TECHNOLOGICAL SELECTION, INFORMATION, AND CHANGING HOUSEHOLD BEHAVIOR, 1850-1914

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Revised, December 1996

An earlier version of this paper appeared as “La Tecnologia, l'informazione e le famiglie” in Renato Giannetti, ed., *Nel Mito di Prometeo: l'Innovazione Tecnologica dalla Rivoluzione Industriale ad oggi*. Firenze: Ponte Alle Grazie, 1996, pp. 145-184.

This paper is part of my forthcoming *Neither Chance nor Necessity: Evolutionary Models and Economic History* (Princeton University Press, 1998). Draft, not to be cited. Comments welcome.

Introduction

In recent years, there has been a veritable flurry of literature dealing with the application of evolutionary models to technological change, both theoretical contributions and investigations of a more historical nature. The adaptationist view considering evolution as basically functionalist and thus little more than a process by which selectors pick the best possible strategy to deal with their environment has not been universally accepted by economists. The most explicit statement in this regard can be found in Geoffrey Hodgson's work and his list of "problems for Dr. Pangloss."[1] Yet actual historical examples of distinctly inferior technological outcomes are, in fact, quite rare. The widely cited example of the QWERTY keyboard, proposed by Paul David, is an interesting curiosum but not entirely persuasive.[2] Other examples can be found, such as the lock-in into a low-definition color television system in the United States and the use of heavy water reactors in power generation (Robin Cowan, 1990), but on the whole it seems that in modern industrial societies the competitive environment provides a selection mechanism that picks techniques reasonably well at least among those that are available.

The evolutionary literature normally considers the "routine" or "technique" as its fundamental unit of selection (Nelson and Winter, 1982). A technique might be regarded as a set of instructions on how to carry out certain tasks that lead to material improvement (e.g. production). As I have argued elsewhere (Mokyr, 1996), techniques are expressions or carriers of the information on which they are based in a way comparable (but not identical) to the way genetic information is expressed in the phenotypes of living beings. Superfecundity (that is, a proliferation of options) leads to competition and competition leads to selection. The net outcome of this process is the structure of technology used by the economy. If firms are sufficiently competitive, there is some presumption that more efficient techniques will be picked, unless there are constraints such as network externalities, economies of scale, or effective political resistance to technological progress that prevent their selection.

This literature has failed to take notice of technological choices made by households. We typically

[1] See Hodgson (1993), especially chapter 13. See also Mokyr (1992).

[2] David (1986). For a criticism, see Liebowitz and Margolis (1990).

do not think of households as units that make such choices, but a moment's reflection reveals that they do so all the time. In the consumption process, households do not just purchase consumer goods but convert them into their final uses by using a set of techniques I will call *recipes*.[3] These final uses include the satisfaction of the biological and psychological needs underlying demand but also the indirect effect of consumption on health and longevity. These recipes like the production techniques of firms, represent technological knowledge available to the household and they determine not only the efficiency with which the inputs into the household production function (that is, the goods the household buys at the market) are converted into final services, but also the composition of the bundles actually purchased. The idea that households actually “produce” in this way and thus employ technology is hardly new and is by now a standard part of neoclassical theory, the protestations of sociologists (e.g., Thomas, 1995, p. 333) notwithstanding. The evolutionary models that a growing number of economists and other writers on technology have been applying to models of technological change should apply to changes in households as well. Yet the generation and diffusion of recipes follows very different rules than firm-level of technology. The historical implications of this difference are profound.

The seemingly most obvious difference between firms and households is that firms are pressed into using efficient techniques because they compete with each other for scarce resources, profits, and market share and eventually survival. Households compete with each other for resources as well, but once they have been given an allocation and purchased a bundle of commodities, there are no comparable competitive pressures on them to use these resources efficiently. This is not to say that no such pressures exist. Partners with very poor household skills using low-efficiency recipes may have found themselves at a disadvantage in the marriage market and failed to reproduce. Conformism and imitation may have been more important than selection: in all ages social conventions evolved that pressured households to follow certain practices customary in a society or risk social ostracism. If such social conventions increased fitness, they would help move society toward an optimum. Yet there is no evidence that they invariably did so as the adoption of

[3]Recipes should not be confused with technologies that are used by the household but generated outside it. Thus the invention of the vacuum cleaner is not a change in household recipe, but learning to use one properly is. In what follows I shall use the term "household technologies" for technologies that are purchased by the household and "recipes" for the knowledge possessed by the household.

smoking and narcotics and changing fashion in clothing suggest.

It might be thought that differential survival would, in the long run, guarantee that inferior and harmful recipes will lose out because badly managed households that use them will suffer higher mortality rates and vanish in the long run just like badly managed firms. The traits of household are acquired from other households. If vertical transmission of information is more important than horizontal or oblique transmission, the children of poorly managed households are more likely to be bad homemakers themselves. If "bad" is defined in terms of "fitness" -- that is, survival or life expectancy, natural selection will eventually provide an advantage to those "germ lines" with better household techniques. In that case selection thus takes place in its most literal Darwinian sense. However, the correct choices of techniques in the household would involve better health as well as better contraceptive techniques, meaning that well-managed households would have both lower death rates and lower birth rates, with the net result unknown. Finally, the objection could be raised that even in highly competitive environments, evolutionary models imply that the actual techniques picked are not necessarily globally optimal and for that reason we will observe a distribution of techniques rather than a single best-practice in use.[4]

The most interesting selection mechanism in the economic history of technology is not the one that selects the most successful agents, be they firms or households. Rather, the firms and households themselves do the selecting. They make direct decisions as to which of the many ways to skin a cat to employ. When a new technique is generated or invented, they must decide whether or not to select this new technique. The competition, in other words, is not just between firms and households trying to survive and reproduce, but between many different techniques which try to be employed by the selectors. Selection here is not metaphorical -- as Darwin's was -- but conscious and purposeful. At this level, it is not clear that there is a qualitative difference between firms and households: is there more competition among engineering prescriptions on how to make sulphuric acid or grow peaches than there is among household recipes how to

[4]This is a standard result in evolutionary theory. Optimizing selection by itself only guarantees that the system will come to an equilibrium at a *local* peak in the fitness landscape. For a recent re-statement, see for instance Kauffman (1995), pp. 149-89, 248. The current state of the art on the issue of optimality in the theory of evolution is clearly characterized by a lack of consensus. See the essays in Dupré (1987), especially the ones by Philip Kitcher and Richard Lewontin.

cook soup and clean the kitchen afterwards? In any event, the basic target of selection here is the recipe, not the firm or the household, and this will be the focus of the discussion below.

Given the unreliability of the blind "survival of the fittest" mechanisms, a second difference between households and firms becomes important, namely the *ability* to choose among competing techniques. Households choose among different techniques based on certain priors and beliefs on what effects and side-effects different alternatives have. Household chores are repeated over and over again and thus would be subjected to revision if they were inefficient. Almost every household learns how long to boil pasta and if it cannot accomplish this, how to purchase ready-made food. More complex information, particularly the impact of consumption on health, is however more difficult to evaluate and that effectiveness of these recipes is hard to test in many cases. The questions the consumer needs the answer to are of the type "is this quantity of a given consumption good best for my health and that of my family?" and "is the recipe by which I transform this good into its final form optimal?" Such knowledge is often complicated and hard to verify. While the difference between households and firms is thus one of degree, the degree is of decisive importance here. All told, households are subject to quite different competitive pressures and information constraints in their choice of techniques than firms and we should not be surprised to see the proliferation and persistence of long-term practices and techniques that appear to us to be inefficient and inferior given certain objective functions.

Consider the question of disease prevention. While it is of course true that to some extent it had always been felt that cleanliness was healthy and desirable, the basic knowledge of infectious diseases and their transmission mechanism was developed in the last third of the nineteenth century, nutrition science was not developed until the 1910s, and a detailed understanding of the immune system not until after 1945. In the absence of scientific knowledge, past consumers had two options. They could either follow folk traditions and *obiter dicta* from people they trusted (priests, schoolteachers, medical people, "wise women,") or rely on their own experience. It seems plausible that in the absence of an understanding of the nature of disease, they tended to accept authority without much question.[5] In a post-enlightenment age of growing rationalism

[5] Pliny writes "minus credunt quae ad suam salutem pertinent, si intelligunt." (People believe less in things pertaining to their health if they can understand them).

and empiricism, authority and tradition necessarily lost power and people started to question age-old beliefs. Testing the effect of consumption goods on health, from garlic to hard soap to quinine, ran into inference problems because the number of variables usually was large, the number of observations small, and the effects of consumption often followed with a long and unknown time-lag. Comparing alternatives, let alone evaluating the costs of type I and type II errors, was thus difficult and many consumers continued to rely on traditional knowledge and old wives' tales in choosing recipes. Many of those practices may have been sound, and some of them are being confirmed in our own age by multivariate research. Yet in the absence of an understanding of what makes one ill, consumers often had to make their decisions on the basis of "black boxes."

More generally, the approach I advocate below is akin to the so-called cognitive limitations model (closely related to Simon's bounded rationality idea), in which consumers are neither perfectly informed nor totally ignorant of the implications of their choices. They try to process the information available rationally in making their choices. Yet in so-doing, they are limited in at least four ways. First, the best information available may be defective or even completely false. Second, best practice knowledge may fail to reach large segments of society. Third, alternative and competing dogmas (scientific or otherwise) may exist, making it difficult for consumers to decide which one to prefer. Consequently, they may have access to best practice knowledge and yet refuse to follow its recommendations, not having been persuaded that the health advantages of a particular good are worth the costs or effort. Finally, because often the costs or benefits were in terms of changed probabilities rather than certain effects, consumers may have made systematic errors in assessing the stochastic impact of their behavior. Low probability events are often either under- or overestimated by consumers depending on how the matter is brought to their attention; large-probability risks are systematically underestimated (See e.g. Viscusi, 1992, pp. 22-24 and sources cited there).

Above all, an explicit consideration of household technology in an evolutionary approach provides another explanation of the Demographic Revolution, especially the second stage of it in the late nineteenth century, when mortality rates (and especially child- and infant mortality rates declined rapidly). This decline has remained one of the most lively subjects in the literature of economic history and historical demography. As well it should be -- surely, from the point of view of the standard of living it ranks among the most momentous events in history. It is apparent that scholars have failed to take technology properly into account in explaining this event (Mokyr, 1993; Easterlin, 1995). Once it became clear that medical science could not take credit for the decline in infectious disease, economic historians hastened to either support the notion that rising incomes led to rising nutritional status which in turn strengthened the body's immune system's ability to ward off infection, or to reject that notion altogether and in its stead to accept the "reduced exposure" notion according to which public works improved the environment in which most people lived enough to reduce the incidence of killer diseases. The framework proposed in this paper combines elements of both these approaches in a somewhat different way. It is proposed as a complement rather than as an alternative to these theories. For more details, see Mokyr and Stein (1996, forthcoming) and Mokyr (1993, 1995).

A Simple Model

To illustrate the insight that this model provides for the decline of mortality in Europe, assume there are two goods, A which actually enhances health, and B, which does not affect it one way or another.[6] This simple set-up is drawn in fig. 1. If the consumer is totally unaware to the effect of A on his health, she will choose point $\hat{E}$, ignoring the indirect effect of A on H in the process, implying an overall level of H of $\hat{H}$ which is taken parametrically. A consumer who is *fully* aware of the healthy effect of A will optimize over A, B, and H (A), choosing E' with the corresponding level of health H**. A consumer who operates somewhere in between will choose a point like E* or E**.

[6] The assumption that B and H are independent is not innocuous. As shown in the appendix, if *both* goods affect health in ways that are imperfectly understood there is no unambiguous relation between learning and health improvement and in those cases "a little learning could be a dangerous thing."

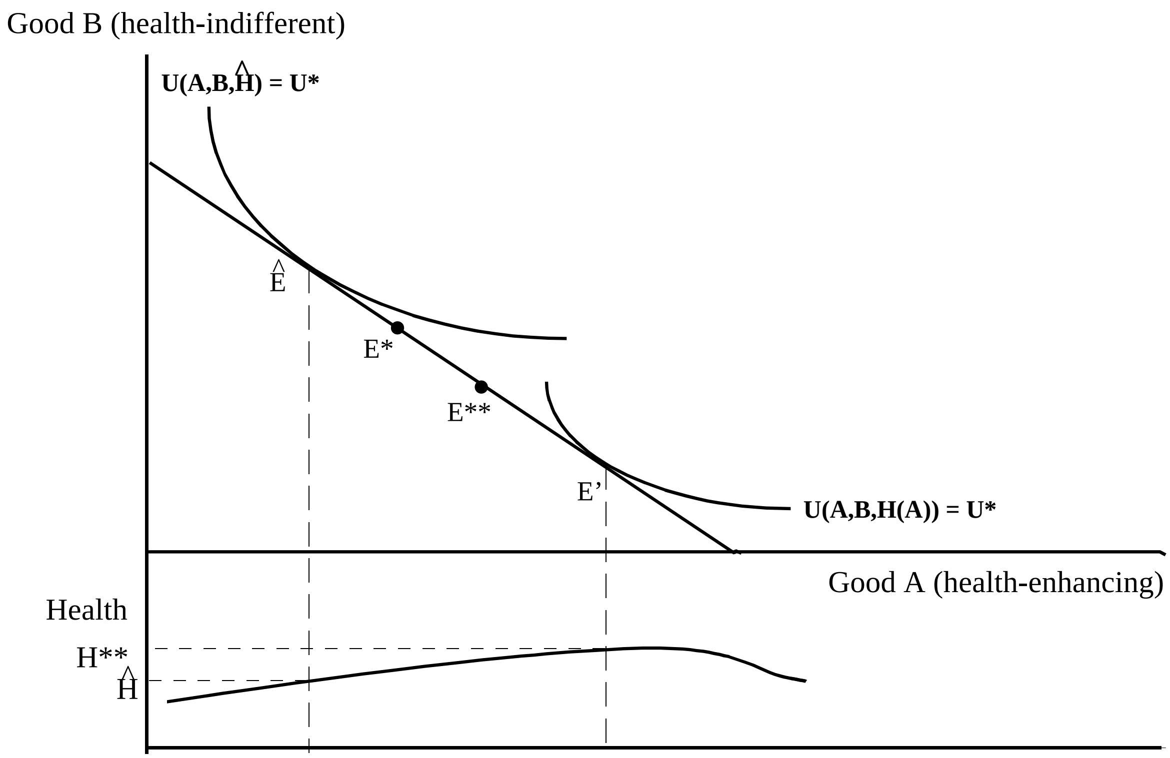
Good B (health-indifferent)
U(A,B,Ĥ) = U*
Ê
E*
E**
E'
U(A,B,H(A)) = U*
Good A (health-enhancing)
Health
H**
Ĥ

Figure 1

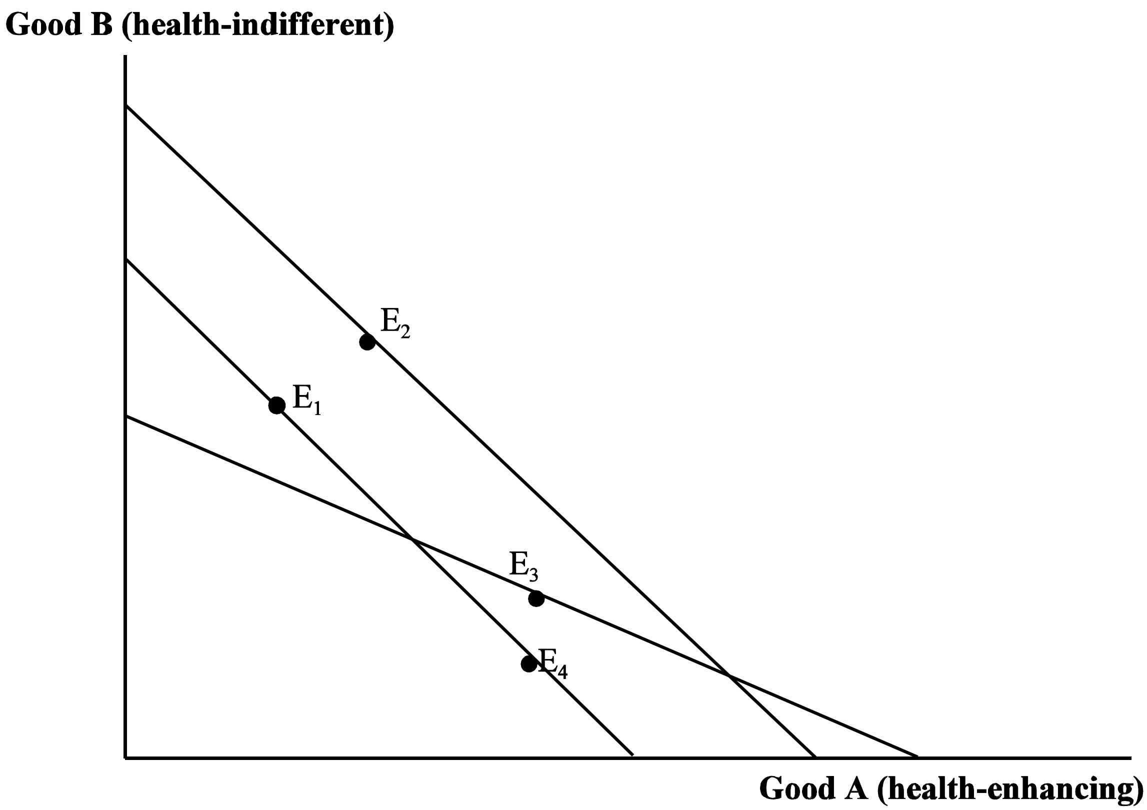

Figure 2

Fig. 2 illustrates that there are three ways in which health can improve. One is through rising income, holding knowledge constant. If A is a normal good, consumption of A rises with income (from E_1 to E_2), and thus health improves. A second change is a change in relative prices, favoring A over B. Technological change favoring A over B (of the type we have termed "household technology") would have this effect, as did the public works projects in the late nineteenth century that provided sewage works, clean running water and inspection of food that can all be regarded as a decline in the relative price of goods with a high health elasticity, causing a substitution effect that improved health.[7] This move is described by the move from E_1 to E_3. Finally, we can view the change as a learning effect in which consumers increase their consumption of A at the expense of B, going from E* to E** in terms of fig. 1. This would cause them to switch shift from

[7]At times, changes in relative prices had totally unintended side-effects on health. Economic reforms in post-Communist Central Europe drove up prices of fatty meat, encouraging Czechs and Slovaks to eat more fruits and vegetables; the result was a drop in cholesterol intake and obesity and a decline in heart disease (*The Economist*, Jan. 7-13, 1995, p. 42).

an initial point like E_1 to a healthier point like E_4. Such a movement would be tantamount to an increase in efficiency and implies a very high rate of return on government programs in nutrition, health education and propaganda.[8]

This kind of setup explains consistent and repeated selection of "inferior" points such as E* in fig. 1 by stressing the failure of consumers to realize the indirect effect of consumption on health. The suboptimality of this point is a matter of definitions. We can, of course, define the maximization process of (1) as subject to three constraints: the budget constrain, the time constraint, and an information constraint. If we allow an information constraint in explicitly, point E* would be considered as optimal.[9] From an ex post analytical point of view this seems a dead end: since the information constraint, which is really a subjective prior on a probability distribution, is never directly observed, no selected technology would ever seem suboptimal. One reasonable approach might be that the "best-practice" science *at the time* be introduced as a constraint. No consumer in the past could be said to have made suboptimal choices by failing to follow rules nobody knew at that time. Yet any consumer who did not use the best available knowledge *could* have done better. That they did not do so is in no way surprising, nor is it necessarily evidence of irrational behavior. The fact that something is known to somebody at a given point of time does not mean that this was obviously accessible to everybody. It does suggest that the diffusion of best practice techniques may lead to increased health and higher life expectancy even without rising living standards (Mokyr, 1993; Mokyr and Stein, 1994).

In practice, distinguishing between changes in household behavior and relative prices is not always easy, and decomposing observed changesbetween movements from E_1 to E_2 and E_3 in terms of fig. 2 in historical reality may prove tricky. In many cases, improved understanding simultaneously affected the

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[8]A modern World Bank study estimates that micronutrient (vitamins, iodine, iron etc.) deficiencies in third-world diets cost these countries 5 percent of their GDP while they could be remedied at a cost of 0.3 percent of GDP -- a rate of return of 1600 percent. The trouble is that even today many governments are unaware, for example, of the importance of traces of iodine in the food causing blindness and cretinism. Very small redeployments of resources can, at times, provide technological fixes for serious medical problems -- the addition of Vitamin D to margarine eliminating rickets in Europe early in this century (*The Economist*, Nov. 23, 1996, p. 100).

[9]The possibility that a consumer is "aware of" better recipes but refuses to adapt (that is, she is not persuaded) must be considered as a special case in the information constraint.

demand and the supply sides, and the shifts were often coordinated.[10] Yet this should not blind us to the fundamental difference between households responding to a change in their knowledge, which is a demand side phenomenon, and a change in relative prices faced by the household which is on the supply side.

To distinguish between the alternatives, it is useful to set up the problem a little more formally.[11] As in standard theory the consumer j maximizes a utility function:

(1) $U_j = U_j(X_{1j} \ldots X_{nj}, H_j, L_E, L_D)$

where H is a composite variable of family life expectancy and health, L's are time spent on leisure and domestic work respectively and consumption is subject to the usual budget constraints $\Sigma X_i P_i = Y$ and $L_E + L_D + L_W = L^*$.[12] The special characteristic of this setup is that H is determined by the household production function:

(2) $H_j = E + f(X_{ij} \ldots X_{nj}; L_D)$

E is a common factor independent of the consumption basket ("environment"), f is the household production function that transforms the goods consumed and time spent producing them into better health and longer lives for the members of the household. The function f is an unobserved technical relationship. It converts the X's and L_D into a vector of characteristics that describe the individual's physical well-being given some level of E. The food component of the X's takes account not only of caloric intake but also of vitamins, minerals, fiber, substances combatting free radicals such as anti-oxidants and so on. Home-heating,

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[10] In some cases, the technical problems were easily solved once the benefits were recognized. An example is the increase in demand for hot water. As Siegfried Giedion has pointed out, the early nineteenth century household still drew most of its hot water in buckets from the kitchen, as it had done in Homeric times. This changed suddenly after 1850 or so, when a variety of boiler designs started to appear. Few of these incorporated technical knowledge that had not been available at the time of Louis XIV, but the universal understanding that hot water was essential to hygiene and thus good health became the driving force behind these changes in technology.

[11] The approach here is a special case of home production, and I have not bothered to include most of the comparative statics results as they are well known. The seminal work here is Becker (1981). For a recent good summary, see Cigno (1993). An application to health of Becker's framework seems obvious. For an early example, see Grossman (1972).

[12] Whether H measures life expectancy alone, "health" (the absence of morbidity) or some combination is a difficult issue. The issue seems more perplexing for today's medical environment in which morbidity and mortality are less closely connected. In the age in which infectious diseases were the main causes of death, the distinction seems less acute, though Riley (1991b) suggests that while mortality declined during the 19th century, morbidity was on a rise.

cleanliness, medical care, and physical exercise are other examples of X's that enter equation (2). The function f describes such effects as exposure to harmful micro-organisms and chemicals, the impact of behavior and nutrition on the cardiovascular system, as well as the interaction between consumption and the human immune system. Moreover, f is assumed to satisfy the condition that the conversion is *efficient* (that is, no X's are wasted in the production process).[13] The shape of f is, however, not fully known to best-practice science, much less to the household. Behavior is therefore determined by the function:

$$(3) \quad H_j^e = E + \sum_i [A_i - \varepsilon_{ij}] F_i(X_{ij}, L_D) \qquad \forall j$$

Where H_j^e is the prior that the consumer has over the determination of H, E is an environment over which the consumer has no control, A_i is a constant shift factor that measures the degree to which the "best-practice" grasps the true effects of recipes, and ε_j is an individual-specific measure of the difference between this individual's technology and the best-practice technology regarding good i. The term $A_i - \varepsilon_{ij}$ measures the degree to which consumer j is aware of and believes the mapping of X_i into H. We define it here for simplicity as a multiplicative deviation from "ideal" priors. There is a vector *A* of best practice recipes associated with the X-vector, but households may not be using the best-practice technique thus being ε below where they would be if they followed 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 U after substituting (2) into (1). This assumes a world of perfect information in which all A's equal unity and all ε's zero, corresponding to point E' in fig. 1. This means not only that scientists have exactly figured out the functional relation between H and every X, but that everyone has access to that knowledge, believes it, and uses it flawlessly so that the consumer maximizes $U(X,H, L_D,L_E)$ "correctly" subject only to the budget constraint. Second, we may define $\hat{X}$, a vector of consumption for a consumer who is completely ignorant of the effect of consumption on health, so that $A - \varepsilon_j = 0$ for all X's, corresponding to $\hat{E}$ in fig. 1. Here consumption is entirely based on "primitive" utility

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[13] By this I mean that each X is directed toward the use where it can achieve the best effect on H. For instance, the body allocates proteins to the formation of new cells rather than burn them up for energy, and there are no parasites consuming some of the X's. This assumption is required so that for each set of X's and L_D there exists a unique level of H for each individual. This implies that the crucial part of each recipe is the quantity and quality of the ingredients and not the details of preparation -- clearly a simplifying assumption.

maximization *strictu sensu* disregarding the effect of the X's on H. We define the actual consumption, conditional on A_i-, $_{ij}$ of consumer j of good i, as X^* where normally for each good X^* … X^{**}, $\hat{X}$. It is possible that the completely ignorant consumer would consume by coincidence just the right amount of some X's ($\hat{X}$ = X_i^{**}), which holds for example if $F'(\hat{X}_i) = 0$, so that X_i has exactly zero marginal impact on health.[14] It is also possible that $\hat{X}$ is such that its *average* impact on health is quite significant even when *A* is quite low. 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 low levels of income and the absence of any systematic knowledge of the nutritional qualities of the potato. Furthermore, if a good satisfies $X^* > 0$ and $\hat{X} = 0$, we have what we may call a *pure health good*, such as snake oil or antibiotics, which conveys no utility except its putative medical effects. If a good satisfies $F'(\hat{X}) = 0$, even a completely ignorant consumer receives the full health-enhancing effect of that good merely as a by-product of his or her appetite.

Second, it may be noted that, because when X^* … X^{**} we are looking at a "second best" kind of situation, a partial improvement (an increase in A or a decline in ,) cannot be *guaranteed* to raise the objective function H (although they are likely to). The formal demonstration of this proposition in a simple two-good model is presented in the appendix, but the intuition is quite straightforward: since the consumer has to spend her income, she will pick a certain combination of goods according to her taste and partial information. By updating her information on one particular good, and learning that this good is better for her health that she had previously thought, she will increase consumption of this good, but therefore by necessity reduce consumption of another good. There is no guarantee that the loss in health from curtailing

[14] This would occur if, for any X^* which maximizes utility, the following condition happened to hold:

$$\frac{\frac{MU}{MH}\frac{MH}{MX_i} \% \frac{MU}{MX_i}}{\frac{MU}{MH}\frac{MH}{MX_i} \% \frac{MU}{MX_j}} \,,\, \frac{P_i}{P_j}$$

Where P_i is the full price of X_i (including time cost) and MH/MX_i=F'_i.

consumption on other goods is less than the gain from increasing the good in question.

Third, there are few a priori constraints on *A* and , and thus on the relation between X^* and $\hat{X}$. Consequently the effect of changes in *A* and , on demand depends on F' (the marginal impact of any good on health) as well as on prior levels of *A* and ,. Normally, we would presume that $0 < A_i < 1$, that is, best practice is neither perfectly informed nor completely ignorant. In principle *A* could be negative, meaning that "best practice" technology is worse than complete ignorance, for example, when it believes that a particular good, which is actually harmful, enhances health (for instance, the smoking of tobacco was widely prescribed by 17th century doctors as a cure for a variety of respiratory afflictions; marijuana, in our own age, may be an example of the reverse). It is possible for *A* to be positive yet *A*-, is negative (when mistaken folk "wisdom" overrides the knowledge of scientists). It is even conceivable that , is negative in which case (assuming A < 1) the consumer is actually doing better than the best-practice technology recommendations. This could occur when the health-enhancing practices are adopted for extraneous reasons (e.g., diet restrictions based on religious considerations). It is possible for *A*-, > 1 to be true. This means that the consumer is exaggerating the perceived effect of the good on her health and thus *over*consuming it to the point where its quantity is superoptimal. Fourth, this set-up shows that health could be improving even without any increase in *A*-, but 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 H. For this to occur, we have to assume that

$$\sum_i \frac{\partial F_i}{\partial X_i}\frac{\partial X_i}{\partial Y} > 0 \qquad (4)$$

that is, the correlation between income elasticity and the health-enhancing effect of all goods together is positive. This condition does not hold invariably: 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).[15]

This formulation abstracts from the historical reality in a number of obvious respects. One is that it makes no distinction between the household and the individual. In the 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, but this time-cost was disproportionately born by women (Ruth Cowan, 1983; Thomas, 1995). In other words, the L_D may be supplied by a *different* person than the person whose , appears in equation (3). If different members of the household disagree about , , it is far from clear how to aggregate the different values of the H^e 's and thus how the actual decisions are made.[16] This is compounded by the nature of H itself: rather than a composite variable, it really is a matrix of variables, with a vector of health characteristics defined for each member of the household. How one trades off the health of one member against another remains an intrahousehold bargaining problem. Another problem is that it abstracts from inter-household 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 H of another. Thirdly, when industrialization caused more and more individuals to spend large amounts of time outside their homes in work places, H was affected by the working environment as well, an effect that could be included in the shadow price of leisure. Fourthly, by migrating between rural and urban environments, individuals could indirectly choose among different values of E. Before 1890, urban environments were, on the whole, far more noisome than rural areas, and urbanization

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

[16] Interestingly enough, recent work on intra-household bargaining deal with cooperative and non-cooperative solutions to the consumption of common ("public") goods on which the members have different preferences, but do not deal with the possibility that they may have different views on *how* common preferences are to be achieved. See Lundberg and Pollak (1996).

in the nineteenth century clearly slowed down the mortality decline. Finally, the analysis above abstracts from the often complex dynamic relation between some of the X's and H: while the symptoms of Salmonella poisoning occur 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. The eating of raw cabbage reduces the probability of 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 ,'s.[17] Many of the X's have the interpretation of investment, as consumption today may affect health many years in the future (Grossman, 1972). 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 he or 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 effort. Yet life expectancy *itself* determines simultaneously the subjective rate of discount, producing positive feedback in the investment in health.

Another dimension in which this analysis oversimplifies is that the consumption of health-enhancing goods may be constrained even if the consumer is aware of their benefits. This would occur if there are, for example, indivisibilities in the consumption of certain goods. One cannot have half a toilet, of course, and while toilets and kitchens were shared between families, this gave rise to serious externalities. A clean water-supply piped in from a distance was clearly something that households could not provide for themselves individually. Many private goods were complementary with these publicly provided goods: a flush toilet was a private good, but could not be used without publicly provided sewage and running water networks. Thus, some of the X's with the most favorable impact on H had a public good character, from the drainage of swamps to the inspection of milk quality. Yet the realization that some of the X's were not easily provided

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[17] Thus, it is difficult to explain the failure of people to give up smoking despite the obvious knowledge that smoking is health-endangering without taking account of the long time lapsing between the beginning of the smoking habit and the penalty. Yet the smoking example also shows that there are more complex forces at work, because the United States is clearly much more attuned to the dangers of smoking yet there is no evidence that the subjective rate of discount is much lower in the United States than in Japan or Europe.

by the market does not invalidate the analysis. Once the consumers are aware and persuaded of the beneficial effects of certain public works, they will demand from their politicians the provision of the goods with the desirable characteristics, shifting the action from the commodity market to the political market (Brown, 1988). Moreover, political decision makers, too, were subject to learning and persuasion, and a function similar to equation (3) above can be written down to describe how they were persuaded by new knowledge to change the bundle of public goods they provided. Much of the literature has, in fact, focused on the *public* dimension of health improvement, neglecting almost entirely the private learning by households.

Furthermore, the simple model ignores the basically stochastic nature of equation 2. When we say that $F'(X_i) > 0$, what we really mean that prob $(H > H^*)|X^* >$ prob $(H>H^*)|X^{**}$ if $X^* > X^{**}$. That is, if the consumer consumes more of X, his or her *chances of being healthier* are better. This observation is immaterial if she fully understands that in some cases the relation does not work and maximizes *expected* utility, that is, the consumer has a prior estimate of ΔP, the difference in the probability of contracting a disease conditional on two different levels of consumption of X. Such "statistical" thinking, much as it is natural to our own age, was still in its infancy in the middle of the eighteenth century.[18] Consumers drew upon the wisdom of the past and upon inferences from their own limited experience. A few exceptions might be misinterpreted as "counterexamples" to an iron rule and persuade consumers that a useless procedure was beneficial or the reverse.

Of central importance to the question of technological selection by households is the allocation of time. Assume for simplicity that the time worked outside the house, L_w, is fixed. Let A_D and ε_D denote the values of A and ε with respect to time allocated to housekeeping labor.[19] Then the equilibrium allocation of time is given by the equation

$$(5) \qquad \frac{\partial U}{\partial H}\frac{\partial H}{\partial L_D}(A_D - \varepsilon_D) + \frac{\partial U}{\partial L_D} = \frac{\partial U}{\partial L_E}$$

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[18] Modern work on risk assessment related to smoking shows that consumers have a reasonably accurate estimate of ΔP. See Viscusi (1992).

[19] Note that L_D can be spent on many different chores, and that the effect of each chore on H may be quite different. We are assuming here that the marginal effect of health work is equal along the various chores.

which describes the equilibrium at point V in figure 3. The left hand of the equation defines the curve DD and the right hand EE. An increase in A_D-, $_D$, due to an increased awareness of the health benefits of clean environments will shift the DD curve to the left and will decrease the consumption of leisure from OL_1 to OL_2 and increase the amount of work carried out inside the house from L_1P to L_2P.

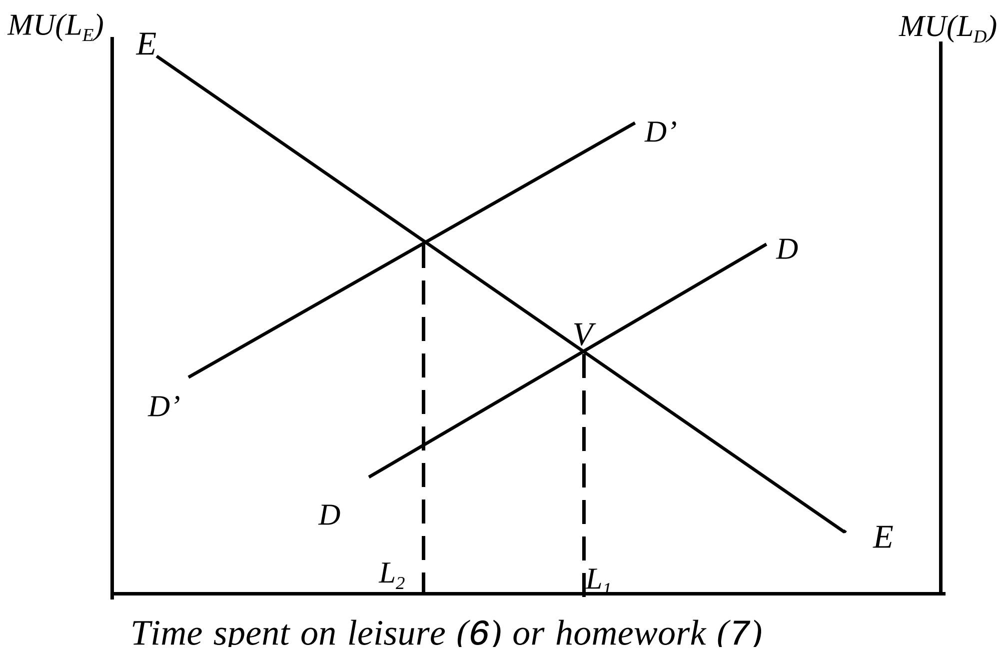

Figure 3

The framework described here also helps in understanding the simultaneous determination of L_D and its price. Consider fig. 4, which resembles a standard demand and supply curve, but is sufficiently different from it to merit some explanation. The X-axis measures the output of domestic work in "units of cleanliness" -- clearly a hypothetical index number. The Y-axis measures hours spent *per unit* of cleanliness. The total amount of time spent on cleaning is thus a rectangle such as HEOC. A technological change in household technology (say, the adoption of the vacuum cleaner) as distinct from household recipes, depicted by a shift in the curve SS to S'S', has an ambiguous effect: on the one hand the marginal product of an hour of homework is higher than before, but on the other hand the marginal utility of more cleanliness is declining. Depending on the elasticity of the DD curve, the number of actual hours worked could increase or decrease. With some reasonable assumptions on the shape of DD, it must be the case that as SS keeps shifting to the right the inelastic segment of the DD curve will be reached and the household will enjoy simultaneously higher cleanliness and more leisure. If, however, the DD curve shifts to the right as well, this result will no longer hold, and at a point such as E" we can be sure that the house is a lot cleaner, and that it is likely that the homemaker has to work harder. The point is of course that any increase in A-, is equivalent to a shift in the DD curve since the demand for cleanliness is a derived demand, dependent on the marginal utility of health and the *perceived* marginal effect of that cleanliness on health. Thus changes in recipes led to an increase in hours spent cleaning. It should be added the curve DD could also shift out in response to other changes, especially rising incomes. Larger houses and wardrobes required increased cleaning time even for a given set of knowledge; a decline in the availability of domestic servants (due, for example, to exogenous

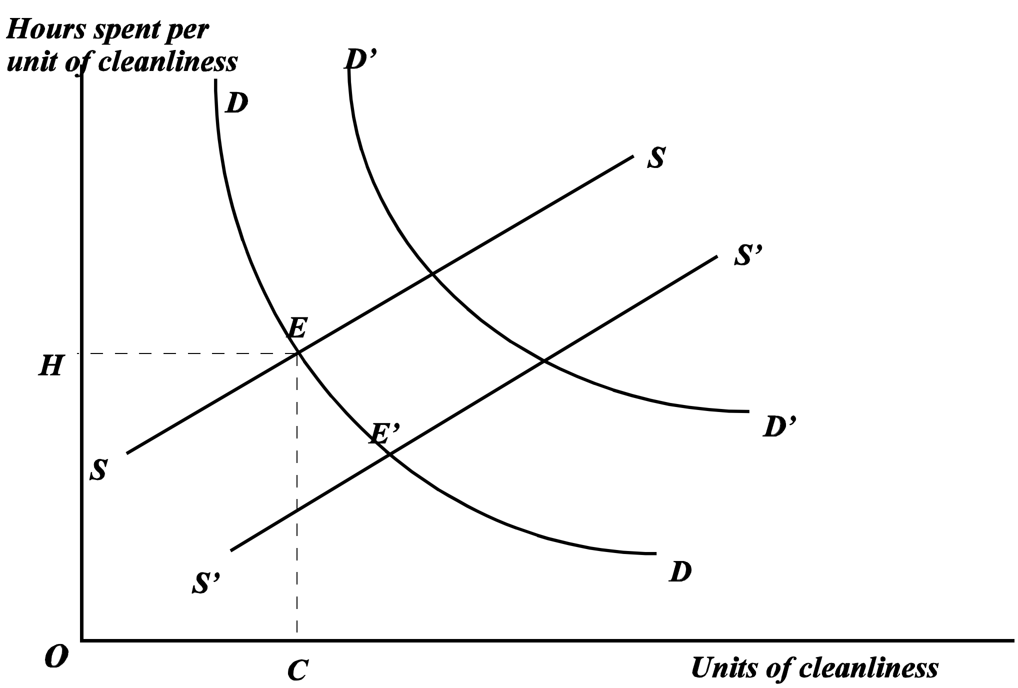

Figure 4

increases in their opportunity costs) would have a similar effect. It is also possible that homemakers increased their appreciation of cleanliness for its own sake, and that as a normal good it increased with income. But leisure was a normal good as well, and the net change in time allocation depended on the respective elasticities.

Three Scientific Revolutions

The economist's model of the diffusion of technology is important to the understanding of the change in household behavior but it is not sufficient. In most technological models the diffusion of knowledge and its implementation are more or less identical, unless there are identifiable barriers to implementation. In the household technology model we live in a different world in which decision makers are unsure about the true effects of the change in behavior. Individuals may think that it is *possible* that the new technology has a positive effect on H, but there is no cheap way to experiment and find out for sure. In other words, they have a prior probability distribution on the size and magnitude of MH/MX_i, but this prior can be updated by new information much of which is external. As long as they are in serious doubt, we need to know what the loss functions are that are associated with type I and type II errors before we can understand why a particular recipe is or is not accepted.

The model presented above suggests that there does not necessarily have to be a "true" value of the optimal consumption or if there is, it may not be knowable. What counts, above all, is what people *believe* to be true about the material world around them and how their actions and the way they run their lives affect their physcial state. People can, however, be closer or further from the truth in measurable amounts. The problem is in part one of knowledge, of course, but there must be more to it than that. As biologist Richard Lewontin (1997) has observed, "the reason that people do not have a correct view of nature is not because they are ignorant of this or that fact about the material world but that they look to the wrong sources in their attempt to understand it." The point, however, is that one can follow better recipes even without having a "correct view of nature" as long as one is willing to accepted procedures and rules of thumb that happen to improve health. Decision makers have to be *persuaded* that, for example, $MH/MX_i < 0$ (the good is unhealthy) means they should reduce the consumption of the otherwise desirable good X_i. Persuasion means rhetoric, conventions, and social pressures, phenomena that normally do not play much of a role in models of technological change.[20] It is at this juncture that the social construction of technology of Bruno Latour meets the natural selection models advocated by Donald Campbell (1960) and Robert Richards (1987). The point is that selection mechanisms determine which new techniques will be accepted and adopted. Here rhetoric, marketing skills, political influence, prejudice, as well as path dependence, emulation, and social learning come into play. The selectors have to pick technologies but absent hard evidence of the superiority of one option, will follow social conventions and traditions. Persuasion requires shared standards of evidence, chains of authority, and accepted rules of logic. Changes in these conditions, no less than the information unearthed by science, are the background to changes in health and longevity.

In the past two centuries household behavior has been affected by science far more than has been realized.[21] This is not necessarily because science is "right" but because scientists have increasingly influenced the way common people have thought about the natural world. Scientific knowledge was generated of course by a few men and women who pushed the best-practice technique *A* forward. Increases in *A* were followed by changes in individual behavior, that is, declines in ,, the gap between best and average practice techniques. To get households to change consumption bundles requires considerable persuasion because any movement, say, from E* to E** (fig. 1) involves a redeployment of the consumption basket. Furthermore, an increase in H thanks to cleaner homes, improved child care, and better prepared food required more work at home, that is, required a reallocation from L_E to L_D as shown in fig. 3. What was

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[20]Innovation in agriculture in premodern Europe, precisely because it too depended on decisions made by households in a weakly competitive environment, is comparable to the framework discussed here. Such innovations usually took the form of higher yield of a given crop or higher income in case of a new crop. Yet what it amounts to is a change in one of many independent variables in an equation where some "income" variable is the dependent variable. The proper test of a favorable innovation is that its partial effect on the farmer's objective function is positive. A formal definition of an improvement would be that the distribution of output conditional on the innovation is in some way more desirable than the distribution conditional on the old technique. However, to persuade the farmers of past centuries to adopt such new techniques must have been less than trivial given their limited opportunities to experiment and their inability to conceptualize let alone carry out the kind of statistical analysis that modern researchers have at their disposal. When somebody truly believed in a new technique, they tried to persuade other practitioners. The rhetorical efforts of such propagandists as Jethro Tull and Arthur Young are only the best-known examples of a rhetoric in which the net effects of certain new techniques were sold to the masses. This persuasion may have been difficult: it certainly was slow and highly uneven. Technological progress in agriculture, according to one witticism, advanced at the rate of a mile a year.

[21]A notable exception is Tomes (1990).

responsible for these changes? The answer is complex, but we can readily identify the advances in best-practice techniques. Describing what exactly households knew and believed and how they were persuaded to change their behavior through persuasion is of course a much more complex task. As a general proposition, however, the decomposition proposed in equation (3) suggests that two elements can be examined separately: the better knowledge that people in authority possessed about disease and health, and changes in the influence that they exerted on daily consumer behavior and household management.

It is my contention that there were three separate elements that changed household behavior in the period between 1815 and 1945 which jointly account for a substantial portion of the decline in the decline in morbidity and mortality rates in the West. In practice it is difficult to separate between these sources, but they have different intellectual origins. One is the statistical revolution that began after 1815, picked up enormous momentum between 1830 and 1870 through the sanitary and hygienic movement that swept the Victorian era, leading to a widespread if unfocused war against dirt under the vague perception that dirt and disease were correlated.[22] The second element is anchored in the period between 1865 and 1914, when the germ theory and other developments led to a fuller scientific understanding of infectious disease and thus to specific recommendations how to avoid infection. The third stage was the development of nutrition science and the basic insight that certain compounds in small quantities are essential to the avoidance of disease, and that therefore diets need to be adjusted to make sure that basic vitamins and minerals were part of the diet. These developments on the whole preceded the emergence of cures to infectious disease due to antibiotics.

The statistical movement grew out of the enlightenment movement and led to the development of nineteenth century epidemiology. It provided data supporting the close relation, long-suspected, between consumption patterns, personal habits, and disease. The statistical movement presented one way out of the household's logical dilemma: how does an individual know that a given technique affects the health of the members without being able to carry out an experiment in laboratory conditions? Until today inferences from large samples have remained the logical foundation of much research in epidemiology and public health.

The roots of this movement went back to the eighteenth century, especially to the debate around the

[22]For some insights in the emergence of the statistical method in post 1830 Europe, see especially T. Porter (1986), Eyler (1979), Coleman (1982) and Cullen (1975).

efficacy of the smallpox inoculation procedure, the beneficial effects of breastfeeding, and the bad effects of miasmas (putative disease-causing elements in the atmosphere) (Rusnock, 1986; Riley, 1987). But its intellectual core was the growing interest in statistics and the analysis of what we today would call "data " dating to the decades after 1815. The founding of the Statistical Society of London in 1834 led to an enormous upsurge in statistical work on public health. The sanitarians' insight that disease was correlated with lack of sanitary conditions was of course correct and hardly new but the persuasiveness of statistics in this regard added a new dimension to the public health debates. The statistical movement, in the best traditions of inductive reasoning, collected large amount of data, analyzed them, and then used the information to lobby for improved hygiene. In Britain, William Farr, William Guy, and Edwin Chadwick were the leaders of this sanitary movement, but it encompassed many others.[23]

The connection between the sanitary movement and data collection was essential. Between 1853 and 1862 no less than a quarter of the papers read before the Statistical Society of London dealt directly with public health and vital statistics[24]. In France, the work of René Villermé and Pierre C.-A. Louis applied, in different ways, the tools of statistics to medical knowledge (Lilienfeld, 1978; Coleman, 1982).[25] The statistical approach had some major successes in clinical medicine: empirical observation led first Ignaz Semmelweiss and then Joseph Lister to conclude that infected surgical instrument and dirty doctor's fingers caused outbreaks of post surgical fevers although neither of them knew precisely why (Lister soon found out after learning of Pasteur's work). Farr and Snow observed empirical regularities in the outbreak of Cholera in London and inferred from them that the disease was transmitted by infected water (though they did not know what it was in the water that made people ill). In a similar way, William Budd demonstrated in 1856 the same for typhoid. Louis in France discovered on the basis of careful counting that the bleeding of patients

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[23]For details see especially Flinn, 1965.

[24]Many social reformers and activists such as Henry Mayhew and Florence Nightingale were life-long and enthusiastic members of the Statistical Society. See especially Wohl (1983).

[25]The statistical movement had to overcome considerable opposition in the medical community. What may seem obvious to us was regarded with great skepticism by nineteenth century doctors who felt that the use of statistics was mechanical by presuming a homogeneity among patients that was inappropriate in medicine (Gigerenzer et al., 1989, p. 46; Porter, 1986, pp. 152-62).

infected with pneumonia did them no good and began a movement that eventually led to the abandonment of the practice altogether. Least emphasized yet demographically perhaps most important was the effect of statistics in helping to persuade the masses to change their lifestyle and household behavior.

It is easy to underrate the rhetorical power that statistics lent to the spread of hygiene. Literally hundreds of tracts, newspaper articles, pamphlets, lectures and government reports were published in the nineteenth century, all pointing to the direction of improved health if the consumer chose to practice the rules of cleanliness. Statistics were used to persuade the masses, but more importantly, they persuaded people of authority in key positions to influence others. Farr and Chadwick were also leaders in the Statistical Movement. Their findings were disseminated by influential people: the Metropolitan Health of Towns Association was founded in 1844 to "diffuse among the people the valuable information elicited by recent inquiries and the advancement of science [and] the physical and moral evils that result from the present defective sewerage, drainage, supply of water, air, and light, and construction of dwelling houses." Among its early members were T.R. Malthus, Charles Babbage, Earl Grey, Disraeli, Bulwer Lytton and the Earl of Shaftesbury, a leader of the factory reform movement (Wohl, 1983, p. 144). The Manchester Statistical Society (founded in 1833) contained primarily members of the industrial and commercial bourgeoisie, people who in many ways were social models, to be followed and emulated by their lessers. The empirical regularities discovered by the statisticians thus filtered down vertically through the social layers of society. Once the scientists and statisticians had persuaded the literate and educated public, well-meaning organizations run by middle-class ladies such as the British Ladies' National Association for the Diffusion of Sanitary Knowledge (founded in 1857) took over the task of persuading the masses.[26] Between 1857 and 1881 this Association distributed a million and a half tracts loaded with advice on pre- and postnatal care, making millions of house-visits, spreading the gospel of soap and clean water, and the evidence is that in the late Victorian period the poor were receptive to these volunteers (Wohl, 1983, pp. 36-37). The Association also

[26]The underlying assumption was that a "principal cause of a low physical condition is ignorance of the *laws of health"* --(cited by Williams, 1991, emph. added). These laws, Williams points out, were the laws of "physiology and chemistry" as well as the ethical commandments of a divine lawgiver. The importance of the propaganda of these organizations is that households should take responsibility for their own health and well-being rather than accept their misfortunes fatalistically.

published tracts on diet and either taught cooking classes or campaigned to have it taught in elementary schools (Williams, 1991, p. 70). At a later stage, statistics and numbers were used with powerful effect on the masses directly. Contemporary pamphlets used statistical rhetoric to underline especially one crucial recipe, the importance of breast feeding.[27] A graphical example of such rhetoric is the famous "Eiffel Tower Diagram" picture produced by Dr Pierre Budin (first published in 1900), which showed the advantages of breastfeeding. The diagram is reproduced as fig. 5.

The statistical movement led to the launching of a variety of public campaigns to reform consumption habits, but its full effects on the population's health remained limited until late in the nineteenth century.[28] It seems plausible that attempts of science to reform consumption habits based on empirical regularities alone would ultimately be limited in their effectiveness. Persuasion based on statistics depends on the susceptibility of society on such arguments and thus on education. Above all, the reliance on quantitative data indicate the lack of understanding in the medical world of the sources of disease and the distrust with which much of the public still regarded them. Moreover, statistics were viewed as furthering our understanding of aggregates, while obscuring the peculiarities of each individual household, so its findings might not provide sound advice to each decision maker. The concept of *expected* utilitarianism, in which the probabilities were determined from population means was still not widely accepted. What was needed was a *model* that could be shown to be responsible for the cause and effect relation and provide guidance in making choices. Without the benefit of such a model, it was difficult for households and the authorities to choose correctly as correlation was perceived to be different from causation.[29] Even when the statistical evidence is so abundant as to be overwhelming (as is the case with smoking in our own time), the rhetorical strength of statistical logic is limited. For that reason, the sanitary movement declared hygiene to be virtuous

[27] Home economics textbooks such as Hitching (1912, p. 148) emphasizes the fact that babies fed on mother's milk have a ten times larger chance of surviving than bottle fed children.

[28] See for example the various essays in Woods and Woodward (1984), esp. pp. 148-202.

[29] William Budd, for one, was actively opposed by those who insisted that typhoid fever was caused by spontaneous generation and it took twenty years until his recommendations were incorporated in the Public Health Act of 1875 was passed (LeBaron and Taylor in Kiple, p. 1075).

in the "cleanliness is next to Godliness" mode, but such campaigns, much like the Temperance movement, were as often based on moralistic arguments as on empirical and logical reasoning and as such their impact remained limited to those susceptible to this type of rhetoric.

Nineteenth century empirical data were, moreover, highly deficient and incomplete as pointed out by contemporary writers such as Henry Rumsey (1875). Most of the inferences used simple tabulations, had no controls, and almost never recognized the distinction between partial and total effects, to say nothing of endogeneity and omitted variables biases. Consequently the movement ran into the dilemma that it recognized that a cluster of social problems -- poverty, urban congestion, lack of sanitary facilities, bad nutrition -- were correlated with high mortality rates and epidemics, but it did not know how and why this was the case, and consequently it ended up recommending the wholesale elimination of poverty and slums as the only possible remedy for disease. The rhetorical power of empirical regularities, no matter how sophisticated the statistical methods employed, runs into diminishing returns.

The rather bumbling, groping, purely empirical approach to the prevention of disease of the sanitarians and statisticians before the appearance of a model provided by the bacteriologists should not be sneered at. Empirical regularities have not been abandoned as a method of understanding health and disease as our own age struggles in rather similar ways with coronary disease, cancer, certain viruses (including HIV), and autoimmune disorders. The continuous rise and fall of red wine, green cabbage, garlic, hot chili peppers, cholesterol, antioxidants, beta-carrotines, megadoses of vitamin, selenium, and so-called phytochemicals are a sufficient indication that even today the modi operandi of the impact of consumption on our health and longevity are far from properly understood and we have to rely on empirical regularities to figure out what works.

The most important breakthrough of the nineteenth century, or in terms of our notation, increase in A, was, without any doubt, the germ theory of disease. It is important to stress that it was more than just a way of attributing certain symptom to certain microorganisms. The germ theory provided an entirely new concept of what disease was, how it was caused, how to differentiate between symptom and cause, and how infection occurred. Most important, it was entirely based on an experimental method widely touted to be a failsafe way of unearthing the “truth” and thus accepted by increasing numbers of people with the same blind faith previously reserved for religion.

For our purpose, the most important corollary of its discovery was the changes that it implied for household consumption patterns. Stein and myself have described the details elsewhere (Mokyr and Stein, 1994), but the main outlines of the story can be sketched summarily. The Pasteur revolution heralded a concentrated and focused scientific campaign to once and for all identify pathogenic agents responsible for infectious diseases. Between 1880 and 1900 researchers discovered pathogenic organisms at about the rate of one a year, and established the main transmission mechanisms. The age-old debates between contagionist and anticontagionists, miasma and anti-miasma theories slowly evaporated although the belief that "bad air" was somehow responsible for diseases such as diarrhea was still prevalent in the 1890s. Pasteur, Koch and their followers used scientific rhetoric as masterfully as they used laboratory methods, forging alliances with the sanitary movement, and were able within a few decades to turn the entire idea of "disease" upside down (Latour, 1988).

In terms of our model, we can regard the discoveries as a sudden leap in the value of *A*. Best practice techniques change when the nature of a particular disease and its transmission is clarified. To be sure, there is a difference between the discovery of a pathogenic microorganism responsible for a disease and the recipes implied by it. However, once it is clear which microbe causes a disease and how it is transmitted, the means of prevention become easier, and the recommended adjustment in behavior can be inferred. A powerful example of this is the idea that diseases were transmitted by vectors. Like the germ theory itself, the model itself had been proposed a few times before, but the work of Patrick Manson, Ronald Ross, and G.B. Grassi demonstrated the culpability of the *anopheles* mosquito in the 1890s and in 1909 Charles Nicholl discovered the louse vector of typhus, five years before the causative germ itself was isolated. These discoveries were decisive in persuading households how such diseases were contracted and thus could be successfully avoided (Rogers, 1989). The discovery of the HIV virus in 1984 had a comparable effect. Yet recall that in terms of earlier notation any discovery in and of itself initially leaves A-, unchanged (that is, , rises at first to match the increase in *A*). It is only when the new knowledge is disseminated to the population and when the public is sufficiently persuaded by it to alter its behavior, that the value of , starts to decline, consumption behavior is modified, and mortality declines.

From the viewpoint of an evolutionary model, the Pasteur revolution thus provided a new and powerful criterion to discriminate between competing technologies. The production-technology literature recognizes no such problem: selection occurs when firms "test" alternative technologies against a common criterion such as profitability. The household's selection problem is more difficult because it has rarely the wherewithal to test alternatives. Therefore, while its objective function ("remaining healthy") was reasonably well understood, the partial effects of particular consumption bundles and the way they were processed on health and well-being remained largely mysterious until deep into the nineteenth century. For countless generations Europeans suffered from discomfort, disfigurement, high infant- and child mortality, stunted growth, and loss of income because of diseases they could have avoided if not cured. This is precisely the meaning of being at a point like E* in figure 1. By identifying the agent, the germ theory imposed a new set of rules that made the choices of recipes clearer and allowed households to switch to a more "efficient" set of recipes. In those terms, it must be judged one of the most important technological advances of the modern era.

Yet this success was slow in the making. Many of the antiquated nineteenth century recommendations to avoid odors and to maximize sunlight and ventilation survived for many decades. Mrs. Plunkett's book (1885), provided an example of a work well-aware of the bacteriological advances of her age, yet at the same time reproduces advice inconsistent with it and recounts tales reflecting miasma theory. As late as the 1920s, household manuals railed against "sewer gas" as much as they did against deadly germs (Tomes, 1990, p. 538). The triumphs of the new recipes in displacing less effective older ones at the household level was not nearly as thorough as we imagine happens in production technology. Indeed, the survival today of "alternative" medical paradigms such as homeopathy, chiropractice, herbal medicine, and similar approaches suggests that the victory of "modern" medicine is far from complete and that the selection mechanism here is not working very thoroughly.

A theory of disease that identified a clear-cut enemy that could be fought with mop, sponge and kitchen range, focused the efforts of European home-makers in a clear-cut direction. The rhetorical power of the germ theory was based on two components. One, emphasized by Latour (1988), is that the microbial theory came in the wake of the sanitary movement which had prepared the ground for many of its recommendations.[30] Second, the modification of household behavior was enhanced by the powerful rhetorical image that microbes provided, an image that is hard to replicate with more elusive pathogenic substances like ozone or cholesterol. Microbes were an invisible, omnipresent evil agent, a live monster threatening with infinite malice to attack the most vulnerable members of society (Campbell, 1900, p. 196). After 1890 an anti-bacterial obsession took shape. Home economics textbooks pulled out all stops: "a dirty house is full of poison germs...Try to imbue the children with a *horror* of dirt in any shape or form..." exhorted Hitching (1912, pp. 26, 33, 64) in a handbook for teachers in girls' schools.

Cleanliness no longer was *next to* Godliness, it became almost the same thing. Health is the birth-right of every individual, proclaimed the new handbooks in home economics. Yet health was now neither a matter of divine intervention nor social evils but rather one of individual responsibility: informed by the science of bacteriology, every household was now responsible for its own health and the burden of that responsibility placed squarely on the shoulders of the woman because she spends most of her time at home (Elliott, 1907, pp. 1-3).[31] Advertising and marketing capitalized on this trend, and an unprecedented expansion occurred in the demand for cooking stoves, disinfectants, soap, washing and cleaning equipment, toilets, water filtration methods, and safer foods. Tomes (1990, p. 535) notes that many of these goods had been available before 1875, yet the revelations about the existence of microscopic life greatly increased their appeal. The growing demand for consumer goods that would combat infectious disease led to a further development: the generation of *new* consumer goods whose invention was induced by the growing need felt by consumers to live in germ-free homes. All the same, persuasion was a drawn-out process, and clearly encountered much resistance from consumers who did not believe that the germ theory presented a radically

[30]As Tomes (1990, p. 529) notes, "popular hygiene writers had little trouble ... in associating dirt, infection, and germs... The ability of microorganisms to produce dangerous toxins or poisons could be easily assimilated into older notions of decay and putrefaction as sources of infection."

[31]Williams (1991, p. 80) argues that with the increasing adoption of the germ theory of disease the importance of women’s sanitary work became severely diminished. Perhaps in terms of persuasion and propaganda there is some truth to this view, as lay preventive medicine was gradually replaced by that of professionals, but clearly in terms of household work the effect was quite the reverse.

more useful insight into the nature of disease.[32]

Of particular importance to consumer health was the insight that the germ theory provided to the purchase and preparation of uncontaminated food. During the nineteenth century in general unwholesome food was sold to the poor at low prices: until the 1880s, for example, the poor in Britain could buy "third-day" fish, mackerel with a "horrid stench" at six for a shilling. Bacon became cheaper when its fat had turned yellow and when it showed black spots (caused by anthrax) (Smith, 1979, pp. 204-07).[33] During the nineteenth century, authorities made efforts to curb the worst excesses of these markets, and it is clearly not the case that people had to wait for Louis Pasteur to tell them that eating spoiled foods was dangerous. From 1857 there had been attempts to control the sale of diseased meat, and in the 1860s there were repeated seizures of spoiled food in London (Smith, 1979, p. 206). Yet the germ theory added enormous impetus to the intuitive and empirical insights that made authorities concerned about food quality, made them enforce the law with greater energy, taught them that some substances could be dangerous even without the signals of color and odor, and above all persuaded increasing numbers of consumers at the receiving end that cheap milk, fish and meats may not have been such a bargain after all.

The diffusion mechanisms of the new anti-infection movement to the mass of lower middle- and working class consumers were of course diverse. As babies were particularly vulnerable victims of infectious disease, much of the campaign was directed toward new mothers, in such organizations as *goutte de lait* and the *consultations de Nourissons* pioneered by Budin in France and the Mothers and Babies Welcomes in Britain that were patterned after them. These organizations specialized in distributing free clean milk and instructing mothers in infant care. The school systems increasingly enforced stricter cleanliness standards

[32]Campbell (1900, p. 194) cites a "vigorous old lady" who complains that she does not see "why we are so much dirtier than we used to be...'Dangers of River water'! We drank what we pleased when I was young. This talk about bacteria seems to me like all other fads...For my part I have some faith in gastric juices [which] I fancy will manage bacteria."

[33] The negative relation between price and wholesomeness does not always hold, as in the case of bread, where the more expensive white varieties were subjected to adulteration by chemical bleaching agents such as alum.

on children while indoctrinating them in the need to avoid germs and infection.[34] School curricula began to include cooking, infant care, and laundry in home economics courses, with cleanliness and avoidance of infection the highest priorities. Books on good housekeeping proliferated, repeating ad nauseam the gospel of cleanliness.[35] Ignorance of good household practices was increasingly being blamed for poor health conditions, indicating an instinctive sense of a growing , , that is, a growing gap between the best possible and average practices. One consequence of these breakthroughs was a furious debate on the effects on health of working class mothers being employed outside the home.[36]

Another agent of diffusion was the medical profession. The Pasteur Revolution, despite some pockets of resistance, was embraced by the medical profession and led to a complete re-definition of the tasks of medical personnel (Latour, 1988). Physicians could now assume a new role of household consultants, advising families on how to avoid disease by following new sets of recipes in the preparation of food, cleaning, and child-care. While the cure of infectious disease was still elusive, prevention became a reality. Many of the old prescriptions such as ventilation (to avoid miasmas) and bleeding were abandoned. Instead, asepsis and hygiene became the watchwords. The discovery of vector- and water-borne diseases opened new avenues for public policy in terms of insect control and water supply. The slow realization of the existence and working of an immune system led to more controlled environments ("avoid drafts") to prevent opportunistic diseases. The definitive realization that contagion could occur and how it happened meant that living

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[34]Most of the research carried out confirms strongly a connection between literacy or education on the one hand and "health", however measured, on the other. The best statistical work for the period before 1914, Preston and Haines (1991) for the United States and Woods, Patterson, and Woodward (1988-89) for England and Wales, both confirm this finding. These results do not lend themselves, however, to a distinction between alternative interpretations: did schools simply "drill" students in the habits of hygiene, or did they improve their ability to absorb logical and statistical arguments on preventive medicine? Modern research suggests that even recommendations based largely on empirical regularities such as abstaining from smoking and eating a full breakfast are strongly correlated with education (Evans and Montgomery, 1994). That suggests that education and schooling also improved the ability of individuals to reason statistically although it seems likely that in part the relation is complicated by the fact that well educated people tend to have lower rates of time preference and therefore more likely to invest in their health.

[35]A typical example is Campbell (1900, pp. 198-201) who stressed the dangers of "flourishing colonies of bacteria" and stressed how keeping the house clean was the best way to deal with this "enemy." Another example is *The Woman's Book* (1911) which filled no less than 734 pages with helpful hints on cleaning.

[36]This debate is ably summarized by Dyhouse (1978).

space became more valued and age-old habits of putting children in the same bed came under fire.

The third revolution consisted of scientific advances of two kinds: antibiotics and nutritional science. Antibiotics completed the war against infectious disease by the invention of effective cures against them. The advances were made by the medical profession and are well-known: the development of sulpha drugs (sulphonamides and sulphanilamides) by scientists working at I.G. Farben and the Pasteur Institutes, and the discovery of antibiotics proper by Fleming and Florey. The demographic effects of antibiotic medicine on third world populations was enormous and has been widely explored although it may be in retreat.[37] The effect of antibiotics on consumer economics was to remove the production of health partially from the household and to transfer it to experts who exercised a monopoly on the wonder substances that took over the war against microbes. From an economic point of view this meant that H increasingly became a function of a set of pure health goods that conveyed health specifically rather than a by-product of the consumption of other goods.[38] This tendency was counteracted by the discovery of vitamins and minerals and their effects on the body and the growing awareness of health benefits and risks in various consumer goods and environmental factors.[39] The increase in the demand for fresh fruits and vegetables, for example, was in part fueled by the realization of the beneficial effects of "an apple a day." Moreover, with the decline of infectious and nutrition-deficient disease, non-infectious diseases took their place and as their causal mechanisms are at present almost as poorly understood as those of infectious diseases before 1860, empirical observations -- albeit backed up by far more sophisticated statistical techniques -- are once more becoming a major selection

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[37]The triumph of antibiotics has not been complete as the return of tuberculosis and other bacterial diseases suggests. In part, the failure to find an anti-viral substance comparable with antibiotics has been a limiting factor. In part, bacteria have become drug resistant and have rendered many wonder drugs impotent. See for instance M.F. Perutz (1994).

[38]For these goods, increasingly, it was the case that $\hat{X} = 0$, that is, these are purely medications that would not be consumed were it not for their health-enhancing effects (unlike grapefruits or garlic).

[39]Of particular interest to the kind of argument I am trying to make here is the history of scurvy. The empirical regularities that pointed to its cause were already unearthed by Edward Ives and James Lind in the mid eighteenth century. Yet scurvy kept re-appearing during the Irish Famine, the Crimean War and the Russian army during World War I. Infantile scurvy was prevalent among wealthier families in which weaning occurred earlier. The discovery of the germ theory led to decades of futile search for a causative microorganism. Only after the seminal papers by Holst and Fröhlich after 1907 did it become clear that certain diseases were *not* caused by infectious agents but by nutritional deficiencies, and only in 1928-32 was the crucial ingredient isolated (Carpenter, 1986; French, 1993).

mechanism between competing recipes.

Changes in Household Behavior

Households allocate both consumption bundles and time. In recent years a growing and influential literature has argued that households overallocate labor to domestic work, leading to inferior outcomes. Such an outcome, as we have argued, is consistent with the unique characteristics of the household as a production unit, but they merit a closer look. Juliet Schor (1991), Ruth Cowan (1983), and other scholars have raised the paradox of household work in the twentieth century. They have shown that the number of hours worked by the housewife in the household were around 52 hours a week in the beginning of the century, rising to 56 in the late 1960s, to about 50 in 1987 (Schor, 1991, p. 87).[40] The paradox is that household work has increased in the past century despite dramatic labor-saving changes in what I called household technology. The vacuum cleaner, the washing machine, and the dishwasher at first glance do not seem to have reduced the burden of housework; if anything they seem to have increased it. Ruth Cowan (1983, p. 100) notes that the American housewife of 1950 produced single-handedly what her counterpart in 1850 needed a staff of three or four to produce: a middle class standard of cleanliness, health, and comfort for herself and her family.

Cowan's observation holds, however, one of the keys to the paradox. The point is that if three or four servants were needed to attain this standard for one household, only a fraction of the population by simple logic could enjoy it. The technological advances allowed a growing fraction of the population to enjoy these standards, thus substituting capital for labor.[41] The number of hours worked by the wife alone is a false starting point; the *total* amount of household labor per household has actually declined -- servants and

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[40]Stanley Lebergott (1993, p. 58) disputes these numbers and estimates that weekly chores fell from 70 hours in 1900 to 30 in 1970. The difference does not result from different sources used since both Schor and Lebergott rely on the research by Joann Vanek. As far as I could ascertain the difference is in definitions: Schor's definition of housework permits the housewife to define the activities she denotes as housework, whereas Lebergott looks at cooking and cleaning.

[41]Formally, the problem is similar to the question whether labor-saving innovation reduces total employment. It is of course no paradox to note that by and large any innovation which increases the capital-labor ratio does *not* create in and of itself unemployment, because the total demand of labor depends on the demand for final goods.

washmaids have all but vanished in western societies and teenage daughters are all too seldom asked to participate in homemaking activities and even more rarely respond affirmatively.

Although this analysis seems straightforward, it has eluded some scholars. Schor for example suggests that the main reason why L_D is so large is because the market places no economic value of work inside the house. This cannot possibly be right: even when women have no outside jobs, the opportunity cost of housework is leisure, and women who set their own schedules will work in their homes until the marginal utility of leisure equals the perceived value of the marginal product of housework. Precisely because of the technological changes in the household, the nature of L_D changed considerably, and, in Ruth Cowan's words, eliminated drudgery, not labor (1983, pp. 100-01).[42] It seems that today some forms of household labor can hardly be distinguished from leisure and will be carried out if they had zero marginal product on H: pet care, gardening, cooking, and shopping are all counted by Schor and others as household work; yet they differ from the backbreaking work of nineteenth century home-making as much as a modern thermostatically controlled central heating system differs from a coal fired stove. Schor's witty appeal to Parkinson's law ("household works expands to fill household time") is misleading and to some extent elitist, as she seems to believe that the various activities around the house that housewives engaged in are unproductive forms of labor.[43] A more charitable view would regard them as hobbies and transfer them from the L_D to the L_E column. Furthermore, income effects alone could be responsible for increases in household work even if leisure is a normal good. To the extent that the X's and L_D in equation (2) are complements, increases in X will require more work.[44] People desiring spacier homes and who can afford them also have to be able to find the time to clean and maintain them. Carol Thomas (1995) explains the increase in housework (which

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[42]Laundering, to choose but one example, was an exceedingly hard chore in the nineteenth century, carried out once a week and consisting of endless scrubbing, wringing, drying, ironing, folding, carrying and heating water, disposing of the washwater and so on. Compare this with today's fully automated washing machines in which the labor input consists of some sorting and the pushing of a few buttons (without ironing) up to the point where the clean laundry is folded and put back in place (a process that has eluded mechanization so far).

[43]The exact quote is "middle class women were trapped in a stultifying domesticity, following "Hints from Heloise" on how to prepare home-made dog food or turn Clorox bottles into birdfeeders" (Schor, 1991, p. 94).

[44]In terms of the model, this depends on the elasticity of substitution between X_i and L_D in the production of H. If this is low, an increase in X will lead to an increase in L_D.

she rightly sees as an important source of reduced mortality through the internal dynamics of changes in capitalist production during the second Industrial Revolution. With rising wages and a reduced work week, women were increasingly relegated to home-making as the result of an increasingly rigid sexual division of labor (p. 339). While this may be true, the explanation is incomplete without noting the rapidly changing notions of disease and health.

The resolution to the paradox implied in the approach proposed here is that the demand for L_D rose, through either a rise in MU/MH (the marginal utility associated with good health and longevity) or a rise in A-, in equation 3. This is in part an income effect, as health and longevity are more appreciated in richer societies. In addition, however, large segments of the population in the past century acquired more knowledge and understanding about the connection between what they consume and their health. To see this, note that any changes in household recipes which increases the perceived marginal product of L_D in producing H (an increase in A-,) will lead to an outward shift of the DD curve in fig. 4. For the *total* number of hours worked in the home to go up, all we have to assume is that either only SS shifts but the elasticity of the DD curve is large (so that shifts in the SS curve yield an increase in total number of hours worked) or that shifts in SS were accompanied by shifts in the DD curve. Translated into ordinary language this means that homemakers spent more time cleaning, laundering, and cooking because they had become convinced that wholesome food, clean clothes and bedsheets, and a hygienic environment were essential to good health and longevity.[45] Schor argues that this perceived value is erroneous, and that far more cleaning and cooking is carried out than is necessary. Without actually estimating the *perceived* marginal impact of scrubbing and sweeping on health and comparing it to the *true* value, we cannot be sure that health production is overusing L_D just because household labor is not a traded market good as Schor maintains. The demand for domestically produced health increased significantly in the past century because of changes in household

[45]It would also explain an increase in breastfeeding, although the improvements in baby formula and milk quality since the early 1900 tended to offset this. It should be realized that most of the early breastfeeding campaigns emphasized the clean nature of mother's milk and were not aware of its additional immunological and psychological benefits. Dwork (1987, p. 36) maintains that as late as the early twentieth century, while it had been recognized for many decades that breast-feeding was the most effective preventive measure against lethal attacks of childhood diarrhoea, "the precise reason for this was absolutely unclear." The statistical evidence seemed irrefutable, but the mechanisms poorly understood.

knowledge: there can be no demand for a germ-free house or germ-free clothes unless people know and believe that germs cause disease. Note that there is a real possibility for L_D to be *over*supplied when households believe that household labor is more health-enhancing than it really is. It should be added that DD shifted for other reasons than increases in knowledge about physical health: a growing awareness of the importance of the home-produced component of education, for example, led to an increase in time spent with children.

We are then back to the selection problem: how did the household choose the optimal technique to produce H? It would be naive to recount it in terms of a Whiggish tale of growing enlightenment and rational choice of recipes following the triumphs of science. The relation (3), which defines household behavior, is determined by its *priors*. Precisely because the difficulties the household has in updating these priors in the face of bewilderingly complex relationships, it is subject to outside influences, some of which may be systematically biased. Consequently households could be persuaded by altruistic organizations like the British Ladies' National Association for the Diffusion of Sanitary Knowledge or the French *Goutte de Lait* centers, by teachers, lecturers, and essays in popular magazines, by their own neighbors, friends, relatives, fellow congregationists, or home visitors. Such information would engender a fall in , and thus lead to a movement such as from E* to E** in fig. 1. Yet other outcomes are possible, including *over*shooting to a point to the right of E' in fig. 1. In the twentieth century the role of advertising in this respect was crucial, as Schor notes when she states (1991, p. 97) that "Businesses subjected women to a barrage of advertising and social pressure, in order to sell more products... they spread the message that a woman who did not purchase the growing array of consumer products was jeopardizing her family." The fundamental message sent to homemakers by advertisers was one of personal responsibility. If their children did not develop properly or became sick, if their husbands were unhappy, if they themselves grew old and tired before their time, they themselves were to blame for not cooking the right meals, not scrubbing the bathroom floors enough, or not insisting that her family clean their teeth (Ruth Cowan, 1983, pp. 187-89).

In terms of our model, this type of rhetoric may have led them to *negative* values of ,, thus consuming more of some X's than best practice techniques called for. Overshooting occurs if , < 0 and 1+, < A. To make the argument that these conditions led to “overworked housewives” we need to assume either that there was a low substitutability between the "overconsumed" X's and L_D so that they also led to overwork, or that the overshooting conditions applied directly to A_D and $,_D$. This is not implausible if the products marketed were items such as laundry detergent and toilet cleaning equipment. One result of "overshooting" in the case of housework would occur when married women, brainwashed by overzealous sanitary propaganda, dropped out of the labor force altogether in order to "keep house." It remains to be seen how much of the low labor force participation rates of married women, as argued by Thomas (1995), could be accounted for this way.

Perhaps the best example of such unscrupulous marketing can be found in the soap industry, always strapped for markets because of the economies of scale in soap production and its highly competitive nature. The Cleanliness Institute, established by the American Association of Soap and Glycerine products in 1927, embarked on an unprecedented campaign to sell soap at all cost and in the process all but brainwashed Americans that "microbes were everywhere, omnipresent, ever-ready to spread disease, debility, and death" (Vinikas, 1992, p. 85). The institute worked through the most effective means of persuasion: schools and children, selling or giving away hundreds of thousands of storybooks, pamphlets, flyers, teachers guides, and free samples. It also advertised at an unprecedented scale, aiming their resources at women rather than at men, and using fear, guilt, and hope to sell soap (ibid, pp. 79-94). In the process they may have also helped to bring about millions of overworked housewives, even if that was not their intention.

All the same, the net effect of advertising on L_D is not clear. Soap happens to have a low elasticity of substitution with household labor; it does not clean but in conjunction with labor. A large proportion of advertising, however, was aimed at *replacing* domestic labor. The fast-food industry, for instance, must have saved housewives all over the world trillions of hours of cooking and cleaning. Schor's flat statement that industry has had no incentive to come up with labor saving devices in the household (Schor, 1991, p. 102) is contradicted by endless innovations that did just that: throw-away paper napkins, self-cleaning refrigerators and ovens, cake mixes, pressure cookers, and chemical toilet cleaners are just a few examples.

The more difficult question is not why was there no more substitution of household capital for household labor but why did it take so long for markets selling commercial health-enhancing goods and services to emerge? Not until the 1970s did consumers resort to take-out and pre-cooked food on a large scale. Commercial laundries and vacuuming services existed but never got close to controlling a large share of the output.[46] The reason, I suggest, is that households did not regard the market-purchased goods and the home-made goods as good substitutes because quality monitoring in the production of H is difficult and expensive.[47] If the household has a certain prior over A-, , hiring someone else who may have a different prior may create serious principal-agent problems. When there are small differences in price, and when the stakes are viewed as high (since these involve the health of the members of the family) such problems may have been decisive. An alternative explanation focuses on the question *who* in the household makes decisions. The allocation of time between housework and leisure was by and large up to the homemakers; switching from household-produced services to market-purchased substitutes requires cash outlays and thus may have needed the consent of other household members.

To summarize, then, household behavior can be modelled as a process of selection with learning. As science after 1870 discovered new facts about the human body and its interaction with the environment and this knowledge filtered down to the population at large, households learned and were persuaded to change consumption to improve their health, changes in demand for goods and the allocation of time were inevitable. This selection process resembled the choice of technique problem faced by firms but differed from it in some crucial aspects especially in the likelihood that competition led to efficient outcomes in the long run.

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[46]British working class households often used the "bag wash" in which the laundering of clothes was farmed out of the household but returned damp and unironed, so that the homemaker still had to dry, iron and fold it. The main reason for the bag wash was the absence of adequate laundry facilities in working class households (Daunton, 1983, pp. 243-44).

[47]Household efficiency experts such as Christine Frederick advised that commercial laundries may have been unsanitary because of contaminated clothing of others or contaminated workers (Cowan, 1983, p.107).

Appendix

Below we show the working of a simple static model in which the consumer has "priors" on the effect of goods on her health. The utility function is:

(1) $$U = U(X,Y,Z)$$

Specifically, assume for ease of exposition that the utility function has the simple Cobb-Douglass form

(2) $$U = X^{\alpha} Y^{\beta} H^{\gamma}$$

Where H is in turn determined only by the quantities of X and Y:

(3) $$H = X^{a} Y^{b}$$

Now assume that equation (3) is not fully known to the consumer but instead the consumer uses the following equation for his maximization:

(4) $$H = X^{\lambda_1 a} Y^{\lambda_2 b}$$

Where the λ's are equivalent to the terms of the type *A-,* we used in the text. Using the budget constraint

(5) $$P_x X + P_y Y = Z$$

We can easily derive from the first order conditions the equilibrium level of Y, Y^*:

(6) $$Y^{*} = \frac{Z}{P_y} \frac{\mu}{1+\mu}$$

where:

(7) $$\mu = \frac{\beta b \lambda_2 \gamma}{\alpha a \lambda_1 \gamma}$$

It is easy to see that the demand for Y will rise with increase in λ_2 and fall with an increase in λ_1. A rise in Z and P_y work just like in the standard case. A rise in γ, the marginal utility of H, will usually have an effect on demand for Y, but its sign depend on the four parameters. To see the effect of changes in Z, prices and the λ's on H, the equilibrium solutions for Y* and X* can be substituted into H. For values of $\lambda < 1$, it would be expected that H varies positively with either λ. If, for example $\lambda_1 < 1$ and $\lambda_2 < 1$, an increase in λ_1 will raise the consumption of X which *in and of itself* will raise H; but the budget constraint then forces a decline in Y which may offset the effect on H. Depending on the original values of the consumption parameters, H may increase or decrease. Indeed, it can also be shown that consumers for whom the λ's are not unity can still "get it right" (that is, combine X and Y inadvertently in such a way as to maximize H). This would be true if by accident the values of λ_1 and λ_2 were such that:

(8) $$\frac{\beta b \lambda_2 \gamma}{\alpha a \lambda_1 \gamma} = \frac{\beta b \gamma}{\alpha a \gamma}$$

which of course is trivially true for $\lambda_1 = \lambda_2 = 1$ but also for an infinite number of other pairs. If, therefore condition (8) happened to be holding for an arbitrary pair $<\lambda_1, \lambda_2>$ where $\lambda_1, \lambda_2 < 1$, clearly H is maximized and thus any increase in either λ will be health-decreasing. Yet it is not necessary for condition (8) to hold to get that result. Of course that would not be the case in the world of fig. 2 in which only one good has an impact on health.

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