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# 4 Science, Health, and Household Technology: The Effect of the Pasteur Revolution on Consumer Demand

Joel Mokyr and Rebecca Stein

The rise in life expectancy, in particular the decline in infant mortality, remains one of the most impressive achievements of modern technology. Much of this progress was made before 1914 and long before the advent of modern antibiotics. This paper proposes that one key to the decline of the mortality rate is essentially technological in nature. In a simple model of consumer behavior, the household can be viewed as “producing” health for its members, based on a certain set of priors that the household has on what causes disease. These priors changed radically in the closing decades of the nineteenth century as a result of growing knowledge that dictated certain “recipes” to the household regarding food, hygiene, personal and medical care, and so on. The paper discusses the origins of this new knowledge and how households were induced to change their behavior. The central role of changes in the understanding of disease, especially the emergence of the germ theory as the undisputed ruling paradigm, is recognized and some attempt is made to quantify the importance of those changes. We conclude that much of the credit for the increase in life expectancy goes to household decision makers in addition to scientists, physicians, and civil servants.

## 4.1 Introduction

Consumers purchase goods for two different reasons: because they “enjoy” these goods (i.e., utility *stricto sensu*) and because they believe that these goods are in some way good for their health, that is, that these goods are inputs

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into a household production function which produces, among other things, physical well-being.<sup>1</sup> The health-related component of demand is, however, rarely made explicit and is usually subsumed under “preferences.” Thus, if the consumer learns that a certain good that she has been consuming is actually harmful to her health, she may reduce her demand, which would be tantamount to a change in taste. However, no actual change in preferences has occurred; instead, the information available to the consumer has changed. As is widely understood, changes in preferences and changes in information available to the consumer are observationally equivalent.<sup>2</sup>

Although consumer theory typically allows for various kinds of uncertainty, it is unusual for economists to assume that the consumer does not know her own preferences. It is usually assumed that the ordering of preferences is complete and the maximand itself is understood and fully known. In the case of the interaction between consumption and health, however, the information upon which the consumer bases decisions is clearly variable. In the past, consumers have typically been poorly informed about the effects that consumption had on their bodies. As new information became available to them—we shall discuss below how that happened—they changed their behavior. The approach we take in this paper is to define a separate “health” function as a combination of the physical well-being and life expectancy of members of the household, which is being maximized jointly with pure “utility.”<sup>3</sup>

The decline in mortality in the West after 1850 is still imperfectly understood. There are at least four explanations in the literature that purport to account for the decline in infectious disease in the industrialized world before 1914. One explanation focuses on the rise in income and living standards, which resulted in improved nutritional status. Improved nutrition enhanced immunity and thus reduced susceptibility to disease and case-specific mortality rates. This hypothesis, associated with McKeown (1977) and Fogel (1991a, 1991b, 1992), has come under heavy criticism (e.g., Szreter 1988 and Ryan Johansson 1994) but has more recently found defenders (Guha 1994). An alternative hypothesis, supported by Szreter (1988) and Brown (1988, forthcoming) gives more credit to public works and local government, especially sani-

1. More generally, consumer goods can be inputs into other ultimate goals in the classic Lancaster-Strotz manner. This approach has long been central to the analysis of the household as pioneered by Becker (1976). Historians have expressed the same idea, e.g., De Vries (1993) and Cowan (1983). Empirical studies of such models are reviewed by Strauss and Thomas (1993). For the purpose of this paper, however, we focus exclusively on physical well-being.

2. For a restatement, see Pollak and Watkins (1993). Many of the issues that come up in the economics of fertility and contraception are isomorphic to the issues that come up in the economics of health. The difference, above all, is that it seems reasonable that preferences with respect to health tend to be relatively stable over time, in contrast with the demand for children.

3. A similar approach to the one in this paper can be found in the works of Samuel Preston and his coauthors (Preston 1976; Ewbank and Preston 1990; Preston and Haines 1991), referring primarily to infant mortality decline in the United States after 1900.

tary improvements.<sup>4</sup> These two competing explanations, the protestations of some of their defenders notwithstanding, do not exclude each other. Yet there is some lingering doubt whether, even taken jointly and allowing for synergistic effects between nutrition and infection, they explain the entire phenomenon. If not, there remains an unexplained residual which requires further investigation. One scholar (Fridlitzius 1984) feels strongly that there is more to the story and has speculated about exogenous climatic and microbial changes which reduced infectious disease.

Our view is that these stories pay insufficient attention to technology. As in the measurement of total factor productivity, when all inputs have been accounted for, the prime suspect in the residual is changes in knowledge.<sup>5</sup> Technological changes in food preservation, textiles, water supply, transportation, and home appliances have long been mentioned as contributing factors. Even medical treatment did not stand completely still and had a number of major successes to its credit, above all the conquest of smallpox which is still regarded by some as the most important medical success before 1914. Yet there is another aspect of useful knowledge which has not been given sufficient credit, namely the mundane, day-to-day techniques by which homemakers used consumer goods and hard work to keep themselves and their household healthy. In a pioneering paper, Tomes (1990) has termed this "the private side" of the nineteenth-century public health movement. In an age in which an ounce of prevention was worth many pounds of cure, such techniques included domestic sanitation as well as baby care, food quality and composition, proper home heating and ventilation, isolation of patients with contagious afflictions, and care for those with minor sicknesses (e.g., colds, small wounds, and diarrhea) to prevent complications. It should be recognized from the outset that until the twentieth century, the technology employed by households to produce health was highly imperfect by our standards. That is, given incomes, relative prices, and preferences, people could have been healthier and lived longer. Consumers' knowledge about their own bodies, deficient even today, has changed dramatically in the past century; and changes in perceptions about what determines health have been of central importance to changes in demand. Our main argument is that part of the decline in the mortality rate can be interpreted as the result of technological progress at the household level (Mokyr 1993). Such technological progress consisted of course of a supply side, but improved knowledge by households affected their demand for consumer goods as well.

How did households learn about what makes them sick and how to stay

4. Serious misgivings about the positive effects of public policy are sounded in the studies collected in Woods and Woodward (1984). Their conclusion is basically that "public health improvements were unlikely to succeed: traditionally control could only be exerted over levels of exposure to food- and waterborne diseases, and the improvements themselves were patchy" (35).

5. This conclusion was also reached recently by Easterlin (1995).

well? The most dramatic change in medical history occurred in the half century before 1914: the understanding and gradual extinction of infectious disease from Western society. This transition was not complete by 1914, but had made enormous progress—decades before the development of effective antibiotics.<sup>6</sup> The most important scientific change in this period, and probably the greatest scientific breakthrough in the history of medicine, was the germ theory of disease, first enunciated by Louis Pasteur in 1864 and subsequently refined and developed by him and by Robert Koch and his followers in the 1870s and beyond.

In what follows, we develop a simple model of consumer demand that explicitly allows for health as part of what is being maximized. This is, of course, hardly new in the demographic literature, in which it has long been recognized that life expectancy is a function of the goods consumed by the individual (of which medical care may be one, though not necessarily one of great importance). What is novel is that we explicitly take into account the difficulty consumers have in understanding their own bodies and the complex interaction of microbes, the external environment, and their immune systems. The understanding of this interaction will never be perfect; unlike mechanical devices or chemicals, the human body is extremely complex and the consumer's control over her body cannot be total. All the same, a lot of progress was made between 1870 and 1914.

## 4.2 A Simple Model

To distinguish between the alternatives, it is useful to set up the problem formally. As in standard theory, the consumer  $j$  maximizes a utility function

$$(1) \quad U_j = U_j(X_{1j}, \dots, X_{nj}, L_j),$$

where  $L$  is a composite variable of family life expectancy and health, subject to the usual budget constraint  $\sum X_i P_i = Y$ .<sup>7</sup> Leisure should be regarded as one of the  $X$ 's (requiring the appropriate reinterpretation of the budget constraint).<sup>8</sup>

6. Latour notes wryly that World War I was the first major war in which one could kill immobile masses: "Without the bacteriologists, the generals would never have been able to hold on to millions of men for four years in muddy, rat-infested trenches. These men would have died before gas and machine guns had carried them off" (1988, 112). Following the war, however, the influenza epidemic wiped out tens of millions, and scientists were unable to identify the agent.

7. Whether  $L$  measures life expectancy alone, health (the absence of morbidity), or some combination of the two is a difficult issue. The issue seems more perplexing in today's medical environment in which morbidity and mortality are less closely connected. For an age in which infectious diseases were the main causes of death, the distinction seems less acute, although Riley (1991) suggests that while mortality declined during the nineteenth century, morbidity was on the rise.

8. In a more extended version of the model, domestic labor, market work, and leisure are dealt with separately, subject to a time constraint. Presumably all three activities enter the utility function, with domestic and market labor both entering with a negative marginal utility. A critical extension of the model is to include domestic labor explicitly in the  $L$  function. We shall treat it here simply as one of the  $X$ 's.

The special characteristic of this setup is that  $L$  is determined by the household production function

$$(2) \quad L_j = E + f(X_{ij}, \dots, X_{nj}).$$

$E$  is a common factor independent of the consumption basket (“environment”),  $f$  is the household production function that transforms the goods consumed into longer lives. The function  $f$  is an unobserved technical relationship. It converts the  $X$ 's into a vector of biological characteristics ( $X$ ) that determines the individual's physical well-being given some level of  $E$ . The food component of  $X$  takes into account not only caloric intake but also vitamins, minerals, fiber, substances combating free radicals such as antioxidants, and so on. Home heating, cleanliness, medical care, and physical exercise are other examples of  $X$ 's that enter equation (2). The function  $f$  describes not only exposure to harmful microorganisms and chemicals and the effects of consumption on the cardiovascular system, but also the interaction between consumption and the human immune system. Moreover,  $f$  is assumed to satisfy the condition that the conversion is *efficient* (i.e., that no  $X$ 's are wasted in the production process).

The shape of  $f$ , however, is not fully known to “best-practice” science, much less to the household. Behavior is therefore determined by the function

$$(2') \quad L_j^e = E + (A - \varepsilon_j)f(X_{ij}, \dots, X_{nj}),$$

where  $L_j^e$  is the prior that the consumer has over  $L$ ,  $A$  is a common technology-shift factor that measures improvements in the best-practice priors on household technology, and  $\varepsilon_j$  is an individual-specific measure of the difference between this individual's technology and the best-practice technology. The disadvantage of a simple formulation like equation (2') is that any changes in the technology of converting  $X$  into  $L$  are assumed to be Hicks Neutral so that improvements affect all recipes *pari passu*. A more general formulation would allow for separate effects on each good:

$$(3) \quad L_j^e = E + \sum_i (A_i - \varepsilon_{ij})F_i(X_{ij}) \quad \forall j.$$

The term  $A_i - \varepsilon_{ij}$  is the *recipe* with which consumer  $j$  converts  $X_i$  into  $L$ . We define it here as a multiplicative deviation from best-practice priors. There is a vector of best-practice recipes associated with the  $X$ , but households may not be using the best-practice technique, thus being  $\varepsilon$  below or above where they would be if they followed the best practice.

A few remarks on equation (3) are in order. First, we can define a level of consumption  $X^{**}$ , which is the vector of consumption which maximizes utility by substituting equation (2) into equation (1). This assumes a world of perfect information in which all  $A$ 's equal unity and all  $\varepsilon$ 's zero, meaning that not only have scientists figured out the exact functional relation between  $L$  and every  $X$ ,

but everyone has access to that knowledge, believes it, and uses it flawlessly. In this case the consumer maximizes  $U(X, L)$  “correctly” subject only to her budget constraint. Second, we may define  $\hat{X}$ , a vector of consumption for a consumer who is ignorant of the effect of consumption on health, so that  $A - \varepsilon_j = 0$  for all  $X$ 's, meaning that the consumer disregards the effect of the  $X$ 's on  $L$ . In this case,  $L(\hat{X})$  is a purely unintended by-product of consumption. It is possible that by a fluke the completely ignorant consumer will consume just about the “right” amount of  $X$  ( $\hat{X} = X^{**}$ ).<sup>9</sup> Even if there are goods for which  $F'(\hat{X}) = 0$ , so that they have no marginal impact on health, their consumption may not be optimal.<sup>10</sup> This also implies that an increase in any  $A - \varepsilon$  (given that  $0 < A - \varepsilon < 1$ ) does not necessarily improve  $L$ . For a more detailed discussion, see Mokyr (1996). In some historical cases, consumption patterns did lead to high levels of health as an unintended by-product. Perhaps the best-known example is the heavy dependence of the pre-famine Irish on potatoes, which produced a comparatively healthy and tall population despite the economy's appallingly low levels of income.

Third, there are few a priori constraints on  $A$  and  $\varepsilon$  and thus on the relation between  $X$  and  $\hat{X}$ . Consequently the effect of changes in  $A$  and  $\varepsilon$  on demand depends on  $F'$  as well as on prior levels of  $A$  and  $\varepsilon$ . In principle  $A$  could be negative, meaning that best-practice technology believes that a particular good, which is actually harmful, enhances health (e.g., the smoking of tobacco was widely prescribed by seventeenth century doctors; marijuana, in our own age, may be an example of the reverse). It is possible for  $A$  to be positive yet  $A - \varepsilon$  negative (when folk “wisdom” overrides the knowledge of scientists). The reverse is equally likely: folk wisdom long advocated the use of garlic and red wine as health-enhancing products, and only recently has science begun to catch on. It is thus conceivable that  $\varepsilon$  is negative, in which case (assuming  $A < 1$ ) consumers are actually doing better than they would be by following the recommendations of best-practice technology. This can also occur when health-enhancing practices are adopted for extraneous reasons (e.g., diet restrictions based on religious considerations). Fourth, this setup shows that health could be improving even without any increase in  $A - \varepsilon$ , simply because income went up and with it the quantities of health-enhancing goods consumed. This is not necessarily the case, however: rising income does not guarantee an increasing  $L$ . For this to occur, we have to assume that

9. This would occur if, for all  $X_i^*$  which maximize utility, the following condition happened to hold:

$$\frac{\partial U}{\partial L} \frac{\partial L}{\partial X_i} + \frac{\partial U}{\partial X_i} = P_i,$$

where  $P_i$  is the full price of  $X_i$  (including time cost).

10. This is *not* an “optimum” in the sense that a consumer who consumes the “right” amount of  $X_i$  (in that  $F'(X_i) = 0$ ) may still improve her health by shifting consumption from  $X_i$  to  $X_j$  if  $F'(X_j) > 0$ .

$$\sum_i \frac{\partial F_i}{\partial X_i} \frac{\partial X_i}{\partial Y} > 0,$$

that is, that the correlation between income elasticity and the health-enhancing effect of all goods together is positive. This is not invariably the case: many goods were desirable but health-impairing (such as alcohol, urban living, prostitution, or tobacco) and others were healthy but had negative income elasticities (potatoes).<sup>11</sup>

The environment variable,  $E$ , can similarly be decomposed into a purely exogenous element (such as changes in weather) and a policy-dependent environmental element (changes in local public goods). Converting resources into life-extending public goods itself involves a technology and provides another channel through which changes in knowledge can affect life expectancy. Thus

$$(4) \quad E = E_1 + E_2$$

where  $E_1$  is purely exogenous, and

$$(5) \quad E_2 = \sum_i (B_i - \phi_i) G_i(Z_i)$$

constrained by  $\sum_i P_i Z_i = T$ , where the  $Z$ 's are goods purchased by the government, the  $G$ 's the "true" function that maps the  $Z$ 's onto the environment,  $T$  the total tax revenues,  $B$  the best-practice technology to convert local public good  $i$  into improved health for all members of the community, and  $\phi$  the gap between the best-practice technology and the one actually used by the local authority. Equation (5) is thus the public sector analogue of equation (3). Again, quite a number of health-enhancing public works occurred at low levels of  $B$  and were by-products of other projects, as in the case where the local government adopted drainage plans (for land reclamation) which had the unintended side effect of eliminating malaria-carrying mosquitoes. Many years before the germ theory, governments had considerable success with health-enhancing public projects, such as the campaign against plague.<sup>12</sup>

There are two sources of market failure in the supply of health-enhancing goods. The public sector has a role in producing the health-enhancing goods  $Z_i$  themselves, because the  $Z$ 's, unlike the  $X$ 's, cannot be produced efficiently by the single household. This is because of large fixed costs and free-rider problems in public works and because of the inherent problem of externalities

11. Furthermore, an increase in wages increases the opportunity cost of time and thus increases the cost of household work, an important input into the  $L$  function. The income effect of higher earnings may work in the same direction. It is possible that an increase in income will thus increase the demand for leisure and lead to a withdrawal of household labor from the home and to the purchase of substitutes that are not as effective in maintaining health. Increased use of day-care centers may be a good example of such an effect of a rise in income.

12. During the antiplague campaigns in the sixteenth and seventeenth centuries, physicians were made to wear long tunics to protect themselves against the evil vapors and miasmas that were thought to cause the disease. These coats also happened to protect them against the flea bites that transmitted the disease—an inadvertent by-product of the strategy (Cipolla 1992, 55).

in infectious disease. Furthermore, knowledge as used here is itself a public good, in that it is costly to produce but costless to transfer to another user. In other words,  $A$  is a public good because much of the cost of discovering and evaluating new recipes is fixed. Similarly, the public sector has an important function in the diffusion of  $A$ . It is not surprising that governments and other public bodies played an important role in supporting health-related research and education. Even if the  $X$ 's that entered the household production function in equation (3) were purely private goods, the knowledge necessary to transform them into  $L$  was not.<sup>13</sup>

This formulation abstracts from the historical reality in a number of obvious respects. First, it makes no distinction between the household and the individual. In actual historical experience, the household made decisions and allocations that affected a collection of individuals in different ways, and complex bargaining may have been involved to determine how the  $X$ 's would be allocated. This is especially important because the new recipes of cleanliness and good housekeeping tended to be costly in terms of time, and this time cost was disproportionately borne by women (Cowan 1983). Second, it abstracts from interhousehold externalities. In an age of highly contagious disease and shared kitchen and toilet facilities, neighborhood effects were of substantial importance. In effect, these would introduce the  $X$ 's consumed by one household as arguments in the equation for  $L$  of another. Third, when industrialization caused more and more individuals to spend large amounts of time outside their homes, in workplaces,  $L$  was affected by the working environment as well, an effect that can be included in the shadow price of leisure. Fourth, by migrating between rural and urban environments, individuals could indirectly choose among different values of  $E_1$  or  $E_2$ . Urban environments were, on the whole, far more noisome than rural areas, and the urbanization in this era clearly retarded the mortality decline. Finally, the analysis above abstracts from the often complex dynamic relation between some of the  $X$ 's and  $L$ : while salmonella poisoning occurs within a few hours of exposure, some parasites do not cause symptoms until months later, and resistance to tuberculosis can take years to build up. Eating raw cabbage reduces the probability of developing colon cancer decades later. Such lags may make it difficult for a household decision maker to draw inferences about  $A$  and thus may be responsible for the persistence of large  $\varepsilon$ 's. It is tempting to incorporate the dynamic aspects by including a set of different time periods and a discount factor, to weigh the future less than the present and to account for the probability of not surviving the next period. This discount factor itself has an interesting interpretation: as life expectancy improves in society as a whole, each consumer will believe that

13. Insofar as the government produces public goods at the demand of political groups, we may define a third area of knowledge, namely what the individuals in these groups know about the value of  $B$ . Changes in their perception of  $B$  may lead to growing pressure on the government to produce certain  $Z$ 's.

she has a greater probability of survival. The discount factor will fall and as a result the consumer may wish to participate more in life-enhancing efforts. Many of the  $X$ 's are interpreted as investments, as consumption today may affect health many years in the future (Grossman 1972). Yet life expectancy *itself* determines simultaneously the subjective rate of discount, producing positive feedback in the investment in health.

Until about 1750, the pattern of health technology and consumption might be roughly described as long periods in which  $A$  fluctuated but in the long haul followed a stationary process with a mean value not much above zero. The complete lack of understanding in premodern society of the nature of disease and the ability of the body to resist it led to an amorphous body of largely erroneous medical knowledge and a huge and highly diverse body of folk wisdom and old wives' sayings about good diet, child care, and other recipes. It is far from obvious whether, in preindustrial Europe, the techniques practiced by official medical science or by folk wisdom should be described as best practice. Formal medicine after 1700 was increasingly subject to radical new approaches that purported to produce a monocausal explanation of disease and suggested cure-all remedies. Such medical messiahs often gained huge followings which melted away as fast as they appeared. Precisely because the medical profession was so severely fractured, it is, in fact, impossible to define best-practice technology, and distinctions between quackery, medicine, and folk wisdom are largely anachronistic.<sup>14</sup> It is quite likely that some traditional herbal treatments and placebo effects gave the knowledge of "wise women" a positive value of  $A$ . Yet their ability to fight devastating infections such as pneumonia and diphtheria was obviously limited, and many of the home medicines recommended must have been hard to carry out in addition to having been useless.<sup>15</sup>

The understanding of the nature of disease and the realization of the interaction between consumption and health gradually increased in the nineteenth century, and  $A$  and  $\varepsilon$  started to creep up. Then followed, with long delays, a decline in  $\varepsilon$  as the new knowledge became accepted. One example of these

14. One example will serve to illustrate this principle: A Scottish physician by the name of John Brown (1735–88) revolutionized the medicine of his age with Brownianism, a system which postulated that all diseases were the result of over- or underexcitement of the neuromuscular system by the environment. Brown was no enthusiast for bleeding; instead he treated all his patients with mixtures of opium, alcohol, and highly seasoned foods. His popularity was international: Benjamin Rush brought his system to America, and in 1802 his controversial views elicited a riot among medical students in Göttingen, requiring troops to quell it. A medical revolutionary in an age of radical changes, his influence is a good example of the difficulty contemporaries had in selecting among alternative techniques and of the enormous possibilities for failure in this area (Brown was asserted to have killed more people than the French Revolution and the Napoleonic Wars combined).

15. One wonders about the recommendation for a cure for whooping cough: drink water from the skull of a bishop, if available. An alternative was to catch a fish, hold its head in the patient's mouth, and return it live to the river so it would take the disease with it. For a list of such examples, see, e.g., Gordon (1993).

changes was the growing realization in Enlightenment Europe that somehow dirt was a cause of disease, an attitude that eventually resulted in the hygienic movement of the Victorian age (Riley 1987). Through much of the eighteenth century, enlightened officials tried to clean up urban environments, “struggling against the thrifty complacency of the inhabitants, unless an epidemic struck” (McManners 1985, 43). Another example is the growing support for breast-feeding by biological mothers instead of artificial feeding or the use of wet nurses; this practice was vociferously advocated by Jean-Jacques Rousseau, among others. It took many decades until the recipes implied by these movements filtered down to the bulk of the population. The slowly changing attitude toward cigarette smoking in the modern Western world is perhaps the best-known example of such diffusion lags in our time.

### 4.3 Best-Practice Techniques and Their Diffusion

The idea of a best-practice technique in this context can only be defined *ex post*, with the knowledge and tools now available to us. The definition of equation (2) makes this inevitable, and although even today we do not know exactly the shape of that equation, we certainly know more than people did in the past. The modern scholar must try to sort out what seems in retrospect the “best practice.”<sup>16</sup> During much of the nineteenth century, however, it was impossible for contemporaries to identify the best-practice medical knowledge for the purpose of household decisions. As we have seen, there were widely divergent views among scientists and physicians on the nature of disease and therefore on what constituted a healthy lifestyle. Rather than an accepted best-practice technology, there were many different competing recipes, traditions, and fads, and confused consumers often had to make difficult choices on the contradictory recommendations of contagionists and anticontagionists, germ theorists and anti-germ theorists, nurses, midwives, patent medicine salespeople, apothecaries, nutrition “specialists,” and quacks.<sup>17</sup> Indeed, the decline in  $\varepsilon$  can be interpreted not only as the diffusion of knowledge of new recipes and techniques, but also in part as the improved ability to select among these competing alternatives.

16. Thus breast-feeding and aseptic surgery can be defined as best-practice techniques, whereas bloodletting must be regarded as a useless procedure against fever despite its popularity and viability. A good practice in case of diarrhea is to keep up a *high* rather than a *low* level of liquid. Administering laxatives, emetics, and large quantities of opiates were by and large useless or harmful medical practices, and anticontagionist theories of disease were erroneous. It is again only in retrospect that we can determine, similarly, that fresh foods and lemon juice were a good preventive measure against scurvy whereas relieving congestion and ventilating seamen’s quarters were not.

17. Certain fads, like Horace Fletcher’s theory that health was enhanced by chewing each mouthful at least one hundred times (which was adopted enthusiastically by, among others, economist Irving Fisher and novelist Henry James), survived into the twentieth century despite their scientific uselessness.

There are two major differences between the diffusion of new best-practice technologies among competitive firms and the diffusion of best-practice technology among homemakers.<sup>18</sup> First, households do not compete directly with each other, so the standard mechanism which forces firms to adopt better techniques or risk being competed away does not hold. In fact, even if the information is known to households, there is no guarantee that they will change their behavior. Instead, households will adopt a new recipe if they can be *persuaded* that it works and that it is worth the price and inconvenience. Persuasion, of course, involves theory, evidence, and rhetoric and in that regard the adoption and diffusion of new knowledge is quite different from that in production technology. Second, access to outside information is often more difficult for households than for firms (due to increasing returns in information acquisition and processing), and this is compounded by the inherent complexity of the information at hand.<sup>19</sup> From a statistical point of view, both firms and households need to assess the effect of a factor while holding others constant when evaluating a new technique, adjusting for omitted variables and unobservables and other inference problems. A firm can learn from other firms and from technical literature; when those sources run out it can learn by updating its private information set after each production run and by drawing statistical inferences from production data. By contrast, if the household wishes to make inferences about the effect of certain consumption patterns on survival probabilities, it may not have enough degrees of freedom as long as it learns primarily from its own experience, where it is confined to a small number of observations on mortality.

How did scientists and civil servants determine what the best-practice recipes were, and how did they convey this knowledge to consumers? In this regard, the past two centuries have witnessed a true revolution. Until the end of the eighteenth century, much medical knowledge rested on the obiter dicta of a small number of authorities. Diseases were believed to be caused by chemical imbalances in the human body and health was maintained by moderation. Consequently, even those writers who were genuinely interested in public health often confounded sound medical advice with sanctimonious moralizing and preaching against “intemperance” and “debauchery” (e.g., Frank [1786] 1976, 153–60). The modern mind, with its optimistic belief in learning and rationality, has difficulty understanding how concepts such as the humoral theory of disease survived and were accepted, at least by the practitioners of medicine, for so long despite their contradiction of observation and despite merciless attacks by critics such as Paracelsus. Best-practice science lacked the modern concept of the specific disease with a unique causation, and conse-

18. For a theoretical discussion much concerned with this issue of “social learning” see Ellison and Fudenberg (1993).

19. Households may have an incentive to promote others’ health awareness if they believe it has positive externalities to their own health status. The idea of contagion should, therefore, enhance public persuasion efforts and it is not surprising that during epidemics such efforts increased.

quently it was not best practice, at least not *ex post*. The bulk of the population before the nineteenth century wisely ignored what formal medical science had to tell them about the relationship between consumption and health and often relied on traditional folk wisdom, embodied in proverbs and home remedies. The easy accessibility of folk knowledge meant low values of  $\epsilon$  but also—with some notable exceptions—low values of  $A$ .

The Enlightenment in Europe led to the discovery of a tool that was to overturn this persistent but inefficient system. The collection of *data* and their use in detecting empirical regularities about health gradually became common practice in western Europe during the late eighteenth and early nineteenth centuries (Rosen 1955; Porter 1986). Suddenly large samples of organized and systematic medical information started to become available through “tables of death,” or nosologies. Political arithmetic first emerged in the late seventeenth century, and the term “statistics” appears around 1800. At first statistics was a political tool, to chart general economic and social laws with little impact on medical practice narrowly defined (Porter 1986). Yet within a few decades, statistics and numerical methods began to challenge age-old practices in clinical care.<sup>20</sup> The sanitary (or hygienist) movement used statistics as a basis for recommendations about nutrition, cleanliness, housing, water supply, cooking, infant care, and so on. In the 1830s British doctors published a variety of reports on “physical causes of sickness to which the poor are particularly exposed,” culminating in the vastly influential summary in the 1842 Chadwick Report. Hygienists regarded statistics as irrefutable facts which demanded action (Wohl 1983, 145). By 1850, for the first time perhaps, something of an amorphous consensus of hygienists began to emerge, and the new Victorian gospel of cleanliness and proper housekeeping took shape.<sup>21</sup> The sanitary movement grew in strength and claimed increasingly that it had found the “correct” levels of private and public consumption. In terms of our model, they raised the values of  $A$  and  $B$ . In France a parallel movement was spearheaded

20. Rusnock (1990) describes the use of crude statistical methods in evaluating smallpox inoculation during the eighteenth century. The development of statistical methods to test the efficacy of curative technology owed most to Pierre C. A. Louis who developed a “numerical method” for evaluating therapy and in about 1840 provided statistical proof that bloodletting was useless, leading to the gradual demise of this technique (Hudson 1983, 206). A few years later Ignaz Semmelweis observed, on the basis of significant differences in the mortality rate, that puerperal fever was caused by contaminated hands and could be reduced by doctors and attendants washing their hands in antiseptic solution. In Britain the use of statistics in the nineteenth century was pioneered by William Farr, superintendent of the statistical department of the Registrar General (Eyler 1979). After 1850, the use of statistics in public health became almost a rage: between 1853 and 1862 a quarter of all papers read at the Statistical Society of London were on public health and vital statistics (Wohl 1983, 145).

21. The most famous triumph of the “empirical” approach to preventive medicine was the discovery of the waterborne sources of cholera in 1854 by John Snow and William Farr through the quantitative analysis of the addresses of the deceased. At the same time, William Budd demonstrated the contagious nature of typhoid fever and its mode of transmission and successfully stamped out a typhoid epidemic in Bristol.

by the journal *Annales d'hygiène publique et de médecine légale*, edited by René Villermé and his colleagues.<sup>22</sup>

The purely empirical statistical inferences on which these recommendations were based are still a widely used methodology in modern studies of public and private health, even though statistical sophistication has increased a great deal. Whether statistically sophisticated or not, these mid-nineteenth-century methods lacked a model or *modus operandi* that associated behavior with health effects. Dirt and congestion were known to be correlated with disease, but how and why the causal mechanism operated was unknown. It was an empirical regularity in search of a scientific theory.<sup>23</sup> In that regard, the medical research of Louis and Farr resembled Adolphe Quételet's work on crime and suicide. At times, empirical regularities led science astray, as in the belief (especially widespread in the case of cholera) that the correlation between weather and disease demonstrated the pathogenic character of fog and humidity.

Statistics and probability theory were important because they provided more than observations, they provided a mode of thinking. Especially thanks to the pathbreaking work of Quételet, people slowly learned to think in terms of probability rather than certainty, still largely a novelty in the nineteenth century. After all, the way equation (2) works is through probabilities: if we observe that  $F' > 0$ , what we really mean is that the conditional probability of contracting a disease given some  $X_i$  is higher than the probability given some higher  $X_i$ . But these probabilities are not zero nor one, and counterexamples might have obscured the regularities that the sanitarians appealed to.<sup>24</sup> Unlike physics or chemistry, the scientific laws determining private and public health were stochastic, and the implicit statistical models were poorly specified. Health technology was a stochastic science, and empirical work must allow both type I and type II errors. Even a very successful method will normally not work 100 percent of the time. Yet the notion that a few exceptions on either side did not disprove or prove a rule grew as people learned to interpret statistical data.

22. French mathematicians also worked on the theory underlying the use of such statistics. In 1837 Denis Poisson published his celebrated work on the probabilistic properties of jury voting. Three years later his student Jules Gavarret applied these results to public medicine, arguing for rigorous standards for hypothesis testing. Unfortunately, the medical leaders of the hygienic movement were not well trained in mathematics and biostatistics took many decades to develop.

23. Many of the statistical inquiries were undertaken by such freelancers as Henry Rumsey and Henry Mayhew. Another enthusiast for statistics was Florence Nightingale, a member of the Statistical Society of London for fifty years. It seems clear, however, that in the area of data collection the public sector had an advantage, and eventually parliamentary commissions and the Registrar General provided the hygienic movement with the most important pieces of its empirical basis (Hodgkinson 1968).

24. In a famous case, a conservative German doctor, Max Pettenkofer, drank a glass of cholera-infected water to refute the theory that the disease was transmitted through microorganisms in water.

The rhetorical force of statistics was relentless, yet it was ultimately limited. Just as statistical studies without much of a model in our own time have persuaded millions to change smoking and eating habits but have left many more unconvinced, the European household after 1830 was increasingly subject to a barrage of statistics and recommendations based on them that were meant to make civil servants and households see the light and change their consumption bundles to improve their health. This barrage, however, eventually ran into diminishing returns. Nineteenth-century empirical data were deficient in ways fully understood by such contemporary writers as Henry Rumsey (1875). Most of the inferences were based on simple tabulations, had no controls, and almost never recognized the distinction between partial and total effects or worried about statistical significance, let alone endogeneity and simultaneity biases. Consequently the movement ran into the dilemma that although it recognized that a cluster of social problems—poverty, urban congestion, lack of sanitary facilities, bad nutrition—was correlated with high mortality rates and epidemics, it did not know how and why this was the case; consequently it ended up recommending the elimination of poverty and slums as the only possible remedy for disease. Medical statistics turned out to be a more tricky subject than early enthusiasts like Louis had envisaged (Porter 1986, 238).

All the same, the data gathered by the sanitarians changed best-practice thinking about the importance of the environment to health. The historical issue is how these changes in  $A$  filtered down to change consumption patterns. In other words, the decline in  $\epsilon$  required more than exposure to data, it required inducing people to change their behavior. Persuasion was difficult because by definition any shift in the allocation of the  $X$ 's involved either an expense or some other kind of adjustment by the consumer, either in terms of time and convenience or in terms of changes in consumption. In interpreting the change in household behavior, it is important to realize that equation (3) reflects *full* prices, including the cost in terms of time. Much of the household production function involved time as much as money: for example, taking a shower today takes no more than ten minutes; a bath in the middle of the nineteenth century, in the absence of indoor plumbing, involved elaborate work in carrying and warming the water and disposing of it later on.<sup>25</sup> The same is true for scores of other household chores, from washing dishes to proper child feeding. In the final analysis, the choices were made by households constrained by budgets and guided by relative prices, but otherwise free to allocate their resources as they saw fit. Short of coercion and the manipulation of relative prices through taxes, the best that those who had seen the light could do was to inform and persuade.

25. Even with bathrooms, however, the amount of work implied by the new household technology was large. As Cowan (1983, 88) remarks, cleaning a bathroom was heavy work and it had to be performed thoroughly and frequently "if the health of the family was to be maintained." Though cleaning technologies improved, the time devoted to cleaning increased, and this time has to be factored into the budget constraint.

How did social reformers, scientists, statisticians, civil servants, teachers, and medical people persuade the population to change its habits?

There were basically three modes of persuasion, then and now. One, as noted, was pure empiricism. A second mode of persuasion was what could be best termed “social control.” Without being justified in detail, certain patterns of behavior were turned into social virtues and customs. The tools of this form of social control were the popular press (including such magazines as *Good Housekeeping*), cookbooks, domestic advice books and manuals, schools, the church, exhibitions, and well-meaning organizations run by middle-class ladies such as the Ladies’ National Association for the Diffusion of Sanitary Knowledge (founded in 1857).<sup>26</sup> Sanitary missionaries started health campaigns to teach and instruct the ways of good hygiene and child care. Cleanliness was next to godliness, and certain patterns could be imposed on the population by subtle manipulation, falling in the gray area between persuasion and coercion. Furthermore, an effective mode of diffusion was imitation of the social customs of groups that were perceived to be higher up on the social ladder.<sup>27</sup> The social prestige of the early leaders of the hygienic movement helped them gain and persuade audiences almost regardless of the content of their message; the effectiveness of rhetoric is not independent of the social status of the speaker. Later in the century, philanthropists were reinforced by salesmen and advertisers. Commercial interests selling household appliances and cleaning materials used fear, ambition, self-doubt, and every other human weakness to peddle products that were supposed to keep the house clean and its inhabitants healthy.

Yet the most effective weapon in the arsenal of the reformers was a *model*, simple and powerful, that would underpin the empirical regularities discerned by statistics and explain disease as a consequence of household recipes and of the quantities of goods consumed. The importance of such a model was not so much that it could suggest to doctors new medical methods to treat patients (although eventually it did) but that it cleared up the confusion about the best-practice recipes for the household and for the providers of public goods. A model that explained how diseases were caused had immense rhetorical power: it convinced households to choose bundles as similar as possible to the ones recommended by what soon became the undisputedly best practice. It is the argument of this paper that there has been only one macroinvention in

26. Between 1857 and 1881 this association distributed a million and a half tracts loaded with advice on pre- and postnatal care, spreading the gospel of soap and water, and the evidence is that in the late Victorian period the poor were receptive to these volunteers (Wohl 1983, 36–37). For a recent treatment from a feminist perspective, see Williams (1991).

27. One of the poignant documents illustrating indoctrination and social control of housewives by the dogma of cleanliness can be found in the autobiographical notes appended to Cowan (1983). Roberts’s (1990) autobiographical book on life in the classic slum of Salford depicts clearly the toil of working-class Edwardian wives and mothers struggling to keep up to the middle-class Victorian standards of cleanliness.

the determination of *A* and *B* that has really had that effect: the discovery of the germ theory of disease (see also Spree 1988, 122). Pasteur's model cleared up the confusion, explained the causes of infectious disease, reconciled miasma theory with contagionism, and provided a convincing, and within a short time widely accepted, theory of disease which had far-reaching implications for the best-practice technologies of households and the public sector. It should be stressed that by the term "Pasteur revolution" we really mean a multinational joint effort between 1880 and 1900, led by Germans such as Robert Koch, Albert Neisser, Karl Eberth, Theodor Escherich, and Albert Fränkel, in which pathogenic organisms were discovered at the average rate of one a year. This multinational scientific effort, despite some dead ends, was larger than the germ theory alone and provided a coherent and powerful theory of infectious disease. Moreover, the work of Metchnikoff and Behring on a phagocytosis supplemented the germ theory by showing why in many cases infection and exposure did not lead to symptoms, a favorite argument of the opponents of the germ theory. Similarly, between 1890 and 1900 a series of experiments (most notably by Hallock Park and Alfred Beebe) established the reality of healthy human carriers of infectious diseases, thus filling in another important hole in the logical structure of infectious disease.

In terms of our model, the germ theory has significance in terms of both *A* and  $\epsilon$ . With a few exceptions, such as pasteurization and the methods of antiseptics and asepsis, it did not immediately supply a whole net set of recipes. Nor did it right away provide a cure for any disease, though the diphtheria vaccine came quite early. Above all, it made it possible for households to better select from among existing techniques, reshuffle their resources, and adjust their consumption bundles to reflect the new knowledge. How many households were fully aware of and persuaded by the bacteriological revolution is of course hard to determine.<sup>28</sup> Long before Pasteur, household behavior had been influenced by teachers, journalists, public servants, and physicians calling for improved standards of hygiene in households. Now these admonitions were reinforced by new and powerful rhetorical ammunition. This process of persuasion inevitably moved slowly.<sup>29</sup> The new bacteriology, however, also affected the elite and the role models of the middle class and intelligentsia. As long as these people understood the implications of household choices in terms of the new bacteriology and could translate the new knowledge into advice and social codes of behavior, the positive effects of changes in consumption on life expectancy could be realized. Rather than statistics or admonitions, homemak-

28. Compounding the ambiguities of persuasion was the fact that some of the leading sanitarians stubbornly resisted the germ theory (Stevenson 1955).

29. Reading through the *Popular Science Monthly* gives an interesting notion of how the ideas of Pasteur were spread among the educated laymen and of how the old and new paradigms fought over the minds of the public. An article on bacteria was published in 1874 and two public speeches given by Pasteur were translated and published in the magazine in 1875, but in 1877 there was still a lengthy article on spontaneous generation—as if Pasteur had never written.

ers were faced with a clear-cut villain, a concrete if invisible parasite which caused disease, misery, and death. The smoking gun handed over by Pasteur, with its powerful rhetorical image, was as important as a means of propaganda as in its inherent scientific value.

Pasteur was not the first to argue for the microbial explanation of infectious disease.<sup>30</sup> But unlike his predecessors, Pasteur succeeded in changing medical science, public health, and household behavior. The new theories persuaded those who set the tone that microbes caused disease, with all the epidemiological implications thereof. As argued forcefully by Latour (1988), Pasteur told the sanitarians what they wanted to hear by telling them why the recipes they had been recommending all along were by and large correct.<sup>31</sup> We would add that his model, as well as the pioneering experimental techniques that confirmed it and permitted the identification of specific pathogens, vastly augmented the persuasiveness of the sanitary arguments and expanded their domain.

Pasteur's discoveries and their impact on the choices made by households and civil servants also illustrate a pervasive phenomenon in the history of technology. It is commonplace to observe that techniques can be employed by firms and households who do not have the faintest clue *why* they work. As we have seen, in the century before Pasteur, hygienists and sanitarians made many recommendations that were consistent with the germ theory without any understanding of the epidemiological and bacteriological underpinnings. These recommendations made some contribution to the decline in mortality before 1870, though it is hard to know with any precision how large this contribution was. The weakness of recipes without a sound scientific base is that not knowing why something works also means that it is hard to identify what will *not* work. Consequently, the sanitarians often made recommendations that were erroneous and at times downright harmful, thus reducing their credibility.<sup>32</sup> Although

30. The idea of germ-caused infection was first proposed by Girolamo Fracastoro in his *De contagione* in 1546. In 1687 Giovanni Bonomo explicitly proposed that diseases were transmitted because minute living creatures that he had been able to see through a microscope passed from one person to another (Reiser 1978, 72). Bonomo's observations and the microscopy of pioneers like Leeuwenhoek ran into skepticism as they were irreconcilable with accepted humoral doctrine. The great chemist, Justus von Liebig, noted in 1845 that attributing a causal effect to microbes was akin to arguing that the rapid flow of the Rhine was caused by the movement of the water mills of Mainz (Hudson 1983, 154). As late as the 1860s, at least four incompatible "theories" of infection can be discerned (Crellin 1968).

31. Latour (1988) argues that the success of Pasteur's discoveries can be explained by his ideas being coopted by the hygienists, who realized that his discovery underpinned the policies they had been fighting for all along. To a large extent this is an accurate view of Pasteur's amazing scientific success, but Latour does not fully credit the scientific elegance and completeness of the new bacteriology and its unprecedented success in verifying its findings through experimental work. Tomes (1990, 414) and Easterlin (1995, 400) both stress the basic complementarity of the sanitarian movement and the germ theory.

32. Attempts to clean up urban cesspools often led to the dumping of raw sewage into rivers, replacing one set of diseases with another (Mathias 1979, 284 n. 18; Szreter 1988, 20–21). The "miasmatic" theory of disease (which held that infectious disease was spread by bad air) espoused

the post-Pasteur era had its share of mistakes as well, they were discovered quickly and corrected.

Our conclusions are similar to those of Preston and Haines (1991, 209), who note that changes in know-how were the principal factors in twentieth-century advances in survival. Their evidence suggests a somewhat later occurrence, placing most of the effect in the decades after 1895. The differences they detect between the United States and Britain (chap. 5) suggest that this time frame may be peculiar to America. In any event, while they suggest that such know-how may have been important, they do not discuss in detail the technological and conceptual innovations that led to the changes in recipes. It is to those that we now turn.

#### 4.4 Health and Consumption

Below we survey the main changes in recipes brought about by the germ theory of disease.

##### 4.4.1 Food

The changes in recipes regarding food occur in two dimensions: one is the avoidance of disease through a properly germ-free consumption environment and ingredients; the other is a balanced diet containing the proper elements of fresh foods, proteins, and minerals. Pasteur, of course, did not have to teach people not to eat spoiled foods. Some food preservation methods, such as pickling, drying, smoking, and preserving with sugar, were known long before the Industrial Revolution. To that was added in the nineteenth century the technique of vacuum canning (first explored by Appert in 1796). The effects of canned foods on overall health were at first modest because canned food was expensive (the cans were handmade) and of low quality, and it was thus sold largely to ships and the military. Without an understanding of microbiology, killing the bacteria in the cans was largely a matter of trial and error, and it was not until Pasteur that the principles of food canning were understood and its benefits fully appreciated. In 1870, the heated autoclave made by Albert Fryer was based on the explicit idea that heating preserved food by destroying germs (Thorne 1986, 94). The bacteriology of canned foods was further advanced by Americans in the late 1890s when it was realized that vacuum packing was not necessary as long as the air in the can had been properly heated (144–49). Two other inventions are of importance here: dehydration of food (by Gail Borden in 1851) and the gradual introduction of industrial refrigeration.

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by most hygienists made many positive suggestions but also recommended permanent ventilation, the burning of sulphur, and the dispersing of acids to counteract pathogenic stenches (Riley 1987, 100). The influential German physician Max Pettenkofer fought the microbial theory of disease tooth and nail, yet he was responsible for the implementation of radical public health measures to prevent the spreading of infectious disease in the city of Munich (Goubert 1989, 61).

An important consequence of the acceptance of the germ theory was the fact that food could now be inspected and judged either good or bad by objective and scientific standards. Bermondsey's Medical Officer of Health (Brown 1908) describes in his annual report a case in which five barges of rice tipped into the Thames and lay in the water through three tides. After retrieving and drying the rice, the owner asked to sell it. It was examined and found to be contaminated, and the request was refused. Prior to the discovery of germs it is not clear that such a decision would have been made. Practically every industrialized nation experienced governmental regulation when it assumed responsibility for the purity of its food supply, as exemplified in the Pure Food and Drug Act of 1906.

Of particular interest here are the changing recipes regarding milk, because the groups consuming it (babies and toddlers) were high-risk groups. The information here was complex and choices were often hard. Even after the connection between bad milk and infant mortality was made, without detailed knowledge of the mechanism that led from milk to mortality, attempts to break this linkage often went astray. There was widespread concern about the adulteration of milk, which by being watered down or skimmed could deprive children of much needed nutrients. Second, there was the growing awareness after 1900 that contaminated milk caused infant diarrhea, a major cause of infant mortality. Third, there was a growing suspicion that milk could transmit other diseases, either from the cow or from a variety of sources en route from the dairy to the kitchen. Tuberculosis was identified in milk at an early stage (1888), and the presence of other diseases such as typhoid and scarlet fever was also suspected. For two decades American health organizations saw the adulteration of milk as the source of the problem (Meckel 1990, 62–70). The theory was that watered or skimmed milk lacked some of the necessary chemical components the infant needs, a theory that led to a shower of legislative effort to stop this adulteration. Between 1880 and 1895 twenty-three American municipalities passed ordinances governing the sale of milk, and by 1905 thirty-two states, the District of Columbia, Hawaii, and Puerto Rico had adopted and were enforcing chemical standards (69).<sup>33</sup> This flurry of legislation only helped combat sickness to a limited extent; by prohibiting adulteration of milk it limited contamination of milk that was mixed with contaminated water, but in and of itself it was not enough to ensure a pure milk supply. The various milk acts did have an important impact on future food and milk acts, for they asserted the right of a city to regulate its milk supply even if the milk originated outside city limits. Ambiguities and complexities abound: the effect of legislation and the improvement in the milk supply may have persuaded

33. Adulteration of all foods was feared, and although major efforts were directed against the adulteration of milk, there was legislation regarding other food products too. In 1881 New York passed a state law against food adulteration which was followed by similar laws in Michigan, New Jersey, Illinois, and Massachusetts (Kramer 1948, pt. 1).

some women to switch earlier to cow's milk which, even when improved, remained inferior to breast-feeding.

The Pasteur revolution provided a mechanism to explain how milk was responsible for infant mortality, but it took decades until the exact implications were worked out. Milk preservation has always been a central problem of public health, to the point that fresh milk has been explicitly discouraged as a food for children. Fresh milk ("warm from the cow") was of course unspoiled but could carry the tuberculosis bacilli that spread bovine tuberculosis. Pasteur pointed out in the 1860s that heating milk could eliminate bacteria, effectively destroying mistaken theories of spontaneous generation (Thorne 1986, 138–42), but it took years until these insights were translated into widespread consumption of safe milk. In both the United States and England, books on infant care and infant feeding placed the emphasis on the chemical composition of milk, comparing human milk to that of cows, asses, and goats (Routh 1876; Cheadle 1889; Cautley 1897). Subsequent books did incorporate the new knowledge on fermentation (Cheadle 1896) and even added whole new sections on microorganisms in milk (Cautley 1897). In France, too, the specialists were at odds: while microbiologists recognized the danger of milk serving as a medium for bacteria and the need to sterilize milk by heating and boiling, doctors resisted this recommendation for most of the 1880s (Rollet-Echalier 1990, 173).

Milk could be made safe using a variety of techniques (Rollet-Echalier 1990, 175). The most efficient was "sterilization," an industrial technique which consisted of heating the milk under pressure at a temperature beyond boiling and then rapidly cooling it. Pasteurization, which was cheaper, was little more than a means of preserving fresh milk somewhat longer and was widely felt to harm the flavor. By about 1910 the proportion of pasteurized milk in major American towns was between 15 and 20 percent (Preston and Haines 1991, 23). Finally, households had the option of boiling their own milk for three to four minutes, which in most cases made it safe for use. Yet boiling cow's milk, despite its obvious microbiological advantages, was unpopular. Part of its unpopularity stemmed from the different taste it had (due to the caramelization of the milk sugar), but of equal importance was the belief that boiling milk reduced its nutritional properties.<sup>34</sup> By the 1890s bottled and pasteurized milk were available in London, and even if only the medical profession and a few educated families were aware of the gross bacterial infection of milk which contributed to infant diarrhea and tuberculosis, "this growing inter-

34. For example, sterilized milk was thought to cause scurvy (Apple 1987, 8). This led baby food companies (e.g., Doliber-Goodale) to promote the mixing of their food with fresh milk, which was claimed to be more wholesome. As late as 1912, half the members of the American Pediatric Society still believed that pasteurized milk was harmful to babies because it deprived them of essential nutrients (Meckel 1990, 82). Cheadle writes, "Always have the milk boiled. . . . This is the first grand rule I would lay down. Nurses will fight against it, and mothers object, perhaps, for there is a common prejudice against it; they say it is less nourishing and that it is binding. . . . that it is constipating. . . . that children don't like it" (1889, 54–55).

est in hygiene encouraged consumers to be suspicious of 'cheap' milk and to favor larger firms with cooling depots in country districts, with steam powered plant for washing churns" (Whetham 1964, 378–79). Vertical imitation and persuasion were the diffusion mechanisms: the knowledge filtered down very slowly from the educated classes to the middle classes and from there through the working classes.<sup>35</sup> The demographic benefits of the Pasteur revolution thus took decades to be realized. Dwork (1987a, 1987b) and Rollet-Echalier (1990) have documented in detail the difficulties in cleaning up the milk supply in Britain and France and have demonstrated how slow and halting progress was in the years prior to the First World War.

From the 1890s on, physicians played an important role in spreading the use of better-quality milk by calling for the establishment of local milk supplies to minimize infection and for regulation of milk production, handling, and transportation (Apple 1987, 57). The movement in the United States was led by Henry Coit, a Newark, N.J., physician, and led to the foundation of medical milk commissions, in which physicians set strict bacterial standards on the milk coming out of dairies. In a number of American towns, milk depots were established to supply mothers with clean milk. The first was founded in New York and was followed by similar institutions in Chicago and Philadelphia (59). Although the number of infants served by this system was small, such institutions helped spread the gospel that clean, pasteurized milk was necessary to ensure healthy babies. Apple surveys other methods by which the importance of clean milk was spread in the United States; these included such journals as *Ladies Home Journal* and *Good Housekeeping*, pamphlets (including the federal government's infant care manual that was circulated among the poor), women's groups and meetings, and more (102–3).

Condensed milk and powdered milk, invented in the 1860s, became widely available in the first decade of the twentieth century. It is therefore tempting to relate qualitative improvements in milk supply to the decline in infant mortality which resumes in Britain after 1900 (Beaver 1973). Such inferences may be rash (Tranter 1985, 80–81; Woods, Watterson, and Woodward 1989, 120). The adoption of safer milk was clearly gradual and was still far from complete in 1900 when the decline in infant mortality started.<sup>36</sup> Furthermore, buying condensed milk was not a sufficient condition for clean baby food. Buchanan (1985) points to the hazards involved in using condensed milk: the high sugar content of condensed milk attracted flies, and tins, often not finished in one feeding, were kept half full, unrefrigerated, and often uncovered until the next meal. Can openers were not available in every household and there is evidence

35. In books on infant care written by doctors and aimed at the professional classes, the boiling of milk was emphasized already in the 1880s (Cheadle 1889; Cautley 1897), but in the more popular books this emphasis is clear only in the early 1900s (Davies 1906; Cradock 1908).

36. A parliamentary commission reported in 1903 that in Finsbury 32 percent of the milk supply contained pus and 40 percent contained dirt. At the same time it was found that 10 percent of all cows produced tubercular milk.

that shopkeepers opened the tins for their customers. The net effect of using condensed milk may have been a higher infant mortality rate rather than a lower one (Ewbank and Preston 1990, 124).

#### 4.4.2 Infant and Child Care

Infant mortality rates have traditionally been a good indicator of the household's ability to convert its consumption into health. Although it would seem at first glance that income would play a central role here, a more careful analysis reveals that the way this income and other household resources, such as the mother's labor and time, were spent was often of much greater importance than the budget constraint itself (Ewbank and Preston 1990, 142). In earlier societies, similarly, the deployment of household resources seems to be the pivotal variable. Imhof (1984) has demonstrated how the variability of infant mortality in Germany depended above all on the socioeconomic structure of society. In regions such as Bavaria where women worked outside the house or were for other reasons incapable of taking care of newborn babies, infant mortality remained high.

Much of our understanding in this area for the United States is due to an important paper by Ewbank and Preston (1990) and by the subsequent work of Preston and Haines (1991). In their view, it was a set of behavioral changes that brought down infant mortality. Whether mothers knew about the germ theory and were persuaded by it or not, they were, during the first years of the twentieth century, exposed to the practical implications of this theory. Mothers were seen as the "first line of defence against childhood disease" (Ewbank and Preston 1990, 119), and the germ theory "focused attention on the transmission of germs from person to person, including transmission within the household." Two components of infant care were stressed in the years 1900–1930: good infant feeding practices and the need for maintaining hygienic conditions in the home. Accompanying these messages was an increase in physical involvement and intervention. By 1906 good child care included such measures as removing children from households containing a person with tuberculosis, if at all possible (122). Infants were to be kept away from children with whooping cough and other infectious diseases. Such efforts were easier in big houses and were probably more common among wealthy households. A cheaper practice was hand washing, and this too was highly recommended during the first decades of the twentieth century. We should note, though, that even such mundane activities as washing hands carried a price before a clean, reliable, and convenient water supply was available.

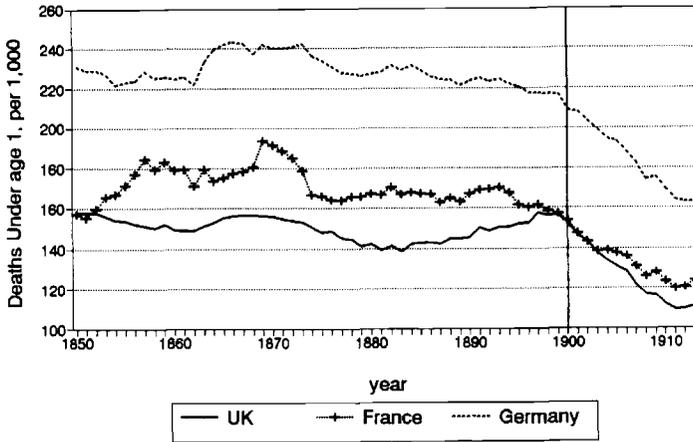
Advice and education on child care spread through the same sources that promoted the use of sterilized milk: magazines, household books, pamphlets, and milk depots. Ewbank and Preston (1990, 128) note that for the milk depots the distribution of clean subsidized milk may have been only a means to a wider goal of spreading information about hygiene and of changing mothers' day-to-day child-care activities. Other countries had similar organizations:

the Royal New Zealand Society for the Health of Women and Children, Lady Home Visitors, Baby Welcomes, and Infant Consultations in England and *Goutte de Lait* in France. All these organizations aimed to influence intra-household decisions based on the insights of the new bacteriology: choosing breast-feeding over bottle-feeding when possible, heating milk, keeping infant food germ free, spending time and effort in keeping the house clean, and isolating sick household members.

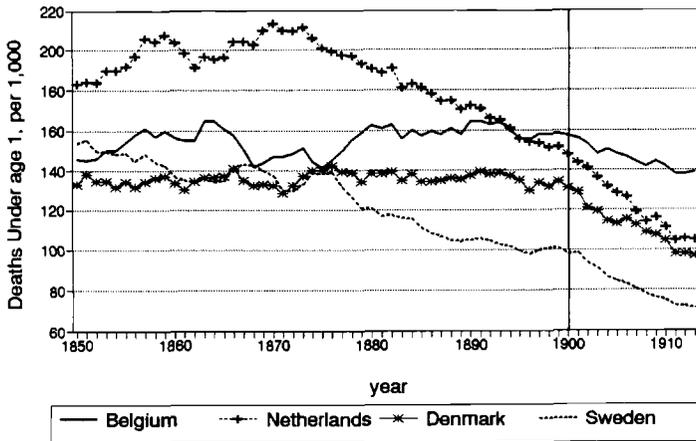
The argument made by Preston and his collaborators about behavioral changes can be interpreted as a change in taste or as one in relative prices or income. In terms of the model presented earlier, a third possibility emerges: that the germ theory constituted a dramatic increase in  $A$  which then filtered down to the population through a variety of the mechanisms mentioned above, thus reducing  $\varepsilon$ . In child care, as in other aspects of household behavior, the new information implicit in an increase in the  $(A - \varepsilon)$  term meant a redeployment of household resources. And yet, the remarkable thing about infant mortality is that its decline seems to lag behind that of the rest of mortality and the diffusion of the new knowledge. The year 1900 seems to be the turning point (figs. 4.1 and 4.2). This is most striking in Britain, where infant mortality rates stayed stable and even rose slightly during the last third of the nineteenth century, fell steeply between 1900 and 1914, and underwent an accelerated further decline during the war and its aftermath (Dwork 1987b).<sup>37</sup> Almost identical movements can be observed for Prussia (Spree 1988, 37). The same steep decline in infant mortality in the 1900–1914 period can be observed for every country in western Europe, whereas in the previous forty years the movements had been erratic, uneven, and inconsistent even in neighboring countries, with the Netherlands and Sweden experiencing a consistent decline while Belgium and Denmark did not (figure 4.2). The conclusion must be that the germ theory as it emerged in the 1870s and 1880s was not a miracle theory that explained all and instantaneously converted the masses to the true faith of hygiene, but rather marked the beginning of a way of thinking that eventually would lead to further breakthroughs down the road. Pasteur's macroinvention did not attain its full impact until it was complemented by a host of microinventions. The cumulative force of the advances in bacteriology eventually had irresistible persuasive power, but clearly this process was drawn out over decades.

As in the history of technological change, there is a lag of decades between the original macroinvention and its effect on any kind of aggregate statistical data. A striking example of very persistent high levels of  $\varepsilon$  can be observed with regard to breast-feeding. The advantages that breast-feeding conferred

37. The rise in infant mortality at the end of the nineteenth century might have been due to a series of warm summers that increased the breeding of houseflies and therefore the instances of infant diarrhea (Buchanan 1985, 159–60). Woods, Watterson, and Woodward (1989) point out that infant mortality from causes other than diarrhea started to decline around the middle of the nineteenth century. Guha (1994) argues that the temporary increase in diarrhea is due more to a change in diagnosis than to a true change in morbidity patterns.



**Fig. 4.1 Infant mortality rates, 1850–1914: five-year moving averages**  
 Source: Mitchell (1975, 127–32 table B7).



**Fig. 4.2 Infant mortality rates, 1850–1914: various countries, five-year moving averages**  
 Source: See fig. 4.1.

upon infants had been known for centuries.<sup>38</sup> Yet its adoption was uneven and halting, and the advantage in monetary cost of breast-feeding seems to have been more of a consideration than health. This is borne out by the German statistics: in the first decade of the twentieth century mothers whose husbands

38. The English physician and follower of Sydenham, Hans Sloane (1660–1753) noted that the ratio of mortality of dry-nursed to wet-nursed children was 3:1. Johann Peter Frank, whose influential book on “medical police” was widely read in the closing decades of the eighteenth century,

earned less than nine hundred Marks were 50 percent more likely to breast-feed their babies than mothers whose husbands made over three thousand Marks. Better-educated families weaned their babies at an earlier age (Spree 1988, app. tables 7, 12). Since in most other respects wealthier and better-educated families were experiencing lower infant mortality rates, this is an unexpected finding. Part of the reason for the long lags in the decline of  $\varepsilon$  may have been a failure to convince. Dwork maintains that while it had been recognized for many decades that breast-feeding was the most effective preventive measure against lethal attacks of childhood diarrhea, as late as the early twentieth century “the precise reason for this was absolutely unclear” (1987b, 36). The statistical evidence seemed irrefutable, but the mechanisms were poorly understood.<sup>39</sup> It stands to reason that wealthier mothers may have believed that the cause underlying the negative correlation between breast-feeding and infant mortality was the poor hygienic conditions in lower-class kitchens, which created health hazards with artificial feeding that did not apply to more expensive diets.<sup>40</sup> It is also possible, however, that the costs in terms of inconvenience were assessed to be higher among wealthier and better-educated ladies. The proportion of children ever breast-fed was increasing, however, no doubt in part due to the campaigns in favor of the practice. In 1910, about 75 percent of all German babies were ever breast-fed, a proportion which rose to about 95 percent in 1933 (Kintner 1987, 251).<sup>41</sup> Breast-feeding, of course, only reduced the occurrence of certain diseases, but the sudden dramatic decline in infant mortality after 1900 in most Western countries must have been related to the ever-growing propaganda to breast-feed babies.

Many years elapsed between Pasteur’s macroinvention and the full understanding of its implications, and more time elapsed before these implications were accepted by those who had the most impact on child care: the mothers. This was understood by English social reformers who came to view the schools as the preferred place for teaching future mothers how to raise their children. Dyhouse (1981) describes a shift in the subjects taught to English working-

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preached that there was no substitute for mother’s milk for a newborn and pointed out that women tended to withdraw from nursing if pregnancies were unwanted (Frank [1786] 1976, 112–13). The most influential proponent of breast-feeding was Jean-Jacques Rousseau, in his *Emile*.

39. One of the most elegant and persuasive rhetorical devices was a bar diagram that showed the startling increase in the death of bottle-fed babies in the summer months, compared to a much smaller increase among breast-fed babies. The diagram was dubbed the “Eiffel Tower” because of its steepness (reproduced in Rollet-Echalier 1990, 465 and Dwork 1987b, 96).

40. The advantages conferred by breast-feeding persist, if in somewhat diminished form, with higher incomes. The average ratio in infant mortality between breast-fed and substitute-fed children for families earning less than 1500 Marks in Düsseldorf between 1905 and 1911 was 1:3.26 and for families earning over 1500 Marks 1:2.58 (Spree 1988, app. table 8).

41. On the basis of cross-sectional regressions for 1910, Kintner suggests that the impact of breast-feeding on infant mortality may have been less than is commonly thought and suggested by the high raw correlations between the two. As she does not control for income, and as income was negatively related to breast-feeding and infant mortality, her coefficients are downward biased and the actual effect of breast-feeding is larger than her equations suggest.

class girls. All through the nineteenth century there was a major emphasis on domestic subjects, but after 1870 the time and effort spent teaching needlework declined and the role of other, more health-related domestic subjects increased (89–90).<sup>42</sup> Originally parents were opposed to such classes being taught in school: mothers felt they could teach cooking just as well at home. As long as knowledge was stable it was possible to rely on mothers to pass household technology on to their daughters, but during periods of scientific advancement mothers were unfamiliar with best-practice technologies, and by having child-care classes in school future mothers were exposed to novel practices and information. After 1870 these classes became an important channel through which knowledge about germ theory and ideas of hygiene and child care were diffused. The teaching of domestic subjects continued to expand through the first decades of the twentieth century, when specific lessons on infant and child care were introduced (Dyhouse 1981, 95).<sup>43</sup> A number of books on infant care were written explicitly to help teachers and students in these new subjects (Davies 1906; Cradock 1908). These included chapters on infant bathing and clothing, infant and child diet, and care in case of accidents and sickness, and stressed cleanliness and hygiene throughout. These books used the persuasive force of the new bacteriology to the fullest.<sup>44</sup>

#### 4.4.3 Water and Energy

Clean water and energy were crucial to the increase in life expectancy. Here, too, the most difficult part of the analysis is to separate supply- and demand-driven changes. Technological changes in water and energy supply were supply-driven factors which reduced the relative prices of clean water, the ability to dispose of waste products, and the means of warming water, food, and air (in terms of financial as well as time costs). A large number of supply-related changes can be listed here, but many of the technological improvements in water and fuel supply depended on known principles of engineering and did not require major breakthroughs in technological knowledge to be discovered.

42. Grants from the department of education for teaching cookery were made available in 1882, and for laundry work in 1890. The number of girls who qualified for the cookery grant rose from 7,597 in 1882–83 to 134,930 in 1895–96. The number of schools teaching laundry work increased from 27 in 1891–92 to over 400 in 1895–96.

43. Following the Boer War there was great concern over the bad health of English men and women. The Inter-Departmental Committee on Physical Deterioration was set up to study this problem and provided many recommendations, including changes in the school curriculum for girls. The education department was quick to expand domestic classes as suggested (Dyhouse 1981, 95–98).

44. A typical passage from one such book reads as follows: “Several ailments and serious diseases from which babies suffer are caused by impure milk. Doctors tell us that there are often things, called ‘germs’ in the air which are poisonous. We cannot see these ‘germs of disease’, as we call them, but they really exist. They easily get into milk, and we can see that if a baby drinks milk containing germs the result may be serious. The dust that is blown about the roads on a windy day, or the dust which we can see in a dirty house, often contains some disease germs. That is why it is so important to try to keep our houses and streets clean; it is not only that they may look nice” (Davies 1906, 63).

Like other microinventions, they seem likely to have been brought about when demand for them was perceived. That demand, of course, was coming partially from the public sector, so that changes in  $\phi$  as well as in  $\varepsilon$  were of importance. The discovery in the early 1850s that contaminated water was beyond any doubt a carrier of disease, and the realization of why this was so when the typhoid and cholera bacilli were discovered in rapid succession (1880 and 1883, with dysentery to follow in 1898), created a veritable clamor for clean, piped water for the masses. Supply responses to such outcries were to be expected.

Although major improvements in the water supply and the provision of sewer systems came before the age of Pasteur and Koch, the influence of their discoveries was crucial to the decline of waterborne diseases.<sup>45</sup> The idea that water carried pathogens remained controversial for many years.<sup>46</sup> Pasteur himself believed at first that bacterial infection was primarily airborne, and it was not until the discovery of the typhoid and cholera bacilli that water was fully recognized to be a potentially dangerous substance. Even after the link between living microorganisms and disease was confirmed, no fixed standards for water purity could be constructed, and this led to a continued debate over what water should be declared clean enough.<sup>47</sup> After Koch's gelatine process of water examination was introduced in England in 1885, the water could be accurately examined and compared to his standard of one hundred microbes per cubic centimeter. Yet as the recent work of Hamlin (1990) suggests, the discovery that water carried bacteria that could cause diseases was only the beginning. Not until the mid-1890s did bacteriology change the methods of water analysis, and even then many of the bacteria were hard to identify with specific diseases. Bacterial counts could now be carried out, but their interpretation remained in dispute as it was unclear what levels of counts were unsafe. Filtration and sedimentation were widely used, although they were imperfect. To these we should add chlorination, which was found in the late 1890s to be effective against bacterial pathogens. Chlorine had been known since the early 1800s to be an effective and inexpensive disinfectant and deodorant, but the

45. Improvements to water supply and sewage disposal systems centered, in this age, around urban communities and therefore had a comparatively bigger effect on the urban population. It was during these years that urban mortality in England started to decline, and the gap between life expectancy in rural and urban populations decreased sharply. The "urban penalty" of ten years in 1810 declined to seven years in 1861 and to only three years by 1911 (Kearns 1988).

46. In 1836 the French doctor Parent-Duchâtelet realized that water involved some principle of infection that "defied analysis" (Kirby et al. 1990, 427), yet it was not until twenty years later that the link between cholera and contaminated drinking water was established by John Snow's famous discovery, which linked the cholera epidemic in London to the water supply. In 1880, when Koch set his famous microbial standards for drinking water, the war against bacteria in drinking water was seriously begun.

47. Hardy (1984, 276) quotes Dr. Beale of King's College Hospital, who stated that small fragments of dead animal or vegetable matter placed in pure water and left for a few hours would result in the development of simple living organisms which "cannot well be considered prejudicial to health."

idea of using it as an additive to drinking water was not to be seriously considered before the emergence of the germ theory which specified its *modus operandi*. In 1897 the German bacteriologist Sims Woodhead used bleach solution to disinfect the distribution mains at Maidstone, and the world's first chlorination facility was set up in Middelkerke, Belgium, in 1902.<sup>48</sup> By 1900 it was understood that filtration was essential to rid water of disease-causing germs, and the number of people using filtered water in the United States increased from 1.8 million in 1900 to 10.8 million in 1910 (Preston and Haines 1991, 23).

The period under question here thus witnessed the democratization of access to piped water. In the 1840s, running water was clearly reserved for the rich.<sup>49</sup> By 1914 it was basically universal. Such statistics understate the amount of progress, because they do not take into consideration the improvement in the quality of the water. The same is true for waste disposal. The technology of domestic sanitation improved gradually from open cesspools to the water closets of the twentieth century. In between was a range of intermediate disposal technologies, but it was recognized that despite the higher water costs there was no real alternative to flushing toilets, which had become all but universal in Britain by 1914. Statistical and bacteriological examination revealed to the Medical Officers of Health that other techniques such as middens, pails, and ash closets were associated with typhoid and other diseases and these techniques were gradually abandoned. Without running water, of course, flushing toilets could not work, and thus the change in water technology provided a package deal of improved domestic conditions.

Systems for water supply and sewage disposal needed large capital investments, and before there was full understanding of their necessity both the public and the private sector were inhibited in making such investments. After the 1870s water was no longer seen as a luxury for the rich but as a necessary safety measure to combat disease, and the press, the schools, and the hospitals joined forces to conquer water so that "it was finally water that conquered us by transforming the world and becoming part of our daily life" (Goubert 1989, 25). The need for such large investments made cost-minimizing measures attractive, and before the harmful component in sewage was identified, such measures could not be correctly evaluated and often caused much more harm than was assumed. Thus for example as long as smell was seen as the main indication of a threat, disposing of the smell was the main objective. As the

48. Chlorination is another classic example of bad theory guiding correct policy. Chlorine compounds had been added to water in the 1830s to combat the bad odors of water that were thought by miasma theorists to be the cause of diseases. Although the odor itself did not cause disease, it was a by-product of something that did, even if that agent was still unknown at that time.

49. In London running water was reasonably common even by 1850 (with the faucets usually located in common yards), but in the rest of Britain it was not. For instance, only 4 percent of the population of Bristol had access to piped water in the 1840s, 8 percent in Newcastle (Daunton 1983, 246).

smell would disappear if sewage was mixed with enough water, disposal of sewage in rivers was a natural conclusion. Ideas of the “self-purification powers” of water mentioned by chemists were quickly accepted by water companies eager to avoid the costs of water filtration (46). When such ideas were dropped, towns became more careful, disposing of their sewage downstream. This alleviated the problem for that town but did not solve the health hazard for towns further downstream. Germ theory expanded the public-good problem of sewage disposal from the domain of one town to an issue concerning all the population along one waterway.<sup>50</sup>

Goubert (1989, 50–51) claims that bacteriology caused hygiene to replace cleanliness in water analysis. Cleanliness is closely related to aesthetics and civility and its rules are based on culture. Hygiene, on the other hand, is modern and advanced and based on the laws of science. One of the practical implications of this change from cleanliness to hygiene was the new attention to sewage disposal. It was no longer enough to supply water that looked clear and was therefore assumed to be “innocent”; it had to be scientifically acceptable. From the 1870s London’s water closets could no longer be discharged into the water system. This regulation did not come in order to keep the water “clean” but to keep it hygienic. The design of water closets came to address the same problems—many sanitary engineers in England and the United States felt that water for the cleaning of the water closet should not be connected to the rising main of clean water because of the risk of backflow, but only after they understood germ theory did they fully comprehend the threat of backflow and widely implement the separation of the two systems of water supply.

Water-supply issues are usually discussed as public-good questions, but in the nineteenth century, as is the case today, the consumer did have choices to make. One decision the consumer made was the choice of water source. London dwellers could choose between water supplied by the various water companies and water from local wells. These wells were shallow surface wells, and they collected water from drainage as well as from cesspools, slaughterhouses, and graveyards (Hardy 1984, 272).<sup>51</sup> Another decision to be made on the household level was the number of taps and faucets to include in a house. The fewer the taps, the more time and effort involved in fetching water, the more utensils used between collecting the water and consuming it, and the higher the probability that water will be stored, usually uncovered, before use.

50. It was on these grounds, for example, that Missouri, acting on behalf of St. Louis, filed suit against Illinois, demanding that the city of Chicago cease dumping its raw sewage into the Illinois River (Marcus 1979, 193).

51. Hardy (1984) notes that the water from these wells was considered sweet and pure despite warnings to the contrary by medical officers, but it does seem that it was mainly the poor who relied on these sources, which implies that given a choice consumers preferred piped water. Abolishing the surface wells was a slow process, especially before 1891 when the local authorities had no power to compel house owners to supply piped water for domestic purposes unless supplying wells were found to be unfit for use.

Throughout the latter part of the nineteenth century more and more houses had water pipes and water cisterns installed.<sup>52</sup>

Another important question was the reliability of the water supply. Water companies often suffered water shortages and for many years water was not supplied at all on Sundays. On this issue too, however, the consumer had a say.<sup>53</sup> The problem of the Sunday supply was solved in 1870, and over time other shortages and failures were limited too, although it seems that improvements to poor neighborhoods came more slowly. Plumbing was not the only issue in water hygiene. Water suspected to be contaminated could be boiled or filtered by the household; in extreme cases drinking water bought from water carriers or beer could be drunk. By the 1880s, households could buy their own filters, many of them made of carbon, which improved the taste and cleaned away minerals. Goubert (1989, 99) remarks that these filters, which were of course largely ineffective against microbial agents, received a mortal blow when the germ theory became widely accepted. At the same time, the germ theory clearly indicated to rural families, who were not attached to an urban network of filtered water, that private measures to insure a germ-free water supply were crucial. Hand-powered under-the-sink pumps supplemented water carried from nearby wells or rivers, but once the notion that contaminated water could carry infectious disease had sunk in, households could react.

Energy supplies may have been of almost equal importance. Laundry and dishwashing required hot water as did personal hygiene and cooking. The constraint on hot water imposed on most working-class families a strict regime of wash day on Monday and bath night on Saturday (Daunton 1983, 242). Yet the closing two decades of the nineteenth century experienced major changes here too. The large cast-iron coal- or wood-burning ranges or stoves satisfied, through most of the nineteenth century, the need for hot water, cooking, and home heating simultaneously. After 1880, gas, which had primarily been used for lighting until then, came to be used for heating as well. Demand for gas for lighting began to decline as electricity spread, and on both sides of the Atlantic gas for heating and cooking began to spread in the 1890s (Cowan 1983, 90). The slot meter and the gas cooker changed the way homes were being heated, meals cooked, and water boiled (Daunton 1983, 238–41). The price of gas did not decline much (245), but given the much greater convenience of its use the full price was certainly much lower. The changes were thus jointly determined

52. The tenement houses managed by social reformer Octavia Hill were supplied with a communal tap (of cold water) for every floor. This was regarded by her as sufficient and was indeed a great improvement over many of the poorer houses that had only one tap per house, if any at all. The fact that the number of taps supplied to tenants was an issue raised by the Royal Commission on the Housing of the Working Classes in 1884–85 portrays a changing attitude toward the question of water supply.

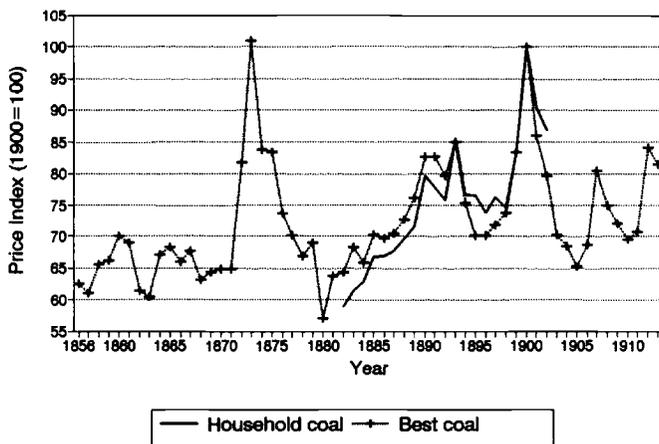
53. When in January 1866 the local company in Camberwell failed to provide water on a Saturday, a number of gentlemen arrived the next morning at the local turncock's home, threatening to sue the company and the turncock for failing to supply water (Hardy 1984).

by shifts in technology and shifts in demand, the latter motivated in large part by changing notions of the causes of health and disease.

Did the relative price of energy decline during our period? We have noted above that the introduction of gas stoves reduced the time and effort needed to cook food and heat water. For a long time, however, coal remained the main source of energy for both cooking and heating. In figure 4.3 we see that the price of household coal increased until 1900. The price of “best coal,” for which we have a longer time series (Mitchell 1988, 748), shows a similar trend, with price increases resuming after 1905. Once again, changes in relative prices do not seem to tell the whole story.

#### 4.4.4 Washing and Hygiene

The importance of the concept of hygiene in connecting consumption and health was not limited to the issue of water supply alone. When hygiene became a scientific term it did not lose its moral connotations. Part of the social-control mode of diffusion was that hygiene would be spread by moral as well as logical persuasion. Thus it is not surprising that in 1882, when religious education was ousted from French lay schools, hygiene became a compulsory subject in primary school curricula (Goubert 1989, 146). The need to keep clean was taught directly through stories and poems and indirectly in dictation passages and grammar books. The school was also a source of practical information: advanced hygienic facilities were often installed earlier there than among the population at large, thereby giving children their first experience with sanitary water closets, baths, and showers (163). The teacher, always



**Fig. 4.3** Real price indexes: coal, 1856–1913

*Sources:* Household coal is the London retail price as given in United Kingdom (1903, 360). Best coal is from Mitchell (1988, 748). General price index is from Feinstein (1972, T140).

viewed as a role model for the future citizens, was required to set an example in cleanliness, and appearance was considered as important as teaching ability.

Education in hygiene was not limited to the children. A cleanliness check was recommended for the beginning of each class, which in effect made the parents involved in this new doctrine. To ensure that a child came to school clean, the parent (or, to be more precise, the mother) had to wash both the child and his or her clothes. Teachers were often also the town clerks, reinforcing the school system in spreading the creed of cleanliness. Consequently, the frequent washing of clothes, like the washing of bodies, became an accepted practice in the latter part of the nineteenth century. Laundry was a strenuous job, carried out mostly by women—either by the female head of the household or by a washerwoman. For washing, a water supply was needed; as cleaning was done by beating and rubbing on boards, there needed to be a working area close to the water supply; and there was also need for lines or fences for drying. To overcome these logistical demands, public and private washhouses were erected. Between 1870 and 1900, more than two hundred washhouses and laundry rooms were opened in Paris (Goubert 1989, 76–77). How much washing was done during this time? Goubert claims that in Paris between 1870 and 1880 three kilograms of clothes and other items were washed per capita per week. This is a vast amount of washing, quite close to our modern standards. The impact on consumption was immediate: the increase in demand for clean clothes led to an increase in demand for water, fuel, and detergents.

An increase in the purchase of health-enhancing goods could, of course, have resulted from a supply-induced change in their relative prices. Table 4.1 shows a large increase in the per capita purchase of soap in Great Britain throughout the second half of the nineteenth century. From a consumption of 8 pounds of soap per year in 1861 it rose to 10.7 pounds in 1871 and 14 pounds in 1881. The increases in soap consumption continued, at a somewhat slower pace, through 1912. Following the technological advances during the Industrial Revolution, the soap industry expanded rapidly, and by 1851 it was a thriving industry. At the Great Exposition of that year, 103 soap manufacturers pre-

**Table 4.1** Consumption of All Soap Products

Year	Annual Consumption per Capita (pounds)
1851	7.1
1861	8.0
1871	10.7
1881	14.0
1891	15.4
1901	17.4
1912	18.0

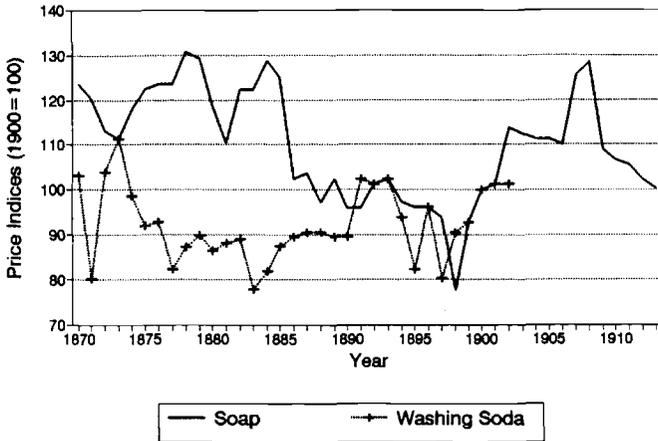
*Source:* Edwards (1962, 135).

sented an array of products: honey soap, white curd soap, mottled soap, and more (Edwards 1962, 136). With the entrance of William Hesketh Lever into the soap industry in 1885, a new era began (Wilson 1954). Lever's great innovation was packaging the new oil soap Sunlight in separately wrapped bars, thereby breaking the old marketing tradition of producing soap in 3-pound bars that were then cut into smaller pieces by shopkeepers. With a strong marketing campaign that included advertisements and prizes, Lever's market share rose to a peak of 23.1 percent in 1905. But other producers continued to fare well, with total market sales increasing fast enough to accommodate both them and Lever. Edwards (1962, 151) writes that the main element contributing to the increase in soap sales per capita "was undoubtedly the increased consumption of soap among the working classes" due to Lever's advertising that promoted soap to the "factory housewife." This came in conjunction with changes on the demand side, which were spurred by changes in knowledge and a growth of the understanding of soap's role in producing health. It seems likely that the growing awareness of pathogenic microbes created a fertile soil in which the seeds sown by advertisers germinated rapidly.

To what extent was the growth in soap consumption a consequence of supply changes? Figure 4.4 shows the development in the prices of soap and washing soda during this time, deflated by the consumer price index. The real price of soap did fall substantially between the mid-1880s and 1898, but then it rose again until 1908.<sup>54</sup> Changes in prices may explain increased consumption in the late 1880s and 1890s, but they cannot explain the continuous increase in soap consumption throughout the period. It is interesting to note that the period characterized by the sharp decline in infant mortality (post-1900) is one of increasing soap consumption despite price increases. Another important product used in cleaning was washing soda. As figure 4.4 shows, its real price declined through the 1870s but then stabilized and even rose again toward the end of the century.

To return to the issue stated at the outset of this paper, it is hard to believe that a shift in preferences (narrowly defined) occurred that steered households into demanding more goods conveying cleanliness. Nor does it appear to be true that changes in relative prices of the goods associated with cleanliness can by themselves explain the phenomenon. Instead, the information term  $A - \varepsilon$  that multiplies the goods in equation (3) increased and changed age-old habits. Statistical evidence on its own would not have brought about a change so drastic; but statistical evidence coupled to a theory that claimed to know why the statistics held true was too powerful to ignore. The full cost of the new recipes consisted of, to a large degree, household time. It is clear from Cowan's (1983) work that households improved their health not only because new, health-enhancing implements and commodities became available or affordable, but

54. The development of the price of primrose soap is almost identical to that of other soaps (yellow, household) and to the prices in other establishments (see United Kingdom 1903, 372-73).



**Fig. 4.4 Real price indexes: soap and washing soda, 1870–1913**

Sources: Soap prices up to 1902 are the London retail price of primrose soap as given in United Kingdom (1903, 372). Soap prices since 1902 are from Edwards (1962, 156). Washing soda prices are from United Kingdom (1903, 364). General price index is from Feinstein (1972, T140).

also because households devoted more scarce resources—above all, labor—to them. De Vries (1993, 119) notes that after the mid-nineteenth century households increasingly withdrew female labor from the marketplace and allocated it to housework, reversing the effects of what he has felicitously called the “Industrious Revolution” which redeployed labor from housework to the market in the eighteenth century.

What could explain this “industrious counterrevolution”? Housework was not leisure and was often unpleasant and physically exhausting (Cowan 1983, 43–44). A likely explanation is that homemakers were increasingly convinced that such housework was correlated with health and survival. A connection between female labor participation and infant and child mortality has been proposed by Imhof (1984); it should not be assumed that this connection was entirely unconscious.<sup>55</sup> The decision about whether a mother and her children should work was endogenous on the information available to the household. Germ theory showed that preserving children’s health is best accomplished by investing more time within the house in cleaning and child feeding. Household labor could not easily be substituted by inputs purchased in the market, so that the effective wage earned by women was lowered. The result was a shift of married women out of the labor force and consequently a decline in child mortality and morbidity.<sup>56</sup>

55. A recent analysis connecting health and domestic labor and making a similar argument from a Marxist perspective is Thomas (1995).

56. The costs were compounded by an excessive zeal for cleaning that often led to practices that were not always necessary. An 1872 article in *Popular Science Monthly* cried out against “careless disinfection” and stated, correctly, that “mere exposure to disinfecting vapors is not enough to

One of the major inputs into the health production function is time, usually women's time. If the relative price of household work, female wages, decreased over this time, it may help to explain an increase in work within the home. Unfortunately, time series of female workers are hard to come by. In figure 4.5 we show the development of real wages for men in the United Kingdom from 1870 to 1913 (Williamson 1995). We also show a series of female laborers' wages on a Northumberland farm (Fox 1903).<sup>57</sup> Both men's and women's wages seem to go up during the later part of the nineteenth century. Thus the opportunity costs of household time did not decline. The gradual decline of female labor force participation in the Victorian era is consistent with information-generated changes in household behavior.

Typhus in England makes an interesting case study of the impact of new standards of cleanliness on morbidity and mortality (Hardy 1988). Typhus was a typical "dirt disease." Until the 1870s the distribution of typhus in London was linked to specific areas within the central, southern, and eastern registration districts. In these areas there were specific places, popularly designated "fever nests," that were recognized by the public health authorities as particular haunts of typhus.<sup>58</sup> Typhus almost disappeared after the late 1870s. Hardy (1993, 204–10) links this disappearance with improvements in the sanitation of housing, improvements in water supplies and hospitals, and the change in the nature of social dislocation. Part of the improvement can be attributed to the construction of the railways and the demolition of houses that stood in the way; some of the poorest and least sanitary houses were destroyed this way. Part of the decline in typhus resulted from public policy aimed at combating disease.<sup>59</sup> Once the connection between cleanliness and health was made, any

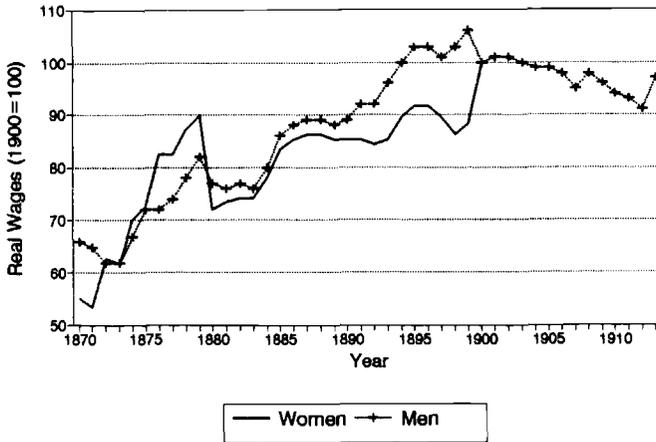
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thoroughly rid the apartment of danger to future inmates" (Careless disinfection 1872, 122). The recommended procedure was not only to scour the floor and woodwork and to clean the walls and ceiling but also to remove all wallpaper, for "it unquestionably has the power of absorbing and retaining contagious matters, that are not reached by the ordinary processes of disinfection." Works such as *The Woman's Book* (Jack and Strauss 1911) go through pages upon pages of chores to be done around the house. In tersely written prose and in tight print the authors fill 734 pages with "many hints with regards to cleaning etc."

57. We would like to thank Joyce Burnette for providing us with this series.

58. Hardy (1993, 197–98) describes one such house, located in St. Giles. It housed a secondhand clothes shop in the basement, offered rooms to let further up, and housed, among many others, some makers of trinkets for ladies' heads and dresses. An outburst of typhus began with the second-floor family whose daughter, living in nearby Drury Court, had caught the infection from a fellow lodger there. For two months the disease spread from family to family within the house, and all through this time the work within the building did not stop. If such a house was not cleaned and disinfected after an appearance of typhus, infected louse feces might lie undisturbed for years until a new nonimmune occupant arrived. Overcrowding and high turnover of people in such cases as St. Giles only assisted the spread of typhus.

59. Following the passing of the Artisan Dwelling Act of 1875, further houses were demolished under the sponsorship of the Medical Officer of Health. The Nuisance Removal Act helped rectify some specific sanitary defects by encouraging houses to be cleaned and lime washed. In St. Giles, for example, 12,573 improvement orders were issued between 1875 and 1883, and 7,700 houses were cleaned—an average of 971 per year. Out of the 3,968 inhabited houses, therefore, 24.5 percent were cleaned every year.



**Fig. 4.5 Real wages for men and women, 1870–1913**

*Sources:* Men's wages are from Williamson (1995, A20–A21 table A1.1). Women's wages are for ordinary women workers from Fox (1903, 323). Price index from Feinstein (1972, T140).

outbreak of disease brought forth a flurry of antiseptics and disinfection that helped eradicate infectious diseases of any kind. Outbreaks of scarlet fever in 1868–70 and smallpox in 1870–73 and 1876–78 brought widespread house-to-house visitations in search of carriers and unvaccinated children. These epidemics also resulted in the widespread disinfection of homes, bedding, and clothing of victims throughout London, eradicating such diseases as typhus at the same time. The disappearance of typhus is especially interesting because it was just as complete in districts whose sanitation caused much contemporary worry, such as Manchester, as it was in relatively well-administered towns, such as Birmingham (Pooley and Pooley 1984; Woods 1984). Other dirt diseases also went on the decline: typhoid fever, cholera, scarlet fever, and food poisoning account for much of the mortality decline after 1870. Prevention, through changed household technology and public goods, was the main cause of the decline in disease after 1870.<sup>60</sup>

#### 4.4.5 Insects

The recognition that insects could serve as vectors of bacteria seems an obvious extension of the germ theory to us, but in fact did not occur for decades after Pasteur's initial breakthroughs. Two discoveries are particularly im-

60. Here, too, schools were an important administrative center. Thus, for example, in Bermondsey, one of the poorer boroughs in London, an inspector went around the schools and noted those children unfit to go to school "owing to their verminous condition" (Brown 1908). These 331 children were sent to newly erected baths, where "all received 'a good warm bath' and in the case of vermin in the head a 2 per cent solution of lysol very soon got rid of them." Roberts (1990, 79) describes similar scenes from the viewpoint of a schoolchild remembering the awful shame of children thus disgraced.

portant: the malaria-carrying *Anopheles* mosquitoes, and the yellow fever-carrying *Aedes aegypti* mosquito. Although suspicions that mosquitoes were to blame for disease had been expressed since Carlos Finlay y Barres speculated in 1878 about the sources of yellow fever, the major breakthroughs did not come until the closing years of the nineteenth century. In 1899 the leading bacteriologist in Britain, George Nuttall, codified the best-practice knowledge, saying, "it is certain that under certain conditions insects may play a most important part—both active and passive—in the propagation of bacterial diseases" (quoted in Dwork 1987b, 45). From a European point of view, the most important reinforcement of this view came in 1909 when Charles Nicolle identified the louse as the vector of typhus (the bacterial agent was identified two years later). Typhus and malaria were the most important vector-borne diseases in Europe, but some food-borne diseases like dysentery could also be spread by insects.

The battle against mosquitoes had been, for many years, unintended and indirect. Swamps were associated with fevers and sickness and their ill effect was feared, but the true reason for this connection was not understood, and mosquitoes were not suspected as the villains. All the same, during the eighteenth century, long before Pasteur, a huge amount of private and public effort was invested in swamp drainage. The intention of much of the investment was to clear land for agriculture—not for public health. Yet physicians and agricultural reformers encouraged these efforts, and to facilitate them public authorities offered tax cuts and financial aid (Riley 1986, 840). The effect of the decline of malaria on overall mortality rates is hard to evaluate. The strain of malaria common in the temperate European climate caused more weakness than death, increasing susceptibility to other diseases rather than adding to mortality directly. Such interactive effects make the identification of specific measures hard to pin down. Similar measurement problems face us when we try to evaluate the effect in the decline in the number of fleas, ticks, lice, and so on. The fact that mortality from some diseases (e.g., dysentery) was seasonal, peaking during the warm season when insects thrive, is consistent with the view that insect control played an important part in mortality decline. Warm temperatures, however, would also speed up the division of bacteria, thus accelerating food spoilage and the incidence of food-borne diseases.

Insect control thus was often the unintended beneficial consequence of other efforts. Measures directed at food cleanliness reduced insect contact. So, for example, although covering milk pails was not a good alternative to pasteurization, it reduced contamination by flies. The regular washing of clothes and bed linen got rid of ticks, bedbugs, and lice and reduced insect-borne diseases even though the connection between insects and disease was still unknown. The discovery of the role of insects in disease transmission in the 1890s brought with it a general change of attitude toward insects. From then on they became not just a nuisance, but a menace. The changing attitude toward the common housefly during the first years of this century is an illustrative example: once

regarded as an innocent and friendly domestic insect, it was transformed into a “germ with legs” (Rogers 1989), an enemy to the housekeeper and her family.<sup>61</sup> Germs could not be seen, so that even when the knowledge of germ theory spread it was difficult for the housekeeper to fight them. Flies, cockroaches, fleas, and mosquitoes, on the other hand, were an easy and palpable target, and keeping them away from the house was a concrete, practical recommendation that could be followed. Though insects were easy to see and identify, eradicating them took time and effort. To help in this task public baths supplied a disinfection service where poor households could take their beds, linens, and clothes to be disinfected at low or no cost (Brown 1908; Roberts 1990). As insects joined unclean milk and dirty houses as signals of germs to be avoided, some overreaction to the sheer rhetorical power of the anti-insect hysteria was inevitable and relatively harmless creatures such as spiders and cockroaches became victims of the war on germs.

#### 4.4.6 Medical Practices

We finally turn to the consumer good that most directly affects health: medical services. The most significant change brought about by the germ theory was perhaps to transform the status and function of physicians. The impact of the new theories went beyond the demonstration that microorganisms caused infectious disease: the entire concept of disease was clarified and altered. The distinction between cause and symptom, the mechanics of prevention, and a rudimentary notion of immunity, which soon followed drove home the basic idea that the chances of getting sick and the severity of the affliction were determined to a large extent by the action of the household and its allocative decisions. Doctors became the pivotal agents for disseminating this idea. After the emergence of the germ theory and before the emergence of effective antibiotics, the knowledge that infectious diseases were caused by bacterial agents left doctors with a primary function of prevention. In a few cases, the new microbiology found a cure or a vaccine (syphilis and diphtheria). On the whole, however, their role was educational: by realizing the importance of minimizing exposure to bacteria, physicians became agents in the diffusion of the new knowledge. This novel function was a central reason why  $\epsilon$ , the lag between best-practice and average technique, declined. In that regard, Pasteur's discovery affected both  $A$  and  $\epsilon$  in terms of equation (3). While the bacteriological revolution demonstrated that different microorganisms caused different diseases, the effort directed at improvement of hygiene was not disease specific. Changes in consumption patterns and environment affected a range of diseases, and through the complexities of the immune system, diseases interacted with one another in ways that are hard to unravel.

61. When the link between diarrhea and flies was established in the second decade of the twentieth century, infant mortality from this disease was still significant. Posters were put up in infant-care centers and local government offices to alert the public to this matter and to advise them on ways to fight flies and protect food and milk from contamination.

Even without antibiotic medication, changes in treatment followed directly from the improved understanding of disease. The treatment of cholera provides a vivid example. When first confronted with the disease in the late 1820s, traditional medicine recommended the use of emetics and purgatives in cholera patients to help the body rid itself of the morbid material there by expediting “natural” diarrhea. The prevailing treatments included bleeding, opium, laudanum, and calomel (mercurous chloride, a powerful laxative prescribed for dozens of diseases). Another popular prescription was tartar emetic (antimony and potassium tartrate) which also was a medication of choice in the eighteenth and nineteenth centuries (Haller 1974). Without a true understanding of disease, the use of harmful “cures” persisted, and potentially beneficial drugs were prescribed in incorrect dosages.<sup>62</sup> By the end of the century, the recommended treatment changed completely, and clinical intervention focused on relieving the symptoms by keeping up high levels of liquids.

Bleeding was revived in the 1820s, along with many practices and doctrines associated with it.<sup>63</sup> It was noted, for example, that a high proportion of patients who could not be bled because their blood was “too thick” died. This led to the conclusion that bleeding was a crucial part of treatment and should be induced as much as possible, especially in difficult cases. The use of statistics and numerical methods finally undermined bleeding practices (Rosen 1955), and after decades of long and often heated debates, it fell into disuse (King 1961). Between 1840 and 1870, a protracted struggle took place between the “old” and the “new” schools of medicine, but the germ theory put an effective end to bleeding as a best-practice technique—although here, too, diffusion was far from immediate. Another clinical practice that fell into disrepute after the bacteriological revolution was the indiscriminate use of panaceas. After 1890, for example, quinine was no longer used against typhus, fluxes, gangrene, cachexias (scrofula, rickets, scurvy), or as a tonic and was restricted to the treatment of malaria (Ackerknecht 1962, 412). The deepest and most revolutionary consequence of the bacteriological revolution, however, was that diseases were demonstrated to be separate entities caused by different agents.

62. One doctor in 1844, perhaps an extreme case, prescribed a tablespoon of calomel (about 250 grains) an hour whereas in 1940 the prescribed dosage was 2 grains (Hudson 1983, 205).

63. François Broussais’s career in this regard is telling. His magnum opus, *Examen des doctrines médicales* (1816) made him so influential and popular that his lecture halls at the Val de Grâce medical school had to be changed twice to accommodate his students. His book was translated into many languages, and as late as the 1860s his work was regarded as a milestone in French medicine. The “antiphlogistic” theories invented by Broussais started from the assumptions that nature had no healing power and that the body had to be weakened in order to be rid of disease. He thus recommended depriving the patient of food and administering heavy localized bleeding. His influence raised the imports of leeches from 320,000 in 1823 to an average of 31 million in 1833–34. It is easy to dismiss his work, but his criticism of competing theories and therapeutics was probably helpful, and his basic idea that therapeutics should be directed toward the organ causing the symptoms rather than the symptoms themselves is plausible. All the same, his central doctrine, which designated gastroenteritis as the sole disease that caused all other symptoms, was another attempt to find a holistic approach to the causes of disease and did little to advance clinical treatment.

The holistic approaches of Brown, Broussais, and others were finally abandoned for good by the medical profession.

A major contribution of germ theory to clinical medicine was in surgery: it provided Joseph Lister with a missing link in his chain of discoveries. With the insights that the germ theory provided, Lister's recommendation carried a great deal more conviction than those of his precursors, Holmes and Semmelweis, who owed their insights purely to empirical regularities. If suppuration of wounds was due to living organisms, the immediate problem at hand was to kill these organisms without injuring the living tissues. Lister's discovery of antiseptics came after a long period of rising hospital mortality. The introduction of anesthesia two decades earlier had made operations easier for both patients and doctors, but prior to antiseptics a rise in operations led directly to a rise in mortality as postsurgical infection claimed a growing number of victims. By the 1870s hospitals were in dire straits, and there was even talk of pulling old hospitals down and building new ones in the hope that this would break the vicious cycle of operations and death (Latour 1988, 48). Pasteur and Lister focused the issue and gave a concrete solution to the problem: antiseptics.<sup>64</sup> Doctors no longer needed to follow Bouchardat's advice and wait several days between assigning one maternity patient and another—it was enough to wash one's hands in carbolic lotion (48).<sup>65</sup> The understanding of germs and contagion brought a change in the architecture of hospitals: instead of having one big ward, patients with contagious diseases were placed in smaller areas linked to the public wards but completely isolated from them (Goubert 1989, 133), and maternity patients were provided with their own area surrounded by an antiseptic cordon.<sup>66</sup>

As with other medical discoveries, the germ theory did not spread overnight and the use of antiseptics diffused slowly.<sup>67</sup> Not using the newly acquired

64. The story of Lister's discovery is well known: he heard of Pasteur's discovery by chance and was, in fact, not the first English doctor to note its significance. Unlike other surgeons, however, he realized that it provided a theoretical justification for his belief that treatment with carbolic acid reduced the chances of infection. Lister's own techniques quickly became obsolete when antiseptic methods were replaced by the aseptic ones of boiling and autoclaving instruments before use.

65. The next step was the use of rubber gloves. These were first used in 1889 by a nurse on the staff of Dr. William Stewart, Halsted Professor of Surgery at Johns Hopkins Medical School. The nurse complained that the solution of mercuric chloride produced a dermatitis on her arms and hands, and Dr. Stewart ordered two pairs of gloves from the Goodyear Rubber Company. The gloves went into regular use by assistants and were used sporadically by surgeons until finally entering into general use (Proskauer 1958).

66. The risk of the mother dying at childbirth or during confinement did not decline appreciably in England during the second half of the nineteenth century. On the other hand, there was a marked decline in maternal mortality in hospitals over the same period (Loudon 1986). The increasing gap between maternal mortality in hospitals and in rural homes (where help during labor was given by "ignorant midwives") emphasizes how important it is to distinguish between health practices in different populations and households. The discovery of germs may have enhanced the survival rates of those women who went to hospitals, but it was another thirty years before all English women reaped the same benefits.

67. An enlightening anecdote is provided by Fish (1950). When President Garfield was shot, sixteen years after the introduction of antiseptics, the numerous physicians who saw him did not

knowledge was but one part of the problem; trying to apply it unconditionally was another. The logic of antiseptics was so compelling to some that it was promoted for internal as well as external use (Crellin 1981). Internal antiseptics, for example, were introduced to combat respiratory ailments and were administered by spray or steam. As in so many other examples of new technology, successful and effective use of the macroinvention depended on the supplementary microinventions as much as on the original breakthrough.

Many general physicians, in contrast with hygienists and public-sector physicians (such as the Medical Officers of Health), at first objected to the germ theory and tried to keep its recommendations at arm's length. American physicians in the late nineteenth century were unusually conservative and fought the germ theory of disease tooth and nail. Only the development of the diphtheria antitoxin persuaded American doctors that the old miasmatic theories of disease had to be abandoned and the practice of medicine reformed (Preston and Haines 1991, 8–11). Yet it became clear soon enough that doctors could not turn the Pasteur revolution back, and soon the majority who could not beat the new science joined it (Latour 1988, 129–37) and played a growing role in a transformed medicine. In many ways we should regard physicians in this age as household consultants, advising homemakers how to avoid infectious disease by the proper combination of goods and household work in the kitchen, toilet, and bathroom. Their role was to spread the new knowledge as much as to implement it themselves, a distinction overlooked by McKeown's indictment of the medical profession.

#### 4.4.7 Public Policy

The Pasteur revolution had profound implications for public policy. Above all, new knowledge altered best practices employed by the public sector, that is, it affected the parameter  $B$  in equation (5) above. The understanding that there were public-good properties to health was of course an age-old one and had been formulated sharply by Frank in the late eighteenth century in his concept of "medical police." But the lack of a knowledge of what disease was and the uncertainty about transmission mechanisms (resulting in bitter disputes between contagionists and anticontagionists in the nineteenth century) made public policy, with a few important exceptions, rather ineffectual. Policymakers and the citizens whose opinions influenced them had to change their views of public health after Pasteur just as much as homemakers had to account for it in private health.

When households acquired the information about what made them sick and what kept them healthy, they often exerted pressure on the authorities to initiate reforms to produce goods that they could not produce for themselves and that

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think twice before poking his wound with their fingers. The surgeon general of the navy introduced his finger to its full extent into the wound, as did Dr. J. J. Woodward and Dr. Bliss, two physicians present. A homeopathic physician who rushed into the room added a deep finger of his own. It is not surprising that Garfield died, not of the shot itself, but from infection and complications ten weeks after the incident.

the market would not supply. Consumers were also voters, and in most nations their worries and demands found their way to the politicians' programs, if often in an incomplete and uneven fashion (Brown 1988; Cain and Rotella 1994). It is thus somewhat artificial to separate, as we do in equations (3) and (5), the knowledge of the public servants and the knowledge of the consumers at large. Insofar as policymakers are sensitive to public opinion, public works will be affected by the levels of  $A - \epsilon$ , that is, private knowledge.

Nineteenth-century public medicine had increasingly been convinced that many diseases had a profoundly social nature. Epidemiologists in Britain, France, and Germany had established beyond doubt that disease was strongly correlated with poverty and hunger. As no causal model was available, scientists and public reformers leaped to the convenient conclusion that infectious diseases would be eliminated if and when poverty, misery, and hunger disappeared. Public health, therefore, was part and parcel of a wider set of social reforms. To be sure, certain public projects such as a clean water supply and sewage works were understood to have a more direct impact on the incidence of epidemics, but the general feeling was well expressed by the founder of modern physiology, Rudolf Virchow, when he declared in 1849 that "if medicine is really to accomplish its great task, it must intervene in political and social life" (Rosen 1947, 679). His colleague, Salomon Neumann, added that poverty, hunger, and misery were "the inexhaustible sources from which death, disease and chronic suffering originate." Similar positions were espoused at that time in Britain by Edwin Chadwick, Henry Rumsey, John Simon, and others. The nonspecific nature of the causes of disease meant that they could only be fought with a wide array of social-reform measures dealing with housing, sanitation, child labor, education, working conditions, and so on. The masses, the social reformers felt, could not be healthy unless they were at least moderately prosperous. In Rosen's words, medicine was perceived to be social science. Individual health would not be improved until general social conditions were.<sup>68</sup>

The nature of the Pasteur revolution was not to obviate such policies but to sharpen and focus them. Poverty was a correlate of disease but not necessarily its cause. It was no longer necessary to eliminate poverty to combat infectious disease: society could have a class of healthy poor provided they lived a relatively healthy lifestyle. George Newman's important book *Infant Mortality: A Social Problem*, published in 1906, exemplified this change. Writing about infant mortality, he stressed that "poverty is not alone responsible, for in many poor communities the infant mortality is low. Housing and external environment alone do not cause it, for under some of the worst external conditions in the world the evil is absent. It is difficult to escape the conclusion that this loss

68. Nineteenth-century socialist thought found this line of reasoning extremely amenable to their cause and often maintained that because the causes of poverty were economic, so were the causes of sickness. By eliminating poverty, socialism would eliminate sickness (Spree 1988, 25).

of infant life is in some way intimately related to the social life of the people." By redeploying existing resources, both in the public sector and in the household, disease among the working classes could be reduced and perhaps eliminated within the existing structures of society. Public health was thus redefined and disease was taken out of the social realm and placed back in the household.<sup>69</sup> The role of the public sector remained important, but it was more carefully circumscribed by market failure. Households could infect each other and shared certain common goods such as sewage and drinking-water supply. Provided, however, that they were properly informed, they could on the whole be held responsible for their own physical well-being.<sup>70</sup> Authorities were to focus on specific diseases which, for one reason or another, could not be controlled by the household. This left a large part for the public sector, from vaccination to the drainage of malaria-causing swamps. Proper child care, domestic and personal cleanliness, and adequate nutrition, on the other hand, were no longer regarded as the essential domain of policy measures since they were not incompatible with poverty and were properly regarded as part of household choice. The poor did not get sick because they were poor, but because germs infected them. Eliminate the germs and you will have healthy poor, as long as they do not fall below a level where their physical well-being cannot be supported—hence the idea of a poverty line.<sup>71</sup> Beyond that, however, the interaction between social problems and medical issues could be defined with some precision. In 1893 the great bacteriologist Emil Behring wrote laconically that thanks to the methods of Robert Koch, the study of infectious disease could be pursued without being sidetracked by social considerations and welfare policies (Rosen 1947, 675).

These policies were most effective in Germany, where, despite lower incomes and lower standards of living, the biggest gains were made in the struggle against infectious disease (Brown 1988, forthcoming). Although there can be no question that until 1914 Germany was a poorer country than Britain, it was more successful in mitigating the worst impact of the urban environment. Brown attributes much of this to public works, yet it must also be possible that German households were more susceptible to the growing pressure from

69. As Newman wrote, "Sanitation and preventive medicine have in the past done much to protect the individual from the evil of his environment. The future will lie with the State that is able to protect the individual against himself. And to do that it must build on the family life in the home, for the home is the unit of the State" (1906, 180).

70. Many reformers who doubted the premise called for further education of both adults and children. While mothers were increasingly accused of carelessly promoting infant mortality, Davies defends them, writing, "The fatal mistakes made by mothers in regard to their babies are more often the result of ignorance than of carelessness. It is only by teaching the mothers how to care for babies that we can remove that blot on the home-life of the nation, the alarming mortality of infants under one year old" (1906, 5).

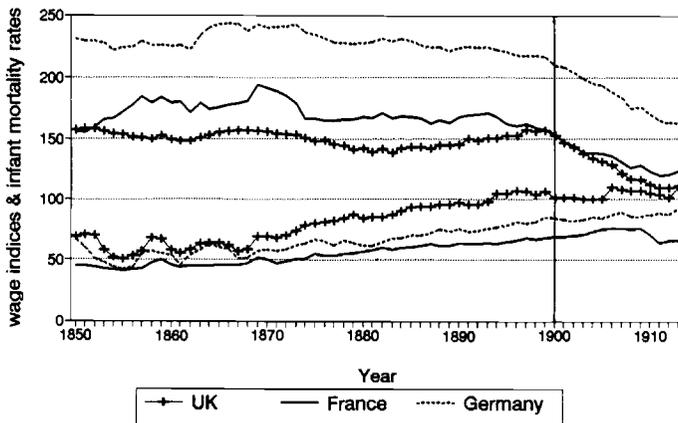
71. The germ theory was not a necessary preamble to this more conservative approach: the leader of the German hygienic movement, Max Pettenkofer, resisted the germ theory yet made it quite clear that in his view health depended first and foremost on consumption choices made by individuals about diet, housing conditions, and so on (Rosen 1947).

authorities to follow a certain set of household rules deemed by them to be healthy, thus allowing households to reduce the gap  $\varepsilon$  more quickly than elsewhere. It should be added, however, that Germany had much further to go. In the late 1870s, crude death rates in Germany were still around 26.5 as opposed to 21.2 in the United Kingdom, and infant mortality rates, though highly variable within the country, were about 228 per 1,000 in Germany compared to a mere 145 per 1,000 for England and Wales.

## 4.5 Quantitative Dimensions of the Pasteur Revolution

### 4.5.1 Aggregate Rates of Income and Mortality

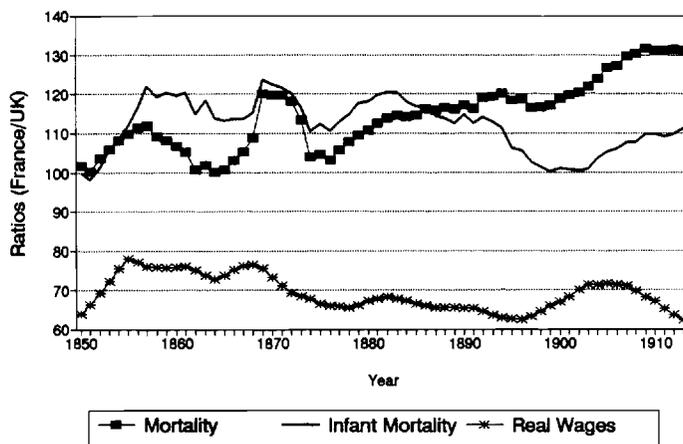
As we have noted, it is hard to discriminate between the different factors that have been argued to have affected general and infant mortality. To test whether rising incomes were a factor in infant mortality decline, we have plotted real wages and infant mortality in the United Kingdom, France, and Germany (fig. 4.6). All three countries show a steady increase in real wages from the mid-1860s, but in all three cases infant mortality did not decrease steadily. Rather, infant mortality seems to vary around a steady plateau until the turn of the century when it suddenly declines sharply. Note also that although France had lower real wages than Germany throughout this period, it had a lower infant mortality. Overall mortality rates do decline steadily, and there can be little doubt that in the long term nutritional status improved, leading to the decline of some nutrition-sensitive adult diseases, especially tuberculosis. This cannot, however, be the whole story.



**Fig. 4.6** Real wages and infant mortality, 1850–1914

*Sources:* Infant mortality data, see fig. 4.1. Real wages are from Williamson (1995, A26–A27 table A2.1).

*Note:* Top three lines are infant mortality rates; bottom three lines are wage indexes.



**Fig. 4.7 Mortality, infant mortality, and real wages: ratios between France and the United Kingdom**

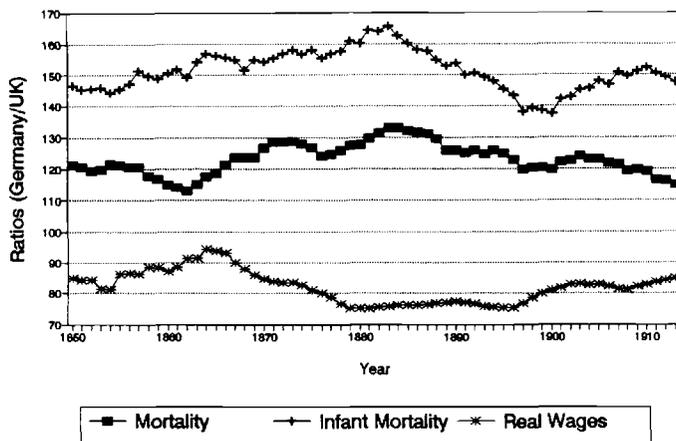
Sources: Infant mortality data, see fig. 4.1. Real wages, see fig. 4.6. Mortality data are from Mitchell (1975, 104–20 table B6).

Comparing the ratios of real wages, overall mortality, and infant mortality in England and France (fig. 4.7) also suggests that income by itself is not a sufficient explanation. As a whole, wages in France were lower than those in England and mortality figures were higher, as the income hypothesis would predict; but closer examination shows that the relative trends were not the same. During the 1890s and the early 1900s, real wages in France were rising relative to those in England, but relative mortality rates in France increased. A similar comparison between Germany and England (fig. 4.8) shows that infant mortality in Germany declined relative to that in England during the 1880s, even though relative wages did not change. After the mid 1890s, real wages in Germany rose relative to those in England, but relative infant mortality increased at the same time. While these data do not prove the income hypothesis to be wrong, they indicate that rising incomes could not be the only factor affecting mortality and infant mortality rates.<sup>72</sup>

#### 4.5.2 Nosologies and Household Perception of Disease

The main argument of this paper is that the Pasteur revolution accelerated a trend that had already begun around the middle of the nineteenth century. This trend consisted of a growing understanding by households of the natural processes that caused disease. The growth in household information and the belief that this information was helpful were spurred on by the germ theory, but evi-

72. This finding is wholly consistent with those of Preston and Haines (1991) who conclude that “the growth of income during the twentieth century could not have been the principal factor causing mortality to decline” (210, emphasis in original).



**Fig. 4.8 Mortality, infant mortality, and real wages: ratios between Germany and the United Kingdom**

Sources: See fig. 4.7.

dence of these changes can be detected earlier. One set of data that bears indirectly on the question of technological change in health is the ideas households had about the causes of death and the relationship of death to disease. This information is not included with most data on death by cause, since the cause of death is often reported by physicians or civil servants. An exception to this is the American census between 1850 and 1880, in which American citizens were asked by the census takers whether somebody had died in the household in the past twelve months and, if so, at what age and of what cause. The causes reported are a very poor indicator of the *actual* causes of death, but that is not what we want to use them for. Instead, they provide some indication of what people *thought* had killed their family members. The classification of these causes provides a clue to the changes in the way the cause of death was perceived in the United States. In particular we are interested in two kinds of issues: (1) whether the reports confused symptoms with disease and (2) to what extent the diseases they identified were real diseases as opposed to more primitive concepts of illness. Of course, these declarations may have reflected the opinions of doctors rather than those of households, but the fact that households had access to doctors, and remembered their verdicts on the causes of death, is in itself an interesting phenomenon.

The sample we used was drawn from three states, Arkansas, Connecticut, and Delaware, for four census years (1850, 1860, 1870, 1880).<sup>73</sup> It included data on 34,113 individuals and provided age at death, gender, place of resi-

73. The data were collected and transcribed from the census manuscript by Accelerated Indexing Systems International, Salt Lake City, Utah. We are deeply indebted to Joseph P. Ferrie for placing the data set at our disposal.

**Table 4.2** Reported Causes of Death in the United States, 1850–1880

	1850	1860	1870	1880
Diseases of digestive tract	13.65	5.36	5.56	4.87
Diseases of respiratory tract	22.55	29.93	31.66	30.05
Identified infectious diseases	15.93	19.11	20.23	21.18
Unidentified infectious diseases	11.89	11.85	8.90	6.42
Identified noninfectious diseases	5.09	6.53	9.59	8.19
Unidentified noninfectious diseases	14.77	14.95	14.75	20.70
Nondisease	3.96	4.19	4.65	4.00
Other	0.03	0.03	0.05	0.25
Unknown	12.12	8.06	4.61	4.33
Total	100	100	100	100

*Source:* See text.

dence, place of birth, cause of death, and, in a very small number of individuals, occupation. The transcribed data contain a number of errors, some of which were obvious and could be corrected. These include gender errors (e.g., males declared to have died during childbirth) and misspellings of diseases. To make it amenable to our needs, we divided the declared causes of death into six major categories.<sup>74</sup> The basic findings are presented in table 4.2.

The data clearly show a continuous decline in the proportion of digestive tract diseases, possibly indicating a cleaner food preparation, better food preservation methods, improved urban water supplies, and better basic treatment of patients against dehydration. Equally interesting is the continuous decline in the fourth row, which shows unidentified infectious diseases such as “fever,” “chills,” “inflammation,” “brain congestion,” and so on. These are primarily descriptions of symptoms rather than causes, and their decline points to an increase in sophistication. It might appear that this decline is offset by the sharp increase in unidentified noninfectious diseases in 1880, but this result is largely due to an increase of people dying of “old age” and “exhaustion,” an increase which was itself perhaps a result of improved medical conditions. Leaving out such questionable categories as well as “debility” and stillborns reduces the difference between 1870 and 1880 from a 6 to a 2 percent gap.

A further analysis of the data reveals some interesting patterns. One is that the two main killers, digestive and respiratory tract diseases, follow the classic premodern seasonal pattern, with high summer mortality for digestive diseases. But the pattern weakens over time. Two crude measures are the coefficient of variation for all twelve months and  $U$ , the mean of the months in which mortality exceeded the annual average by more than one standard deviation divided by the annual average. The data for digestive diseases are presented in table 4.3.

74. Because of the nature of the reported causes of death, we could not make use of the International Classification of Diseases prepared by the National Center for Health Statistics.

**Table 4.3** Seasonal Variation in Digestive Tract Diseases

	1850	1860	1870
Coefficient of Variation	1.15	0.64	0.58
<i>U</i>	3.34	2.97	2.06

Source: See text.

A third approach to this data set exploits the age distribution reported by the census. As the figures were compiled from reports made by the survivors, the age data reveal something about the population, in that it is well known that age heaping tends to correlate (inversely) with literacy, sophistication, and numeracy.<sup>75</sup> The question is, of course, whether such sophistication also indicates better medical knowledge and understanding. If so, it would provide us with a better clue to how education and rising literacy enhanced people's understanding of disease and reduced mortality. We would therefore expect that lower levels of age heaping would be associated with lower levels of unidentified diseases. The heaping index we use here is rather crude but very easy to calculate; some minor gains can be made by using more sophisticated methods to smooth the age distribution and then computing the deviation of the reported age distribution from the smoothed one. At this stage, we compute a statistic *V* where

$$V = \frac{\sum a_i/3}{\sum a_j}$$

for  $j = 19, 20, 21, 29, 30, 31, 39, 40, 41, 49, 50, 51$  and  $i = 20, 30, 40, 50$ . In the absence of heaping, assuming approximate linearity of the age distribution,  $V \approx 1$ .

The value of *V* declines over time, as might be expected (see table 4.4). More interesting, it tends to be high for poorly defined diseases associated with a primitive knowledge of medicine, and it declines with better-defined knowledge. In other words, our data, however indirect, suggest that education and numeracy were associated with better understanding of the nature of disease and eventually how to avoid it. Much of this chain of inference is still speculative, but we plan to explore it in future work.

#### 4.5.3 The Welfare Impact of Mortality Decline

We have argued that the acceptance of the germ theory fundamentally changed mortality patterns, bringing a decline in death rates at all ages and a

75. The technique of age-heaping analysis was first applied to economic history by Mokyr and Ó Gráda (1982) and Mokyr (1985). The principle is that the degree at which populations heap at round ages is strongly and negatively correlated with their ability to compute and their overall degree of mental sophistication.

**Table 4.4** Values of  $V$ 

Cause of Death	$V$
All causes	
Males 1850–80	1.42
Females 1850–80	1.44
Total	1.43
Both genders	
1850	1.48
1860	1.42
1870	1.43
1880	1.36
By cause (all years)	
Convulsions, chills, fevers	1.65
Dropsy, paralysis, unidentified infectious diseases	1.55
Consumption, cholera	1.32
Identified infectious diseases	1.30
Typhoid	1.38

Source: See text.

sharp decline in infant mortality. In this section we wish to quantify this change and to give some rough estimates of its welfare implications. What we are estimating is the welfare impact of the decline in mortality as a whole, not the net welfare effect of the germ theory of disease. Insofar as the decline in mortality was caused by supply-related factors, the net effect of the Pasteur revolution should be prorated to the contribution of the demand-side factors. At this stage, it is too early to do justice to this complex problem, and what we present below is both incomplete and preliminary.

The welfare losses of a death include two components: the loss to that person and the loss to the person's family and friends. In what follows, we restrict ourselves to one aspect of the mortality decline: the gains in welfare to the consumer himself.

For the first calculation we use the framework suggested by Usher (1973). Usher attempted to find a measure to evaluate the historical decline in mortality rates by expanding the concept of real income to include the fall in mortality rates. In this model the consumer seeks to maximize her own welfare, represented by the function

$$(6) \quad U = \sum_{t=0}^n P_t U_t,$$

where  $P_t$  is the probability of living for exactly  $t$  years and  $U_t$  is her welfare if she lives for exactly  $t$  years. Each possible length of life is therefore represented by a different state of the world and the probabilities are those of being in each state. Given a length of life  $t$  the consumer's welfare is an increasing function of her consumption from year zero through year  $t$ :

$$(7) \quad U_t = \sum_{i=0}^{t-1} \frac{C_i^\beta}{(1+r)^i},$$

where  $r$  is a rate of discount and  $\beta$  is the elasticity of annual utility with respect to consumption. Two additional mortality variables are useful:  $D_t$  is the mortality rate in  $t$  years, and  $S_t$  is the probability of surviving up to year  $t$ . So,

$$(8) \quad S_t = \prod_{j=0}^{t-1} (1 - D_j),$$

and

$$(9) \quad P_t = D_t S_t = D_t \left[ \prod_{j=0}^{t-1} (1 - D_j) \right].$$

From the equations above one can derive the consumer's willingness to pay for an improvement in the chances of survival. The value of a reduction in the mortality rate at year  $t$  becomes

$$(10) \quad - \frac{\partial C_0}{\partial D_t} = \frac{1}{\beta} C_0 \left[ \sum_{j=t}^n \frac{(C_j/C_0)^\beta S_j}{(1+r)^j} \right] \frac{1}{(1 - D_0)(1 - D_t)}.$$

Under the further assumption that consumption is constant across all ages so that  $C_i = C_j = C_0$ , we get the price of an instantaneous reduction in today's mortality rate:

$$(11) \quad - \frac{\partial C_0}{\partial D_0} = \frac{1}{\beta} C_0 \sum_{j=0}^n \frac{S_j}{(1+r)^j} \frac{1}{(1 - D_0)^2}.$$

If  $D_0$  is very small, so that  $1/(1 - D_0)^2$  approaches unity, the right-hand side simplifies even further.

This formulation was chosen for its relative simplicity and its minimal data requirements, but it does rely on numerous assumptions which should be stated clearly. First, one should note that the specified utility function is separable over time and that both consumption and the discount rate are assumed to be constant over the consumer's life. Second, utility here is derived only from consumption—the consumer does not value life independently of the level of consumption. Third, the consumer does not incur any effort in obtaining  $C_t$ ; loss of utility from work, for example, does not enter the formula independently. Fourth, it is assumed that consumption is independent of the number of people living. If the entire cohort born in 1870 lived to the age of twenty, the wages and consumption would probably be different from those of the 1890 cohort. These externalities between consumers are disregarded in the following calculations.

Subject to these caveats we can proceed to derive an imputation of growth rates. Using the definitions of  $S_j$  and  $P_j$  we can rewrite the consumer's utility function as

$$(12) \quad U = \sum_{j=0}^n P_j \left[ \sum_{i=0}^{j-1} \frac{C_i^\beta}{(1+r)^i} \right] = \sum_{j=0}^n \frac{C_j^\beta S_j}{(1+r)^j}.$$

Using our assumption that  $C_i = C_j = C$  we get

$$(13) \quad U = C^\beta \left[ \sum_{j=0}^n \frac{S_{j+1}}{(1+r)^j} \right],$$

$$U(t) = C(t)^\beta \left[ \sum_{j=0}^n \frac{S_{j+1}(t)}{(1+r)^j} \right].$$

One can interpret the term in brackets as a measure of discounted life expectancy. Denoting this expression by  $L(t)$  we get

$$(14) \quad U(t) = C(t)^\beta L(t).$$

We can now define  $\hat{C}(t)$  to be the consumption that will leave the consumer indifferent to the choice between two mortality schedules: that of date  $t$  and that of the base year (here, 1870). So that

$$(15) \quad U[\hat{C}(t), D(1870)] = U[C(t), D(t)],$$

and using equation (14), we get

$$(16) \quad \hat{C}(t) = C(t)[L(t)/L(1870)]^{1/\beta},$$

or, in growth rates

$$(17) \quad G_{\hat{C}} = G_C + (G_L/\beta).$$

An important aspect of this calculation is that changes in life expectancy are assumed to be independent of the rise in income and consumption. Williamson (1984) objects to this assumption and extends the model to allow changes in life expectancy to be partly endogenous. He assumes that consumption's impact on longevity is best described by a hyperbola, so that the effect of an increase in consumption is bigger at low levels of consumption and then drops off. While this effect may have been important at the early stages of the decline in mortality, during the eighteenth and the early nineteenth centuries, we are not persuaded that it had a comparable impact at this later stage. In the critical post-1890 decline, it was primarily the *composition* of the consumption bundle rather than its *level* that brought about further changes in mortality. Learning about germs implied an awareness of how consumption affected health and this, in turn, brought changes in consumers' allocation of time and resources that led to lower mortality rates. It follows that it is legitimate to count the growth in life expectancy as separate from and in addition to the growth in income, for it was new knowledge, an exogenous change, that brought mortality down.

Two more parameters are needed for the estimation. The discount rate is

assumed here to be 5 percent per year. This follows both Usher (1973) and Williamson (1984) and is appealing because it is close to the yield of consols in England during this period; but the discounted life expectancy calculations are somewhat sensitive to this estimate, as both Usher and Williamson show. In choosing the elasticity of utility with respect to consumption,  $\beta$ , we once again followed the suggestions of Usher and Williamson and chose  $\beta$  to equal 0.3. The results are presented in table 4.5.

In table 4.5 we present the annual growth rates in real wages for Sweden, England and Wales, France, and Germany with and without accounting for changes in mortality levels. The first row shows a large growth rate in discounted life expectancy for all four countries, though the estimates range from a 0.1 percent change for Sweden (1871–1911) to a 0.22 percent change in England and Wales during the same period. There is also variation across the different periods. In England the major growth in life expectancy came after 1891 while in Germany and Sweden it is fairly constant across both periods examined.

Converting these annual growth rates in discounted life expectancy to annual growth rates in utility (using the elasticity  $\beta = 0.3$ ), we get the annual growth rate in utility due to an increase in life expectancy. These estimates vary from an annual growth rate of 0.72 percent in England (1871–1910) to 0.32 percent in Sweden over the same period. To interpret the impact of these changes, we have computed the annual increase in real wages for the countries

**Table 4.5** Welfare Analysis of Mortality Decline, Selected Countries:  
Annual Growth Rates (%)

	England 1871–1910	England 1871–91	Germany 1871–1901	Germany 1871–91	Sweden 1871–1911	Sweden 1871–91	France 1881–1910
Discounted life expectancy	0.22	0.06	0.2	0.2	0.1	0.13	0.11
*(1/ $\beta$ )	0.72	0.22	0.65	0.67	0.32	0.44	0.35
Real wages	1.12	1.74	1.26	1.24	3.57	2.95	0.7
“True” real wages	1.84	1.95	1.91	1.91	3.89	3.39	1.05
Growth due to increase in life expectancy	39.18	11.03	34.06	34.96	8.25	12.96	33.45

Sources: Mortality data:

England: Williamson (1984).

Germany: *Statistisches Jahrbuch für das Deutsche Reich: Herausgegeben von Kaiserlichen Statistischen Amt*. Berlin: Verlag von Puttkammer & Fühlbrecht. Population figures are from the 1904 issue, p. 6; survival probabilities are from the 1915 issue, p. 39.

Sweden: *Historisk statistik för Sverige, del 1, befolkning* (Historical statistics of Sweden, part I, population), 2d ed., 1720–1969. Stockholm: Statistiska Centralbyrå, 1969, pp. 16, 112–13.

France: Ministère du Commerce (service de la statistique générale de France), *Annuaire statistique: Statistique de la France*. Paris: Imprimerie Nationale, various issues. 1881 data are from the 1884 volume, pp. 7, 36–43; 1911 data are from the 1914–15 volume, pp. 9, 34.

Wage data: Williamson (1995, A26–A27, table A2.1).

in question, using real-wage data from Williamson (1995). The annual growth in real wages during this period ranged from 3.6 percent in Sweden to 0.7 percent in France. Adding the two together we get an annual increase in “true” real income of 1 percent (in France) to 3.9 percent (in Sweden). The last row of table 4.5 compares the impact of growth in life expectancy to that of the growth of true real wages. In all four countries the share of growth due to increased life expectancy is important. In England, over the period as a whole, nearly 40 percent of real growth is due to increased life expectancy. In Germany almost 35 percent of the annual growth rate is due to the decline in mortality, and in France the figure is 33 percent. It is interesting to compare these figures with those of Sweden (1871–1911 and 1871–91) and England (1871–91). In Sweden, during the half century in question, real wages rose faster than in the other countries, but mortality (already relatively low at the start of the period) did not decline much further. As a consequence, the increase in discounted life expectancy added only 8 to 13 percent of total true growth in income. In England growth in real wages was slightly higher during the first twenty years, while decline in mortality was faster during the later period. As a result the share of annual true growth due to an increase in life expectancy is much lower in the first period: 11 percent versus 39 percent.<sup>76</sup>

These results help address the McKeown-Fogel hypothesis once again. The data do not reveal a consistent relation between increases in income and increases in life expectancy. Some countries had higher income growth than others but smaller changes in mortality. Even for the same country, rises in life expectancy do not necessarily follow growth in income, as the case of England shows. These rough calculations are only a lower bound to the welfare improvements due to overall mortality decline, and yet they are impressive. Even though these forty years were not characterized by technological stagnation, these figures attribute some 8 to 39 percent of all welfare improvements during this time to a decline in mortality. If only, say, a third of this decline is ascribed to the increase in the demand for health-enhancing goods due to changes in consumer information, it no longer seems an exaggeration to place the Pasteur

76. The computations are rather sensitive to the choice of  $\beta$ , which should underline the need for treating them with great caution. The higher  $\beta$ , the lower the contribution of increased life expectancy to welfare increase. The reason for this is that we express the welfare gains of increased life expectancy in terms of consumption equivalents: the lower  $\beta$ , the bigger changes in consumption would have to be to make the consumer indifferent to the choice between two different mortality schedules. The sensitivity of our estimates of the annual growth rate in utility due to increased life expectancy is given below.

$\beta$	England 1871–1910	England 1871–91	Germany 1871–1901	Germany 1871–91	Sweden 1871–1911	Sweden 1871–91	France 1881–1910
0.1	2.16	0.65	1.95	2.01	0.96	1.32	1.06
0.3	0.72	0.22	0.65	0.67	0.32	0.44	0.35
0.5	0.43	0.13	0.39	0.40	0.19	0.26	0.21
0.8	0.27	0.08	0.24	0.25	0.12	0.16	0.13

revolution at center stage in the history of economic progress in the half century before 1914.

Although the figures in table 4.5 are in one sense upper bounds of the contribution of growing knowledge to economic welfare through higher values of  $A - \varepsilon$ , they are also downward biased because they only take into account the loss in consumption of the survivors themselves. A second calculation would add to that the benefits to parents of lower child and infant mortality. This research is still in progress, but its broad outline can be sketched here. The idea is that infant mortality imposes a cost similar to that of "child default" in the emigration literature. The technique involves a life-cycle model in which parents raise their children at a cost that is repaid when children reach maturity and pay society back by maintaining their aged parents and raising their own children. A death that occurs before the break-even point at which the individual has fully paid back his or her debt involves a net cost to society. The estimation of this cost parallels the computation carried out in Mokyr and Ó Gráda (1982).

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## Comment John C. Brown

This paper by Joel Mokyr and Rebecca Stein argues that the discovery and successful diffusion of the germ theory of disease—a new technology for household decision making—substantially explains that part of the great mortality decline that ended with the onset of World War I. Two perspectives have generally set the terms of the debate over what prompted the decline in mortality before effective medical treatment became available in the 1930s and 1940s. Nutritionists emphasize that improved resistance to disease resulted from rising living standards. Environmentalists credit enlightened public investments in sewers, waterworks, and other programs with reducing exposure to disease. Both approaches have eschewed developing models of economic behavior that go beyond these medical models of etiology and outcome to interpret mortality as the result of household choices constrained by relative prices, limited resources, and environmental risk.

Mokyr and Stein extend our understanding of the causes behind mortality decline by sketching out just such a model of household decision making within a household production framework. The model focuses upon the importance of household knowledge about what influenced health and diminished the risk of death. The germ theory of disease, developed initially by Pasteur and given strong empirical grounding by Koch's discoveries of the early 1880s, offered households new technologies for transforming consumption and time into better health. Households may have been so far away from best practice that simple reallocation of a limited budget may have had a powerful impact upon reducing mortality. Spending more time on washing and less on work, or more earnings on soap and less in the corner tavern, may have improved the chances that family members, particularly children and infants, survived the risk of infectious disease that characterized late-nineteenth-century living. The germ theory may have provided local officials with important suggestions about best-practice techniques, although most were already convinced by prevailing miasmatic theories that clean and abundant water, fresh air, and effective sewage disposal offered payoffs in reduced mortality. The germ theory's major role was its influence on household behavior. Its logic and consistency with the facts could persuade mothers to replace the treacle-soaked rag with a sterilized pacifier, where decades of carefully tabulated statistical regularities could not. If the germ theory takes on the leading role in the pre-1914 decline that the authors assign it, the welfare payoffs in longer lives from this single innovation rival the fruits of a half century of invention and capital accumulation. While I remain somewhat skeptical about the quantitative estimates of the germ theory's impact, I do not doubt that this paper's provocative thesis will enrich the debate on mortality decline.

The argument requires first winning acceptance for the model. It must then demonstrate that the key insights of bacteriological science of the 1880s had

diffused widely among households and community leaders by 1910. Finally, it requires convincing evidence that the diffusion of this innovation, rather than higher incomes or shifts in relative prices, account for the bulk of declines in mortality that yield such substantial increases in lifetime utility.

The paper achieves the first task with a fascinating historical narrative that casts turn-of-the-century campaigns for infant health, battles against flies, and fights for clean water in terms of exogenous changes in household technologies for improving health. The tales of ignorance of good hygienic practice and the diversity of applications of the germ theory hint at the size of the task that well-informed physicians, social workers, and others faced. The case that the gap was big between the best practice dictated by germ theory and the practice current among households would be strengthened with more evidence that household practices in matters hygienic in the 1880s were significantly different from practices in the 1920s or 1930s.

A more important issue arises from the key role of subjective risk assessment in the model. At the margin, the decision on how much more soap to buy (or whether to rent an apartment with an indoor tap) hinges upon the household's assessment of the payoff: its guess about the likelihood that more soap and accessible water will reduce the prospect of an infant contracting diarrhea. A key result of the literature on risk perception is the difficulty households have in assessing just those kinds of common, everyday risks that are essential to decision making on hygiene. Consumers today generally underestimate the probability of relatively low-risk, but more likely events and overestimate the probability of high-risk, but unlikely events (Slovic, Fischhoff, and Lichtenstein 1985, 246). The same may be true of consumers in 1900. It was not tuberculosis, the ubiquitous but silent killer of the nineteenth century, but the infrequent cholera and typhoid epidemics, with high case-mortality rates, that first attracted the sanitarians' attention. Were the same true of households, we would expect that even when medicine was armed with the germ theory of disease, there would still be slippage between medicine's best (and imperfect) knowledge about the payoff for doing things hygienically and households' own assessments of that payoff. Perhaps for this reason, many turn-of-the-century public health campaigns supplemented educational efforts with efforts to coerce or even bribe households. Housing inspection, regulation of milk supplies, and mandatory inoculations were all designed to enforce appropriate (or even excessive) levels of consumption of goods believed to reduce mortality. Efforts of German cities to increase breast-feeding typically included allowances to nursing mothers (Kintner 1985, 175–77).

While medical historians still debate the question of when the germ theory won out, most evidence points to the 1890s as the decade the best-educated physicians in the United States and Germany accepted the germ theory (Garipey 1994; Evans 1987, 490–507). The authors acknowledge the potential for a long lag between acceptance by physicians and diffusion into the practice of the poor of Dublin or Hester Street. As in any case of identifying changes in

demand for a nonmarketed good, the question of diffusion is difficult to resolve empirically. The authors choose the imaginative strategy of looking for evidence on shifts in the derived demand for inputs into health, holding prices and incomes constant. Thus, the evidence they present on the rise in the per capita consumption of soap in England in the face of price increases (particularly after 1900) offers encouraging support for an outward shift in demand and perhaps diffusion of the germ theory. Evidence that the time and cash price of water did not also fall during this period, as waterworks and indoor plumbing replaced the occasional well and pump in even small towns and villages, would strength this point. More of this kind of indirect information, including a closer examination of the correlates of trends in the labor force participation of married women and of breast-feeding throughout the industrialized West, would buttress the case for diffusion.

Perhaps the most vexing issue raised by this paper is how much of the eventual mortality decline resulted from the advances associated with the germ theory. The problem is straightforward. While this paper emphasizes exposure to infectious disease as an important influence on mortality, mortality also depends on resistance to disease and environmental influences such as weather conditions and pollution of the environment. The evidence on contrary trends in real wages for common labor and infant mortality presented by the authors offers a start at confronting the alternative hypothesis that incomes and prices mattered the most for mortality decline. There are further complications. The declines in child and infant mortality that the paper argues were most responsive to improved household hygiene occurred during a period of declining fertility. Some authors (e.g., Woods, Watterson, and Woodward 1989, 121–26) suggest that fertility decline, by lengthening birth intervals and diminishing the number of higher-parity births, could have contributed to mortality decline. Identifying the separate contribution of the germ theory is also difficult, since miasmatic theories dominant until at least the 1880s recommended many of the same general principles as the new bacteriology: lots of clean water, clean air, and effective disposal of sewage.

A convincing explanation for mortality decline must also be consistent with the observed pattern of change in disease-specific mortality. Some diseases were susceptible to the prophylaxis recommended by the germ theory; others were not. The fall in mortality from tuberculosis contributed substantially to reduced deaths among adults in many industrialized countries, but it is uncertain whether it resulted from a decline in exposure to the disease. Tuberculin testing in England and Germany from 1913 to the 1940s revealed rates of exposure to tuberculosis of up to 90 percent, enough to suggest that other factors also contributed to the decline (Otto, Spree, and Vögele 1990, 301–2; Guha 1994, 104).

These considerations suggest that the lower-bound estimates of welfare gains that can be ascribed to the germ theory, as presented in table 4.5, should be revised downward. The experience of German cities suggests the magnitude

of such an adjustment. Confining the period of potential influence to the years after 1880 seems reasonable in view of the historical literature. This adjustment reduces the annual growth in discounted life expectancy over the entire period 1871–1900 to about 0.15 percent. The diseases where application of the germ theory offered the soundest prophylaxis—gastrointestinal disorders, typhoid, and diphtheria—accounted for about 18 percent of the overall mortality decline from the late 1870s until the 1900s (Vögele 1993, table 5). Assuming the same other parameters as the paper, the annual gain to lifetime real wages suggested by this lower-bound calculation is about 0.09 ( $3.3 * 0.15 * 0.18$ ) percent. As a share of “true” real-wage growth reflecting gains to lifetime consumption, the lower bound is about 7 percent.

Is this lower bound a reasonable estimate of gains from the germ theory? Three things suggest that it is too low and why the Pasteur revolution merits a closer look. Demographic historians emphasize the interrelatedness of morbidity experience and resistance to further infection. In particular, the gastrointestinal diseases that afflicted infants and young children left the survivors weakened and prone to other sources of infection (Preston and Van de Walle 1978). Reducing morbidity from these diseases could have yielded substantial payoffs in reduced mortality from other diseases. More research is needed on how large the payoff from breaking into the gastrointestinal complex may have been. Little is also known about how much households valued reductions in mortality risk. Data from housing markets, labor markets, or episodes of cholera or typhoid may offer some clues. Facing a risk of upward of two in one hundred of dying from the 1892 Hamburg cholera epidemic, over 2 percent of the population—middle and upper classes—fled the city in the few days before a quarantine cut off Hamburg from communication with the outside, and they remained out of the city for about three months (Evans 1987, 348, 408).

Indeed, although the case for substantial benefits before 1914 may need closer examination, World War I and the years following offer potential for substantial gains from the germ theory. The germ theory is widely credited with saving the lives of thousands of combatants who would otherwise have fallen prey to the traditional battlefield killers of typhoid and dysentery. During the subsequent two decades of peace, gains to well-being from continued increases in life expectancy must compare favorably with the anemic growth in real wages of the period.

In the end, this paper raises a key question about the allocation of public resources. The essential hypothesis of the germ theory revolution is that social conditions—poverty, irregular incomes, and poor living conditions—mattered less for household health than how households used what limited resources they had. For this reason, it poses a direct challenge to those who argue that living standards were crucial for improvements in health outcomes during an era when access to medical care made only a minor difference. Did the concern of the social hygienists with the striking correlations between mortality and difficult social conditions distract them from the underlying true cause of ill

health of the entire population: ignorance? This question is important for evaluating debates about living standards during the era of industrialization and the success of efforts to reform urban living conditions. It is one of the many issues this thought-provoking paper raises that will likely inform future debates about the great mortality decline.

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