The Transport Revolution in Industrializing Britain: A Survey

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Abstract

Between 1700 and 1870 Britain's transport sector improved dramatically. This paper surveys the literature on Britain's transport revolution and examines its contribution to economic growth during the Industrial Revolution. It reviews the important infrastructural and technological developments, documents the evolution of transport markets, and examines the developmental effects of transport. The most striking finding is that freight charges decreased by 95 percent in real terms from 1700 to 1870 implying an annual TFP of more than 2 percent. The broader conclusion is that transport improvements were major factor in raising the standard of living in Britain and were as significant as other innovations. At the same time, Britain's history shows that many transport improvements were difficult to implement because they required financial innovation and involved taxation and vexing property rights issues.

JEL Codes: N43, N73, R4

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Introduction

The British economy c.1700 was mired in a world of high transport costs. It is true that one could travel by coach between London and important cities in the southeast already in 1700 and that coal was being shipped on coastal vessels from Tyne to London, but for much of the economy high transport costs were a major constraint on economic activity and travel. In the one hundred and seventy years that followed transport improved greatly. Road transport evolved from packhorses and small wagons to large wagons and stagecoaches running continuously between London and major cities. Eventually steam powered rail wagons and coaches would displace both horse-drawn wagons and stagecoaches resulting in a fundamental change in freight transport and travel. Similarly large barges and vessels powered by steam eventually displaced smaller vessels on rivers and in the coastal trade. Along with technological change there was tremendous investment in transport infrastructure most notably in the canal and rail network.

By 1870 Britain had experienced what historians have called a transport revolution (Bagwell 1988). The most clear indicator being the dramatic increase in travel speeds and decline in freight rates. As this paper will document, railway freight charges per ton mile in 1870 expressed in real terms (i.e. adjusting for inflation) were equal to one-twentieth the freight charge per ton mile for horse-drawn wagons in 1700. Journey travel times by railway were one-tenth the travel time of coaches in 1700. Although such calculations emphasize the importance of railways, this paper will show they are not the entire story. There were significant reductions in road transport freight charges and journey times before the railways and of primary importance to industry and mining there were large reductions in transport costs associated with the shift from roads to canals. There were also major improvements in coastal travel speeds with the coming of the steamship. Long distance shipping also witnessed dramatic reductions in freight charges especially along the North Atlantic routes.

Productivity growth was the driver of the transport revolution and played a key role in determining fares and freight charges in the transport market. This paper summarizes estimates of productivity growth in the literature. It also gives a new estimate for the rate of productivity growth in the overland transport as a whole including within mode changes (i.e. improvements within road or rail transport) and between mode changes (i.e. shifts from road to rail). The estimates demonstrate that transport experienced high productivity growth on par with other key sectors of the industrial revolution like textiles, iron, and mining.

Market structure and institutional factors were also important in influencing transport markets. Competition was a key factor in driving down freight charges and fares for carriers and coastal shippers. At times there was also competition among infrastructure providers like turnpike roads, canals, ports, and railways and for this reason rates of return on infrastructure investments were generally modest. Britain's transport policies were generally laissez faire: barriers to entry were modest, private ownership was common, and the property rights of infrastructure providers were generally protected. At the same time there was government intervention. Governing authorities protected the property rights of landowners creating some complications for canals and railways. Moreover Parliament set toll caps on turnpike roads and inland waterways partly with the aim of reducing monopoly profits. A general assessment of transport policies is beyond the scope of this paper, but there is a case that Britain's regulatory institutions had salutary effects up to the railway age. By 1870, however, there are signs of regulatory failure.

The final section of this paper considers the developmental effects of transport improvements. The social savings method is discussed as well as alternative approaches emphasizing changes in land values and growth accounting techniques. The estimates point to a large role for transport improvements in contributing to income per capita growth from 1700 to 1870. Transport improvements—both infrastructural and technological—were central to Britain's early industrialization.

Technological and Infrastructural Developments

There were many important developments in Britain's transport sector between 1700 and 1870. It is impossible to cover all the details here, but a brief outline of is useful. Interested readers should consult Bagwell and Lyth (2002) and Freeman and Aldcroft (1988, 1983) for the broader histories. The traditional segments of the transport sector were road, river, and coastal shipping. Despite their label, all three experienced technological and infrastructural development from 1700 onwards. Road transport could take various forms, including travel by horse, wagon, or coach. Wagons became progressively larger in size during the 1700s. The typical loads increased from a few tons to 6 or 7 by 1800. There were also innovations in wheels, springs, axles, and frames allowing coaches to achieve higher speeds and greater comfort. Coach designs became noticeably varied and included the stagecoach, post-coach, the phaeton, and landau (Strauss 1912). The organization of road transport also became increasingly sophisticated. The London market was known for having professional carriers by the late 1600s and provincial services became increasing professionalized as the eighteenth century progressed (Gerhold 2005, Turnbull 1977). As professional carriers came to dominate they became larger and better organized. Schedules were designed so that wagons and carriages would remain idle as little as possible. Firms also entered into long-term contracts with innkeepers and cut major components of their costs (Gerhold 1996).

Road quality and capacity were crucial to the functioning of road transport. Simply put: it was very difficult to run wagons and coaches at high speeds or with large loads over roads with uneven surfaces or steep inclines. It is often thought that Britain had poor roads in the seventeenth century. This is only partly true. Gerhold (2005) shows that wagons and coaches were used to travel between London and most provincial cities in the South and Midlands in the late seventeenth century. Packhorses were the superior technology on bad roads and remained common in the North and West of Britain. While the image of seventeenth century roads has been rehabilitated to some degree, one should keep in mind that traffic volumes were extremely low by late eighteenth century standards. In the pre-industrial era, highly trafficked roads deteriorated rapidly if there was insufficient maintenance.

Britain's system of road financing c.1700 was ill-equipped to meet the growing need for maintenance. Since 1555 parishes were made responsible for road maintenance within their boundaries. Parishioners were required to work six days and donate teams of horses and materials. Later parish and county officials were allowed to levy highway rates for local road maintenance (Albert 1972). The system of parochial road maintenance proved to be ineffective and various solutions were tried like limiting load sizes or forcing parishes to levy taxes to improve their roads. In the end an alternative solution was found: the turnpike trust. Trusts were authorized by acts of Parliament to levy tolls, purchase land, and issue bonds on specific highways. They proliferated in the eighteenth century and created a large toll road network. Around twenty thousand miles or roughly 20 percent of all highways for wheeled carriages came under the authority of turnpike trusts in the early 1800s. Pawson's (1977: 51) map illustrates the density of the turnpike road network in 1770.

Although turnpike trusts were created to improve roads, there are reasons to question whether they increased road maintenance and investment spending. Perhaps parishes were already spending a lot and turnpike trusts simply displaced their efforts. Detailed research on individual highway spending has confirmed that parishes actually spent very little prior to turnpike trusts (Bogart 2005a). However, there is a still a possibility that parishes might have spent the same in the absence of turnpike trusts. To address this concern the present author has studied the behavior of parishes along roads where proposals for turnpike trusts failed in Parliament in the early 1700s. In such settings one can plausibly examine how parishes would have spent in the absence of turnpike trusts. The evidence suggests that parishes would not have ramped up their spending levels (Bogart 2005a). Before leaving this issue, it is worth noting that parishes did more on local roads. Parish spending levels increased significantly in the early 1800s. Their efforts were bolstered by the growth in local traffic and by engineering innovations associated with John Macadam and Thomas Telford.

How effective were Britain's road network and its carrier or coach services on the eve of the railway age? Some insights can be gained from a comparison with other countries. At the very least, Britain had a more dense road network. Around 1840 Britain had more than two times the number of paved road kilometers per square kilometer than France or Spain (Bogart, Drelichman, Gelderblom, and Rosenthal 2010: 89). Only the Southern Netherlands had comparable road density by 1840 and interestingly it was one of the few countries or territories that also relied extensively on tolls. In terms of travel speeds, Britain's road network also compares favorably. Szostak (1991: 70) uses a sample of routes to show that in 1760 the average travel speed in France was 50 percent of the average travel speed Britain. By 1780 speeds increased in both countries but the average in France was still around 70 percent of the average in Britain. Britain had a communications advantage over its military rival at the beginning of the Industrial Revolution.

Britain had a further advantage over much of Europe in that it had an extensive network of navigable rivers and a long coastline. As demonstrated by Willan (1964) many of the populated parts of Britain were within 15 miles of a navigable river or coastline already in 1600. Many of these rivers, like Thames and Severn, were the main conduits of trade between the interior and large cities like London and Bristol. The main advantage of river transport was cost. Freight charges by river were one-fifth or one quarter of the charges by road. The problem was that rivers did not exist everywhere and they did not always provide the most direct route to cities. As a result, road transport could co-exist and sometimes exceed river transport in terms of total volume. Consider, for example, overland trade to London. Areas in the Thames river valley could ship grain by water but much of the grain surplus from the Home counties, including Bedfordshire, Hertfordshire, and Buckinghamshire had to be shipped by road as they had no river route to the capital. Such regions relied on road transport until the canal and railway era.

The inadequate coverage of the waterway network was addressed to some degree by improvements in river navigation. Much like turnpike trusts, Parliament endowed river navigation companies with rights to levy tolls. The stated aim was to extend the navigation of rivers into the interior. Since the middle ages, 'Sewer Commissions' had powers to tax landowners to cleanse rivers, but they were wholly inadequate to pay for expensive and large scale improvements in navigation. For this one needed clear legal authority to take land and property as well as a source of income to pay for the fixed costs and damages like flooding of land. River navigation companies were given the necessary powers to finance improvements and their accompanying legislation addressed some of the property rights dilemmas that could plague such projects (Willan 1964).

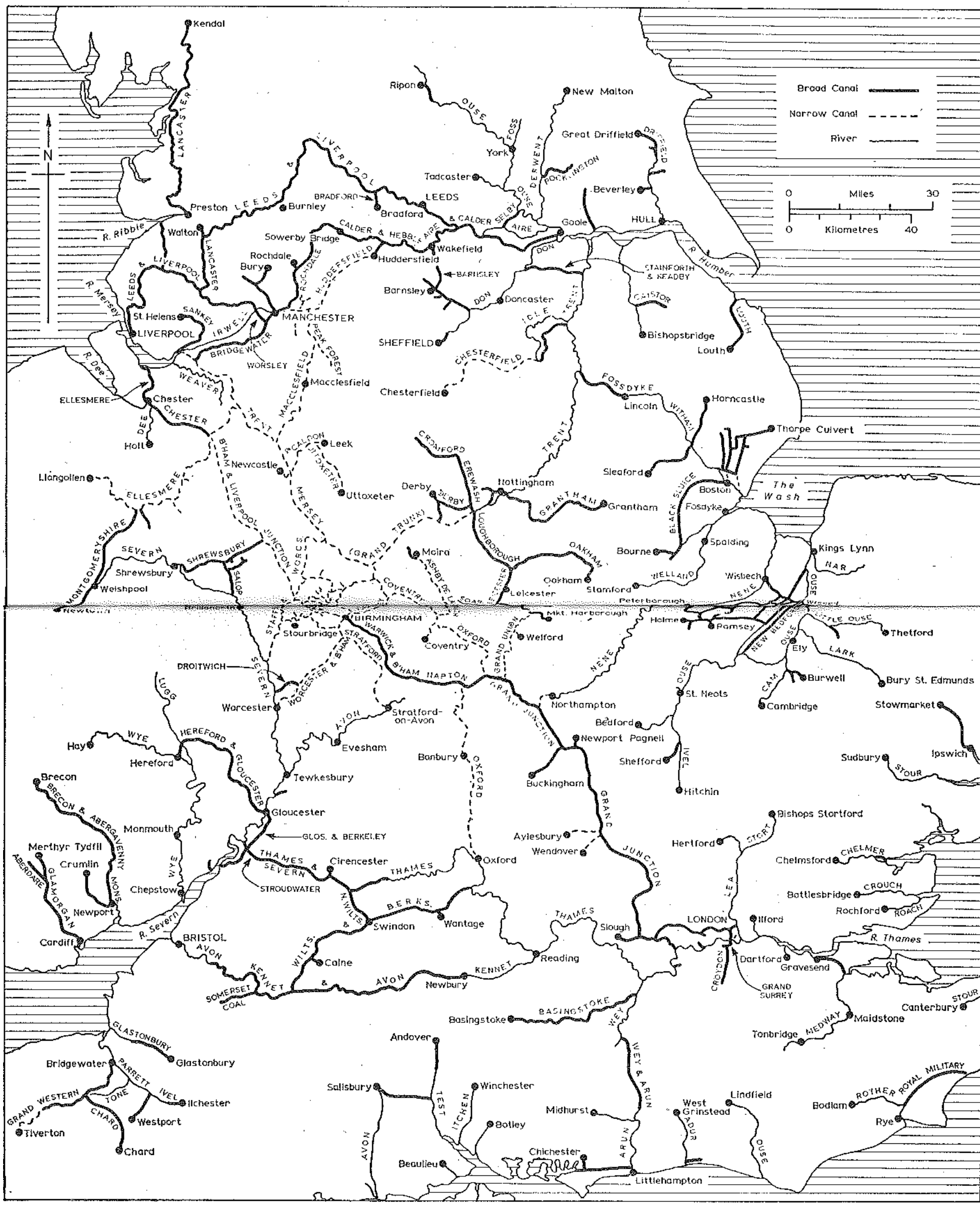
River navigation companies invested significant sums from 1690 to 1750. The result was an extension in the number of miles of navigable river from around 850 to 1600 by the year 1750. Improvements in navigation were made to the rivers Trent, Derwent, Aire, Mersey, and Weaver among others. Many would serve industrial regions in the Midlands and North.

Coastal shipping was another vibrant form of transport in the early 1700s. Freight rates on coastal vessels were lower than on any other mode of transport including river barges. The only problem was that ships could be delayed due to weather and shipwrecks were always a concern. For these reasons, the eighteenth century coastal trade was largely concentrated on the east coast. The largest port was London which also served as the center for foreign or colonial bound vessels. The next largest coastal ports included Newcastle, Sunderland, and Scarborough all in the northeast (Jackson 1983). The most common cargo was coal. Its low value to weight meant that coastal shipping was by far the best mode of transport. Other commodities like grain were common on coastal vessels especially in the East Anglia region.

The degree of technological and organization change in coastal shipping appears to have been extensive during the eighteenth century and was derived from various sources. According to Ville (1986), the design of hulls and sails improved allowing for more power and durability. Vessels increased in size allowing for greater capacity. There were also changes in loading practices and technologies that led to more voyages per year. Finally, there were also increases in port capacity over the eighteenth century. Major dock works were undertaken in Lancaster, Liverpool, Hull, Goole, Grimsby, Bristol, and London during the early 1800s. As in the case of river navigation and roads, projects were authorized by acts of Parliament and were undertaken by joint stock companies or trusts (Jackson 1983). In spite of these developments, Hausman (1987) has raised doubts about the degree of improvement in coastal shipping. The critique is based on estimates of the rate of total factor productivity growth in coastal shipping. The methodology will be discussed below, but for now it is worth stating that technological and organizational change does not necessarily translate into large productivity growth. The magnitude of improvements and the cost of the inputs being saved by technologies matter for productivity growth.

Transport Revolutionized: Canals, Railways, and Steamships

Traditional forms of transport were improved through technological and infrastructural developments between 1700 and 1830, but even allowing for their significance, canals, railways, and steamships were the locus of the transport revolution in Britain. Canals were important because they extended water transportation to important areas of the economy. Birmingham, for example, had no navigable rivers and Manchester was ill-served in its hinterland. The problem was partly a matter of endowments. In some areas there were no streams or rivers to make navigable or the terrain was too rugged. The other problem was technological. Engineers needed to learn how to build reservoirs, to divert water long distances, and to use sophisticated locks to deal with changes in elevation. Canals embodied these innovations and brought inland water transportation to much of the interior regions of Britain. The waterway network c1830 is shown in Duckham (1983)'s map.



Canals introduced a number of property rights issues, much like the rivers that preceded them. Local landowners were aware of the potential gains from shipping their produce to market more cheaply, but they bore the brunt of the costs. Their land needed to be taken and what remained might suffer residual damage from flooding and traffic along tow paths. How was the 'takings problem' solved? Like most infrastructure improvements in Britain, canal companies received authorization from Parliament before implementing their project. One of the most important provisions of these acts concerned negotiations with landowners. The acts stated that in the event landowners and canal companies could not reach agreement, a jury was to be impanelled to determine compensation. Juries were arguably necessary because landowners would like to hold-up canal companies by charging them an excessive price for their land. Of course, the canal company had the opposite goal and wanted to minimize the price. The specificity and the multiplicity of landowners made coming to an agreement difficult. Juries offered a quick resolution to this bargaining problem but they did so at a price. Case studies have shown that juries were friendly to landowners when determining compensation (Kostal 1994, Bogart 2011).

Even beyond the need to compensate landowners, canals required substantial capital investment. According to Ward (1974), 17 million pounds was invested in canals between 1755 and 1815. To put this figure into perspective, the value of capital invested in turnpike roads is estimated to be around 10 million in the early 1820s (Bogart 2012). Canals were the largest infrastructure investment in Britain by their time. Canals relied on local sources of financing. The landed interest played a role, but it was the mercantile and industrial sector in the area that provided the majority of funds (Ward 1974). The size of investment in canals appears to have stretched local capital markets to the limit particularly during the canal mania of the 1790s. London financiers stepped into to provide some needed capital. A number of financial innovations increased London's involvement. One was the emergence of intermediaries like brokers. In several provincial cities, like Oxford and Leicester, brokers helped transfer shares in newly formed companies (Ward, 1974: 106-107). Another innovation was the interest-bearing optional note. Optional notes were first issued by the Grand Junction canal in the late 1790s. It gave the holder the right to convert the bond into a share at face value. They were particularly popular among London investors (Ward 1974: 71).

There was a strong link between banks and canals as well. Ward documents several cases where banks extended credit to canal companies in the 1790s (p. 112). He also notes that bankers were typically treasurers for canal companies. Bankers' knowledge of the London capital market might have been imparted on the directors of canal companies who generally had more expertise in local affairs or engineering. Moreover bankers likely conveyed information about canals to investors in London, which would further reduce search costs between companies and investors.

Canals provided for the transportation of bulky goods, most notably coal, which arguably could not have been met with land carriage. One indicator of their importance is the close association between the construction of canals and reductions in the price of coal or the growth of coal output. Turnbull (1987: 550) gives an example of the Lancashire coalfield where output more than tripled between 1773 and 1790 following the construction of the Leeds and Liverpool canal. One complication in linking canals with economic growth concerns their endogenous development. Canals were often constructed in areas and at times of substantial economic growth. In the previous example, Lancashire was booming in the late eighteenth century in part because of innovations in the textile industry. One might argue that output growth in the Lancashire coalfield would have continued without canals. As we shall discuss later, more sophisticated methods are needed to identify the contribution of transport innovations like canals.

The role of canals in the transportation of industrial goods is less clear than for heavy goods like coal. There are numerous examples of factories locating near canals, but these were also places with turnpike roads. Freeman (1980) has studied the relative advantages of road and waterway transport in the case of the cotton textile industry. The records of spinning firms suggest they relied on roads when speed was essential. Canals companies tried to increase the speed of services through the introduction of 'fly-boats,' but they were not entirely successful. Regulation is one reason. Parliamentary acts gave canal companies a monopoly over the infrastructure, but not the services using the waterway. Canals might have been more successful in taking passenger and high value traffic if they could dictate the types of services offered.

Britain's canal network was a major achievement in spite of any limitations on speed. Its significance can be seen in a comparison of waterway density across countries. As late as 1850, England and Wales were ahead of France, Spain, and the German Empire in kilometers of navigable waterways per square kilometer. Only the Netherlands and Belgium had more (Bogart, Drelichman, Gelderblom, and Rosenthal 2010: 89). Britain's waterway advantage over France was greatest by the end of the Napoleonic Wars when Britain had nearly three times the waterway density of its economic and military rival (Szostak 1991: 55).

Railways were of equal and possibly greater significance to inland transportation than canals. Railways succeeded in market segments where canals failed. They came to dominate passenger travel and the shipment of high value goods because they offered speed and comfort on an unprecedented scale. Long distance travel by wagon and coach had no chance of surviving. Railways companies were also vertically integrated, owning both the track and the vehicles. It was the first time in British transport history where market power was so heavily concentrated.

Railways were a major technological achievement and innovations in steam power were crucial to their development. Railways began as horse-drawn wagons on iron rails. George Trevithick was the first to develop a steam powered road carriage to replace horses. George Stephenson made further improvements and along with his son Robert they developed the first high-pressure steam locomotive in the 1820s. One of the most important technological decisions was the choice of gauge width. George Stephenson used the 4 ft. 8.5 in. gauge in constructing the Manchester and Liverpool railway during the 1820s. Stephenson's gauge became the most common width among early railways, but others were tried ranging from 3 ft. 10 in. to 5 ft. Interestingly it does not appear that Stephenson favored this width because of any advantages in steam locomotion. By the 1840 several prominent engineers advocated gauges ranging from 5 ft. to 7 ft. on the grounds that operating costs would be lower, especially on high volume routes (Puffert 2010). Gauge width had become a contentious issue and broad gauge regional networks emerged in western Britain following the lead of Brunell's Great Western railway. As it turns out the savings from broad gauges proved to be illusory and the costs associated with breaks of gauge mounted with time. By the 1870s many broad gauge networks were converted to the Stephenson gauge, but not after substantial costs had been incurred (Puffert 2010).

Like turnpikes and canals, railways were authorized by acts of Parliament. As a result, investors and private interests dictated the development of the network much more than the Government. The Railway Mania of the mid-1840s was one of the most famous episodes of private railway promotion. In the pace of a few years, several hundred railways were authorized in parliament. Although some good quality projects were proposed, more were speculative. A fraction of the lines authorized in the Railway Mania were completed, resulting in large losses for some investors (Odlyzko 2012). The railway board proposed a more rational development of the network around the same time, but their recommendations were largely ignored (Casson 2011).

Along with technology and regulation, financing played a key role in railway development. By 1870 the railway capital stock is estimated to be £232 million in 1869 prices (Hawke 1970: 200). To put this figure in perspective, recall that around £17 million was invested in canals by 1815 and £10 million was invested in turnpikes by the 1820s. Although much larger in scale, railway investment was similar in character to canals. Local landowners, merchants, and industrialists subscribed the most capital. London financiers played a complementary role at first and increased their contributions with time. Why did financing consist of a mixture of local and centralized financing? Trew (2010) argues that London financiers initially faced an initial informational disadvantage, but they become more efficient through learning by doing. At that point, the London market took over and railway investment accelerated.

The last revolutionized transport sector was shipping. The application of steam power was one of the key developments. Steam power was first applied to coastal shipping with passenger services starting in the 1810s. On some routes, steam ships had a speed and cost advantage over stagecoaches. Their market share reached its zenith in the early 1840s (Bagwell and Lythe 2002: 25). Steamships continued to fill a gap in the market not be met by railways even as late as 1910 (Armstrong 1987).

The application of steam power was clearly important, but how much of an advance was it compared to earlier developments in shipping? North (1968) and Walton and Shepherd (1972) examined this issue in the context of North Atlantic shipping. They argued for significant productivity growth in the age of sail and emphasized shorter loading times and improvements in packaging. There is another intriguing explanation relating to piracy. Previously ships had to arm themselves to protect their crew and cargo. However, there was a possibility to reduce these costs as there were economies of scale in defense. North argues that the British Navy performed this task well enough so that private ships became more cost efficient. North's argument's arguments have not gone unchallenged. Harley (1988) showed that most freight rates in British shipping did not decline substantially until the 1860s. Harley emphasized the importance of steam power and metal hulls. The North-Harley debate raises some interesting questions. Can the transport sector become more productive solely through technological change or do organizational and institutional changes matter in a significant way? Research will continue to debate this question.

The Evolution of the Transport Market

Transport markets evolved greatly from 1700 to 1870 due to the technological and infrastructural developments. Prices and output are good indicators of these changes. Table 1 gives an estimate of average passenger fares and travel speeds for stagecoaches and railways. In 1700 passenger fares were around 0.18 shillings per passenger mile. In other words, the price for one person to travel one mile was 0.18 shillings. By 1760 stagecoach fares had risen to 0.23 per passenger mile and by 1800 they were 0.4 shillings. Fares clearly increased in nominal terms, but not necessarily in real terms. Dividing the fare by a consumer price index gives the real change. I use Clark's (2010) consumer price index to convert fares into 1700 prices. The resulting calculation shows a modest increase in real passenger fares from 1700 to 1800.

Table 1: The Evolution of Transport Costs and Travel Speeds

Stagecoach Fares in shillings per passenger mile			Stagecoach Speeds in journey miles per hour		Time cost per passenger mile
	current prices	constant 1700 prices			current prices
c.1700	0.18	0.183	c.1700	1.96	0.08
c.1760	0.23	0.22	c.1750	2.61	0.07
c.1800	0.4	0.21	c.1820	7.96	0.04
Railway Fares in shillings per passenger mile			Railway speeds in journey miles per hour		
	current prices	constant 1700 prices			
c.1865 second class	0.13	0.08	c.1870	23.2	0.02
c.1865 third class	0.08	0.05			

Sources: for stagecoach fares and speeds see Gerhold (2005: 177-236), Bogart (2005: 505-506) and Laudner (1855: 180). For railway fares and speeds see Hawke (1970: 77) and Leunig

(2006: 642, 646). Time cost is calculated as the time for a one mile journey multiplied by one half the hourly wage of a building craftsman. See Clark (2010) for building craftsman day wages and the 10 hour working day.

Although stagecoach fares were roughly constant from 1700 to 1830, journey times were not. Travel speeds are difficult to measure because of stoppages along the way. Journey miles per hour (journey distance divided by total travel time) are measured better and serve as the usual indicator. Average journey miles per hour were 1.96 in 1700, but there was a difference between summer and winter travel times. In summer the average journey speed was 2.26 and in winter the average journey speed was only 1.48 (Gerhold 2005). Moving forward in time, the average journey miles per hour in 1750 was only slightly higher at 2.61. The large changes occur from 1750 to 1830. By the 1820s journey miles per hour are 7.96 and the differences between winter and summer had narrowed.

The really big changes in passenger travel came with railways. In Table 1 a comparison is made between average fares and journey speeds for stagecoaches and railways in 1865. Not surprisingly passenger fares by rail were much lower than by stagecoach. Third class rail fares in 1865 were one-quarter of the stagecoach fare in 1800. The increase in journey miles per hour was even more dramatic. In 1865 speeds were nearly three times as fast as in 1800 and were more than 10 times as fast as in 1700.

The final column in table 1 shows the time cost of passenger services. The convention in transport economics is to assume that an hour lost in transit is worth half the hourly wage (see Leunig 2006). Multiplying the travel time required to move one mile by Clark's (2010) average wage rates for building craftsman gives an estimate of the time cost of a passenger mile. The time cost is generally lower than the fare, but it exhibits the same general trend with time costs falling significantly from 1700 to 1865.

Table 2 shows the changes in freight rates per ton mile for inland transport. In 1700 freight rates by road were around 1.2 shillings per ton mile. There were differences by wagons and by packhorses with the latter being around 12 percent higher on average (Gerhold 2005). By the 1750s road freight rates had changed little in nominal or real terms, but by 1800 freight rates per ton mile were around 1.46 shillings per ton in current prices and 0.7 shillings in 1700 prices.

Thus in real terms road freight rates decreased by around 40 percent in the second half of the eighteenth century. There was a noticeable decline in seasonality as well. Before 1750 road freight rates could be 30 or 50 percent higher in winter compared to summer on the same route. By the early 1800s winter freight rates were only marginally higher or equal (Bogart 2005b).

Table 2: The Evolution of Freight Rates in Overland Transport

Road freight rates in shillings per ton mile			waterway freight rates in shillings per ton mile		
	current prices	constant 1700 prices		current prices	constant 1700 prices
c.1700	1.2	1.2	c.1700 free rivers	0.12	0.12
c.1750	1.24	1.17	c.1730 river nav.	0.41	0.43
c.1800	1.46	0.7	c.1790 canals	0.38	0.25
			c.1840 canals	0.2	0.12

Railway freight rates in shillings per ton mile

	current prices	constant 1700 prices
c.1845	0.15	0.09
c.1865	0.1	0.06

Sources: for roads same as table 1. For rivers Willan (1964: 119-128) and the Journals of the House of Commons 31.3.1734 and 13.2.1733. For canals Bagwell and Lythe (2002: 14) and Hawke (1970: 85). For railways Hawke (1970: 77).

Freight rates on inland waterways were lower than by road, but by how much? The answer depends on the time period and type of waterway. The average freight charge per ton mile on anciently navigable rivers like the Thames and Severn was only 0.12 shillings per ton mile (Willan 1964: 119-121). In other words it was one-tenth the freight rate by road around 1700. On rivers that were made navigable in the early 1700s the average freight charge was higher. An estimate from a (small) sample river navigations shows it was 0.41 shillings per ton mile or approximately one-third the freight rate by road in 1700 (see table 2). The higher freight charge for river navigations is due in part to the tolls but it also reflects a lack of competition. The Aire and Calder river navigation, near the woolen textile region of Leeds, had few competitors and as result it charged high rates (Wilson 1971).

Canal freight rates were similar to river navigations and much lower than by road. Even after incorporating reductions in road freight rates by 1800, canals freight rates were around one third of road freight rates and even less by 1840. As canals spread throughout Britain and became more efficient, it is clear why much traffic shifted from roads to waterways. The extent of the shift to canals remains a matter of debate, especially concerning long-distance traffic.

Freight rates by rail were less than road and were similar to canals in the 1840s. Rail rates decreased even more by 1865. Railways offered one of the cheapest and certainly the fastest inland transport option by the third quarter of the nineteenth century. If we look over the entire period we see that railways were the culmination of a steady decline in freight rates. In 1865 the freight rate per ton mile was one-twentieth the freight rate in 1700. Inland transportation was clearly revolutionized from 1700 to 1870.

The last transport markets to consider are coastal and North American shipping. The top of table 3 reports freight rates for a ton of coal from Tyne to London at various dates. The first two columns report the rate per ton mile assuming a nautical distance of 283 miles (see Armstrong 1987). The third and fourth columns show the freight rate without adjusting for distance. Several conclusions emerge. First, coastal freight rates did not decline significantly in real terms before 1850, a point made by Harley (1988) and Hausman (1987). Second, there is a significant rise in coastal freight rates around 1800 and is likely due to war. Unlike other transport sectors, shipping freight rates fluctuated greatly between times of war and peace. Third, coastal freight rates were very low compared to other transport options. The last column shows the price equivalent of moving a ton of coal from Newcastle to London by road (1750 and 1800) and by rail (1850). There were more costs associated with coastal shipping that are not included here (taxes, insurance, delays, etc.), but still it is clear that coastal shipping freight rates were much cheaper. It is no wonder that Britain had a very active coastal trade from the late middle ages onward.

Table 3: Changes in Freight Rates for Coastal and North American Shipping

Tyne coal freight rates in shillings per ton nautical mile			Tyne coal freight rates in shillings per ton			
	current prices	constant 1700 prices		current prices	constant 1700 prices	constant price equivalent for road/rail
c.1750	0.019	0.017	c.1750	5.37	4.93	321.75
c.1800	0.049	0.024	c.1800	13.9	6.785	192.5
c.1850	0.022	0.014	c.1850	6.17	3.878	24.75

North American Shipping freight rates in shillings per ton

	tobacco		sugar		rice	
	current prices	constant 1700 prices	current prices	constant 1700 prices	current prices	constant 1700 prices
c.1715	130.7	120.5	73.7	67.9	60	55.3
c.1770	82.1	64.3	70	54.8	40	31.3

Sources: For Tyne coal shipping Harley (1988: 875-876) and Menard (1997: 255-269)

Changes in North American shipping freight rates are shown at the bottom of table 3 for three markets: tobacco from Chesapeake Bay to London, sugar from Jamaica and Barbados to London, and rice from Charleston to London. The time periods correspond to peacetime (Menard 1988). In all cases, real freight rates decline but the changes are most dramatic for tobacco and rice, where freight rates in 1770 were just over half their level around 1715. Comparing changes in freight rates for coastal and North American shipping, it is clear that the latter was more dynamic.

Official data on the volume and average distance of transport services is relatively scarce and the estimates for output in the literature tend to be controversial (see Gerhold 1988, Armstrong 1989). Nevertheless it is possible to give some figures for a few sectors and to compare it with price changes and national income growth. The coastal trade grew at around 1.1

percent per year over the eighteenth century. By comparison Greg Clark's (2010) estimates national income grew by 0.6 percent in the eighteenth century. The London road transport sector also grew relatively rapidly, especially passenger services from 1750 to 1800. The aggregate economy grew at 0.8 percent on average in the second half of the eighteenth century while London road transport (both freight and passenger) far exceeded that. Travel by railways was a new good in the mid-nineteenth century. As expected its growth was extremely rapid. The average annual rate of growth was 13.4 percent for rail freight and 9 percent for passenger traffic from 1840 to 1870. National income growth from 1800 to 1860 is estimated to be 1.9 percent which is again much lower than the growth for railways.

Table 4: Output Growth in Selected Transport Sectors

	output index	average annual growth rate in percent
coastal trade		
c.1700	100	
c.1795	284	1.1
road freight		
c.1700	100	
c.1750	188	1.3
c.1800	796	2.9
road passenger		
c.1700	100	
c.1750	116	0.3
c.1800	1494	5.2
railways freight		
c.1840	100	
c.1870	4400	13.4
railways passenger		
c.1840	100	
c.1870	1318	9

Sources: for coastal shipping see Ward (1974), for roads see (Bogart 2005b), for railways see Hawke (1970: 48, 68)

How can we explain the rapid output growth of the transport sector? Higher national income is one major factor. The elasticity of transport demand with respect to income is estimated to be around 2.5 for Britain 1870 by some scholars (Fouquet and Pearson 2012). In other words if income increased by 1 percent then transport usage would increase by 2.5 percent. Using 2.5 as the elasticity implies transport output should have grown by 2 percent per year in the eighteenth century purely as a result of higher national income. Based on table 4, it would appear that Britain's national economic growth would account for much of the change in coastal and part of road transport. The remaining increase in road transport is likely due to lower freight rates and travel times. In road transport, freight rates declined at an average annual rate of 1 percent from 1750 to 1800 (see table 2). Using Fouquet and Pearson's (2012) estimate of the price elasticity of transport demand equal to -1.5 suggests that road freight output should have grown by 1.5 percent per year due to freight rate decreases. Coach speeds increased dramatically as well and individuals certainly prefer to travel more when speeds increase. If we take the elasticity of transport demand with respect to travel time to be -0.8, then there should have been a 1.75 percent annual increase in coach traffic from 1750 to 1800 purely due to lower travel times. A similar exercise for railways shows that lower fares and travel times explain a good portion of output growth.

Productivity Growth in Transport

Productivity growth is arguably the key indicator of performance in the transport sector. Productivity is higher if transport providers increase ton miles and passenger miles at a faster rate than they increase inputs like labor, capital, and fuel. The change in output relative to a weighted average of all inputs is called total factor productivity growth (or TFP for short). There is a large body of research estimating the average rate of TFP growth in various British transport sectors. The research points to a clear conclusion: transport experienced substantial TFP growth from 1700 to 1870. Gerhold (1996: 494) gives estimates for road freight and finds it to be 0.8 percent per year from 1700 to 1840. TFP growth was highest from 1740 to 1800 when it averaged 1 percent per year. Shepherd and Walton (1972) have found evidence for large TFP growth in North American shipping equal to 0.8 percent per year over the hundred years from 1676 to 1776. For coastal shipping there is less evidence for a dramatic change until the 1820s, after which Harley (1988) estimates an average TFP growth rate of 0.6 percent per year. After

1850 all shipping experiences a productivity acceleration rising to 1.3 percent per year. British railways have been criticized for having low productivity growth, but this was not the case in their formative period. Hawke estimates TFP growth to be high in the early phases of the railway age. The average annual growth rate is 3.0 percent from 1840 to 1870 (Hawke 1970: 303). Crafts, Mills, and Mulatu (2007: 617) show that the trend was towards lower TFP growth in railways as the nineteenth century progressed.

The standard practice in the literature is to report TFP growth estimates for segments of the transport sector like road transport or rail transport. However, the biggest gains in productivity were often associated with mode shifts, especially from roads to waterways and railways. Thus the introduction of water or rail transport in an area was associated with a substantial one-time increase in transport productivity. Here we give a preliminary estimate of the total increase in productivity in overland transport by comparing the relative prices of road transport in 1700 and rail transport 1860 with the relative prices of inputs in the transport sector. Comparing input and output prices gives a proper estimate of TFP growth under many circumstances and is most convenient for transport history as prices are more available.

Table 5 shows the relative prices of capital, fuel, and labor using price series from Clark (2010). A weighted average across all three shows that input prices more than doubled and over the whole period and the average annual rate of growth was 0.49 percent. Using the data in tables 1 and 2, the annual rate of decline in freight charges was 1.57 percent and the annual rate of decline for generalized passenger costs was -0.6 percent. The difference between input price growth and output price growth implies an annual rate of TFP growth of 2.06 percent for freight and 1.09 for passenger services. An un-weighted averaging the two gives an annual TFP growth rate of 1.59 percent for overland transport as a whole.

Naturally, there are some caveats associated with these figures. First, they only apply to freight and passenger services going by road in 1700 and by rail in 1860. That being said, most passenger travel went by road in 1700 and by rail in 1860 so the estimate on passenger productivity growth is likely to be close to the true value. For freight, some cargo on railways went by river in 1700 or possibly by coastal ship. In these segments of the market, the rate of TFP growth would have been less perhaps 0.5 to 1 percent. Second, the input price series may not exactly match input prices in transport. Because it was necessary to have a single series cover the whole period, the price of spade shovels was used for capital goods prices. Obviously shovels were not widely used in transport, but it is hoped they provide a reasonable proxy for capital prices more generally. Despite these caveats, there is a lesson from the TFP estimates. The productivity performance of the transport sector was very good and higher than the economy as a whole. The average annual TFP growth rate is estimated to be less than 1 percent from 1700 to 1870 (Crafts 2004). On this basis, transport must be considered was one of the 'revolutionized' sectors during the Industrial Revolution period.

Table 5: A New Estimate of TFP Growth in all Overland Transport from 1700 to 1870

	Freight financial cost only	Passenger generalized Cost
Relative Price of capital 1860/1700	1.96	1.96
Relative Price of Fuel 1860/1700	1.06	1.06
Relative Price of Labor 1860/1700	3.02	3.02
Relative Input Price 1860/1700	2.19	2.19
Average Annual Growth of Input Prices in %	0.49	0.49
Relative freight rate/fare 1860/1700	0.08	0.38
Average Annual Decline in Freight rates/Fares in %	-1.57	-0.6
Average Annual rate of TFP growth in %	2.06	1.09

Source: for the relative price of inputs see Clark (2010) series on prices for spade shovels, fuel, and wages. Shovel prices are further multiplied by interest rates and depreciate rates to estimate capital prices. For freight charges and generalized costs see tables 1 and 2. The generalized cost is the fare plus the time cost of a passenger mile. The weights for capital, fuel, and labor are 0.6, 0.1, and 0.3.

Profits and Regulation

Thus far we have considered the transport market from the users' point of view. The suppliers of transport services, like carriers, coach-masters, and barge-masters, were naturally concerned about their profits. Most road carriers and coastal shippers operated in a market with low barriers to entry and so their profits were probably limited by competition. By contrast there were high barriers to entry in infrastructure provision and so in this segment of the market, profits could be large. Indeed investors eagerly looked to earn high returns in the infrastructure sector beginning with river navigation projects in the early 1700s. How did they fare?

Arnold and McCartney (2005) measure rates of return on capital invested in all British railways from 1830 to 1912. They find modest returns ranging between 3.5 and 4.5 percent on average. Outside of railways, rates of return are less clear. There are documented instances of super-normal profits and abuse of authority, but their representativeness is unclear as much of the evidence is based on non-random samples of company records. For example, Arnold and McCartney (2011) estimate the rate of return on equity for five canals from 1770 to 1850 and find an 8 percent average return. However, as they recognize their sample contains better performing canals. A broader indicator comes from a survey of dividends for eighty canals in the 1820s. It shows that the average dividend as a percent of capital was near 6 percent.

Turnpike trusts were non-profit organizations and thus legally forbidden from profiting through the tolls. All capital was to be raised through bonds. In spite of these legal provisions, various forms of profit-taking were still possible. Trustees, for example, might accept payments in exchange for road repair and improvement contracts. Likewise bondholders may have been paid an above market return. Did turnpike officers and investors profit from the tolls despite legal attempts to limit their returns? It appears they did not. The evidence shows bondholders earned a return around 4 percent, while net revenues as a percent of the capital invested were close to 5 percent (Bogart 2012).

The modest rate of return in Britain's infrastructure sector suggests there was some competition in the transport market. This conclusion is supported by evidence on market structure. Arnold and McCartney (2005) find that the market share of the top 10 railways was less than 75 percent for most of the nineteenth century. Several railway companies served the British market and often the same region. There was a similar market structure for canals and turnpike trusts. In the latter case, it was not uncommon for several different turnpike trusts to serve the same city with nearly parallel roads. There are also some well documented cases of competition between different modes of transportation. As one example, second class steamship fares between London and Edinburgh were cut from £2 10s to £1 15s. when a railway link was established between the two cities (Bagwell and Lyth 2002: 27). The early railway age arguably marked the height of inter-modal competition in British transport as railways competed with canals and steamships for freight and passenger travel.

Competition is usually thought to be good for market efficiency because it prevents monopoly pricing. There is a caveat in that competition in infrastructure services can lead to duplicative network investments. For example, if a railway company is earning monopoly profits serving some city, then another railway company might enter the market and it is possible that both railways end up earning less than competitive rates of return on their investments. The resulting misallocation of capital can diminish the benefits of competition. Casson (2011) has made this argument for railways arguing that customers could have been equally well served with far fewer railways. Casson places the ultimate blame on regulators and specifically Members of Parliament for failing to implement a more rational network design.

Casson's critique raises a more general question about the effectiveness of Britain's regulatory policies. It has been said that Britain followed a laissez faire approach to transport (Bagwell and Lythe 2002). This is only partly true as the government authorized entry into infrastructure through legislative acts. Local promoters would submit a petition to the House of Commons and if successful it would result in an act of Parliament authorizing a project and regulating its implementation and use. Although government authorized entry, it does not appear that entry was politicized. Some projects were denied in Parliament in the short-run, but rarely in the long-run. The relatively low barriers to entry enabled competition and up to the railway age it appears that competition was benefial. Freight rates were falling and profits were sufficient to stimulate new investment. There may have been a turning point with railways because of the large capital investments involved and because of greater consolidation between railways and waterways.

The high degree of regulatory commitment is another important feature of Britain's policy environment. In addition to authorizing entry, parliamentary acts set regulations for tolls, taxation, and the takings of land. In exercising this power, Parliament could have expropriated from infrastructure investors. Once a railway, canal, or road was built, there were few options for investors if Parliament decided to lower the maximum tolls or increase taxes. For the early eighteenth century there is evidence that Parliament rarely violated investors rights (Bogart

2011). Its commitment to investors is important because infrastructure diffusion is often delayed if governments cannot credibly commit to protect rights (Newberry 2002). Probably the greater risk in Britain from 1700 to 1870 was that Parliament would be captured by infrastructure providers, most notably railways.

Developmental Effects of Transport

It has long been argued that transport improvements foster economic development, but the size of their effects is still in debate even after nearly 40 years of research. This final section reviews the literature studying the impact of transport improvements on industrializing Britain.

Nineteenth century boosters argued that railways were crucial to economic development, but they did not have a clear method to test their argument. Economic historians of the 1960s approached this issue using a novel approach known as the “social-savings” methodology. The goal is to measure how much income was gained from railways at some benchmark date. A simple approximation for the social savings is the difference between freight rates for wagons and railways multiplied by quantity of rail traffic in 1865. Prices are meant to capture the marginal costs of railways and some alternative technology under perfect competition and the quantity of traffic proxies for consumer demand. Two prominent studies argued that national income in the United States would have been lowered by only a few percentage points in 1860 or 1890 had railways never existed (Fogel 1970, Fishlow 1965). Hawke (1970) concluded that railways generated slightly larger social savings in England and Wales, around 7.5 percent of national income in 1865, but only if the increased comfort from passenger travel was incorporated. The social savings from lower fares and freight charges alone were around 4 percent.

Leunig (2006) revisited the passenger social savings of railways emphasizing the increase in speed over alternative forms of transport. In the modern world ‘time is money’ and Leunig shows that something similar applied to nineteenth century Britain. The value of time saved on British railways was above 5 percent of national income in 1870. Leunig argued that in the absence of railways most third class passengers would have walked to work and other destinations. As walking speeds are only 2.5 miles per hour, the shift to railways travelling at 20 or 25 miles an hour represented a dramatic change.

Despite its wide-spread use, the social savings methodology is controversial. Critics point to a number of problems. First, it is not clear what the price of road or water transport would have been in the absence of railways. Congestion would have increased on roads and rivers with the increased traffic volume. The cost of using alternative transport modes is arguably underestimated as a result. Second, the social savings calculation omits what are called backward and forward linkages. Railways increased demand for iron and steel as inputs and thus they fostered the development of these important industries. Innovation was also spurred by railways and other transport improvements. Szostak (1991) offers a compelling argument that blast furnace and textile technologies were fostered by turnpikes and canals in the mid eighteenth century. Lastly, there are also changes in economic geography to consider. Lower transport costs can lead to agglomeration of economic activity, like the emergence of cities.

There is another way of gauging the contribution of transport improvements which holds some promise of addressing these critiques. It compares land income in areas with and without transport innovations. The advantage of this approach is that most externalities should be reflected in land income as it is the fixed factor of production. Only one study to my knowledge has applied this approach to Britain before 1870. It finds that parishes with turnpike trusts in their jurisdiction experienced a 20 percent increase in property income above that experienced by neighboring parishes (Bogart 2009). In the aggregate, the results suggest that turnpike trusts increased national income in Britain by around 2 percent by 1820.

Another method for assessing the contribution of transport improvements to economic growth focuses on national income accounting and productivity growth. The productivity level of the macro-economy is equal to the productivity of each sector multiplied by its revenue share in national income. Following this identity, the contribution of any sector to national productivity growth is equal to its rate of productivity growth multiplied by its revenue share. Crafts (2004) used this approach to argue that productivity growth in railways contributed 0.05 percent to income per capita growth from 1830 to 1860. This average rate would amount to a social savings of 1.5 percent over the thirty year period from 1830 to 1860.

The preceding calculation understates the contribution of railways because it omits productivity gains associated with the displacement of road transport services. As we have seen some of the biggest changes in transport have occurred from eliminating expensive modes of transport. The impact of all productivity growth in Britain's overland transport sector can be assessed using the TFP estimates in table 5. The average TFP growth rate for overland freight and passenger services was found to be 1.59 percent from 1700 to 1860. The revenue share of overland transport in national income is estimated to be 0.06 by Crafts (2004). Multiplying the 1.59 percent average productivity growth rate by 0.06 implies that all transport innovations contributed approximately 0.1 percent per year to national income growth. How large is this? Consider that aggregate TFP growth is estimated to average 0.56 percent from 1780 to 1860 (Crafts 2004). Therefore transport would account for just under one-fifth of all productivity growth in the British economy. As this ratio implies, transport innovations were a major factor in raising the standard of living in Britain and were just as important as innovations in textiles, iron, and mining.

Conclusion

Aside from illuminating British history, estimates of the effects of transport improvements are useful in informing policy discussions. Investing in infrastructure and new technologies is expensive. If the developmental effects are small relative to the costs then transport funding should be reduced. More generally if transport innovations change the way we live, as in the case of suburbanization, then it is useful to know how much. The literature also speaks to the importance of transport improvements in the development of economies over the long-run. Today lower transport costs are crucially linked with trade costs and the extension of markets much as they were 200 years ago. As a final remark, transport innovations have been difficult to implement historically because they involve taxation and vexing property rights issues. There are also potential inefficiencies in transport infrastructure due to monopoly power and regulatory failures. British history tells us that attention needs to be paid to transport efficiency if the social gains from investment and innovation are to be realized.

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