation of their economic structure as well. In extreme cases, the development was actively resisted, as witnessed originally by the institution of slavery that in some places persisted well into the second half of the 19th century. The resistance to change took other, milder forms as well: for example, farm workers in Iceland were throughout the 19th century prevented by law from leaving their employers, a form of serfdom that significantly delayed the transformation of the Icelandic economy from agriculture to industry.

This paper adds to an expanding literature on the long-run sectoral implications of economic growth.[4] While we emphasize endogenous technological adoption at the farm level, other contributions have emphasized human capital accumulation. Galor and Moav (2003) model the transition from a rural agricultural society to an urban industrial society by showing how the complementarity of human and physical capital in industry generates an incentive for industrialists to support educational reforms. Human capital accumulation also plays an important part in the transition in Tamura (2002). In Galor and Weil (2000), skill-biased technical progress raises the rate of return on human capital, which causes human capital to grow, hence creating steady-state growth. Jones (1999), in contrast, argues that

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increasing returns to the accumulation of technology and labor sustain growth. We do not dispute the importance of human capital for the transition but, instead, want to describe some of the determinants of endogenous technological adoption in agriculture.

We argue that the extent of the transition from an agrarian economy to an industrial economy depends not only on the access of industrial producers to unlimited supplies of rural labor (Lewis, 1954) and on productivity developments and availability of work in urban areas (Kaldor, 1966; Harris and Todaro, 1970), but also on farm size reflecting geography, the fertility of land and the ability of farmers to adopt new technology. In this we are perhaps motivated by the experience of our own native Iceland, an island in the far North Atlantic where agriculture was the main economic activity for centuries, supporting a population that lived on the margins of subsistence. Harsh climate, unfertile soil, small disparate plots of arable land and a population not familiar with foreign cultures or languages hampered economic development for almost a thousand years. It is difficult to conceive of any form of institution building that could have helped inject dynamism into such an overwhelmingly agricultural economy. What was needed, instead, was the diversification of economic activity away from agriculture.

I. Efficiency gains in agriculture and growth

In this section we describe the behavior of farmers as they adopt new technology. Our aim is to endogenize the extent of allocative as well as organizational efficiency gains.[5] We take the economy to consist of two sectors, a rural agricultural sector and an urban manufacturing sector. Unlike Lewis, we assume that farmers engage in maximizing behavior. We are interested in their decisions

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about the adoption of new labor saving technology as well as in the implications of those decisions for economic growth in a two-sector world.[6]

Sectors

Agricultural output is produced with land and labor. Land is a fixed factor that limits the maximum feasible production. The land is divided into different farms that differ in size and fertility. The distribution of size and fertility is exogenous to our model and assumed to depend solely on geography and climate. In contrast, urban industrial output is not constrained by any fixed factor. Instead, output is produced with labor using a constant-returns technology. Individuals in our model are either farmers – that is, owners of land – farm workers or urban dwellers. An individual may move between these three states; higher farm profits induce workers to become farmers, higher rural wages create an incentive for becoming a farm worker and for people to move from urban to rural areas, while higher urban wages pull workers to the cities.

Markets

There is perfect competition in the market for industrial goods, agricultural goods and labor in the two sectors. Individuals differ in their preferences for rural versus urban labor. When relative wages in urban areas rise, more people decide to migrate from the farms to the cities but not everyone will move. It follows that expected wages in the two sectors do not have to be equal. Cultural differences as well as education and family pressure may also create an attachment to either rural or urban living.

As in Harris and Todaro (1970), the relative price of agricultural output in terms of manufacturing goods is a decreasing function of agricultural output and an increasing function of manufacturing output: $P_A / P_M = p = p(Y^A/Y^M)$, with $p' < 0$. This assumption captures the demand side of our model; we do not model consumption choices.

Utility

Preferences are separable in the utility of income, on the one hand, and the utility from living in rural versus urban areas, on the other hand. Utility of income is homogenous and linear in income while workers are heterogeneous in terms of the utility of residence. Farmers maximize the present discounted value of future utility using an exogenous and fixed rate of time preference r. For simplicity, we assume infinite horizons. Farmers compare the present discounted value of future utility to the present discounted value of working on other farms and they switch between owning land and working for others when the latter gives higher future utility.

The production technology

We assume a Leontief production function in agriculture and a linear production function in urban industry:

(1)
$$Y_t^A = \min[A_t N_t^A,\ FL]$$

(2)
$$Y_t^M = B_t N_t^M$$

Y^A denotes the level of output of agricultural produce and Y^M is modern urban output, A denotes the level of labor-augmenting technology in agriculture and B, technology in manufacturing. N^A is the number of workers in agriculture and N^M, in manufacturing. L is arable land and F denotes the fertility of the soil. It follows that

if the number of effective labor units AN^A is up to the task, sustainable farm output is *FL*. There are constant returns to scale in industry but sharply diminishing returns in agriculture once we hit the capacity of land.[7,8]

The production frontier consists of two linear segments HE and EI as shown in Figure 2. The distance OH in the figure equals *FL*, the maximum output possible in agriculture. The slope of the segment EI equals the ratio of marginal labor productivities in the two sectors, *-A/B*. At point E, modern output is shown by the distance OC and farm output, by OH = *FL*, and total output at world prices is shown by the distance OJ. Maximum possible output in manufacturing *BN* is shown by the distance OI and is assumed constant. Labor-saving technological progress in agriculture increases *A* and shifts the production frontier outwards from HEI to HFI, increasing modern output and total output by CD = JK.

Figure 2. Technological Change
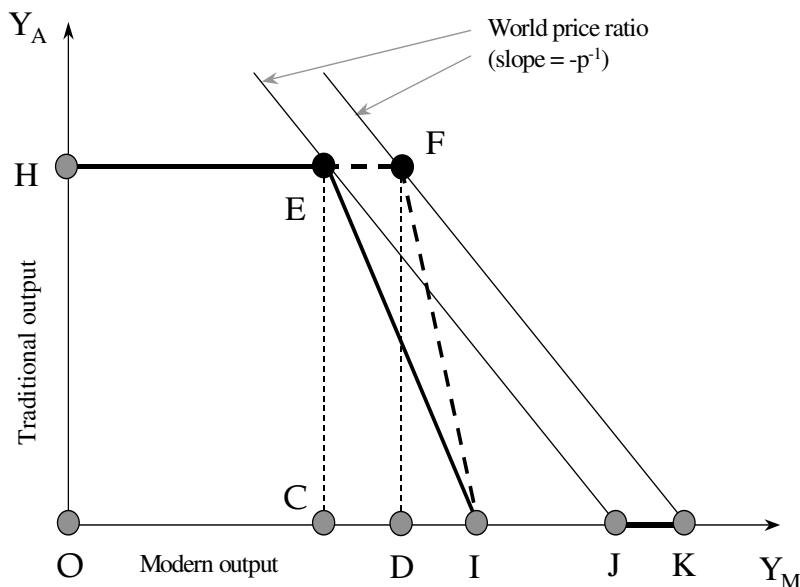
We assume that farmers differ in their ability to understand and adopt leading-edge technology.[9] The cost function h is rising in the rate of technology adoption, a, but falling in the ability to take on new technology, b:

(3) $$h(a,b),\ h_a > 0,\ h_b < 0, h_{ab} < 0,\ h_{aa} > 0$$

We assume that the cross derivative is negative implying that the marginal cost of learning is falling in the ability to learn.

Profits and the value of land

A farm generates a stream of revenues. The farmer pays wages w to his workers and retains all profits. We assume for simplicity that farmers do not work in the field so that their utility is simply linear in profits. Farmers continue to farm their land using paid labor until it becomes optimal for them to abandon the farm and become agricultural workers elsewhere. This happens when the expected lifetime utility of working at a different farm (perhaps a bigger and a more fertile one) exceeds the expected utility of continuing to farm one's own land.

Farmers maximize the present discounted value of future utility (profits) from time zero to infinity. It follows from our assumed utility function that this amounts to the maximization of the value of land. Profits for a given farmer i in real terms are defined as follows in terms of traditional output:

(4) $$\pi_i = F_i L_i (1 - w/A_i) - h(a_i)$$

where w/A is the cost of producing one unit of output and the cost of technology adoption a is denoted by $h(a)$ Equation (4) implies that the value of a given farm i is given by

(5) $$V_i = \int_0^\infty \left[F_i L_i \left(1 - w/A_{it}^*\right) - h\left(a_{it}^*\right) \right] e^{-rt} dt$$

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which is the present discounted value of expected profits (utility) along the optimal,
value-maximizing path per unit of land. In steady state where $a = 0$ and $h(0) = 0$,
equation (5) simplifies to

(5')
$$V_i = \left[F_i L_i \left(1 - w/A_i^{\,*}\right)\right]/r$$

where A^* is the profit-maximizing level of technology – which, as we show below,
does not have to equal the state of frontier technology – and r is the exogenous rate
of time preference.[10]

The farm will stay in business as long as V_i is greater than the discounted
expected value of agricultural wages.[11] If farm wages were to rise dramatically, or
if the fertility of land were to fall due to adverse climatic conditions, the farmer
might be better off closing down and working for someone else. Clearly, any
adverse climatic change or increase in wages will first push those farming the
smallest and least fertile plots into abandoning their land.

The labor market

We have assumed that labor is heterogeneous with respect to preferences towards
living in rural versus urban areas. Some workers will decide to migrate to cities
when rural wages fall below urban wages but by no means all, and it follows that
expected wages are not equalized across the two geographic areas. Labor supply in
rural areas N^A is an increasing function of the ratio of agricultural to industrial
wages and vice versa for labor supply in urban areas N^I. The sum of labor supplied
in the two areas equals the aggregate labor force minus the number of farmers,

(6)
$$N^A\left(\frac{wA}{w^I}\right) + N^I\left(\frac{w^A}{w^I}\right) = \overline{N} - N^F\left(\frac{w^A/r}{V}\right)$$

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where $\overline{N}$ denotes the labor force and N^F, the number of farmers, which is a decreasing function of the ratio of the discounted value of future farm wages and the value of owning land.

Labor demand in rural areas is determined by the size of the land, its fertility and the state of technology and is – at each moment in time – independent of agricultural wages.[12] By equation (1) $N^A = \sum F_i L_i / A_i^*$ where F is the fertility of land and A^* is the optimal level of technology along the optimal path. Labor demand in rural areas is independent of wages – for a given, fixed level of technology A – as long as all farms stay in business. In contrast, the labor demand schedule in urban areas is horizontal at level B. Together, the two labor supply equations and the two labor demand equations determine wages and employment in both sectors.

Technology adoption and closing in on the frontier

A farmer maximizes the value of his land V_i. She needs to decide whether to adopt cutting-edge technology or to lag behind, and if so by how much. Backward farms employ low-level technology and compensate by having many workers while modern farms have cutting-edge technology and fewer workers. We assume that worldwide potential, leading-edge technology A^p is constant in the short run but subject to infrequent unanticipated discrete jumps:

(7)
$$A_t^p = \overline{A}$$

The farmer decides on the speed of adoption of state-of-the-art technology – denoted by a – such that his own level of technology evolves according to

(8)
$$\dot{A}_{it} = a_i \left(A_t^p - A_{it} \right)$$

where $\dot{A} = dA/dt$. We define a to be a choice variable and assume below that the cost of learning depends on his ability to digest and adopt new technologies. [13] In this we follow Schultz (1944) who proposed the idea that the gap between traditional production methods and frontier technology in agriculture creates the conditions necessary for growth.

The essence of the farmer's problem is to choose how many resources to use up today in order to have better technology tomorrow that will allow labor to be shed and wage costs to be cut for a given level of output, which is constrained by the supply and fertility of arable land.[14] There is one control variable: the rate of technology adoption a, and one state variable, the level of technology A. Equation (9) gives the optimal rate of technology adoption:

(9)
$$h_{ai} = q_{it}\left(\overline{A} - A_{it}\right)$$

The left-hand side shows the marginal cost of learning about new technology and the right-hand side shows the marginal benefit, which is equal to the product of the value of new technology at the margin, q, and the marginal effect of increasing the learning intensity a on the accumulation of technology. Finally, there is the differential equation for the value of new technology:

(10)
$$\dot{q}_{it} = (r + a_i)q_{it} - w\frac{F_i L_i}{A_{it}^2}$$

Combining equations (9) and (10) gives the rate of change of the intensity of technology adoption:

(11)
$$\frac{\dot{a}_{it}}{a_{it}} = \frac{1}{\varepsilon(h_a, a)}\left[r - \frac{w_t F_i L_i\left(\overline{A} - A_{it}\right)}{A_{it}^2 h_a}\right]$$

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The interest rate reflects the marginal cost of learning about new technology and the second term within the brackets is the marginal benefit of learning, i.e., the marginal benefit of increasing a. The marginal benefit consists of the reduction of wage payments made possible by investing in new technology today. The marginal (current) cost of raising a is h_a, and shows up in the denominator in the marginal benefit term, while the absolute fall in wage costs per unit of time is $wF(f)\overline{L}(\overline{A}-A)/A^2$. The ratio of the two is the rate of cost savings per unit of spending on technology adoption – that is, the rate of return to investing in, or learning about, new technology. When the marginal benefit term exceeds the marginal cost r, the rate of adoption a is high but falling. When the marginal benefit falls short of the marginal cost, the intensity is low but rising. The term $\varepsilon(h_a,a)$ denotes the elasticity of the marginal adoption cost with respect to adoption a. The higher this elasticity, the more responsive is the farmer to changes in the marginal benefit and marginal cost of learning.

The two differential equations (9) and (11) are solved together in the phase diagram in Figure 3. The $\dot{A}=0$ locus starts at the origin, follows the horizontal axis to point Q and then becomes vertical, the distance OQ equals $\overline{A}$. The $\dot{a}=0$ locus slopes down throughout and cuts the horizontal axis at M to the left of Q when $r>0$. Importantly, as long as $r>0$, the farm will never converge to $\overline{A}$ because the marginal benefit of increasing a is falling and in the end this is not enough to justify the sacrifice of current profit due to a positive interest rate.

The horizontal segment MQ shows the distance from the technological frontier in steady state. This segment shows the extent to which the representative farm does not adopt leading-edge technology. It is optimal not to converge all the way to the frontier. A country with small agricultural plots lacking in fertility and farmers

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who find it difficult to adopt new technology (h_a very large) is likely to choose a point far from the frontier.

Figure 3. The Farmer's Problem
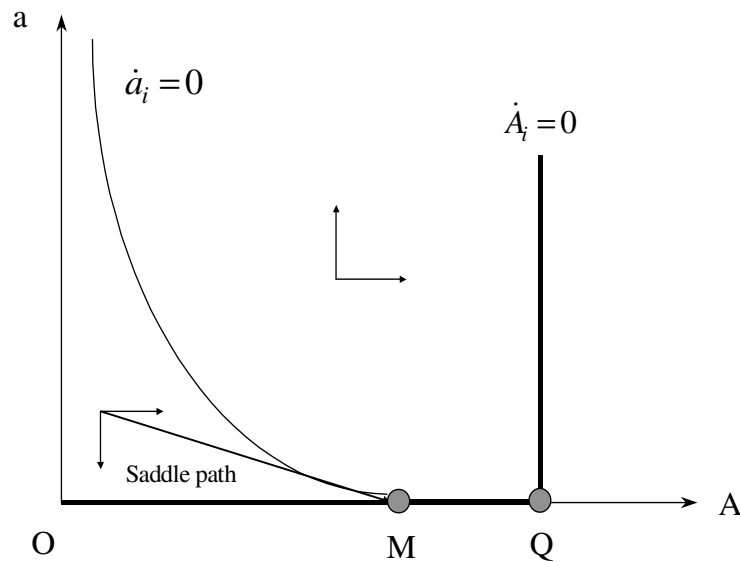
Optimal backwardness

It is common nowadays to view economic growth as being driven initially by learning about – that is, imitating – new technologies and converging to a technological frontier. Once the frontier is reached, a process of inventions and discoveries takes over.[15] In contrast, our simple analysis – as depicted in Figure 3 – shows that it may be optimal for farmers to stay away from the technological frontier for reasons having to do with factors beyond their control and exogenous to economic models. Relative backwardness may be the optimal strategy. We can see from equation (11) how the length of the segment MQ – the degree of technological backwardness – is determined within our model, and this gives us several interesting implications.

Optimal backwardness varies directly with the state of frontier technology. The reason is diminishing returns to investing in new technology – the marginal

reduction in wage costs is falling in the level of technology *A*. For this reason, the representative farm finds it optimal *not* to keep a constant gap between its own level and the level of leading-edge technology.[16] Instead, the gap is larger the more advanced is frontier technology.[17]

The lower are wages in rural areas, the weaker the incentive to invest in new technologies since farms can avail themselves of cheap rural labor. If a large segment of the population only wants, or is confined by cultural and institutional factors, to live in rural areas, then equilibrium wages will be lower and the incentive to learn about new production methods will be weaker. Clearly, there is no incentive for technological improvements in a slave economy with abundant labor. A lower level of urban technology *B* has an effect in the same direction by not creating attractive employment opportunities.

The size of each farm and the fertility of its soil are important for how close to the frontier we come. The bigger the farm, and the more fertile the soil, the greater is the incentive to adopt new technologies. Bigger farms using more fertile soil will adopt better technologies than the smaller and less fertile ones. At the aggregate level the size and fertility distribution will matter for overall agricultural productivity.

Low costs of adopting technology will also speed up the adoption of modern technology and bring us closer to the frontier. This implies that the marginal cost of adoption – the cost of adopting new technology at the margin – is low. One reason could be an educated workforce (see Nelson and Phelps, 1967). Again, the distribution of learning abilities among the population of farmers will matter for aggregate outcomes. Also, the higher the rate of time preference *r*, the farther away from the frontier we find us.

At last, the speed of adjustment along the saddle path depends on the convexity of the adoption cost function h. When this function is very convex (h_{aa} takes a large value), the speed of adjustment is slow.

The Harris-Todaro effect: labor pulled to the cities

Technological improvements in the urban manufacturing sector raise urban wages and cause labor supplied to agriculture to fall. Fewer people are now willing to work in agriculture for the prevailing rural wages. There follows an increase in rural wages and the attendant increase in wage costs encourages farmers to invest in better technology, which lowers labor demand in agriculture. In Figure 4 the speed of adoption of new technology initially picks up as indicated by the upward shift of the $\dot{a} = 0$ locus, but then falls until a new steady state is reached at point N where technology A is closer to the unchanged frontier at Q.

Rural wages are higher in the new steady state than before because the technological progress and the accompanying fall in labor demand only partially offset the initial fall in labor supply. We are left with the empirical prediction that living standards in rural areas should be rising if the cause of the migration is technological progress in the cities. Notice also that the value of land should be falling. Farmers lose and farm workers gain.

The Schultz effect: labor pushed to the cities

From the preceding analysis we can see that the steady-state level of technology at the farm level is increasing in the level of frontier technology $\overline{A}$. With more and better technology available around the world, each farm ends up more advanced as long as $h_a < \infty$, $w > 0$ and $F_i L_i > 0$. Clearly, a slave economy would not adopt any

new technology because labor savings are of no value in this case; the same applies

to a farm where the land is useless or the cost of technology adoption is infinite.

The increase in $\bar{A}$ shifts both loci to the right in Figure 4 as well as the saddle path.

The level of a jumps to the new saddle path and then gradually falls as we move to

the new steady state at N with a higher level of steady-state A.

The effect on the standard of living in urban areas will now depend on the

elasticity of labor supply with respect to wages. If labor supply is very inelastic,

i.e., if people have a strong preference for living in rural areas, the fall in labor

demand will cause the rural wage and hence also the standard of living in rural

areas to fall drastically. In contrast, the value of land will increase.[18]

Figure 4. Urban "Pull" vs. Rural "Push"
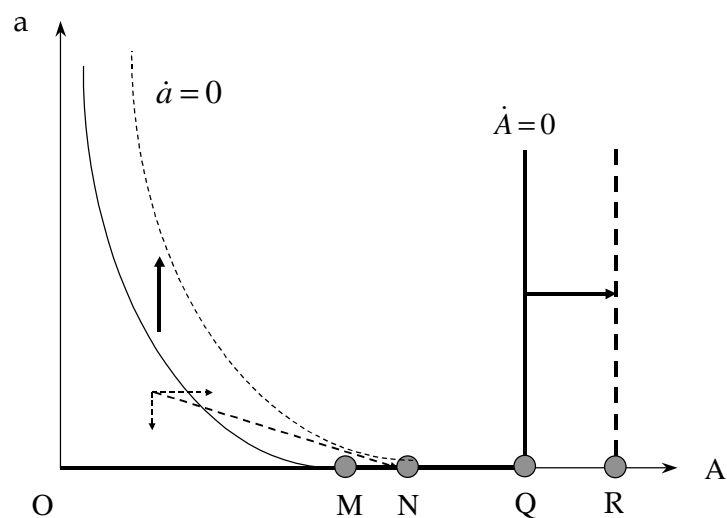
II. Pushing and pulling in Iceland

We have found changes in farm technology to be induced either by technological

advances in urban areas or by progress in agriculture at the world level, holding

fixed the size and fertility of land and the ability of farmers to take on new

technologies. One can test which type of process is at work by looking at the evolution of wages per unit output w/A. If labor is pushed to urban areas by technological developments taking place within the agricultural sector, we have a prediction that A goes up on all farms leading to a fall in labor demand and lower wages per unit output. If, in contrast, it is the urban pull that is driving the process, we have rising wages causing farmers to take up labor saving technology, hence raising A on each farm. In this case wages per unit output w/A may not fall.

Iceland provides ideal testing grounds for our hypotheses. The economy was based almost solely on agriculture and remained stagnant until the end of the 19th century. Individual farmlands varied greatly in size and natural yield. The agricultural technology was very basic throughout and no important improvements occurred before 1900. For example, the use of chemical fertilizers only started after 1920 (Jonsson, 1993), more than 50 years after their introduction elsewhere. Produce was limited to a small selection of vegetables and hay for feeding livestock over winter. The population remained stagnant for almost a thousand years. It was 50,000 in 1703 and had not grown since the years after the settlement of the island 800 years earlier. It remained stagnant for the rest of the 18th century and by the late 19th century had grown to only 70,000. There was considerable social mobility between servants, tenants and landowners, which contributed to a less rigid class system than that of European societies (Jonsson, 1993).

Icelandic farmers had a larger labor force at their disposal than those of other European countries. This was mainly due to the absence of competing sectors on the island but also helped by legal restrictions on the movement of people from the traditional farm sector to other pursuits. In 13th century law a formal permission from local authorities is required for leaving agriculture and local authorities are

obliged to provide a form of social insurance for non-farm workers. A similar law can be found on the books as late as 1887. One rationale for this law was that fishing and commerce were intrinsically more risky or volatile than agriculture. Even so, the law was clearly intended to provide cheap labor to agriculture. The mobility restrictions, which bordered on slavery, affected around 25 percent of the population in the 19th century. Workers who did not have farmland were required to reside with an established farmer who "owned" them and was entitled to all their earnings – on the farm as well as outside. In return, the farmers were required to provide food and shelter as well as an annual allowance that amounted to half the value of one cattle. The allowance was generally *not* sufficient to enable a man and a woman employed on the same farm to marry and have children. In fact, workers were not allowed to leave their masters without permission and corporal punishments were common. The mobility restrictions served basically three purposes. First, they created social stability in that a limited number of workers were allowed to rely exclusively on inherently volatile fishing and commerce. Second, and perhaps foremost, the real wage of farm workers was kept low which helped sustain farming. Third, population growth was kept down by confining a significant part of the population to slave-like conditions. These laws were abolished in 1893 and all individuals over the age of 21 allowed to choose their employment and keep the wages, making farmers face stiffer competition for labor from the expanding fishing villages.

There were some attempts made by Denmark – the colonial ruler until 1918 – to promote agricultural reforms. In the 18th century, the Danes used laws and regulations, financial incentives and the publication of books and pamphlets to encourage farmers to adopt new technologies and more efficient farming methods.

On one occasion, the Danish authorities sent 14 Danish and Norwegian farmers to Iceland to train farmers to grow grain and vegetables (Jonsson, 1993). Also, a new breed of sheep was introduced with calamitous consequences for the local stock. On the whole, these attempts at promoting better technology proved futile, apart from some increase in vegetable production. The abundance of cheap labor made any productivity improvements a low priority.

The economic growth that started around 1870 coincided with a structural transformation from agriculture to fishing, and later to a service economy. Figure 5 shows the ratio of total wage payments on farms, wN^A, and the value of agricultural production, AN^A, in Iceland over the period 1870-1945. This series measures average wages per unit of output w/A, which could rise if labor was being pulled to the cities but would fall if indigenous productivity improvements pushed labor out of agriculture. Notice the absence of a downward trend. The period from 1870 to 1888 has rising wage costs. The same applies to 1895-2005. Cyclical behavior follows. The figure also shows the share of the population living in rural areas. The trend is downwards throughout, starting around 0.84 and ending at 0.29.[19] These numbers indicate that labor was pulled away from agriculture by an expanding urban sector.

If driven by the pull of emerging towns – mostly fishing villages – we would expect farms using the smallest and least fertile soil to be abandoned. During this period the number of farms starts at 5,652 in 1861 but by 1942 there are 652 farms that have been vacated. Another piece of evidence for the pull theory is the evolution of the ratio of the average farm prices to average wages of farm workers, which went from 17.8 in 1922 to 6.34 in 1942.[20] Based on the evidence of rising wage costs, falling land values, and infertile farmlands being abandoned, we

conclude that labor was pulled from rural areas to the cities by the expansion of new industries in the urban areas along the coast.

Figure 5. The ratio *w/A* for agriculture in Iceland, 1870-1945
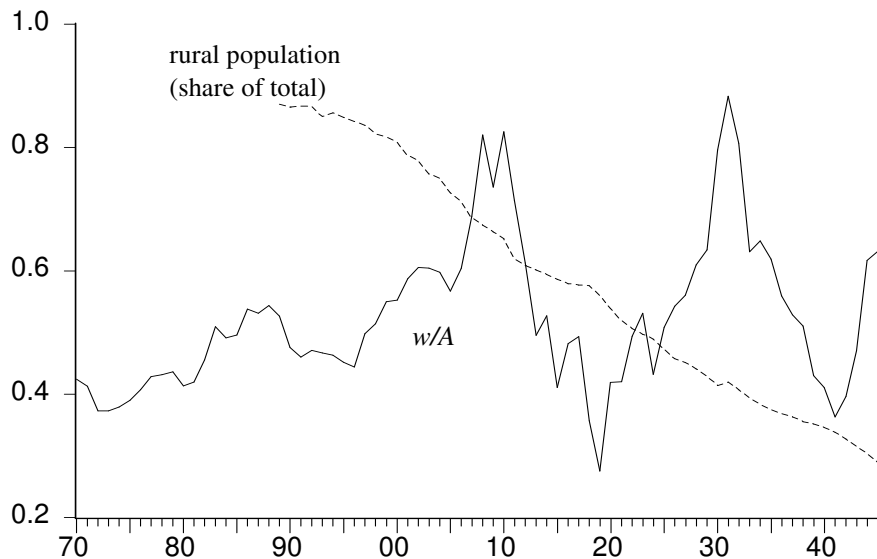
Source: *Hagskinna*, Statistics Iceland.

The story told here accords well with our model. Prior to 1870, agriculture did not take advantage of foreign technology because of the abundance of cheap labor – due to social legislation and a lack of outside opportunities – the small plots of land, the general inhospitable terrain and the isolation of the country due to its remote location and also a lack of familiarity with foreign languages (other than Latin). When progress commenced, it was not due to any changes on these fronts but was caused solely by expanding opportunities in the growing fishing sector, which initially faced constant returns to scale because of the abundance of fish stocks around the island. The increase in urban as well as rural wages induced the agricultural sector to modernize. This we have called the Harris-Todaro effect.

III. Education and structural change around the world

Let us return to the global setting. Ideally, we would want to regress a measure of structural change on all the explanatory variables mentioned in Section I. But the dearth of data forces us to limit the scope of our empirical analysis. Nevertheless, we attempt to find variables that may help explain structural change at the global level for a sample of 86 countries – that is, changes in the share of agriculture in output as well as changes in the share of cities in the total population – and focus on the role of education. We regress the structural change variable used in Figure1 and a corresponding urbanization variable on their initial values (i.e., on the share of the non-farm sector in GDP in 1965 and the share of urban areas in total population in 1965, respectively) as well as on the logarithm of the secondary-school enrolment rate, our measure of education.[21] We expect an initially bloated agricultural sector as well as a large rural population to yield larger changes in the period 1965-1998. Moreover, we expect a higher level of education to make these changes larger – that is, a lower value of h_a in our model above encourages farmers to adopt new technology, thus hastening the structural change and migration to the cities. The regression results are shown in Table 1.

We find that the higher the initial share of the non-farm sector in output, the smaller the value of the structural change variable, i.e., the smaller the decrease in the share of agriculture in total output. Likewise, the larger the initial share of urban areas in total population, the smaller was the migration to the cities. Hence, initial conditions affect both variables in the same direction: the larger the primary sector in 1965, the greater the fall in its share of output and people. As predicted by our model, a higher level of education goes together with greater structural change and more urbanization.

Table 1. OLS Results on Structural Change and Migration

	Structural change	Urban migration
Constant	29.384 (5.76)	12.239 (2.72)
Initial value	-0.717 (8.25)	-0.251 (3.91)
Secondary education	9.532 (5.32)	3.792 (2.18)
Adj. R-squared	0.55	0.15
Observations	55	86

Note: t-values are shown within parentheses. Estimation method: Ordinary least squares. Number of countries: 86. Saudi-Arabia is not included because of difficulties with its economic growth statistics.

We did not have access to data showing the relationship between fertility and farm size, on the one hand, and the pace of structural change, on the other hand. A paper by Engerman and Sokolof (1994) provides indirect evidence. They argue that the superior growth performance of Canada and the United States, when compared to other New World economies, was due to less inequality in the distribution of income, which in our model translates into higher relative wages of farm workers. Elsewhere, in Latin America and the American South, the suitability of land for the cultivation of sugar and other crops – which generated economies of scale in the use of slave labor – in addition to a very large supply of Native Americans created great inequalities which excluded large segments of the population from participation in economic life. The result was lower rates of economic growth. This evidence may at first glance appear to go against our model in that large-scale farming was not conducive to growth. But notice the link between scale, institutions and wages (slave labor!). With farmers facing close to zero wages for their workers, it is clear from our model that the incentives to adopt better technologies are minimal. In this the Latin American countries resembled our

account of Iceland above. Our model implies that rural areas in the North should have shed labor earlier and more rapidly than the South and Latin America. This was the case.

IV. Concluding thoughts

We have tried to shed new light on the determinants of the rate of technology adoption at the farm level, which underlies the transformation of societies from an agrarian base to an industrial one. We motivated our study by showing how economic growth in a sample of 86 countries is directly related to the devolution of agriculture around the world – that is, to the ongoing transfer of resources from agriculture to industry and services. We then presented a model showing how productivity gains in agriculture depend on external factors such as geography, the fertility of the soil and the receptivity of farmers to new ideas and technologies. We found that a certain level of backwardness in agricultural technology was optimal and that its extent depended on the same set of variables. Moreover, we classified technological progress in agriculture into two types; labor pull and labor push, and found that in Iceland – a country that suffers from a harsh climate and soil lacking in fertility – it was mainly the pull of rising wages in the fishing sector that made farmers adopt better technology and ended a 1000 year long period of economic stagnation. Finally, we found that in a sample of 86 countries, the pace of structural change and urbanization was helped by better educational standards.

The existence of abundant labor turns out to be the main obstacle to productivity growth in agriculture. When the fertility and size of the land are limited, in comparison with the number of workers living in rural areas, wages will be low and so will be the living standards for the majority of the population. Farmers, as

owners of land, will, in contrast, enjoy high standards of living. It is true that their land is not very productive but they face an abundance of cheap labor and can enjoy the profits. Attempts at educating them and giving them information on how to improve productivity may make some adopt better technologies, although Iceland's experience in the late 18th century is not promising in that regard. But the pull of an expanding industry – which makes labor increasingly costly in rural areas – is the magic bullet that induces landowners to expend resources to learn about and adopt more modern technologies. This raises productivity, wages and living standards for the majority of the population. But profits fall and landowners may then use their influence to fight the emergence and expansion of other sectors of the economy. The road from agriculture is cleared through creative social conflict.

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[1] The data are taken from the World Bank's *World Development Indicators* (2002).

[2] The Spearman rank correlation is 0.31 and statistically significant.

[3] According to his thesis, the preceding thirty years of depression and wars slowed down the rate of industrialization in many European countries – Britain being the most notable exception – and, therefore, the share of agriculture in the labor force was excessive at the end of World War II. This set the stage for the post-war period of high economic growth when the pent-up energy of underutilized ideas and education were harnessed by expanding industries that needed the workers supplied by rural areas.

[4] In a recent paper, Temple (2001) conducts a growth-accounting exercise in order to measure the effect of a structural transformation away from agriculture on post-war growth in some large OECD economies. He shows that this factor helps explain differences in the rate of post-war growth across countries, as well as the growth slowdown that occurred after 1970 – when the transformation was completed. He uses differences in the marginal product of labor to assess the importance of this transformation by calculating its share of the measured Solow residual. In particular, he derives bounds on the inter-sectoral wage (productivity) differential to derive upper and lower bounds on the magnitude of the reallocation effect. He finds that labor reallocation typically accounted for a twentieth to a seventh of growth in output per employed worker during the period 1950-1979. The effect was greatest in Italy, Spain and West Germany. However, he does not try to identify the forces that drive this structural transformation.

[5] By *allocative* efficiency gains we mean those gains that involve the reallocation of resources along the economy's production frontier from less efficient lines of

employment of labor, capital and other inputs, to more efficient ones, thereby increasing national economic output at full employment. By *organizational* efficiency gains we mean those gains that stem from outward shifts of the production frontier as a result of the reorganization of production, for instance, through the adoption of new production methods or better management.

[6] In this we are close to Schultz (1944) who worried about the ability of an urban sector to absorb labor shed by agriculture due to labor-saving technical progress.

[7] This is as argued by Becker *et al*. (1999) who claim that increased population in urban areas fosters the division of labor creating constant or even increasing returns to scale while increased population in rural areas that rely on traditional industries is bound to hit diminishing returns.

[8] Note that we could have derived all the results in the main text by changing the production technology in the farming sector to a pure diminishing-returns-to-labor technology – without an explicit capacity constraint FL – and a perfectly elastic supply of labor. However, we think the setup we assume is equally realistic with the added benefit of making the mathematics that follow a bit easier.

[9] Nelson and Phelps (1967) argue that education gives people the ability to learn. In our context it helps workers learn about new technology.

[10] The value of land is increasing in the size of land and its fertility as first proposed by Ricardo (1819).

[11] The implied threshold is: $w=F/(1+F/A)$. If wages are higher than this threshold for a farmer with fertility of land F, he will decide to abandon the farming and become a farm worker elsewhere. If not, he continues farming his land.

[12] In the long run, higher wages will make the farmer adopt new technology, which will reduce labor demand.

Equations (3) and (8) imply that technological adoption becomes increasingly costly the closer we get to the technological frontier. Thus, closing half the gap between current and frontier technology always incurs cost *h(1/2)*, but the absolute productivity gain is larger the further we find ourselves from the frontier. We can imagine the farmer first taking on board the most important ingredients of modern technology, then increasingly focusing on less relevant refinements.

[14] The representative farm's maximization problem can be written as follows:

$$\underset{a,f}{\text{Max}} \int_0^\infty \left[FL - w_t N_t - h(a_t, b) \right] e^{-rt} dt$$

subject to $A_t N_t = FL$ and also that equation (8) holds.

[15] A recent paper by Acemoglu, Aghion and Zilibotti (2003) makes the point that a different set of institutions may be desirable in the transition to steady state than on the frontier.

[16] The first derivative of the marginal benefit of improved technology in equation (11) is negative:

$$\frac{d\left[-wf\overline{L}(\overline{A} - A)/A^2 \right]}{dA} = -wF\overline{L}/A^2 \left[2\overline{A}/A - 1 \right] < 0$$

while the second derivative is positive:

$$\frac{d\left[-wF\overline{L}/A^2 \left[2\overline{A}/A - 1 \right] \right]}{dA} = 2wF\overline{L}/A^3 \left[3\overline{A}/A - 1 \right] > 0.$$

[17] Taking the total differential of the terms in the square bracket of equation (11) we find that :

$$\frac{dA}{d\overline{A}} = \frac{1}{2\dfrac{\overline{A}}{A} - 1} < 1$$

for the $\dot{a} = 0$ locus while we have $dA/d\overline{A} = 1$ for the $\dot{A} = 0$ locus. Hence the latter

shifts more than the former and the gap between the level of frontier technology

$\overline{A}$ and the steady–state techology A is increased.

[18] An improvement in the ability of farmers to adopt new technology, an increase

in the size and fertility of the land and a fall in the rate of time preference would all

make productivity in agriculture improve and so push workers to the cities.

[19] The transformation has continued until recent years, the share is currently below

5 percent of the total population.

[20] Sources: *Hagskinna* (Statistics Iceland) and *Hagvöxtur og iðnvæðing* (National

Economic Institute).

[21] We are also interested in the size of each farm and the fertility of the soil but we

have not been able to come up with variables that measure these factors with any

precision.