NBER Summer Institute - Development of the American Economy

Private Water Supply in Nineteenth Century London: Re-assessing the Externalities

Nicola Tynan

Department of Economics
George Mason University
Fairfax, VA 22030
703-359-8876 (tel)
703-993-1133 (fax)
ntynan@gmu.edu

25 June 2000

JEL Classification: D62, L95, N73, N83, R11

Abstract

Externalities played a major role in nineteenth century debates over private versus government ownership of water works in Britain and the US. Public health reformers argued that private water companies failed to internalize positive health externalities from filtration, wastewater removal, continuous supply and new connections. Evidence from London's experience with privately owned waterworks suggests that public health externalities from a pipe network were lower than critics assumed and were largely internalized by the companies. Negative externality shocks can be traced to rapid population growth, scientific uncertainty, and the institutional difficulties in moving from one sanitation technology to another.

1. Introduction

Externalities played a primary role in nineteenth century debates over municipal versus private ownership of water works. Critics of private ownership argued that joint-stock companies failed to internalize a number of externalities, particularly the public health benefits of water supply. In many British and U.S. cities, this debate resulted in a switch from private to municipal ownership and control.[1] Public health improvements in cities switching from private to public ownership provided *ex post* support for market failure. London's experience with private water companies throughout the nineteenth century suggests that the relationship between public health and ownership may be more complex than often assumed. This paper argues for a re-assessment of the simple ownership-externality story.

London's waterworks remained privately owned throughout the nineteenth century. Private companies had first offered pipe delivery of water in 1582 and continued to do so until Parliament approved a switch to public ownership in 1902. Private companies invested heavily in service and quality improvements. During the 1800s, companies moved to supplying filtered water, increased the volume of water delivered, introduced high-pressure and continuous supply, and extended their networks to almost every home in the metropolis. Public health also improved under private supply. London experienced its last cholera epidemic (England's major health scare during the nineteenth

---

[1] On US cities see Keith J. Crocker and Scott E. Masten. "Prospects for Private Water Provision in Developing Countries: Lessons from 19th Century America," unpublished manuscript, and Werner Troesken, "Typhoid Rates and the Public Acquisition of Private Waterworks, 1880:1920," *Journal of Economic History* 59:4 (December 1999): 927-948. On British, see J.A. Hassan, "The Growth and Impact of the British Water Industry in the Nineteenth Century," *Economic History Review* 38:4 (November 1985): 531-547.

century) in 1866, long before government purchase of the waterworks and earlier than many other European cities.

The public health argument for a water supply network assumed that pipe delivery of potable water offered the lowest-cost protection from cholera and other water-borne diseases. A pipe network could supply this public good through one of two roles: 1) by providing non-contaminated water for drinking, cooking, food preparation and washing, or 2) by removing contaminated sewage from residential areas. Neither potable water delivery or sewage removal is a pure public good, however. Consumers demand water and sanitation services for their private benefits, and both are excludable and rivalrous under some technologies. A gallon of water delivered to one consumer is not available for others and potable water can be obtained from private wells, tankers or water carriers. Non-network sewage removal was pervasive in London until the second half of the nineteenth century, and urban households periodically paid collectors to empty their cesspit (cesspool). Non-network sewage removal is still common in developing countries and rural areas today. Nineteenth century advocates of government ownership or regulation implicitly argued that the public benefits of high pressure, potable water were substantial and significantly outweighed private benefits. Critics claimed that private companies would, and did, fail to internalize these external benefits.

In this paper, I re-assess the economic history of private water supply in nineteenth century London, with a view to better understanding the degree of health-related market failure.[2] I argue

---

[2] During the 1800s, London's water companies experienced periods of unstable competition. In this paper, I discuss only public health externalities and not other market failures attributed to the instability of competition and private supply. Nicola Tynan and Tyler Cowen, "Competition in London's Water Market," Working Paper, January

that the private benefits of high quality water were significant. Competition for consumers encouraged companies to improve water quality by moving intakes and investing in filtration. Larger volumes of water offered health benefits, but only when combined with an appropriate wastewater and sewerage technology. The public health effects of a switch in sanitation technology were initially negative as sewers dumped waste into some companies' water supply. Debates over public health and water supply revolved around the optimal path to move from one sanitation technology to another.

The paper makes a contribution to the empirical literature on public goods and externalities. It supports earlier authors who emphasize the importance of institutions for determining the publicness of any good, and who provide examples of privately produced public goods.[3] I argue that the publicness of piped water depends, amongst other factors, on the institutional structure for both water and sanitation services and show that private companies did provide public attributes. The paper adds to recent work that disputes the causal relationship between public health and municipal ownership of water works. Werner Troesken shows that during the progressive era private water companies in US cities invested in filtration at a faster rate than public utilities; a switch from private to public provision played little role in reducing typhoid rates.[4] For English cities during the nineteenth century, J. A. Hassan provides evidence that municipalization of waterworks generated external benefits in the form of reduced fire costs and more abundant supply for

2000, explains the periods of instability in terms of an empty core.

[3] Ronald H. Coase, "The Problem of Social Cost," *Journal of Law and Economics* 3 (October 1960): 1-44, reprinted in R.H. Coase, *The Firm, The Market, and The Law*, Chicago: University of Chicago Press, 1988, 95-156. Harold Demsetz, "The Private Production of Public Goods," *Journal of Law and Economics* 13:2 (October 1970): 293-306. Tyler Cowen, "Public Goods Definitions and Their Insitutional Context," *Review of Social Economy* 45 (April 1985): 53-63.

[4] Troesken, "Typhoid Rates," 927-948.

industrial users, but finds little evidence of an improvement in public health.[5] This paper also complements research that finds little evidence of health improvements solely from upgrading water supply technology in developing countries.[6]

My case against market failure in London's water industry involves four claims. First, I argue that piped water had fewer public attributes than was suggested by nineteenth century advocates of government ownership. Where consumers demand water quality for its private benefits, we would expect companies to respond to a deteriorating resource quality by investing in pre-delivery quality improvements. This is what we find. The London companies improved quality by moving their intake to less polluted waters and by constructing settling and filtration plants. Second, I respond to critics' claim that private companies failed to provide the external benefits of water for sewage removal. I provide evidence that: 1) the volume of water increased before the extension of London's sewerage network, and 2) London had a per capita supply of water comparable to the supply in British cities with public water authorities. Third, I show that private companies extended connections and provided water to London's poorest households. Finally, I focus on the importance of cholera for ownership debates. I show that private companies did respond to evidence that cholera was water-borne, and that they did so faster than public authorities. The evidence suggests that government took a less than optimal path to sewerage and sanitary regulations exacerbated the spread of cholera.

The following section outlines the public good and externality issues involved in urban water supply.

---

[5] Hassan, "Growth and Impact," 531-547.

[6] Steven A. Esrey, "Water, Waste, and Well-Being: A Multicountry Study," *American Journal of Epidemiology* 143:5 (1986): 608-623.

It starts by identifying various attributes that consumers demand from their water and sanitation service providers. Then, using water and sanitation technologies that characterize London in 1800 and in 1900, I show the extent to which these attributes may involve externalities under different types of service. Section 3 provides a summary of the water supply and sanitation situation facing Londoners in the early nineteenth century, outlines the path by which London changed sanitation technology, and provides evidence that private companies invested to improve water quality, increase quantity and extend service. In section 4, I show that cholera rates improved under private supply and that private investment proceeded more rapidly than public. I argue that the initial evidence does not support a negative relationship between private water supply and cholera rates. Section 5 concludes.

2. Locating the Externalities

This section clarifies the potential health externalities involved in water supply. First, I identify the bundle of quality attributes demanded by a water company's customers. These attributes include the location, height, frequency and pressure at which water is delivered; the taste, look, potability, and softness of the water; wastewater and sewage removal; and the availability and pressure of water for fire-fighting.[7] I then characterize each attribute in terms of its publicness and privateness. The privateness or publicness of each attribute depends not only on water supply technology, but also on sanitation and domestic plumbing technologies and on property rights to land and water sources. Other institutional factors, such as contract and property right enforcement mechanisms,

[7] Customers may have little immediate demand for water's fire-fighting services, but the service has option-value. Demand may come indirectly from fire insurance companies.

will affect the cost of delivering water.

Identification of the specific public good benefits of a water supply network is important to assess whether private water companies failed to internalize these externalities. Many critics of private supply assume a significant positive health externality from piped water. The strong correlation between countries with widespread potable water networks and low rates of cholera, typhoid and diarrhea has reinforced this view of a direct link between improved public health and piped water. Recent epidemiological research on infant diarrhea by Steven Esrey weakens this conclusion.[8] Esrey finds almost no evidence of health benefits solely from an improvement in water supply technology. He finds that introducing water-borne sanitation plays the crucial role in achieving health improvements, particularly in urban areas. (Though the impact of improved sanitation is greater for households with higher quality water supply.) An earlier paper by Gaspari and Woolf highlights similar difficulties in linking lower crude mortality rates to water filtration.[9]

Water supply and sanitation services come in a range of technology and service combinations. I choose two examples with quite different characteristics: 1) unfiltered water delivered intermittently at a low pressure, private cesspit and open street drains; and 2) potable water delivered continuously and at a high-pressure, water-borne sewage removal (sewerage) and underground drainage pipes. The first package is a relatively low-cost, low quality, service with significant economies of scale only in water delivery. It characterizes much of London in the early nineteenth century and many urban neighborhoods in developing countries today. The second

[8] Esrey, "Water, Waste, and Well-Being," 608-623.

[9] K. Celeste Gaspari and Arthur G. Woolf, "Income, Public Works, and Mortality in Early Twentieth-Century American Cities," *Journal of Economic History*, 45:2 (June 1985): 355-361.

package represents a higher-cost, higher quality package with significant economies of scale in both water and sewerage. It characterizes Greater London in 1902 and most OECD cities today. Most of London's water-related externalities in the 1800s can be traced to the difficulties of shifting from one package to the other.

Using the two service packages outlined above, table 1 identifies the publicness or privateness of various attributes demanded by water consumers.[10] The table does not provide a comprehensive coverage of all attributes, technologies, or service packages, but focuses on key attributes discussed during the nineteenth century. Nor does the table indicate externalities involved in sewage disposal *per se*; it shows how changes in sanitation technology alter the publicness of piped water.[11] The table shows that most attributes are mixed, i.e. not purely public or private.

Institutions matter for determining the publicness or privateness of any good or attribute, and institutional change can alter the degree of publicness.[12] Table 1 captures the importance of institutions through the change in the publicness of attributes after a shift in technology. The literature on externalities has already highlighted major institutional features that determine a good's publicness. In particular, Coase traces externalities to either the absence of property rights or to high transaction costs. Changing property rights can make a private good non-contractible and effectively turn it into a public good. Similarly, high transaction costs may make existing

---

[10] The table abstracts from the problem of widely different individual valuations of each attribute. It assumes, for example, that everyone values water softness equally or at least positively. In reality, consumers' evaluations of water softness may conflict.

[11] For an account of the public and private characteristics of sewerage, see Paul B. Downing, *The Economics of Urban Sewage Disposal*, New York: Praeger, 1969.

[12] "Publicness is an attribute of institutions, not of economic goods. Every good can be made more or less public by examining it in different institutional contexts." Cowen, "Public Goods Definitions," 62.

contracts or property rights unenforceable and allow people to treat a private good as public.[13] Technological economies of scale are a third major source of externality, when fixed cost technologies change the optimal institution for producing a good. Table 1 uses these three sources of externality and indicates whether each attribute's publicness comes from technology-determined economies of scale in production, from the absence of well-defined property rights, or from transaction or enforcement costs.

Under different institutions, the size of the group for whom an attribute is public will differ. Coase looked at local externalities affecting only one other person.[14] Samuelson focused on goods that were public for everyone. Buchanan in his 'theory of clubs' addressed the problem of optimal group size when it lies somewhere in-between.[15] Table 1 indicates the relevant group size for each attribute, and shows whether externalities would have affected only a small group of close neighbors (local), all customers of a single water company (club), or everyone in a city (public). For some cities, club and public attributes may be synonymous, but since London was supplied by at least eight water companies throughout the 1800s, distinguishing between them becomes

---

[13] Yoram Barzel (*Economic Analysis of Property Rights*, Cambridge: Cambridge University Press, 1997, 2nd edition) calls attributes not explicitly priced in the terms of the transaction "free". Francis M. Bator ("The Anatomy of Market Failure," *Quarterly Journal of Economics* 72 (August 1958): 351-79, reprinted in Tyler Cowen (ed.), *Public Goods and Market Failures*, New Bruswick: Transaction Publishers, 1992, 35-66) argues that technical externalities are a type of public good. See also, James Buchanan, *Demand and Supply of Public Goods*, Chicago: Rand McNally, 1968.

[14] Coase, "Problem of Social Cost," 96 and 111. Coase uses the Court of Appeals' judgement on the *Bryant v. Lefever* case to highlight the reciprocal nature of externalities. This case captures the local externalities of sewage removal indicated in the first column of table 1 when discussing liability for getting rid of one's own sewage. Nuisance liability is used to support the Court's reversal of judgement. "It is as if a man tried to get rid of liquid filth arising on his own land by a drain into his neighbour's land." (110)

[15] Paul A. Samuelson, "The Pure Theory of Public Expenditure," *Review of Economics and Statistics* 36 (November 1954): 387-89, reprinted in Cowen, *Public Goods*, 29-33. James M. Buchanan, "An Economic Theory of Clubs," *Economica* 32 (February 1965): 1-14, reprinted in Cowen, *Public Goods*, 193-208. Jack Wiseman ("The Theory of Public Utility Price–An Empty Box," *Oxford Economic Papers* 9 (1957): 56-74) applied Buchanan's club analysis specifically to utilities

relevant.

The public dimension in piped water largely takes the form of technical economies of scale in treatment and distribution. Once a company constructs a reservoir and pumping station, connecting an additional consumer involves extra private costs but also another person to share the fixed costs - reducing existing customers' share. For any group of consumers connected to a particular network, each gallon of water is a private good in consumption, but it is cheaper to raise and distribute - produce - each person's gallon of water together. Once households are connected to a network, many service improvements, for example, water filtration are best characterized as club goods. Others, such as continuous supply, are more complex. Since a water company may efficiently offer continuous supply to some customers while delivering only intermittently to others, continuous supply is partially a private good.

Both models of water and sanitation technology involve pipe water delivery, so the two columns in table 1 indicate quite similar degrees of publicness; they show that no attribute is usefully characterized as a pure public good. The columns do, however, reveal some differences between the systems. For example, in return for higher water quality and delivery services, consumers cede control over water availability and increase their vulnerability to potential system externalities. Other than resource availability, the publicness of each quality and delivery attribute is internal to the club. Consumption of these attributes by club members does not impose costs on non-members, but as services improve non-members do have a greater incentive to join.

The most significant changes in publicness come from the replacement of cesspits with water-borne sewerage. With a sewerage network, wastewater becomes a valuable input; it is no longer just a cost of consuming water. Nevertheless, contributing wastewater to the sewerage system is not purely public; individuals have a strong private incentive to connect.

Other impacts of the move to water-borne sewerage are even more important in terms of the public health debate. Upgrading from model 1 to model 2 gets rid of potential local externalities from wastewater and cesspit overflow. Both the sewage removal and drainage attributes under the first package are shown potentially to involve negative local externalities. These negative externalities disappear with universal sewerage. What the table does not show so clearly is that this local benefit comes at the expense of an increase in the pollution of public water sources.

Whether they are local or public, the negative externalities from wastewater and sewage are largely due to a combination of ill-defined property rights and costly enforcement. Under model 1, externalities may be less of a problem since the private benefits of avoiding pollution are higher. When cesspits store sewage beneath or near the house, the owner or tenant personally suffers if she does not have it removed. Liability for nuisance from overflow or fumes just raises the already high cost of not emptying a cesspit. In contrast, when sewage is dumped in a public water source it becomes a public bad. Private incentives under model 1 may break down, however, if property ownership and tenancy are temporary and nuisance laws are costly to enforce. Working in the other direction, property rights over public water resources would encourage resource owners or households to treat wastewater before it reaches the river or groundwater.[16]

---

[16] Shibata and Winrich show that when the costs of different forms of pollution abatement are not separable a change in the use of one method may cause the marginal cost function for other methods to shift and create the possibility of multiple local optima. After companies invest in water filtration, for example, the marginal cost of

Upgrading sanitation technology offers one way to remove negative local externalities, but may not be the most cost effective.[17] Any benefit-cost comparison of the two sanitation systems would have to include the full costs of water resource pollution or wastewater treatment. Such calculations are always difficult, but nineteenth century critics made some errors that with hindsight we can take into account. We now know that advocates of sewerage generally over-estimated the local costs of cesspits and under-estimated the public costs of dumping untreated sewage in rivers.[18] The rest of this paper takes into account these miscalculations in reassessing the claims against London's water companies and shows that, in terms of providing public attributes, the London companies generally have a good record.

3. Rising Demand and Shifting Constraints

Nineteenth century London experienced rapid population growth. In 1801, the metropolis had a population of 959,000, living in approximately 200,00 houses in and around the densely populated City (the original square mile of fortified London). During the century, soldiers and expatriates returned home after the war with France, people migrated from Ireland and rural England, and the mortality rate fell. In 1850 the population had risen to 2.3 million and the number of houses to 300,000. By 1899, London had a population of over 6.5 million and the area supplied by London

---

water-borne sewerage may fall. Hirofumi Shibata and J. Steven Winrich, "Control of Pollution when the Offended Defend Themselves," *Economica* 50 (November 1983): 425-437.1983

[17] Many Japanese cities still use non-water-borne sewage removal technologies.

[18] As many European countries are now discovering, dumping sewage at sea does not remove the problem; it just postpones the costs. With rising income levels, however, this postponement may have been optimal.

water companies covered 620 square miles.[19] Population growth was not evenly spread, however. During the first 50 years, population density in the City remained stable (at about 128,000) and grew rapidly in neighboring parishes. By the second half of the century, population density in the City fell, while it rose rapidly in the suburbs. As trains allowed people to live further from their work, London absorbed many peripheral villages.[20] In response to these population and territory increases, water companies made continual investment to extent their network and increase capacity.

a) Demand for water delivery and quality improvements

Population growth and rising middle class income in the late 1700s and early 1800s raised the demand for piped water. New households demanded a connection to one of the company's networks, while existing customers demanded increasing quantities of water and new service attributes. Projectors responded to the growing demand for water in two ways: entry and innovation. Seven new companies entered the London water market between 1805 and 1822 - the West Middlesex, Grand Junction, Vauxhall, Southwark, Kent, East London, and Pocock's. (Table 2 and chart 1 give dates of incorporation for each London water company.) Entrants built new

---

[19] For the 1801 population figure see Stephen Halliday, *The Great Stink of London: Sir Joseph Bazalgette and the Cleansing of the Victorian Capital*, Gloucestershire: Sutton Publishing, 1999, 45 (ref to J. Hollis and A. Seldon, The Changing Population of the London Boroughs (Stat. series no.5, 1985), O.N.S. Library). For the number of houses in 1800 and 1850, see Leslie B. Wood, *The restoration of the tidal Thames*, Bristol: Adam Hilger, 1982. For 1899, see Charles Booth, Life and Labour of the People of London, First Series: Poverty II Streets and Population Classified, New York: Augustus M Kelley, 1902 (2nd Edition: 1969). For greater detail on population changes in London during the nineteenth century see Karl Gustav Grytzell, *County of London: Population Changes 1801-1901*, Lund: CWK Gleerup Publishers, 1969.

[20] This rapid population growth stopped in the 1900s and by 1931 London's population had fallen slightly below its level in 1901. Allen Daley and B. Benjamin, "London as a Case Study," *Population Studies*, 17:3 (March 1964): 249-262.

infrastructure or took over and expanded existing networks. Incumbents and entrants invested in new technology. Water companies employed engineers to design powerful pumps that would allow them to offer 'high' service and installed iron pipes able to withstand greater pressure than wooden pipes.

Before 1800, the primary service supplied by water companies was the transportation of large quantities of water directly to consumers' homes and businesses. Piped water offered an alternative to water carrier delivery or to collecting water oneself. Pipe delivery allowed regular, high-volume consumers to take advantage of economies of scale, but increased the publicness of some water attributes. Households had to accept the company's (i.e. club's) quality decisions, instead of choosing from competing water carriers.[21] The first section of table 1 indicates this publicness of piped water, but the growing demand for piped water suggests that the package provided by London's private companies made this loss of private discretion worthwhile.

Before 1800 companies delivered water intermittently - for example, two hours a day every two days - but households stored water in cisterns making it continuously available for domestic use. Wealthier households who wished to have water raised to higher floors of their home installed small, private pumps. This low pressure, intermittent system left decisions regarding quantity, pressure, delivery location and some control over quality (determined by cleaning the cistern or in-house settling and filtering) as private goods.

---

[21] I have not been able to find evidence of the extent to which households chose water carriers or public taps according to perceived quality criteria, but John Snow's work on cholera suggests that some people were willing to go out of their way to drink from a favorite source. John Snow, "On the Communication of Cholera," 1855, reprinted in *Snow on Cholera*, New York: The Commonwealth Fund, 1936.

By 1800, more households had started to demand high-pressure service to enable them to receive water to higher elevation properties and directly to the top floor of their homes. Customers who installed water closets (flush toilets) and baths demanded larger quantities of water, and many expressed a preference for continuous service.[22] Companies responded to this demand first by upgrading their pumping engines, and then upgrading their network. (See table 3 for details of some major investments by London's water companies.)

i) Investment in delivery attributes

London's water companies started to offer customers new delivery options in the late 1700s and early 1800s.[23] Stimulated largely by demand from London's water companies, a number of engineers started to compete to build superior engines. In particular, James Watt improved on an early steam engine he had designed for the York Buildings Company. By 1800, London water companies had purchased at least a dozen of Watt's engines and more than doubled the number of engines raising water in the city.

As the companies installed more powerful pumps, they soon discovered that their existing wooden mains could not withstand the higher pressure and that pipes burst

[22] To give an indication of the impact that installing a toilet has on the quantity of water demanded, Diana Gibbons (1986, p.8) reports that in 1979, toilet-flushing accounted for 45% of water consumed in-house by California households (another 30% was for bathing, only 5% for drinking and cooking).

[23] As early as 1766, the New River Company had employed a top engineer, John Smeaton, to design an improved engine to enable it to raise water at a higher pressure. As H.W. Dickinson reports, "[John Smeaton's] improvements were the direct outcome of London's water needs, and of the enterprise of the New River Company." *Water Supply of Greater London*, Leamington Spa and London: Courier Press, 1954, 65.

frequently. Rising maintenance costs encouraged an increased uptake of iron pipes, which, due to lower-cost molding techniques, had become increasingly cost effective. In 1802, the Lambeth Company replaced three miles of wood pipes with iron. In 1810, the New River Company went further and started to replace its whole mains network (400 miles) with iron pipes.[24] After 1810, all new companies entering London's water market used iron pipes for their mains.[25]

These improvements in pump pressure and pipe durability increased the capacity of each water company's network. They allowed the companies to deliver water higher and further, and to offer high service or continuous delivery to some customers. Improvements also increased the privateness of some delivery attributes as households could now pay extra for additional services.

Households upgrading to continuous from intermittent delivery incurred private costs in addition to higher company charges. Households were responsible for providing their own storage units, stopcocks and plumbing inside the house. Universal continuous supply would have forced all households to install more expensive plumbing. If companies offered only continuous supply, the higher costs of service would have driven some poorer consumers from the market and back to water carriers or self-collection. Reformers ignored this problem and called for a compulsory switch to continuous supply, but local government officials appear to have understood the incentives better

---

[24] William Matthews, *Hydraulia: An Historical and Descriptive Account of The Water Works of London, and the contrivances for supplying other great cities in different ages and countries*, London: Simpkin, Marshall, and Co., 1835, 65. Before 1810, the company was replacing wood pipes at a rate of about 20 miles each year.

[25] The West Middlesex and Grand Junction companies briefly experimented with stone pipes but found them inferior and rapidly switched to iron.

by failing to enforce the switch in poor areas even when, under the Metropolis Water Act of 1871, they acquired the power to do so.

Although poorer customers could not afford the in-house investments necessary for continuous delivery, the companies' investment in iron pipes and improved engines still brought benefits. By 1850, most companies had increased intermittent supply to an almost daily delivery excluding only Sundays. Even this limitation was partly due to regulation that impeded daily delivery; before 1870, companies faced a legal ban on supplying water on Sundays.[26]

ii) Investment in quality

Into the early 1800s, most of London's water companies distributed water from the River Thames, River Lea or New River. Many of London's water carriers and households relied on the same sources. Some consumers preferred the taste of water from a particular source (sometimes a local well), but on other quality attributes London's water sources were comparable. Consumers also had different expectations of water quality than we have today, partly because habits were different and partly because scientists had no objective way to determine high quality water.[27] Most Londoners used water delivered to their homes primarily for cooking and washing. Few wealthy households drank undiluted or non-boiled water; they preferred home brewed or commercially brewed beer,

---

[26] Anne Hardy, "Water and the Search for Public Health in London in the Eighteenth and Nineteenth Centuries," *Medical History* 28 (1984): 250-282. See p.271.

[27] Christopher Hamlin, *A Science of Impurity: Water Analysis in Nineteenth Century Britain*, California: University of California Press, 1990, outlines the history of water quality analysis during the nineteenth century. He focuses on debates over the quality of London water in moving analysis from advocacy and social commentary towards independent science.

ginger ale, tea or coffee.[28]

By the mid-1820s, however, London water quality became a serious issue. Recent research has shown that after 1815, the quality of water in the Thames started to deteriorate.[29] (See below for an explanation of this deterioration.) Since most of London's water companies obtained their water from the Thames, the quality of water distributed by the companies also fell. By the mid-1820s, companies and consumers could clearly observe this deterioration in quality and critics started to condemn the companies for delivering impure water.

Aware of complaints and at risk of losing customers, the Chelsea Company responded rapidly. A solution was needed, but was neither obvious nor readily available. The Company's engineer, James Simpson, started to experiment with filtration technologies in 1825. Water filtration was still in its infancy. In 1806 and 1808, two water companies in Glasgow had built filtration plants with only limited success.[30] In January 1827, the Chelsea Company directors shifted all their R&D funding towards filtration. Simpson increased the scale of his experiments, traveled to Glasgow to talk to other engineers, and devoted himself full time to the development of filtration beds. In January 1829, the Chelsea Water Works Company opened London's first sand filtration plant.[31] A few years earlier, the Grand Junction Company had responded to consumer complaints by

[28] Hardy, " Search for Public Health," 252.

[29] Wood, *Restoration*, 17-22.

[30] Matthews, *Hydraulia*, 147. Glasgow Water Works was established in 1806 and invested 30,000 pounds in a water filtration, but its early experiments failed. Failure encouraged entry by the Cranston Hill Water Works Company in 1808; the Company had slightly more success, but its filters were still unsatisfactory and required ongoing investment and experimentation.

[31] Matthews, *Hydraulia*, 84. James Simpson was later employed by the Lambeth Company and completed their filtration works in 1841. Bill Luckin, *Pollution and Control: A social history of the Thames in the nineteenth century*, Bristol and Boston: Adam Hilger, 1986, 36.

switching to the Thames and away from the Grand Junction Canal as its water source.

Parliament also responded to consumer complaints and established a Royal Commission to investigate the water quality problem and search for a solution. The Commission reported in 1828 and recommended that Parliament consider other sources of water supply. The Commission's report had brought forth many proposals for schemes - most impractical and costly - to bring pure water to London.[32] Parliament established a Select Committee to consider these alternative sources of supply; in 1834, Parliament established a second Committee. Neither Committee could conclude that an alternative source of supply would justify the cost (most of the discussion focused on consumer complaints about price not quality). Private investors reached the same conclusion and refused to invest in private schemes to deliver water in bulk for London's existing companies to distribute.

During the 1830s and early 1840s, most London water companies invested in screen filters and settling reservoirs rather than filter beds, because the effectiveness of the filter beds was still uncertain. By the mid-to-late 1840s, however, other companies decided to invest in filter beds to satisfy the demands of their customers for improved quality. The Kent Company did so in 1845. The Lambeth Company committed to invest in 1848 and by 1852 had completed its filter beds.[33]

---

[32] Articles critical of London's water companies were often written by advocates of costly schemes to bring water from outside London. These projectors emphasized and exaggerated the benefits of water from other sources. For example, they argued that soft water from Wales would increase the productivity of soap or tea enough to offset the construction costs of an long-distance aqueduct. With a proposal to deliver soft water the projectors gained support of interest groups such as washhouse operators.

[33] Later in the century, London's companies exported their filtration technology. Professor Koch. *Professor Koch on the Bacteriological Diagnosis of Cholera, Water-Filtration and Cholera and the Cholera in Germany During the Winter of 1892-93*, translated by George Duncan, New York: William R. Jenkins. 1895, 25 and 85-101. In Altona, Germany, an outbreak of cholera occurred in 1892-93 in the parts of the city obtaining their water supply from a well. Residents who received piped supply from a private water company using the Chelsea and Lambeth

By formally committing the Company to filter water before distribution, the Lambeth Company's Act of 1848 was the first Act to incorporate a water filtration clause. As part of the Metropolitan Water Act of 1852 (the first government Act specifically to address water quality), Parliament decided that all companies drawing water from the Thames should invest in filtration, so the Grand Junction, Southwark & Vauxhall, and West Middlesex started to build filtration works. When the East London Company abandoned the River Lea and moved to using the Thames, in 1871, it invested in six new filter beds.

In comparing government and company responses to the problems of water quality, critics of private supply used the timing of the Royal Commission's report in 1828 as evidence of relatively rapid government action. Critics compared this date to the later opening of the Chelsea Water Company's filtration plant in January 1829. This argument fails to support the superiority of government action because it compares actual water company investment with government proposals rather than action.

Focusing on the Royal Commission's report also obscures the knowledge problem facing private and public actors in the 1820 and 1830s. Parliament and the companies were trying to respond to a water quality problem for which no one had a clear solution. Investing in water filtration was a highly risky venture in the 1820s, and the Chelsea Company's engineer spent much time researching before the Company started to build a filtration plant. Once the Company started to build, it took over a year before the plant opened. Since the Chelsea Company was actually building at the time the Commission was investigating, the timing does not provide support for

companies' technology to deliver filtered water did not suffer from cholera.

either government or market failure, but shows that both private and public were responding differently to a complex problem.

Critics have argued that the Chelsea Company was an outlier and that other companies did not invest in filter beds as fast (some not until after the Metropolis Water Act of 1852). This is true, but again does not provide the comparison with government response that critics suggest. Chemical analysis of water quality was uncertain throughout the 1800s, particularly before 1850, and the success of filtration in improving water quality remained unproven. Nevertheless, those companies that did not invest in water filtration responded to customer demands for quality with various degrees of success by building settling reservoirs or moving their intake. In comparison, the Royal Commission made many recommendations but these did not result in government action.

Before 1852, Parliamentary Select Committees focused on alternative sources of supply rather filtration as the best way to improve water supplies. Select Committee bias towards other sources could have had negative effects on the companies' incentive to invest. If the companies suspected that the Select Committee would recommend compulsory purchase or a switch to alternative supplies, they would not have had an incentive to invest in filtration. Of course, if the companies suspected that the Select Committee would recommend entry, they should have had an incentive to invest, in order to retain customers. The variance in company action may partly be explained by a variance in expectations.[34]

[34] Two of the companies that were slower to invest in filtration, the Grand Junction and Southwark & Vauxhall, had as their Chairman an outspoken advocate of government purchase of London's water works at a "favorable" rate. Sir William Clay, *Remarks on the Water Supply of London*, London: James Ridgeway, 1849.

Later in the century, critics of private supply reinforced their arguments with claims that municipal authorities that had taken over private companies provided higher quality water. Some evidence against this claim came from Colonel Frank Bolton, the Metropolitan Water Examiner, in his report of 1882. Bolton reported that water delivered by London's water companies had improved in recent years. His analysts' samples had shown that water delivered by the London companies was superior to that provided by the municipal utilities in Manchester, Glasgow or Edinburgh. In these cities municipal authorities had all taken over private water companies (1847 and 1851in Manchester, 1854 in Glasgow, 1869 in Edinburgh) at least partly to improve water quality.

b) From cesspits to sewerage

Rising consumer demand for water had implications for the third group of attributes listed in table 1: wastewater removal. As water consumption increased, so did the volume of wastewater flushed into London's sewers. Larger volumes of water also changed the quantity and composition of wastes that households flushed into the sewers. Piped water made flushing a lower-cost option than carting waste out of town, and the introduction of the water closet offered an alternative to cesspits for human sewage.[35] Because London's system of public sewers was designed primarily for rainwater and drainage, however, flushing larger volumes of wastewater into the sewers rapidly increased the pollution of the Thames and other rivers with sewer outflows.

---

[35] The word sewer changed meaning during the nineteenth century to capture the sewers changing role from drainage to waste removal system. The word sewage also evolved from meaning only animal and vegetable matter to including human waste.

The first model in table 1, representing London in 1800, captures the typical household's reliance on cesspits below or near their homes to dispose of human wastes. Under this system, negative externalities were a potential problem at the local and public levels. At the local level, households could fail to have their cesspit emptied by a night soil collector, allow it to overflow and impose costs on neighbors. With cesspits, however, individuals had a fairly strong private incentive to prevent pollution because they personally suffered a significant share of the costs when cesspits overflowed. To reinforce this private incentive, common law made homeowners' liable for acts of nuisance imposed on neighbors. Public externalities occurred when households laid pipes from their homes to the public sewers. To prevent this pollution of public waterways, London's City Corporation or other local vestries in the metropolis made private connection to the sewers illegal and imposed fines on offenders.[36]

Between 1800 and 1850, a number of changes took place that raised the benefits of connecting to the public sewers, and increased the public externalities. Larger volumes of water and re-invention of the water closet have already been mentioned. Other changes had an impact by raising the price of night soil collection. In particular, the expansion of metropolitan London raised the costs of transporting sewage out of the city, and imports of guano from Latin America after 1847 reduced farmers' demand for human manure.[37] Rising prices for night soil collection also

---

[36] A supporter of sewerage wrote in 1844: "But the use of the sewers as the grand channels for the clearance of water closets, and even for getting rid of some portion of the more fluid dirt of the streets, is so modern, that it was not permitted, until the commencement of the present century, to drain private dwellings into the sewers." Joseph Fletcher, "History and Statistics of the Present System of Sewerage in the Metropolis," *Journal of the Statistical Society of London* 7:2 (June 1844): 143-70, see 166.

[37] R.A. Lewis, *Edwin Chadwick and the Public Health Movement 1832-1854*, 1952, reprint New York: Augustus M. Kelley, 1970, see p.49.

increased the local externalities from overflow (as households equated the marginal benefit of emptying with the now higher marginal cost).

Private and public costs had diverged. London's local vestries could have encouraged households to internalize the public costs of pollution by raising the fine for connecting to the sewers. Under pressure from ratepayers (particularly those with flush toilets), however, London's Commissioners of Sewers decided - in 1815 - to allow private sewer connections conditional on households paying their own sewer construction and maintenance costs.[38] Since households had to pay for sewer connections, the demand for water closets started slowly. By the 1830s demand for water closets increased rapidly - and so did the pollution of the Thames. In 1834, London's six Commissioners of Sewers did not see this as their problem, however. The Commissioners saw their responsibility "only to effect the mechanical transmission of the superfluous fluids to the Thames,"[39] and to therefore generate negative externalities for anyone relying on the Thames for their water.

The decision by London's six Commissioners of Sewers to allow private sewer connections not only created the public bad of river pollution, but also created 'inter-club' externalities as one Commission district imposed costs on another. These inter-club externalities became particularly severe in the City district after sewers were improved and expanded in Holborn and Finsbury to the north. Wastewater and sewage from Holborn and Finsbury had to pass through City sewers to

---

[38] These costs could be quite high. "Down to 1849 a tax of almost ten shillings, six pence, was assessed against every person cutting down a branch-drain. A worse feature, however, was the requirement of an official bricklayer. The most corrupt district was Westminster, where the official bricklayer asked ten or eleven shillings." Dorsey D. Jones, *Edwin Chadwick and the Early Public Health Movement in England*. Iowa: University of Iowa, 1929, 103. This monopoly price for connecting to the sewers allowed official bricklayers to reap the rents. Before 1847, the charge for having a cesspit emptied was one pound.

[39] Joseph Fletcher, "History and Statistics," 164.

reach the Thames, but City sewers could not cope with the increased volume; families in the City experienced the contents of their own drains being forced back into their home. Nonetheless, vestries remained strong advocates of sewerage partly because they saw it as a way to cut their enforcement and street cleaning costs, and partly to satisfy voter who had installed toilets. In 1848, Parliament created the Metropolitan Sewers Commission to overcome these inter-club externalities. Since the Metropolitan Commission immediately compelled the connection of all private cesspits to the public sewers, however, this did nothing to address the pollution of public water sources.[40]

Pollution of the Thames imposed a negative externality on the water companies. It lowered the quality of their major input. Since the companies did not have the power to prevent river pollution, they could only improve the quality of water they delivered by investing in filtration plants or shifting their source of supply. As table 3 shows, they did both. In 1852, Metropolis Water Act did required all companies to move their intakes above the part of the river, but not before some of companies had already done so. Public opinion, as expressed through Parliament debate, did speed up the process and ensured that laggard water companies followed the innovators faster than they might otherwise have done. But, in an already charged political environment, this does not translate into a failure of private supply.

After the Metropolitan Sewers Commission made connection to the public sewers compulsory, the volume of water demanded by households increased. So did the demand for new connections, and complaints of insufficient supply. With the population of London growing rapidly, particularly on the periphery (population doubled between 1850 and 1900 and rose more than eight-fold in the

---

[40] For a history of London's sewerage system, see Halliday, *Great Stink*.

suburbs), the water companies were continually investing to keep up with demand.[41] Complaints generally reveal a time lag in laying the pipes for household connections rather an incentive for sub-optimal supply on the part of the private companies. Companies noted that providing high pressure and larger volumes of water before a customer had installed suitable internal plumbing and had a sewer connection would increase local externalities. Poor households were often slow to install costly plumbing and poor neighborhoods could be made worse off by a switch to continuous delivery or to toilets without proper sewers.

Complaints about insufficient supply were generally short-lived phenomena to which the companies were constantly responding by increasing capacity and connections. As table 4 shows, the number of customers supplied by the private companies increased substantially during the 1800s. Taking London's longest surviving water company, the New River Company, as one example: in 1800 the Company supplied water to 52,000 households; by 1897, this figure had risen to 165,534. London's younger companies expanded even faster: between 1809 and 1897 the number of households receiving water from the East London Company rose from 10,739 to 190,594.[42] The volume supplied by London's companies also increased significantly. In 1830, companies were supplying an average of 27 gallons per capita, by 1897 this had risen to 38 gallons per capita. (Thirty years after public ownership, Londoners were still only receiving a per capita average of 37 gallons.)

By increasing the volume of water supplied, water companies provided a positive externality to the

---

[41] Luckin, *Pollution and Control*, 177.

[42] Alice & Peter Hogg and George & Violet Rhodes, *Fit to Drink: The History of Water in Walthamstow*, London: Walthamstow Antiquarian Society, 1986.

sewerage system. As indicated in table 1, however, the private benefits of water for flushing meant that water companies internalized this externality. Public officials in other cities used insufficient supply for flushing as one argument for public ownership. Hassan argues that municipalization of urban water supply was required to meet the growing demand for water in most English and Scottish cities.[43] He shows that municipal water utilities supplied larger quantities of water on average than did their private predecessors.

London provides a counter-example to his claim of market failure and creates the possibility that capacity would have increased over time irrespective of ownership. Table 5 compares London with other English and Scottish cities at the end of the nineteenth century and shows that per capita supply in London *exceeded* per capita supply in cities with municipal water utilities. This data point provides some evidence that municipal supply was not necessary to internalize the externality from supplying a larger quantity of water.

Evidence from London also suggests that public control was not sufficient for investment and quality improvement. Developing London's sewer system was the responsibility of vestries. In many parishes, however, sewer networks lagged far behind water connections. This was particularly true in parishes east of the city where wastewater overflow and pollution were particularly acute problems. The east of London was also the last part of the metropolis to benefit from the creation of London's intercepting sewer to divert wastewater from public sources. In response to this failure of vestry action, the East London Company built and maintained its own 4-mile intercepting sewer to carry wastewater and sewage below its intake, and to improve its supply

[43] Hassan, "Growth and Impact."

to customers.[44]

4. Water-borne disease

Two water-borne diseases, cholera and typhoid, played a major role in nineteenth century public health debates throughout Europe and the US. In this paper, I focus mostly on cholera because, although typhoid caused more deaths than cholera in London during the 1800s, cholera played a signal role in debates over ownership of the city's water companies.[45] Cholera arrived in observable waves, spread fast, and killed many people in a short period of time. During an epidemic year, deaths from cholera could outweigh deaths from other causes in cities struck by the disease. The fear of an impending cholera outbreak did much to heighten public anxiety and to intensify demand for a solution.[46]

Londoners experienced four cholera epidemics: in 1832-33, 1848-49, 1853-54 and 1865-66. The death rate from cholera rose in the second epidemic compared to the first - about twice as many people in London died from cholera in 1848-49 as had died in 1832-33 - but fell during the next two (table 6). Between the first and the second epidemic, many households installed a water closet to remove the fumes believed to be spreading disease and connected to London's sewers. The sewer connection rate increased even more rapidly after 1848 and by 1866 the water closet (either in-house or out) was an almost universal feature of London homes.

[44] Hogg and Rhodes, *Fit To Drink*, 19.

[45] Even in the 1890s, critics of private supply used cholera as a major part of their argument for municipal ownership of waterworks.

[46] For a general history of cholera in England, see Norman Longmate, *King Cholera: The Biography of a Disease*, London: Hamish Hamilton, 1966.

When households connected to London's sewers, they turned local cesspit externalities into public externalities of river pollution. This river pollution and the move to greater publicness in sanitation played a major role in raising the number of deaths from cholera. In terms of capturing the importance of a switch from local to public pollution, the timing of the 1848-49 epidemic is significant; the epidemic immediately followed the Metropolitan Sewer Commission's 1848 decision to make household sewer connection compulsory.

Table 6 - Cholera rates in London during the 1800s

Year(s)	Deaths from cholera	Deaths per 100,000 population	Population
1832-33	5,275 (6,536)	370 (459)	1,424,896
1848-49	14,137	620	2,280,282
1853-54	10,738	456	2,362,236
1866	5,596	<250	*TBC*

Sources: Halliday, *Great Stink*.

After its 1848-59 peak, cholera mortality fell. Private water companies contributed to the lower death rates in the 1853-54 and 1866 epidemics by their investment in filtration and moving their in-takes up-river. Boroughs supplied by the companies that had invested in filtration earliest had lower cholera mortality. In 1848-49, the only districts receiving water from Thames companies and suffering cholera death rates above 1% (100 per 10,000 population) were south of the River. Households in these districts received water from either the Southwark & Vauxhall or Lambeth Companies. The other companies supplying Thames water had already moved their intake further upriver, invested in filtration or done both. The importance of these investments for public health is reflected in the fall in cholera rates between 1848-49 and 1853-54 in districts supplied by the Lambeth Company; by 1851 the Company had completed its filter beds and moved up-river.[47] In 1866, most of London's cholera deaths were concentrated in the East London Company's supply region; the company had tried unsuccessfully to prevent pollution of the River Lea from towns up-river.[48] In response to the 1866 outbreak, the East London Company moved its source of supply up-river and built new filtration plants.

Contemporaries tended to couch the water supply debate in terms of private vs. public ownership, but this focus fails to capture the general scientific uncertainty amongst scientists and policy makers regarding water quality and pollution. In 1832, doctors and scientists understood almost nothing about the nature or transmission of cholera. Even worse, much of what they thought they knew was wrong. According to the most popular theory, cholera was a pythogenic disease that could spontaneously arise from any filth or sewage with certain predisposing factors making people susceptible to the disease. The pythogenic theory effectively viewed local cesspit pollution (table 1, model 1) as simultaneously a public bad of air pollution. Public health reformers, accepting the pythogenic theory, argued that removing waste and sewage from the city was a priority - even if this meant flushing sewage into public water sources. These reformers censored water companies more harshly for failing to provide a sufficient supply of water to flush London's sewage into the Thames than for poor quality water. With hindsight, the rapid switch in sanitation technology may

---

[47] It is largely because of these company differences that John Snow was able to show that cholera was a water-borne disease.

[48] In 1866, chemists were still unable to accurately determine water quality and still largely worked backwards from epidemiological evidence. According to the government's analyst, Edward Frankland, the East London company's water seemed purer than usual even at the height of the cholera epidemic in August 1866. The tests also showed the water delivered in Manchester and Glasgow to be purer than Thames water, but the higher mortality rates in Manchester and Glasgow suggested otherwise. Hamlin, *A Science of Impurity*, 156-158.

not have been an optimal move.

Only in the second half of the century did Parliament's discussion focus more clearly on issues of quality. After John Snow used London data from the 1848-49 and 1853-54 epidemics to provide evidence that cholera was a water-borne disease, no one could ignore the link between water and public health. Nevertheless, many people did ignore Snow's argument that only contaminated sewage could spread cholera.[49] By far the majority of doctors, public health officials and clergy continued to support the pythogenic theory, though they now saw sewage polluted water as one of the many predisposing factors.[50] By focusing on the potential risks of once-polluted water and calling for a change of water source, chemists detracted attention from lower-cost preventive measures, such as disinfecting cholera patients' waste before disposal and destroying contaminated bedding. Focusing policy advice and support on these private actions could have done more to prevent the spread of cholera than calling for large-scale investment schemes.[51]

Between the first and second cholera outbreaks, the idea that London needed some central government and central planning had started to gain popularity. Edwin Chadwick was at the forefront of this movement with respect to water and sanitation. Chadwick may be seen as

---

[49] Professor [Robert] Koch, discoverer of the cholera bacillus, provides evidence of an ongoing scientific debate over the source of cholera in the 1890s in his book *Bacteriological Diagnosis of Cholera, Water Filtration and Cholera, and the Cholera in Germany During the Winter of 1892-3*, New York: William R. Jenkins, 1895. On p.69, Koch explains that the last outbreak of cholera in London, in 1866, occurred before scientists were able to test the purity of filtered water. In the 1880s, Edwin Chadwick stuck with his belief that cholera was an atmospheric disease (B.W. Richardson, 1965).

[50] Charles Rosenberg, (*Cholera Years*, p.199), argues that in New York in 1866, "Physicians believing in some sort of 'germ theory' were still in a small minority - roughly one in seven." In 1854, the England's Committee for Scientific Inquiry rejected Snow's theory.

[51] New York's experience in 1866 suggests that these actions may be been the most effective. Charles Rosenberg, *The Cholera Years*.

London's city planner attempting to select the optimal sanitation system. Part of Chadwick's problem, in modern terminology, was to select the sanitation package that equated the marginal social cost (MSC) of each form of sewage removal and treatment with the marginal social benefit (MSB) of pollution removal. Chadwick concluded that Londoners should have flushing toilets in every house and a sewerage system that transported sewage out of the metropolis. Modern water and sewerage (table 1, model 2) generally vindicates Chadwick's conclusion. The other dimension of Chadwick's problem - how to move London from cesspits to sewerage at lowest cost - was far more difficult. Hindsight allows us to doubt that Chadwick selected the optimal path.

Changing sanitation technology takes time, particularly when a new system requires large-scale investment in network infrastructure. Re-assessing the public decisions in terms of the lowest cost path weakens the evidence of public success. Understanding that cholera and typhoid are water-borne diseases makes it difficult to imagine that any path to an optimal sanitation system would involve polluting public water sources with potentially contaminated sewage. Public authorities' decision to compel house connections to public sewers four years before requiring water filtration provides some evidence of public failure at least as strong as any evidence of market failure. Not until 1856 did Parliament starting taking steps to reduce the pollution of the Thames.

Not all questioning of Chadwick's vision comes only with hindsight. Many of Chadwick's contemporaries pointed out that his specific calculations were far from accurate. Chadwick advocated water-borne sewage removal because he believed strongly in the pythogenic theory and saw cesspits as the major threat to public health. He believed that a sewerage system would be self-financing from the sale of manure to farmers, but he had no reliable evidence to support this claim and neither the treasury nor private investors were willing to back his scheme. Even public officials who disagreed with Chadwick focused on large-scale solutions to sanitation and public health. Efforts directed at destroying cholera wastes, as implemented successfully in New York in 1866, were largely ignored. So too were improvements in cesspit technology, advocated by some of Chadwick's contemporaries, and monitoring cholera brought in through the port of London, as was done after 1866.[52]

Property rights and enforcement are major factors in determining the impact of any sanitation technology on public health (table 1), but in the mid-1800s the River Thames was almost a commons. Water companies relying on the Thames for water had no power to prevent pollution by cholera-contaminated sewage. Creating a single authority to take control of the Thames did not present an immediate solution; compare to its predecessors, the Metropolitan Sewers Commission increased pollution of the rivers Thames and Lea.

Only in 1856, with Parliament's creation of the Metropolitan Board of Works did the decisions of London's sewer authority take an anti-pollution direction. The Metropolitan Board was specifically created to address the problem of river pollution and given a mandate to ensure the separation of waste from water flowing into the Thames. The Board proposed a system of intercepting sewers to transport sewage five miles below London before disposing of it into the Thames. In 1858, the year of the Great Stink, Disraeli authorized the Board to start work immediately.[53] As with most

---

[52] On the importance of prevention by the port of London sanitary authorities after 1866, see Anne Hardy, "Cholera, Quarantine and the English Preventive System, 1850-1895," *Medical History* 37 (1993): 250-269.

[53] The Great Stink was caused by a particularly hot summer; it made pollution of the Thames obvious to anyone working in the Houses of Parliament.

large-scale projects, the intercepting sewers took longer to construct and cost the public a much larger amount than estimated.[54] The intercepting sewer system was initially predicted to take three years to construct and the official opening took place in April 1865, but the work was not completed until 1875. The sewers on the north side of the Thames were built before those on the south side. Given the intensity of cholera deaths in the south of London, this timing suggests that public construction schedules were based on criteria other than health externalities. When cholera hit Europe in 1866, London's east-end was not yet connected to the city's intercepting sewer system. As noted above, this was the only part of London hit by the epidemic.[55] Sewage pollution of the Thames finally ended in 1887, making the time it took to achieve the Metropolitan Board's mission 31 years.

Media reports show that Londoners continued to worry about cholera well into the 1890s, particularly from people arriving on ships from European cities suffering cholera epidemics. Londoners did not suffer another outbreak, but advocates of public ownership used the public's fear to fuel the water supply ownership debate. Typhoid had not fully disappeared, however. As the nineteenth century's other water-borne disease, critics may be expected to have included typhoid mortality as part of their evidence against private supply. Table 7 suggests that they probably avoiding doing so because the data would not support their case. The table shows that show that London fails to stand out as have a particularly high typhoid mortality rate, and generally does better than other English cities.

---

[54] This point is important not as a criticism of the sewer project, but as an indication that most figures given for large-scale works by people seeking public funding tend to be excessively optimistic. This would apply to cost figures given by people who claimed that their scheme to bring water to London would cost less than the existing companies' supply.

[55] Halliday, *Great Stink*, xiii.

Debates over the ownership of London's water supply took place during a period of rapid urban growth that raised the costs of cesspit sanitation. Innovation and investment by London's private water companies increased the quality and range of water delivery services available to customers. Improvements in water supply also made a shift to sewerage viable, but raised problems of how to get from one technology to another. The path chosen imposed little-understood costs on the water companies and required even greater investment. Private companies undertook this investment, though not all at an equally rapid pace. Differences between the companies allowed critics of private supply to focus on the laggards. Critics ignored the benefits of competition for encouraging rapid investment by the leaders.

5. Conclusion

One difficulty with some of the literature on water supply externalities is that they are rarely well defined. This paper has identified the important externalities in water supply and how these differ with different sanitation technologies. Public health externalities were lower than claimed by nineteenth century critics of private water supply, and companies suffered from pollution externalities as much as caused them. Competition between private companies generated externalities in the form of improved medical knowledge and in investment in water quality and delivery improvements. Private companies extended their networks to increasing numbers of households at the same time as taking steps to improve quality.

The history of water supply in London suggests that ownership was not the crucial dimension for externalities.

Property rights and other institutional incentives played a far more important role. This paper provides initial support for this claim, but further research is needed to understand which institutional incentives were most significant. London's history suggests that future research needs to look at dynamic incentives. A static analysis in terms of natural monopoly is liable to miss important benefits of competition between water providers in a rapidly changing, uncertain environment.

Table 1 - Attributes of piped water under two water and sanitation technologies

The table characterizes each attribute in terms of privateness or publicness, and determines indicates the size of group to which any publicness extends. I assume each system is privately optimal given the prevailing technology, medical knowledge, population and population density, input costs, etc.

Model	1) Unfiltered water delivered intermittently at a low pressure and stored in-house, private cesspit sanitation and open street drains.	2) High-pressure, potable, water delivered continuously, water-borne sewerage, and underground drainage pipes.
Attribute		
Water Quality (providing goods)		
Potability (uncontaminated water)	**Private** Maintain cistern and tertiary pipes. In-house filtering or boiling of water. **Club - economies of scale** Construction of aqueduct, river, waterwheel, pumps, etc. Potability of water determined by choice of source. Selecting higher quality for one customer raises quality for all.	**Private** Maintain tertiary pipes. **Club - economies of scale** Reservoir settling and filtration. Quality of network. Choice of water source. Construction of aqueduct, river, pumps etc. **Negative externality** **Club - contract enforcement** If filtration fails.
Taste	**Private** In-house filtering. Bottled water for drinking. **Club - economies of scale** Choice of water source. Construction of aqueduct, river.	**Private** May still be cost effective to buy bottled water for drinking. **Club - economies of scale** Choice of water source. Construction of aqueduct or river. Filtration or addition of chemicals.
Softness of water (Hard water corrodes pipes faster; reduces productivity of soap and tea.)	**Private** In-house addition of salt or chemicals. **Club - economies of scale** Choice of water source. Construction of aqueduct or river, and other water works.	**Private** In-house addition of salt or chemicals. **Club - economies of scale** Choice of water source. Construction of aqueduct or river and other water works. Water treatment.
Delivery/Storage System (providing goods)		
In-house availability (quantity)	**Private** Determined by size of cistern or water butt. **Club - economies of scale** Construction of water works. **Negative** **Public - property rights** Limited supply due to consumption by other consumers of same natural resource.	**Club - economies of scale** Construction of waterworks. **Negative** **Club - property rights** Potential shortage due to high consumer demand on system; potential peak use problem. **Public - property rights** Limited supply due to high demand on resource.
Delivery location	**Private** Determined by location of cistern; in-house pumping. **Local** Location of shared tap.	**Private** Height of building; location of in-house pipes. **Club - economies of scale** Choice of system pressure.
Pressure from tap	**Private**	**Private**

	Location of cistern. In-house pumping.	Location on in-house pipes. **Club - economies of scale** Choice of system pressure. **Negative externalites** **Club - property rights** Depends on system demand - heavy use by some customers reduces pressure for all.
Wastewater removal (removing bads)		
Human sewage removal	**Private** (Cesspit emptying.) *Water not required*. **Negative externalities** **Local - enforcement costs** Overflowing cesspit. (Addressed through tort action by neighbors under common law.) Smell of cesspit when emptied. **Public - property rights/enforcement costs** Connecting to public sewers. (Illegal -requires City Corporation or vestry action under common law.)	**Private** Internal plumbing and water closet (toilet). **Local, Club or Public - economies of scale/ system externalities** Sewage network requires water to flush system. Some customers' demand for water flushes sewage system for all connected. **Negative** **Public - property rights** Pollution of public water resources. (May be prevented with wastewater treatment.)
Waste removal (E.g. food products, non-human sewage)	**Private** (Treated as solid waste - may be burnt, left to decompose.) *Water not required*. **Negative externalities** **Local - property rights/enforcement costs** Smell from burning/manure piles. **Public - property rights/enforcement costs** Waste washed into public sewers.	**Private** (Treated as solid waste - may be burnt, left to decompose.) (*Water not required*.) **Local, Club or Public - system externalities** Sewage network requires water to flush system. Some customers' demand for water flushes sewage system for all connected. **Negative externalities** **Club - enforcement costs** Some forms of waste block sewage pipes and may cause backup for other customers.
Drainage or wastewater removal	**Private** Connect house overflow to public sewers. **Local, Club or Public - economies of scale** Sewer available to one person in street is available to all. Many street sewers connecting to main sewer to river or out of city **Negative** **Local - property rights/ enforcement costs** Overflow to neighbors if house not connected. **Public - property rights** Pollution of public water resources.	**Private** Connect house to public sewers. **Local, Club or Public - economies of scale, system externalities** Sewer available to one person in street is available to all. Many street sewers connecting to main pipes to river or out of city. Wastewater and drainage flushes sewage through system. **Negative** **Public - property rights** Pollution of public water resources.
Firefighting (removing bads)		
Availability	**Private** Contacting turncock and fire engine; using other sources of water. **Local/Public** Water available to one house in street available to all, diminishes probability of fire spread to	**Private** Contacting fire engine; using other sources of water. **Local/Public** Water available to one house in street available to all, diminishes probability of fire spread to

	neighbors' houses. **Public - negative externalities/property rights enforcement** Requires turncock to open hydrant. Supply depends on demand on system.	neighbors' houses.
Pressure	**Private** Fire engine with additional pumping power. **Negative externalities** **Public** Pressure depends on demand on system**.**	**Private** Fire engine with additional pumping power. **Public - economies of scale/property rights** High pressure usually available in all parts of network, but may depend on demand.

Table 1 - Private Water Companies in London, 1582-1902

Company	***Established or Incorporated***	***Closed or Purchased***	***Details of closure/purchase***
London Bridge Water Works Company	1582 (1701)	1822	Sold to New River Company. Network south of the river became part of Southwark Water Works.
Broken Wharf Waterworks	1594	1703	Works taken over by London Bridge Company.
New River Company	1613 (1619)	1902	Purchased by Metropolitan Water Board.
Somerset House Waterworks	1655	1667	Works taken over by New River Company.
Shadwell Waterworks	1669 (1680-1)	1807	Land and assets bought by London Dock Company. Water works sold to East London Company.
Millbank Waterworks	1675	1727	Rights and assets transferred to the Chelsea Company.
York Buildings Company	1676 (1691)	1818 / 1829	Assets leased to New River Company in 1818. Officially disolved in 1829.
Hampstead Waterworks	1692	1856	Bought by the New River Company.
Marchant's Waterworks	1695	After 1741	Not known.
Ravensbourne Waterworks	1699 (1701)	1810	Assets absorbed by Kent Water Works.
Bank End	1720	1771	Became Old Borough Water Works (?)
Chelsea Waterworks	1722 (1721)	1902	Purchased by Metropolitan Water Board.
(Old) Borough Water Works	1771	1820	Taken over by Southwark Company.
West Ham Waterworks	1743	1807	Bought by London Dock Company & sold to East London Company.
Lambeth Waterworks	1785	1902	Purchased by Metropolitan Water Board.
South London Waterworks Company (renamed Vauxhall)	1805	1845	Merged with Southwark to become Southwark and Vauxhall Company.
West Middlesex Waterworks Company	1806	1902	Purchased by Metropolitan Water Board.
East London Waterworks	1807 (47 Geo.III Cap.72)	1902	Purchased by Metropolitan Water Board.
Kent Water Works	1810	1902	Purchased by Metropolitan Water Board.
Pocock's Waterworks Company	1810	1815	Not known. New River Company obtained customers.
Grand Junction Waterworks Company	1811	1902	Purchased by Metropolitan Water Board.

Southwark Water Works	1822	1845	Merged with Vauxhall to become Southwark and Vauxhall Company.
Southwark and Vauxhall Water Works Company	1845	1902	Purchased by Metropolitan Water Board.
Richmond Water Company	N/A	1861	Taken over by Southwark and Vauxhall Company.
Bush Hill Waterworks	1875	1887	Works taken over by New River Company.
North Middlesex/Colney Hatch Waterworks	1867	1871	Taken over by New River Company.
Sources: H.W. Dickinson, *Water Supply of Greater London*, 1954; William Matthews, *Hydraulia*, 1835.			

Table 5 - Per Capita Supply in Towns and Cities in England and Scotland

Town/City	Gallons (British) per head in August 1898
Brighton	43
Hull	43
Plymouth	43
London	**38.5**
Bradford	35
Leeds	35
Preston	34
Liverpool	31.5
Croydon	31
Manchester	30
Halifax	29
Swansea	28
Blackburn	25
Bolton	23.5
Bristol	23.5
Birmingham (average)	23
Burnley	23
Huddersfield	23
Cardiff	22
Oldham	22
Sheffield	21.5
Nottingham	19
Birkenhead	18
Leicester	18
Wolverhampton	17.5

Source: Shadwell, *London Water Supply*, 61.

Table 9 - Typhoid Rate Comparisons

City/Town	Period	Rate	Period	Rate	Period	Rate
London	**1871-1890**	**21.4**	**1881-1890**	**19**	**1895**	**14**
Bristol (private)	1871-1890	23.6	1881-1890	15		
Birmingham (public post-1876)	1871-1890	25.4			1895	17
Liverpool (public)	1871-1890	26.7	1881-1890	26	1895	37
Newcastle	1871-1890	28.5				
Leicester	1871-1890	29.1				
Bradford	1871-1890	29.7	1881-1890	17		
Manchester (public since 1847)	1871-1890	30.1			1895	30
Sheffield	1871-1890	31.6				
Hull	1871-1890	34.6	1881-1890	25		
Leeds (public since 1852)	1871-1890	36.7			1895	21
Salford	1871-1890	40.1			1895	30
Nottingham	1871-1890	40.5	1881-1890	29		
Huddersfield			1881-1890	15		
Brighton			1881-1890	18		
Birkenhead			1881-1890	21		
Derby			1881-1890	26		
Cardiff			1881-1890	28		
Preston			1881-1890	38		
Blackburn			1881-1890	41		
Portsmouth			1881-1890	49		

Source: Arthur Shadwell, *London Water Supply*, London: Longmans, Green, and Co, 1899, 64 (except ownership)

References

Clay, Sir William. *Remarks on the Water Supply of London*. London: James Ridgeway, 1849.

Coase, Ronald H. "The Problem of Social Cost." *Journal of Law and Economics* 3 (October 1960): 1-44, reprinted in R.H. Coase, *The Firm, The Market, and The Law*, Chicago: University of Chicago Press, 1988, 95-156.

Cowen, Tyler. "Public Goods Definitions and Their Institutional Context." *Review of Social Economy* 45 (April 1985): 53-63.

Crocker, Keith J., and Scott E. Masten. "Prospects for Private Water Provision in Developing Countries: Lessons from 19th Century America." Unpublished manuscript.

Demsetz, Harold. "The Private Production of Public Goods," *Journal of Law and Economics* 13:2 (October 1970): 293-306.

Dickinson, H.W. *Water Supply of Greater London*. Leamington Spa and London: Courier Press, 1954.

Downing, Paul B. *The Economics of Urban Sewage Disposal*. New York: Praeger, 1969.

Esrey, Steven A. "Water, Waste, and Well-Being: A Multicountry Study." *American Journal of Epidemiology* 143:5 (1986): 608-623.

Fletcher, Joseph. "History and Statistics of the Present System of Sewerage in the Metropolis." *Journal of the Statistical Society of London* 7:2 (June 1844): 143-70

Gaspari, K. Celeste, and Arthur G. Woolf. "Income, Public Works, and Mortality in Early Twentieth-Century American Cities." *Journal of Economic History*, 45:2 (June 1985): 355-361.

Halliday, Stephen. *The Great Stink of London: Sir Joseph Bazalgette and the Cleansing of the Victorian Capital*. Gloucestershire: Sutton Publishing, 1999.

Hamlin, Christopher. *A Science of Impurity: Water Analysis in Nineteenth Century Britain*. California: University of California Press, 1990.

Hardy, Anne. "Water and the Search for Public Health in London in the Eighteenth and Nineteenth Centuries." *Medical History* 28 (1984): 250-282.

Hardy, Anne. "Cholera, Quarantine and the English Preventive System, 1850-1895." *Medical History* 37 (1993): 250-269.

Hassan, J.A. "The Growth and Impact of the British Water Industry in the Nineteenth Century." *Economic History Review* 38:4 (November 1985): 531-547

Hogg, Alice & Peter, and George & Violet Rhodes. *Fit to Drink: The History of Water in Walthamstow*. London: Walthamstow Antiquarian Society, 1986.

Jones, Dorsey D. *Edwin Chadwick and the Early Public Health Movement in England*. Iowa: University of Iowa, 1929.

Koch, Professor. *Professor Koch on the Bacteriological Diagnosis of Cholera, Water-Filtration and Cholera and the Cholera in Germany During the Winter of 1892-93*. Translated by George Duncan. New York: William R. Jenkins. 1895.

Lewis, R.A. *Edwin Chadwick and the Public Health Movement 1832-1854*. 1952. Reprinted: New York: Augustus M. Kelley, 1970.

Luckin, Bill. *Pollution and Control: A social history of the Thames in the nineteenth century*. Bristol and Boston: Adam Hilger, 1986.

Matthews, William. *Hydraulia: An Historical and Descriptive Account of The Water Works of London, and the contrivances for supplying other great cities in different ages and countries.* London: Simpkin, Marshall, and Co., 1835.

Robins, F.W. *The Story of Water Supply*. London: Oxford University Press, 1946.

Shadwell, Arthur. *The London Water Supply*. London: Longmans, Green, and Co, 1899.

Shibata, Hirofumi, and J. Steven Winrich. "Control of Pollution when the Offended Defend Themselves." *Economica* 50 (November 1983): 425-437.

Snow, John. "On the Mode of Communication of Cholera." 1855. Reprinted in *Snow on Cholera*. New York: The Commonwealth Fund, 1936.

Troesken, Werner. "Typhoid Rates and the Public Acquisition of Private Waterworks, 1880:1920." *Journal of Economic History* 59:4 (December 1999): 927-948.

Tynan, Nicola, and Tyler Cowen. "Competition in London's Water Market." Working Paper, January 2000.

Wiseman, Jack. "The Theory of Public Utility Price–An Empty Box." *Oxford Economic Papers* 9 (1957): 56-74

Wood, Leslie B. *The Restoration of the Tidal Thames*. Bristol: Adam Hilger, 1982.

Table 3 - Investment and New Technology

	Water Company							
Year	Chelsea	East London	Grand Junction	Kent	Lambeth	New River	South wark	Vauxhall (South Londo
1785					2 new engines; 3 miles wood mains			
1802					Iron mains			
1804								
1807		Engine; 4 settling reservoirs						Fire destroyed ma
1808								
1809		2 engines						
1810						Start replacing wood mains with iron.		1807-1813 bulk supply
1811				Engine; 2 pumps				
1812			Engine; stone mains					
1813								
1814								
1815					New engine			
1817		Engine						
1820			Moved supply to Thames; 2 engines					
1822				Iron mains				
1824		Engine						
1825								
1826		Engine		Engine				
1827								
1829	Filtration plant opened; 2 reservoirs	Moved intake to Old Ford; water wheel; reservoir					Engine; iron m	
1871		Intake up-river; 19 mile main; 6 filter beds; 3 engines			Moved intake to West Molesey		2 engines; mains extended; 4 c	
1872								
1873			Reservoir; filter beds					
1876		Engine		Engine				
1879		Engine						

1886	Pump	Intercepting drain; intake up-river						
1891					Engine			
1898	Mains connected to Kent Co.			Mains connected to East London Co.				
Sources: Compiled from W.H. Dickinson, *Water Supply*; William Matthews, *Hydraulia*, 1834								

Table 4 - Number of customers (households) supplied by London's water companies

Years	Chelsea	East London	Grand Junction	Lambeth	London Bridge	New River	Southwark	Vauxhall	W Midd
1785-1794				629					
1795-1804									
1805-1814		10,739				52,000			
1815-1824	8,631	32,071	7,180	11,487	10,417	52,082			
1825-1834	12,409	42,000	7,809	15,987		66,600	7,100	12,046	
1835-1844	13,892	46,421	11,141	16,682		70,145	7,100	12,046	
1845-1854									
1855-1864									
1865-1874									
1875-1884									
1885-1894									
1895-1902		190,594		106,888		165,534			
Population							***Southwark & Vauxhall***		
1898	278,662	1,274,735	400,846	674,456		1,183,000	812,822		6

Sources: Shadwell, *London Water Supply*; Fletcher, "Historical and Statistical"; Clifford, *Private Bill Legislation*; Matthews, *Hydraulia*; and Robins, *Story*

Chart 1: Timeline of Water Companies in London, 1582-1902