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Nineteenth Century U.S. Economic Growth: How Important Was the Transportation Revolution?*

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ABSTRACT

*The views expressed herein are those of the author and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

1. Introduction

The nineteenth century (19C) was a period of staggering improvements in transportation technology. A fun way to glimpse these improvements is to consider how freight was shipped between two points, like Pittsburgh and New York City (NYC), over the course of the century. For the first third of the century, goods were often shipped from Pittsburgh to NYC by way of New Orleans. Riverboats carried freight down the Ohio and Mississippi rivers to New Orleans. Ocean-going vessels then moved it through the Gulf of Mexico, around Florida, and finally up the Atlantic coast to NYC. If the riverboats used on the first leg of the journey were not steamboats, they were often destroyed since pulling the boats back up the rivers was not economical. With the development of the Pennsylvania Mainline canal in the 1840s, freight could now be forwarded from Pittsburgh to Philadelphia by water and then by railroad to NYC. But freight on the Mainline canal was portaged over mountains and hence its days were numbered. It quickly gave way to direct train service between Pittsburgh and NYC.

Such developments have deservedly been called a transportation revolution. But were they an economic one as well? That is, were transport improvements a significant source of U.S. productivity growth? In this paper I argue they were. I take two tacks in addressing the question. In the first part of the paper, I present theoretical reasons, and then simple facts about the 19C, that strongly suggest 19C transportation improvements led to significant increases in U.S. GDP per worker. This material is meant to establish the reasonableness of the claim that transport improvement was a major source of growth.

The second part of the paper provides a quantitative theoretical analysis. That is, I formally introduce a transportation sector into a general equilibrium model of regional trade. I then calibrate the model's parameters to the experience of the United States in the nineteenth century using observations on, among other things, productivity differences across regions by industry, price differences across regions and transportation's share of delivered prices. I then ask counterfactual questions, such as: What would productivity growth have been over some period, say 1870-1900, if the only sectoral total factor productivity (TFP) growth had been in the transportation sector? and how does this "computed" productivity growth compare to actual growth?

Turning to the first part of the paper, and in particular the theoretical discussion, I will argue that in the early stages of transportation development, improvements in transportation technology can have very large impacts on GDP per worker. In particular, I will argue that the elasticity of GDP per worker with respect to transportation TFP is larger at low values of transportation TFP than at higher ones, and moreover, that this elasticity at low levels of transport TFP is larger than transport's share of GDP. Let me provide a few sentences of rough intuition, and then a more detailed argument.

When transport TFP is low, transportation is costly and there is little trade. Potential gains from trade are left unexploited. When transport TFP is high, transportation is cheap and gains from trade are more fully exploited. Imagine then a 10% improvement in transport TFP, first at a low level of transport TFP and then at a higher level. In both cases (the low and high TFP cases), an increase in transport TFP means existing transport services are provided more cheaply. However, the 10% increase in transport TFP is of more value at low transport TFP levels because the value of increased trade is higher in this case.

Let me make the same argument with a few more details. Imagine a world with two regions that benefit from trading. Each region produces its own final goods and transportation services (that is, services that move its final goods to the other region). Each region "decides" the fraction of labor to devote to final good production and to transport services. Imagine that at some low level of transport TFP both regions devote 95 percent of their labor to produce final goods and 5 percent to transport services. Also imagine, and I will prove this later, that at some "much" higher level of transport TFP both regions make the same allocation (i.e., 95 and 5). Imagine the value of increasing transport TFP by 10 percent in both cases. Under the assumption that allocations are held fixed (at 95 and 5), then more goods are moved from one place to the next. The value of moving goods is larger when transport TFP is low (since in the low TFP case there are mostly locally produced goods in the consumption "basket"; in the high TFP case there is more "balance").

As a theoretical matter, then, for a given set of potential gains from trade, a given percentage increase in transport TFP has a bigger bang early-on, rather than later-on, in transport development. The size of the bang, that is, the elasticity of GDP with respect to transport TFP, also depends on the potential gains from trade between regions. Continuing with the first past of the paper, I present facts suggesting these potential gains were large in the 19C United States. Perhaps the most obvious source of gain from trade was that regions differed dramatically in their endowments of farm land, minerals, and timber. Hence, the production function for many goods, that together accounted for a large share of GDP, differed by region. Moreover, as I show, while some industries were very productive in a particular region (like cotton in the South), others had very low productivity there (like corn or wheat in the South).

Another important fact about the nineteenth century was that the pace of productivity improvement in transportation was very significant. Kendrick (1961) reports that between

1869-89, labor productivity in transport increased at an annual rate of 3.4 percent, while aggregate labor productivity increased 1.8 percent annually. Not only was the elasticity of GDP with respect to transport TFP high, the pace of productivity growth was also very high.

Another piece of evidence that suggests that transport improvement was a significant source of productivity growth in the nineteenth century comes from sectoral growth accounting exercises. In Appendix A, I show that the transport sector, which amounted to 5.5 percent of hours in 1869, accounted for about 20 percent of aggregate labor productivity growth over the period 1869-89. It accounted for roughly the same growth over the period as did the manufacturing sector, which amounted to 18.3 percent of hours in 1869.[1]

In the second part of the paper, I develop a quantitative model. In this version of the paper, I have kept the level of model-detail to a minimum. So, for example, there will be no intermediate goods (other than transportation services), no international trade, only two regions and a slew of other simplifications, some of which will be relaxed later. Hence, while I can certainly ask the counterfactual questions mentioned above, here I will simply show that in the calibrated model the elasticity of GDP with respect to transport TFP varies with the level of transport TFP.[2]

Turning to related literature, there have been a few studies that have estimated the impact of nineteenth century transportation improvements on GDP, most notably Williamson (1974,1975) and Kahn (1988). The model here is quite a bit different from the "Williamson"

[1] While growth accounting shows that the transport sector contributed on the order of 20 percent of total labor productivity growth at the end of the nineteenth century, this certainly pales in comparison to the contributions of the IT sector at the end of the twentieth century. For example, Oliner and Sicher calculate that IT contributed 50 percent of labor productivity growth from 1974-90. For 1991-95, and 1996-2001, they report 56 percent and 100 percent (wow!), respectively. See also Jorgenson.

[2] The answer to counterfactual questions will depend in important ways on the extent of regional and industry detail that is introduced into the model.

model.

There is, of course, a much larger literature that has examined a more narrow question: What would GDP have been in, say 1890, had there been no railroad by that date? In other words, how much lower would GDP have been in 1890 if this component of the transportation revolution (i.e., railroads) had been removed? (see Fogel, 1964, 1979). The methodology in this literature is such that an upper bound to the loss of output was calculated. With a model like that developed below, I can estimate the loss directly and ask if the loss was significantly less than the upper bound or not.[3]

In the model below, a competitive transportation sector is assumed. Competition between the two major long distance shipping industries, water and railroads, was a factor that limited market power. However, even with this competition, there were still significant amounts of monopoly and market power in the transportation sector in the late nineteenth century (as there were throughout the twentieth century and as there are today) (see Holmes and Schmitz, 2001).[4] So, my assumption of a competitive transport sector is an approximation which may need to be reconsidered later.

In the literature examining the loss of output if railroad services were not available, it is assumed that the transportation sector would have been competitive without the railroad. This is, of course, a stronger assumption than I am making below since without railroads there would have been little to temper market power in water shipping. With a model like that developed below, I can estimate the additional losses in output that would result from

[3] The model below does not have multiple transport systems within the transportation sector. But this is a simple extension.

[4] Holmes and Schmitz show that even with intense railroad competition, there was significant market power in the water shipping industry in the nineteenth and twentieth centuries. There was, of course, market power in railroads as well.

an increase in market power in transportation following a loss in railroad services.

2. Transportation: Early Improvements Have Big Effects

In this section I want to argue that in the early stages of transportation development, improvements in transportation technology can have very large impacts on GDP. I do so in the context of a simple model. I will only sketch the model here; details are given below.

Consider a model with two regions, East and West. In each region, three final goods are produced: an agricultural good, a manufacturing good, both of which are tradeable, and a local non-traded good (like housing services). Both regions also produce an intermediate good, transportation services. The agricultural sector is more productive in the West than the East, and visa versa for manufacturing. The transportation sector takes agricultural goods that are produced in the West, and together with labor input in the West (i.e., transportation sector employees), transforms them into agricultural goods in the East. The transportation sector also takes manufacturing goods that are produced in the East, and together with labor input in the East, transforms them into manufacturing goods in the West.

For the moment, let there be a single period in the economy and let regional populations be fixed. The only inputs are land and labor. Let B_f (B for boardings) denote the food that is set aside in the West to be transported East. Let N_{TW} denote the total amount of labor in the West used to transport goods. Let D_f denote deliveries of food in the East. Deliveries cannot exceed boardings, so I specify the transport technology as

$$D_f = \min(\sigma B_f, g(B_f, N_{TW}))$$

where $\sigma \leq 1$ is the fraction of food that arrives in the East and $g(\cdot)$ is an increasing function of both arguments. For simplicity, let me assume that each unit of food delivered requires

$(1/A_T)$ units of labor, so that $g(B_f, N_{TW}) = \sigma A_T N_{TW}$, where A_T is the transportation TFP parameter. Hence, the technology I use throughout is

(1) $\quad D_f = \min(\sigma B_f, \sigma A_T N_{TW}).$

The deliveries of manufactures in the West are governed by $D_m = \min(\sigma B_m, \sigma A_T N_{TE})$.

Suppose there are large productivity differences across regions (so that if there were no transport costs trade would occur). Let me first consider the fraction of the economy's labor force devoted to transportation services, and how it changes as A_T increases (in a competitive equilibrium). Suppose first that A_T is very small. Then it is not economical to trade. No labor is devoted to transport. If A_T is large enough, then some labor is devoted to transportation; transportation's share of total employment is positive. As A_T increases without bound, trade becomes free. With free trade, the quantity of goods traded is finite. Hence, as A_T increases without bound, less and less labor (see [1]) is needed to transport the (in the limit) fixed quantity of goods. The transport share of total employment goes to zero. This behavior is depicted in Figure 1.[5]

Next consider real GDP as a function of the parameter A_T (by real GDP I mean the sum of spending on the six final goods in the economy [each of the two locations has three final goods], valued at some constant set of prices). Real GDP depends on transport's TFP as in Figure 2. Real GDP does not change as A_T increases when A_T is very small. It then begins to increase as A_T moves beyond the minimum TFP compatible with trade. It finally approaches an upper bound (the real GDP associated with free trade) as A_T increases without limit. Hence, at low levels of A_T, GDP is a convex function of A_T; later it is a

[5] In Figure 1, the only parameter I am changing is A_T. If TFP parameters in other sectors were increasing, then Figure 1 would still be accurate as long as transport TFP grew faster than other sectoral TFP's.

concave function.

Let ε_{A_T} denote the elasticity of (real) GDP with respect to transport TFP, that is, $\varepsilon_{A_T} = \%\Delta GDP \div \%\Delta A_T$. In the introduction, I argued that $\varepsilon_{A_T}(A_T^{low}) > \varepsilon_{A_T}(A_T^{high})$. This is now obvious from Figure 2. At very high levels of A_T, GDP increases little at all with transport improvements. At low levels of A_T, say at the level that is just consistent with trade, improvements in transport lead to "big" increases in GDP, and hence the elasticity is bigger at this low A_T level; also, at this low level of A_T, $\varepsilon_{A_T}(A_T^{low}) > s_T$, where s_T is transport's share of hours, since $s_T \approx 0$.[6]

I argue below that transport in the United States in the 19C was a stage of development where $\varepsilon_{A_T}(A_T) > s_T$.

In the next section, I discuss the potential gains from trade in the 19C United States. Obviously, the elasticity above also depends on the extent of potential gains from trade. In the section following the next, I discuss the pace of productivity gains in transportation in the 19C. The increase in GDP from transport improvement obviously depends on the elasticity and the pace of productivity change.

3. Potential Gains From Trade: Large in 19C

In this section I want to argue that the potential gains from trade between regions were large in the nineteenth century United States.

Perhaps the most obvious source of gain from trade was that regions differed dramatically in their endowments of farm land, minerals, and timber. Hence, the production

[6] If I allow population to be mobile, then I think the above argument that transport improvements have their biggest bang early-on is reinforced. If I added intermediate goods that are produced in one location, shipped to another for processing, and then this processed good shipped back to the original location, then this too would reinforce the argument (see, e.g., Yi (2001)). Cotton is, of course, an example of such a good.

function for many goods, that together accounted for a large share of GDP, differed by region. Moreover, while some industries were very productive in a particular region, others had very low productivity there.

Consider farming first. Gallman (2000, Table 1.14, p. 50) reports agriculture's share of GDP in 1870 as 33 percent, declining to 18 percent by the end of the decade. Its major products were crops and livestock (gross farm product was roughly equally divided between these two products, see Towne and Rasmussen (1966), Table 1, p. 265). The major crops in the United States were cotton, wheat, and corn. Together these three crops amounted to 58 percent of the value of crops in 1860, falling to just under half the value of crops in 1900. Typically, the value of the cotton crop exceeded that of wheat, which in turn exceeded that of corn. In some years, the value of the cotton crop exceeded the sum of the values of the wheat and corn crops (see Towne and Rasmussen (1966), Table 6, p. 291).

The productivity in growing cotton obviously varied dramatically by region. Cotton was grown only in the South because it was not possible to grow it elsewhere. Here is a dramatic example of productivity differences across regions.[7]

The productivity differences in growing wheat and corn, while obviously not as dramatic as cotton, were very significant. Evidence on labor productivity across regions is provided by Parker and Klein. In Table 1, I present labor productivity in the three grains they studied: wheat, corn and oats. In each crop, the West had the highest labor productivity, followed by the Northeast, with the South taking up the rear. In the growing of wheat, the West was about 50 percent more productive than the Northeast and more than twice as

[7] In 1870, cotton accounted for about 30 percent of the value of crops. Crops accounted for about half of farm output, and farm output accounted for a third of total value added. Cotton then accounted for about 5 percent of GDP.

productive as the South. In the growing of corn, the West was more than twice as productive as both the Northeast and the South. Finally, in oats, the West was almost twice as productive as the Northeast and three times as productive as the South.

Table 1 also shows the acres devoted to growing crops in each region. The acres of land devoted to each crop was dramatically bigger in the West than the other regions (except for corn in the South). Given land varies in quality within regions, and the best land is typically used first, one wonders how big the productivity differences would have been if less land was devoted to growing crops in the West and more in the other regions. This issue has been explored, of course, by Fisher and Temin (1970). They argue that if the East had produced many more farm goods, then the regional productivity differences would have been much larger, though they don't provide specific estimates.[8]

So far I have talked about regional productivity differences in crops. How about the other major farm product, livestock and livestock products? I have not seen estimates of productivity differences in raising livestock across regions. But it seems pretty clear that the West was well suited for the activity, as witnessed by the success of the buffalo in the West before white farmers arrived.

Consider the mining and timber/lumber industries next. Before discussing how impor-

[8]In their paper, Parker and Klein conducted a well known productivity decomposition. They sought to divide the growth in labor productivity, from 1840-60 to 1900-1910, in each crop, wheat, corn and oats, into that due to the regional reallocation of acres and that due to all other factors. In their accounting, the westward movement of crops only accounted for on the order of 20 percent of overall productivity growth in these crops. Again, this exercise is subject to the criticism in Fisher and Temin. But also, as a logical matter, the answer to this type of exercise does not tell one anything about how important the westward movement of crops was to GDP growth. For the latter, one needs to know, among other things, how fast was productivity growth in these crops. If it was say 10 percent per year then, everything else equal, westward movement may have been significant for GDP growth. Productivity in wheat in Parker-Klein increased by a factor of 4.15 between their two periods. If I take the period to be 40 years (the smallest possible difference in years), then the annual growth rate was 3.6 percent. If I take the period to be 70 years, it was 2.1 percent. In either case, productivity growth was significant.

tant each sector was in the aggregate economy, let me briefly discuss the productivity of each of these industries across regions. The largest mining industries were coal, iron ore, copper, and petroleum. Herfindahl provides enough detail on employment and output by region to calculate productivity by mineral, though I haven't done that yet. It is readily clear, though, that productivity did vary significantly by region. Take two minerals, iron ore and copper. As new major deposits of these minerals were found in the nineteenth century, in Minnesota and Montana, respectively, production quickly moved to the new deposit even though the new deposits were far removed from where the mineral would ultimately be used, and hence had to incur large transport costs.

The productivity of the timber industry was likewise very different across regions. As regional stocks of timber were reduced, the productivity of cutting timber plummeted. Production quickly moved to new regions which were again far removed from where the timber would ultimately be used and hence had to incur large transport costs. Greely (1925) presents a nice discussion of the movement of logging from the forests of New York, to the Great Lake states, and then to the South and the Pacific Northwest. He also shows how the transport share of delivered prices increased through the century.

How important was timber/lumber in the aggregate economy? In answering this question, I like to think of the timber/lumber sector as two separate industries. The first industry consists of those entities that own the trees. The second industry cuts and processes the timber into lumber. The revenue of the first industry are its royalties (the fees it receives per tree multiplied by total trees). As an approximation, assume the first industry's value added equals its revenues. The revenue of the second industry is the FOB value of lumber at the sawmills (that is, the selling price after the trees have been cut and processed and are ready to leave the sawmill). The value added of the second industry is the FOB value of lumber at the sawmills less the cost of materials used to process the trees and less the cost of the trees before cutting (the revenue of the first industry). One measure of the importance of timber/lumber industry is the sum of value added of these two industries. That is simply the FOB value of lumber at sawmills less the cost of materials used in cutting and processing trees.

At this point I do not know the historical records well enough to approximate this quantity. But I can say few things. The logging and sawmilling of timber is included in the manufacturing sector.[9] In the nineteenth century, it was one of the biggest manufacturing industries. It amounted to perhaps as much as 2 percent of GDP. But I do not know, for example, if the industry's cost of materials includes its purchases of trees or not.

How important was mining in the aggregate economy? Again, I like to think of the mining sector as two separate industries. The first industry consists of those entities that own the minerals. It sells the rights to extract minerals to the second industry. The revenue of the first industry are its royalties (the fees it receives per ton multiplied by total tons). For simplicity, assume the first industry's value added equals its revenues. The revenue of the second industry is the FOB value of minerals at the mine gate (that is, the selling price after the minerals have been extracted and processed and are ready to leave the mine). The value added of the second industry is the FOB mine revenue less the cost of materials used to process the minerals (like explosives) and less the cost of the minerals before extraction (the revenue of the first industry). One measure of the importance of mining is the sum of

[9] Actually, some lumber products are produced on farms and included in gross farm product. It is not a trivial amount. Forest products on farms in some years nearly equaled the value of corn production.

value added of these two industries. That is simply the FOB value of minerals at mines less the cost of materials used in processing.

At this point I also do not know the historical records for mining well enough to approximate this quantity. There is readily available data on employment in mining. Mining's share of employment is reported by Herfindhal to be 1.5 percent in 1870, increasing to 2.5 percent by the end of the decade. Mining tends to be a capital intensive industry, so it's share of capital is likely a bit higher than its share of employment.

There were other industries, in addition to farming, timber and mining, where the production function differed by region. In the nineteenth century, significant amounts of power were generated by the water power industry. In the East there were large numbers of rivers and falls that generated water power. The situation was very different in the West where very few falls generated power. For example, the Mississippi River had only one fall that was used to generate power (St. Anthony's Falls in Minneapolis). While power generated by water in the nineteenth century was not a product that could be traded, industries that were disproportionate users of power would find it economical to locate in the East.

Another factor in the East's advantage as a production center was that it was the location of original settlement. Consequently, it had a more developed infrastructure than other areas had.

These, then, are some of the reasons why potential gains from trade were large between regions. There are other obvious sources of gains that I have not discussed, like regions producing different varieties of goods.

4. Transportation: 19C Productivity Improvements Large

The pace of productivity improvements in transportation in the 19C were, as is well known, significant. In this section, I review some of the available evidence.

Productivity estimates for subsectors within the transportation sector (like riverboats, ocean-going vessels, and railroads) are available for periods throughout the 19C. As far as I know, Kendrick (1961) provides the only estimates of labor productivity growth for the overall transportation sector in the United States in the 19C, and then only for the last third of the 19C.

Before looking at some of these sectoral studies, let me make an obvious but important point. A large source of productivity gain in transportation in the nineteenth century was surely the substitution of railroad transportation for wagon transportation. While ton-miles of wagon transport were not large, employment in wagons accounted for a substantial share of employment in transportation (see footnote below) in the nineteenth century (since ton-miles per man was very low in wagon transport). When a railroad replaced wagon transport over a route, there was a big reduction in wagon employment and overall employment (since ton-miles per man was very much higher on railroads), and hence this substitution led to an increase in overall transportation productivity. Since this substitution of railroads for wagons was a major source of productivity gain, I expect that productivity gains at the total transportation sector level where substantially greater than in subsectors of transportation, like railroads.

Transportation productivity growth within sectors of transportation was significantly faster than aggregate productivity growth; and typically sectors had faster productivity growth in the first half of the 19C than the last half.

Fishlow provides estimates for railroads. Fishlow estimates average annual labor productivity growth in railroads from 1870-90 of 2.58 percent (Table 10, p. 626). For the period 1870-1900, he estimates an average annual growth rate of 2.41 percent.

As far as I know, there is not a sectoral study of water carriers on the Great Lakes during the last third of the nineteenth century but productivity growth was rapid there as well. Fogel suggests that these carriers had productivity growth greater than railroads during this period.

Turning to the overall transportation sector, I present average annual labor productivity growth rates from Kendrick in Table 2. As a comparison, I have also included growth rates for the total economy and for the farming and manufacturing industries. For the period 1869-89, Kendrick estimates that labor productivity in transportation grew at average annual rate of 3.35 percent, significantly greater than the rate for the total economy of 1.8 percent, or the farming and manufacturing sectors, of 1.25 and 1.67 percent, respectively.[10] For the longer period 1869-99, much the same picture emerges.[11]

I mentioned three types of evidence in the introduction that suggested transportation improvements were likely a major source of productivity growth in the nineteenth century. I have discussed two: potential gains from trade were large and productivity growth in transportation was much greater than average. The last type, growth accounting, I have chosen to place in Appendix A. Before turning to the model, let me present one piece of

[10] Unfortunately, Kendrick's book does not allow one to calculate his (i.e. Kendrick's) estimate for prodcutivity growth in railroads over 1869-89 (nor for 1870-90).

[11] Kendrick has measures of output and employment for a number of subsectors in transportation. These are his "covered" sectors; the others are the residual sectors. The sum of employment in the covered subsectors is quite a bit less than total transportation employment. Residual transportation employment varies between one fourth and one third of employment; this seems to be mostly wagon employment. Kendrick imputes output to the residual sector.

evidence on the increase in specialization that was facilitated by transport improvements.

5. Regional Specialization Increases Dramatically

Improvements in transportation permitted potential gains from trade between regions to be more fully exploited. This led to increases in regional specialization in production. In this section, let me very briefly discuss some of the evidence that specialization did increase.

Consider farming. One way to measure specialization in production is to look at the use of capital by industry (relative to population) across regions. A major capital input in farming is land. In Figure 3, I plot improved farmland per person in the East (New England+Middle Atlantic) and the West (East North Central+West North Central) by decade for the Census years 1850-1900. There were 3.9 acres of improved farmland per person in the East in 1850 and 4.9 in the West. There was specialization of production in agriculture even at this early date. Specialization surged over the next half decade. By 1900, improved farmland per person was 1.8 and 8.4 in the East and West, respectively. This was a dramatic increase in specialization in farm production.

The pattern in Figure 3 for the East of falling farmland per person was not due solely to population growth in the East. The amount of improved farmland began falling in the East from 1880. From 1880-1900, improved farmland fell 38 percent in New England and 7 percent in the Middle Atlantic.

6. Description of the model

In this section, I present the simplest possible model to start addressing the quantitative question stated at the outset.

Consider an economy with two regions, East (E) and West (W).[12] Let me first assume there is a single period. Let the populations in the East and West be denoted N_E and N_W, with total population $N = N_E + N_W$. I first assume the populations are fixed, and then let there be free mobility.

Let there be three final goods at each location, food, manufactures and services. The first two goods are assumed to be tradeable, the last is a non-traded good (like housing services). There is a single intermediate good at each location, transportation services.

There is a technology for producing each good at each location. The food produced at E is a perfect substitute for that produced at W. The manufactured goods are perfect substitutes as well.

A. Preferences and Endowments

Let c_f, c_m, c_s denote the consumption of a particular individual of food, manufactures and services. I let utility be given by

$$u(c_f, c_m, c_s) = \sum_{i=f,m,s} \theta_i \ln(c_i)$$

where i indexes type of goods.

Each individual is endowed with one unit of labor. The total labor endowment is therefore N. There will be profits from farming and manufacturing. I assume that profits in a region are returned to individuals living in the region.

[12] Let the East be New England plus the Middle Atlantic and the West be East North Central plus West North Central.

B. Technologies

I have already described the transportation technology above. Here I describe final good technologies.

Final Good Technologies

Consider farming first. In Appendix B, I present a model of heterogenous land, both within regions and across regions. From that model, one can derive a regional farm production function that is given by

$$Y_{fj} = A_{fj}(N_{fj})^{\beta_f} \qquad j = E, W$$

where Y_{fj} and N_{fj} are production of food and farm labor input in region j; A_{fj} and β_f are the TFP and labor output-elasticity parameters. Note that only the TFP parameter varies across regions.

The manufacturing technology can be motivated in a similar way. The regional manufacturing production function is given by

$$Y_{mj} = A_{mj}(N_{mj})^{\beta_m} \qquad j = E, W$$

where Y_{mj} and N_{mj} are production of manufactures and its labor input in region j; A_{mj} and β_m are the TFP and labor output-elasticity parameters. Note that only the TFP parameter varies across regions.

I assume the parameters satisfy

$$A_{fW} > A_{fE} \quad \text{and} \quad A_{mE} > A_{mW}.$$

The pattern of trade, if there is any, is food from west to east, and manufactured goods from east to west.

Let the technologies for producing services be given by, where Y_{sj} and N_{sj} are the total production of, and labor input into, services production in location j,

$$Y_{sj} = A_{sj}(N_{sj}) \qquad j = E, W$$

where A_{sj} is the TFP parameter.

7. Competitive Equilibrium

It is straightforward to define and calculate a competitive equilibrium. Here I just sketch some of the details.

Let p_{fi}, p_{mi}, p_{si}, and p_{ni}, denote the prices of food, manufactures, services and labor in region i. Let the price of food in the West be numeraire, that is, $p_{fW} = 1$. The definition of a competitive equilibrium is straightforward; I will include it later. But roughly it is a price vector and vector of choices that satisfy the usual conditions that households are maximizing utility, firms are maximizing profits and markets clear. Depending on the parameters of the model, there are competitive equilibrium with no trade (e.g., very "small" A_T); for other parameters there is trade (e.g., very "large" A_T). Let me suppose that parameters are such that there is trade and present some of the equations that characterize the competitive equilibrium.

A. Households problem

Households inelastically supply labor to firms in their region. Households in region i share equally in profits of firms (both farm and manufacturing) in their location. Consider the East. Let $\widehat{Y}_E$ denote total income in the East, and $\widehat{y}_E$ per capita income. Then in the competitive equilibrium

$$p_{fE}c_{fE} = \omega_f \widehat{y}_E$$

$$p_{mE}c_{mE} = \omega_m \widehat{y}_E$$

$$p_{sE}c_{sE} = \omega_s \widehat{y}_E$$

$$\widehat{y}_E = \frac{1}{N_E}[p_{nE}N_E + (\Pi_{fE} + \Pi_{mE})]$$

where Π_{fE} and Π_{mE} are the regional farm and manufacturing profits.

B. Firm problems

The problem faced by the farm is

$$\max_{N_{fi}}\{p_{fi}A_{fj}(N_{fj})^{\beta_f} - p_{ni}N_{fi}\}$$

The problem faced by the manufacturing firm is similar. Given there are decreasing returns to scale, there will be profits and these are distributed as described above. The problem for service sector firms is standard.

The transport firms solve the following problem. Consider a transporter in the West. His profit is

$$\max_{N_{TW}}\{p_{fE}D_f - p_{fW}B_f - p_{nW}N_{TW}\}$$

that is, he buys B_f in the West at price p_{fW}, delivers D_f in the East that he sells for p_{fE} and has expenses of $p_{nW}N_{TW}$.

C. Resource constraints

Under the assumptions above, food is shipped from west to east, and manufactures from west to east. Resource constraints for the East are

$$N_E \cdot c_{fE} = Y_{fE} + D_f$$

$$B_m + N_E \cdot c_{mE} = Y_{mE}$$

$$N_E \cdot c_{sE} = Y_{sE}$$

$$N_{fE} + N_{mE} + N_{sE} + N_{TW} = N_E$$

and for the west

$$B_f + N_W \cdot c_{fW} = Y_{fW}$$

$$N_W \cdot c_{mW} = Y_{mW} + D_m$$

$$N_W \cdot c_{sW} = Y_{sW}$$

$$N_{fW} + N_{mW} + N_{sW} + N_{TW} = N_W.$$

8. Calibration

In this section let me briefly describe how I calibrate some of the model's parameters.

The parameters are the labor endowment N (or in the case where populations are held fixed, N_E and N_W), the preference parameters, and the technology parameters.[13] The technology parameters include β_f and β_m, the elasticity of output with respect to labor

[13] The total labor endowment is available from the Census of Population, the persons engaged series. For example, in 1890, $N = 14.64$ million ($N_E = 7.67$ and $N_W = 6.97$).

input. In a competitive model these are equal to non-land shares of income in agriculture and manufacturing. I take non-land's share of income in agriculture and manufacturing to be $\beta_f = .80$ and $\beta_m = .90$. The technology parameters also include the TFP parameters in agriculture and manufacturing, A_{fE} and A_{fW}, and A_{mE} and A_{mW}, and the TFP parameter in transportation, A_T.

A. Agricultural TFP parameter in West

Let me start with the normalization $A_{fE} = 1$. There are two ways to calibrate parameter A_{fW}. I could use the data on physical productivity from Parker and Klein, though the grains above are only part of agricultural output. Another approach is to use the Census of Agriculture which reports data on the value of farm production. Let me look at both approaches.

Let me look at Parker-Klein first. In the model, the ratio of labor productivity in the West to the East equals

$$\frac{Y_{fW}/N_{fW}}{Y_{fE}/N_{fE}} = \frac{A_{fW}}{A_{fE}}[\frac{N_{fW}}{N_{fE}}]^{\beta_f - 1}.$$

From Tostlebe (19xx), I know that in 1890 $N_{fE} = 1.21$ and $N_{fW} = 3.56$. Hence, the ratio of employments (to the power -.2; using $\beta_f = 0.8$) equals .81. Then, if I use Parker-Klein for a ballpark for the relative labor productivities, that is, the left hand side, I can calibrate A_{fW}. If I use the relative labor productivity in wheat, 1.6, I arrive at A_{fW}=1.6/.81=1.97.

Another way to proceed is to use gross farm output per worker by region. Gross farm output per worker in the West relative to the East in the model is

$$(2) \qquad \frac{p_{fW}}{p_{fE}}\frac{Y_{fW}/N_{fW}}{Y_{fE}/N_{fE}} = \frac{p_{fW}}{p_{fE}}\frac{A_{fW}}{A_{fE}}[\frac{N_{fW}}{N_{fE}}]^{\beta_f - 1}.$$

Using the Census of Agriculture, one finds, perhaps surprisingly at first, that gross farm output per worker in the West is lower than the East. But of course it is not surprising once one recalls how large transportation charges are in delivered prices. Prices in the East are much higher than in the West, and the value of farm output is in dollars. Farms with much lower (physical) labor productivity persist in the East because of the large transport costs from West to East.

Let me first consider 1890. Gross farm output per worker in the West equals only 91 percent of that in the East. Hence, the left hand side in [2] is .91. Recalling from above that $N_{fE} = 1.21$ and $N_{fW} = 3.56$, the ratio of employments (raised to the power -.2) is .81. Hence, I can write [2] as

$$1.12 = \frac{p_{fW}}{p_{fE}} \frac{A_{fW}}{A_{fE}}.$$

The value for A_{fW} is then determined by the price ratio. These prices, p_{fE} and p_{fW}, are the prices farmers received at the farm, on average, in the East and the West. If I use $p_{fE} = 100$ and $p_{fW} = 75$ (where this is the New York and Wisconsin price, see Williamson), then I calculate $A_{fW} = 1.5$.

Next consider 1870. Gross farm output per worker in the West equals only 77 percent of the East value. Hence, the left hand side in [2] is .77. For 1870, employment levels are $N_{fE} = 1.11$ and $N_{fW} = 2.24$, hence the ratio of employments (raised to the power -.2) is .87. Hence, I can write [2] as

$$.89 = \frac{p_{fW}}{p_{fE}} \frac{A_{fW}}{A_{fE}}.$$

The value for A_{fW} is then determined by the price ratio. These prices, p_{fE} and p_{fW}, are the prices farmers receive at the farm, on average, in the East and the West. If I use $p_{fE} = 137$

and $p_{fW} = 85$ (where this is the New York and Wisconsin price, see Williamson), then I calculate $A_{fW} = 1.435$.

So, the parameter A_{fW} does not change much relative to A_{fE} over the period. But productivity in the two regions does become closer because employment in the West grew much faster than in the East (which lowers productivity in the West relative to the East). Productivity differences narrow, as one would expect with improvements in transportation.

B. TFP parameter in transportation

If there is trade in food (from West to East), then in order that transportation service providers earn zero profits it must be that

$$(p_{fE}\sigma_T - p_{fW})A_T = p_{nW}$$

which I can rewrite as (with $\sigma_T = 1$)

$$p_{fE} = p_{fW} + \frac{1}{A_T}p_{nW}.$$

This says that the delivered price of food in the East equals the price of food in the West plus the transportation charges to the East.

From the farmer's problem in the West, I have that $p_{fW} = (MP_{fW})^{-1}p_{nW}$, where MP_{fW} is the marginal product of labor in the West in producing food. Hence I can write the above equation as

$$(3) \qquad \frac{p_{fE}}{p_{fW}} = 1 + \frac{1}{A_T}MP_{fW}.$$

This says that the delivered price of food in the East p_{fE} relative to the (marginal) production cost in the West p_{fW} equals one plus the ratio of marginal transport costs to marginal production costs. Let me now calculate A_T for 1870 and 1890.

For 1890, I can write $MP_{fW} = A_{fW}\beta_f(N_{fW})^{-.2} = A_{fW}(.8)(3.56)^{-.2} = A_{fW}(.62)$. Hence, I can write [3] as

$$\frac{1}{A_{fW}}(1.61)[\frac{p_{fE}}{p_{fW}} - 1] = \frac{1}{A_T}$$

If I use $p_{fE} = 100$ and $p_{fW} = 75$, then with $A_{fW} = 1.5$, I have $A_T = 2.8$; with $A_{fW} = 2$, I have $A_T = 3.7$.

In 1870, I can write $MP_{fW} = A_{fW}\beta_f(N_{fW})^{-.2} = A_{fW}(.8)(2.24)^{-.2} = A_{fW}(.68)$. Hence, I can write [3] as

$$\frac{1}{A_{fW}}(1.47)[\frac{p_{fE}}{p_{fW}} - 1] = \frac{1}{A_T}$$

If I use $p_{fE} = 137$ and $p_{fW} = 85$, then with $A_{fW} = 1.4$, I have $A_T = 1.5$.

The transport TFP parameter relative to the agricultural TFP parameters grows significantly through time in this calibration.

C. Manufacturing TFP parameter in East

Again, if there is trade it must be that

$$(p_{mW}\sigma_T - p_{mE})A_T = p_{nE}$$

which following the above I can write as

$$(4) \qquad \frac{p_{mW}}{p_{mE}} = 1 + \frac{1}{A_T}MP_{mE}$$

where $MP_{mE} = A_{mE}\beta_m(N_{mE})^{\beta_m - 1}$.

In 1890, from the Census of Manufactures, I have that $N_{mE} = 2.54$, so that with $\beta_m = .90$, $MP_{mE} = (.82)A_{mE}$. I have that

$$\frac{p_{mW}}{p_{mE}} - 1 = \frac{(.82)A_{mE}}{A_T}.$$

These prices, p_{mE} and p_{mW}, are factory prices in the East and West. Data on these factory prices across regions is harder to come by than farm prices across regions.

If I use the price ratio of 1.2 (as suggested by Williamson), and $A_T = 2.8$, I have $A_{mE} = .69$. If I use the price ratio of 1.1, I have $A_{mE} = .34$. If I use the price ratio of 1.2, and $A_T = 3.73$, I have $A_{mE} = .91$. If I use the price ratio of 1.1, I have $A_{mE} = .45$.

D. Manufacturing TFP parameter in West

The East was well known as the leading manufacturing center in the nineteenth century. Unlike agriculture, there are no studies like Parker-Klein that look at productivity differences in physical units across regions.

Another way to proceed is to use value added per worker by region. Value added per worker in the East relative to the West in the model is

$$\frac{p_{mE}}{p_{mW}} \frac{Y_{mE}/N_{mE}}{Y_{mW}/N_{mW}} = \frac{p_{mE}}{p_{mW}} \frac{A_{mE}}{A_{mW}} [\frac{N_{mE}}{N_{mW}}]^{\beta_m - 1}.$$

The Census of Manufactures provides estimates the LHS. One finds here that, less surprisingly now, that value added per worker is lower in the East than the West. Again, prices in the West are higher than in the East, and value added is in dollars.

Value added per worker in the East is 94 percent of the West, that is, the left hand side above is .94. From the Census of Manufactures, I have that $N_{mE} = 2.54$ and $N_{mW} = 1.41$. Hence, the ratio of employments (raised to the power minus one-tenth) is .94. Hence, I have that

$$1 = \frac{p_{mE}}{p_{mW}} \frac{A_{mE}}{A_{mW}}.$$

9. Elasticities of GDP with Respect to Sectoral TFPs

While I am confident of my procedures to calibrate some of the model parameters, I still have a few that are not calibrated well. And, of course, the model above is only a start at exploring the U.S. nineteenth century. It excludes the South, international trade, capital accumulation, and other important elements that are important for the issues studied here. So, at this point I just present the elasticity of GDP with respect to transport TFP in the (sort of calibrated model). In Table 3, I show that in the calibrated model that when transport's share of GDP is 1.9 percent that the elasticity is 2.6 percent.

Appendix A: Growth Accounting

In this appendix, I present some growth accounting estimates of the fraction of the U.S. nineteenth century aggregate labor productivity growth accounted for by the transportation sector. I first develop a growth accounting equation and introduce terminology.

Gross Domestic Product (GDP) can be defined as the sum of spending on final goods or as the sum of value added across establishments. Under the latter definition, if one assigns establishments to "industries," then GDP can be defined as the sum of value added across industries. Then $GDP_t = \sum_i V_{it}$, where V_{it} is value added by industry i at year t. Real GDP at years beyond t can be defined as the sum of value added at year t prices (where both output and inputs are valued at year t prices). Turning to productivity, GDP *per worker* is

$$\frac{GDP_t}{N_t} = \sum s_{it} \cdot \frac{V_{it}}{N_{it}}$$

where $s_{it} = N_{it}/N_t$.

I can express the differences in GDP per worker as

$$\frac{GDP_{t+1}}{N_{t+1}} - \frac{GDP_t}{N_t} = \sum s_{it} \cdot [\frac{V_{it+1}}{N_{it+1}} - \frac{V_{it}}{N_{it}}] +$$

$$\sum (s_{it+1} - s_{it}) \cdot [\frac{V_{it}}{N_{it}} - \frac{GDP_t}{N_t}] + \sum (s_{it+1} - s_{it}) \cdot [\frac{V_{it+1}}{N_{it+1}} - \frac{V_{it}}{N_{it}}]$$

Given available data, it will be useful to write this as

$$\frac{GDP_{t+1}}{N_{t+1}} - \frac{GDP_t}{N_t} = \sum s_{it} \cdot \frac{V_{it}}{N_{it}} \cdot g[\frac{V_{it}}{N_{it}}] +$$

$$\sum (s_{it+1} - s_{it}) \cdot [\frac{V_{it}}{N_{it}} - \frac{GDP_t}{N_t}] + \sum (s_{it+1} - s_{it}) \cdot \frac{V_{it}}{N_{it}} \cdot g[\frac{V_{it}}{N_{it}}]$$

where $g[x]$ is the (net) growth rate of x. Divide the above equation by GDP_t/N_t; then

$$g[\frac{GDP_t}{N_t}] = \sum s_{it} \cdot [\frac{V_{it}}{N_{it}} / \frac{GDP_t}{N_t}] \cdot g[\frac{V_{it}}{N_{it}}] +$$

$$(5) \qquad \sum (s_{it+1} - s_{it}) \cdot [(\frac{V_{it}}{N_{it}} - \frac{GDP_t}{N_t}) / \frac{GDP_t}{N_t}] + \sum (s_{it+1} - s_{it}) \cdot [\frac{V_{it}}{N_{it}} / \frac{GDP_t}{N_t}] \cdot g[\frac{V_{it}}{N_{it}}]$$

I will use equation [5] to examine the contribution of transportation and other sectors to aggregate productivity growth. The contribution of sector i to overall productivity growth in *percentage points* is then equal to the sum of the three terms in [5] corresponding to i. The contribution as a *percent* of overall growth equals the contribution in percentage points divided by $g[GDP_t/N_t]$.

If all industries had the same value added per worker in the initial period (which therefore was GDP_t/N_t), then I can express the above equation, after dividing both sides by aggregate labor productivity growth, as

$$1 = \sum s_{it} \cdot \{g[\frac{V_{it}}{N_{it}}] \div g[\frac{GDP_t}{N_t}]\} + \sum (s_{it+1} - s_{it}) \cdot \{g[\frac{V_{it}}{N_{it}}] \div g[\frac{GDP_t}{N_t}]\}.$$

Consider sector $i's$ contribution to overall productivity growth as a percentage of growth. Suppose first that the sector had no change in its share of hours. Then according to the first term, if sector $i's$ productivity growth exceeded the aggregate, then the sector's percentage contribution to overall growth exceeds its initial hours share s_{it}. If the sector did have an increase in its share of hours, then this too would contribute to aggregate productivity growth. Its percentage contribution is given in the second term.

Turning to the nineteenth century United States, let me make calculations for both the transportation sector and manufacturing sector for the period 1869-89. Aggregate productivity growth over the period was 43.4 percent (see Kendrick, p. 332), which I report in the last row of Table 4. Consider transport's contribution. Start with the first term in [5].

Transportation's share of hours in 1869 was 5.5 percent (see Kendrick, p. 314); $s_{it} = 0.055$. Transportation's share of value added, $V_{it}/GDP_t = 0.06$ (see Gallman, 2000, p. 50) exceeded it share of hours. Hence, I have $V_{it}/N_{it} \div GDP_t/N_t = 1.09$. The growth in value added per hour in transportation was 95 percent (see Kendrick, p. 540); $g[V_{it}/N_{it}] = 0.95$. Hence, the first term is $(0.055)(1.09)(0.95) = .057$. To calculate the second term I use that transport's hours share in 1889 was 8 percent; $s_{it+1} = 0.08$. Then the second term is $(0.025)(.09) = .002$. The third term is $(0.025)(1.09)(0.95) = 0.026$. The percentage points contributed by transportation is then 8.5, which I report in the first row of Table 4. It contributes then 19.6 percent of total productivity growth.

Consider manufacturing's contribution. Start with the first term in [5]. Manufacturing's share of hours in 1869 was 18.3 percent (see Kendrick, p. 314); $s_{it} = 0.183$. Transportation's share of value added, $V_{it}/GDP_t = 0.22$ (see Gallman, 2000, p. 50) exceeded it share of hours.[14] Hence, I have $V_{it}/N_{it} \div GDP_t/N_t = 1.20$. The growth in value added per hour in transportation was 40 percent (see Kendrick, p. 464); $g[V_{it}/N_{it}] = 0.40$. Hence, the first term is $(0.183)(1.20)(0.40) = .088$. To calculate the second term I use that manufacturing's hours share in 1889 was 18.7 percent; $s_{it+1} = 0.187$. Then the second term is $(0.004)(.2) = .001$. The third term is $(0.004)(1.20)(0.40) = 0.002$. The percentage points contributed by manufacturing is then 9.1, which I report in the first row of Table 4. It contributes then 21 percent of total productivity growth.

Transportation, then, contributed roughly the same amount to labor productivity growth as did manufacturing even though manufacturing accounted for a much larger share

[14] Gallman reports the share of manufacturing, mining and hand trades in GDP in 1870 as 24 percent. As an approximation I have taken manufacturing's share to be 22 percent.

of hours at the outset (more than three times the hours of transportation). I will extend this table to include other sectors.

Appendix B - Model of Heterogenous Land

Consider the farm sector first. I want to have a model with heterogenous land, both within regions and across regions. Within a region I assume that the production on land unit z is given by

$$y_{fj}(z) = A_{fj} \min\left(1, \frac{n_{fj}(z)}{l_{fj}(z)}\right), \quad z \in [0, \infty)$$

$$l'_{fj}(z) \geq 0$$

where $n_{fj}(z)$ and $l_{fj}(z)$ are the labor input on land unit z, and the labor input requirement on z, respectively, and where land is ordered from best to worst (since the labor input requirement is increasing in z).

Let me discuss two ways to think about decentralizing the farm sector.

1. Consider the case where farm land is rented out to farmers. For a given food price and labor price, there is a profit on land unit z. Let $\hat{z}$ be the unit of land at which profits are zero. For $z < \hat{z}$, profits are zero. For $z > \hat{z}$, profits are negative. Let the rental rate on land unit $z < \hat{z}$ be chosen so that profits net of rental rates are zero. Land rents are returned to households.
2. Let there be a single price-taking farmer that runs the entire sector. He decides what farm land to work. Profits from this farmer are returned to households.

Under the second approach, of one price-taking farmer, I can define the aggregate regional farm technology as (using the fact that the farmer will choose $n_{fj}(z) = l_{fj}(z)$),

$$Y_{fj}(N_{fj}) = A_{fj}\hat{z}(N_{fj})$$

where $\hat{z}(N_{fj})$ satisfies

$$N_{fj} = \int_0^{\hat{z}} l_{fj}(z)dz.$$

If I assume that the function $l_{fj}(z)$ is a power function, then I arrive at the regional farm production function given in the text.

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Table 1

Labor Productivity (Bushels per Hour),
Land Yields (Bushels per Acre), and Acres (Millions), 1909
By Major Grain Crop and Region

	Productivity	Land Yield	Acres
		Wheat	
South	.712	12.3	3.9
Northeast	.977	17.5	1.7
West	1.449	14.0	40.2
		Corn	
South	.623	16.1	27.1
Northeast	.620	36.8	1.9
West	1.422	31.0	56.0
		Oats	
South	.940	17.0	2.4
Northeast	1.520	29.7	2.7
West	2.899	26.5	30.4

Source: Parker and Klein, tables 1 and 10.

Table 2

U.S. Labor Productivity Growth
For Total Economy and By Industry
(Average Annual Rates of Growth)

		Industry		
Period	Total	Farm	Manufacturing	Transportation
1869–89	1.80	1.25	1.67	3.35
1869–99	1.86	1.31	1.59	3.23

Source: Kendrick (1961)

Table 3

Elasticity of GDP with Respect to Sectoral TFP's

	Low Transport TFP		High Transport of TFP	
Sector	Sector's Share of GDP	Elasticity	Sector's Share of GDP	Elasticity
Transport	1.9	2.6		
Manufacturing				
Services				
All				

Table 4

Growth in U.S. Labor Productivity, 1869–89
Amount Contributed by Various Industries

Industry	Industry's Hours Share	Percentage Points of Labor Productivity Growth Contributed	Fraction of Total Growth
Transportation	5.5	8.5	19.6
Manufacturing	18.3	9.1	21.0
All	1	43.4	1

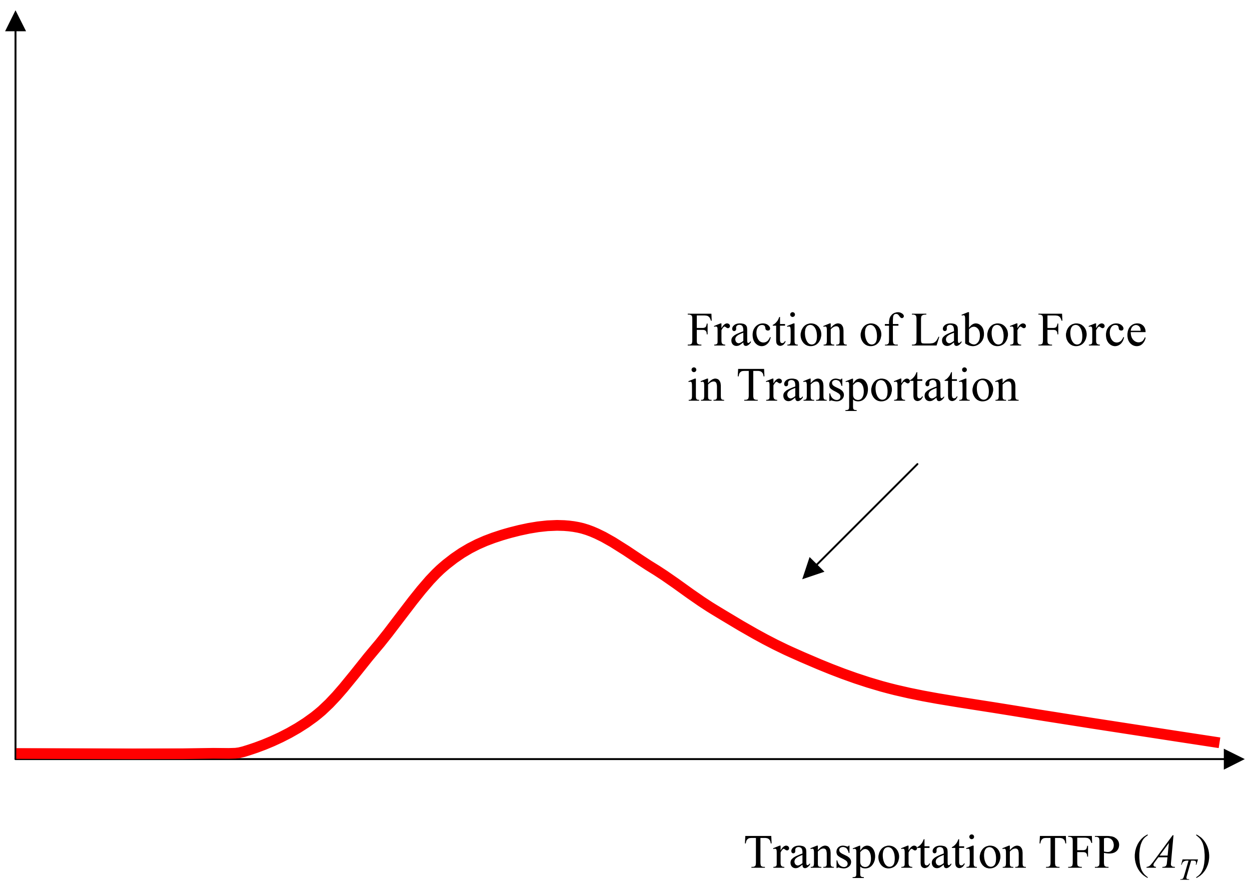
Fraction of Labor Force
in Transportation
Transportation TFP (A_T)

Figure 1

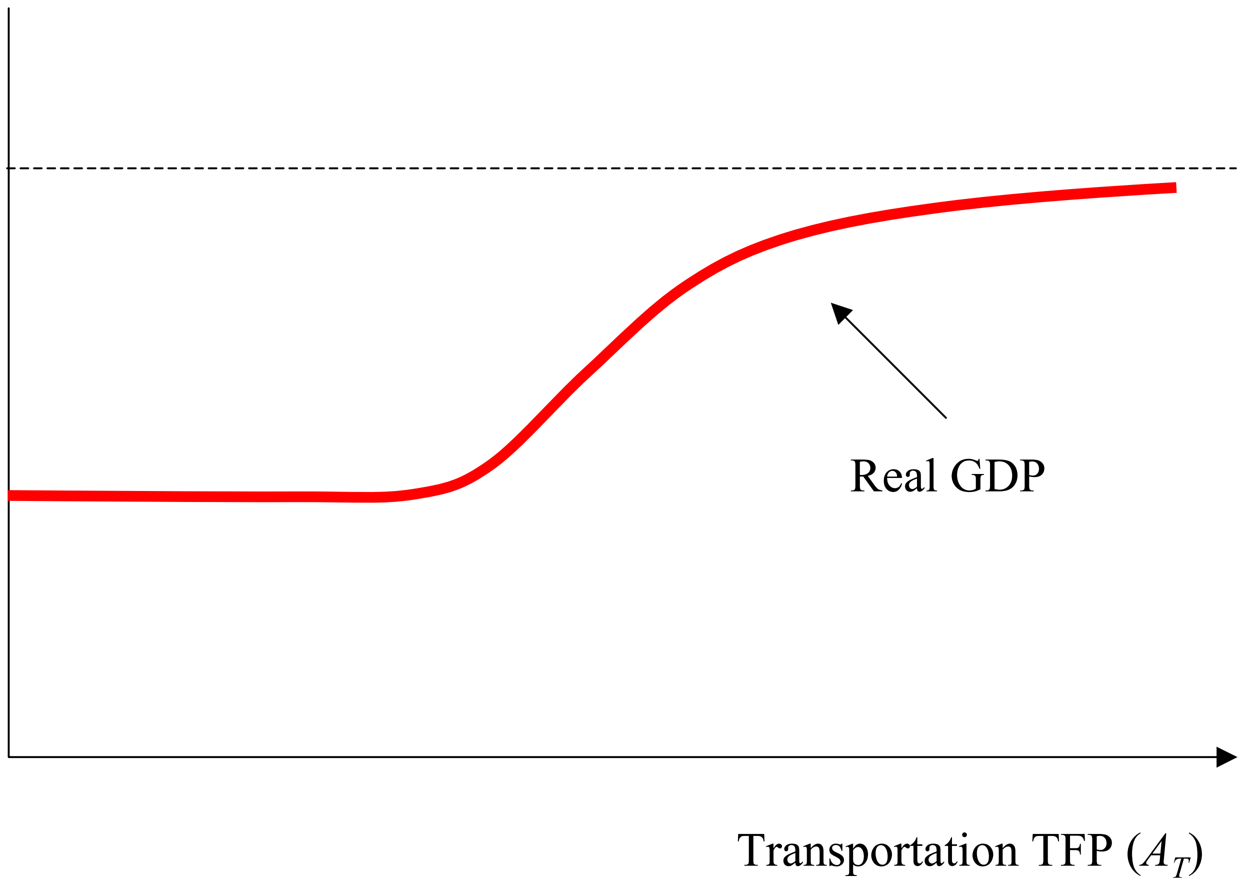

Figure 2

Figure 3:
Improved Farm Land per Person