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by

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Trading-off health risk and latency: Evidence from water pollution in Bangladesh

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Abstract: The Ganges Delta of Bangladesh faces a major environmental and development problem from arsenic groundwater contamination. Here we address the rural population's health preferences and estimate how much a given risk of *arsenicosis* would have to be postponed to make that risk acceptable. We also derive implicit rates of time preference associated with this health hazard based on an experimental field study in Bangladesh. Results suggest that households exposed to arsenic contaminated water do trade-off risk against latency of developing arsenicosis. The results can also be interpreted as if households face a time-varying (hyperbolic) pure rate of time preference.

Keywords: Time varying discounting, Water pollution, Arsenic contamination, Bangladesh

JEL classification: J17, Q25

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1. Introduction

Access to safe water is one of the most important determinants of health and socio-economic development. Estimates suggest that nearly 1.5 billion people, mostly in developing countries, lack safe drinking water and that at least five million deaths per year can be attributed to waterborne diseases (WHO, 2004). The recognition of the importance of safe water supply has led to an emphasis on the provision of appropriate facilities by governments, NGOs and inter-governmental organizations.

Among naturally occurring water pollution, arsenic contamination of drinking water is described as one of the largest poisoning problems given its widespread occurrence around the world (Smith et al, 2000). The most notably affected regions are the Ganges Delta of Bangladesh with about 50 million people affected and West Bengal in India with over 6 million people affected to varying degree. Other affected countries are China, Taiwan, Thailand, Vietnam, Mexico, Chile and Argentina (Tapio and Grosche, 2006).

Until the 1970s most of the population living in the Ganges Delta of Bangladesh used surface water for drinking, but the high level of its contamination lead to widespread diseases from water-borne pathogens such as diarrhoea, dysentery, typhoid, cholera and hepatitis. As a policy response during the 1970s, the Bangladeshi government began an intense programme towards the provision of safer drinking water with international aid. This led to the installation of around 12 million tube-wells to provide drinking water for about 90% of the population (Frisbee et al, 2002). In the last decades, however, after the first cases of arsenic induced skin lesions were identified in 1987, it has emerged that water from many tube-wells is contaminated with naturally occurring inorganic arsenic

(Smith et al, 2000). This has led the Bangladesh Millennium Development Goal progress report to point out that at least 25 million additional people should gain access to arsenic-free groundwater by 2015 (UN, 2003).

Policy makers are often encouraged to evaluate alternative police options that imply the solution to broad environmental problems through cost-benefit approaches. However, calculating the benefits from eradicating water borne health hazards poses special challenges since the subjective value to people of contaminated free drinking water depends on whether the changes to water quality are perceived by the individuals exposed to the problem. Even if perceived, people have different risk and latency perceptions. Hence, whether people can or are willing to express their subjective value to experience an improvement in such health impairing situations should be assessed. In addition, the social acceptability of proposed pollution mitigation alternatives that may be promoted for safer drinking water should be considered (Alberini et al., 2004; Ahmad et al 2005). If exposed people are not aware of the present or future risks from water contamination or do not show concerns about it, any health/environmental programme that involves changing behaviour regarding water consumption patterns is most likely to fail. Therefore it is important to assess the level of concern of the exposed population by taking into account their preferences when searching for alternatives to solve water-borne health problems.

While people are likely to treat longevity as a ‘good’ that provides wellbeing, the risk of developing an environmentally-born disease may be regarded as a ‘bad’. Hence, people may in principle be able to express their preferences regarding the trade-off between a reduction in the environmental risk and an increase in latency, or the time it takes for a given disease to manifest from the time of the exposure to the environmental contaminant. It is possible to elicit people's relative weights about the reduction of risk of mortality relative to given latency periods. This approach departs from assessing the *value of a statistical death avoided* (Alberini et al., 2002). For example, Hammitt and Liu (2004), using a state preference valuation approach have evaluated the preferences of people in Taiwan about the trade-off between latency of liver cancer from water contamination, *vis-à-vis* the potential reduction of the environmental risk that leads to the illness. They find that the willingness to pay to reduce the environmental risk from contaminated drinking water declines with latency at a constant rate of about 1.5% per year for a 20 year latency period.

Our interest is not in estimating people's willingness to pay to reduce the risk of arsenicosis, but to shed light about how exposed people may trade-off risk and latency. By estimating such trade-off implicit rates of time preference (RTP) can be calculated, which in turn is an important information needed to evaluate alternative mitigation actions regarding groundwater contamination as while the costs may be borne in the present, the benefits accrue to the population over their lifetime. We are not aware of any study that has assessed the time preference rates in the context of arsenicosis in any developing country. The approach used here to determine the trade-off between risk and latency is based on the application of a simplified conjoint analysis given the potential cognitive problems associated with such valuation techniques in the context of deprived areas of developing counties.

The paper is structured as follows. The next section sets up the context of the actual arsenic crisis in the Ganges Delta of Bangladesh and Section 3 describes the case study and the data used in the analysis. Section 4 presents a random utility model used to estimate the trade-off between risk and latency of chronic arsenicosis. Then, Section 5 discusses the results about the trade-off between risk and latency and the implicit rates of time preference of the sampled population in the case study. Lastly Section 6 concludes with some policy implications.

2. An overview of the arsenic crisis in the Ganges Delta of Bangladesh

2.1. The effects of arsenicosis in Bangladesh

The Ganges Delta of Bangladesh is prone to chronic arsenic poisoning, arsenicosis, which occurs after a long-term exposure to contaminated water (WHO, 2000).[1] The range of cases of chronic arsenic poisoning through ingestion that have been identified varies significantly due to the difficulties in its diagnosis mostly associated with low level arsenic-induced skin lesions (diffuse melanosis), spotted pigmentation and leucomelanosis, with the most prevalent later symptom being keratosis which can cause considerable pain and disability (Chowdhury et al., 2000; Smith et al., 2000; Frisbee et al, 2002). It is normally assumed that skin lesions have an approximate latency of about ten years, from first exposure to visible symptoms (Smith et al, 2000). Recent studies show that the dose-response functions for arsenic concentration in drinking water and the prevalence of skin lesions are also associated with poor nutrition (Chowdhury et al, 2000; Mitra et al., 2004).

While the mechanism of carcinogenicity is uncertain, the World Health Organization has concluded that there is "overwhelming evidence from epidemiological studies that consumption of elevated levels of arsenic through drinking-water is causally related to the development of cancer at several sites, particularly skin, bladder and lung"

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[1] Arsenicosis is the catch-all term used here to describes all the different effects of long-term arsenic exposure. Symptoms of arsenicosis vary from skin pigmentation to cancer.

(WHO, 2004). There is also evidence for the link between arsenic-induced keratosis and skin cancer (Rossman et al., 2004). In addition, there are recent studies establishing a positive link between internal cancer risks and the concentration of inorganic arsenic (Smith, 2000; Chiu et al., 2004). It has been reported that at a 50 μg/l concentration of arsenic in drinking water, the lifetime risk of dying from internal cancer could be as high as 13 per 1,000 (Smith et al., 2000).

Arsenic probably began to accrete beneath the fertile river delta of Bangladesh long ago after being washed down from the bodies of ores in the Himalayas. The arsenic compounds were submerged in ground water and have remained inert for long time, until the advent of intensive irrigation in the 1960s during the green revolution. The aquifers started to drop and arsenic began to be exposed to oxygen. Once oxidized, arsenic compounds become water soluble and percolated from the subsoils into the water table, especially during the monsoon season (Chowdhury, 2000).

The extent of the arsenic contamination depends crucially on the threshold levels one uses to define 'contamination'. According to a British Geological Survey report, 46% of tube-wells exceed the official Bangladeshi and WHO based guidelines for maximum arsenic concentration in drinking water (Kinniburgh and Smedley, 2001).[2] A spatial distribution of the problem shows that the area containing the highest arsenic concentrations stretches across the central section of Bangladesh from Chapai Nawabganj in the west to Brahmanbaria in the east. However, it is the southern and eastern part of the country which is most affected, especially the districts of Chandpur, Munshiganj and

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[2] While the provisional WHO guideline for maximum arsenic concentration in drinking water is 0.01 mg/l or 10 μg/l (WHO, 2004), the Bangladeshi government (along with the US Environmental Protection Agency) use a higher allowable maximum arsenic concentration of 50 μg/l.

Gopalganj. For instance, in Chandpur 90% of the tube-wells that have been tested have been found to have levels of arsenic above 50 mg/l. As regards the affected population, between 28-35 million and 46-57 million people are estimated to be exposed to arsenic above the 50 µg/l and 10 µg/l levels, respectively (Kinniburgh and Smedley, 2001; Tapio and Grosche 2006).

While there is some recent evidence of a small increase in the number of skin cancers in Bangladesh (Smith et al., 2000), we may yet to see the full effects since the latency of arsenic-induced internal cancers is considered to be between 30-50 years and the population started drinking contaminated water in the 1970s (Tapio and Grosche, 2006). Hence, the high prevalence of arsenic induced skin lesions in the Bangladeshi population may be an early-warning of the potential increase in number of cancer deaths in the future. For less acute arsenicosis effects on health, it is usually assumed that skin lesions have approximate 10-year latency from first exposure to visible symptoms (Smith et al, 2000).

2.2. The cost of the arsenic crisis

Besides the epidemiological findings, there are important economic questions regarding the arsenic contamination problem. Recently, Ahmad et al (2005) have found that individuals in Bangladesh place a ‘surprisingly’ low value on arsenic-free water, i.e., only about 0.2-0.3% of the average household income. Two reasons for such finding are identified; firstly, the limited information that people have about the risks and levels of arsenic contamination may lead to uninformed answers to willingness to pay (WTP) questions based on stated preference methods. Secondly, the relatively long latency period of arsenicosis may affect people's perception of the problem.

The effect of latency on people's WTP to avoid the risk of developing arsenic-based health impairing effects was tackled by Maddison et al (2005). They attempted to estimate the aggregate cost of the arsenic crisis in Bangladesh using information about individuals' WTP for given hypothetical declines in mortality risk. Taking into account the number of people likely to be exposed to and influenced by arsenic contamination and considering the different symptoms that people are likely to suffer, the cost of arsenic contamination is estimated by aggregating the WTP across the population exposed. They take into account how current risk depends on past exposure, implying that the benefits from implementing a scheme to provide clean drinking water are not felt immediately, but are instead deferred by the latency time. In addition, they calculate how latency might impact the value of a project that eliminates the arsenic problem using a constant exponential pure utility discount rate (3%) for the lives saved in the future. This allows them to conclude that the annual cost of the crisis is around USD 2.4 billion. Furthermore, assuming a constant annual increase in population growth of 1.6% they estimate that the present value of a policy that eliminates the arsenic problem by drilling wells to a depth of above 250m declines from USD 192.7 billion when latency effects are ignored to USD 112.2 billion if latency is set at 39 years.

Based on the analysis by Maddison et al (2005), we argue that while accounting for latency is important, it is also important to consider whether a constant discount rate of 3% reflects people's implicit rate of time preference. It can be argued that the time that passes before a health hazard shows its symptoms and the level of perceived risk of developing a disease, affect the utility level of individuals. Thus, it is plausible to think that exposed individuals may weigh risk versus latency when deciding on actions that may be conducive to developing a chronic disease such as arsenicosis.

But how do individuals view latency regarding their own risk to life from a health hazard from drinking contaminated water? There is a wide literature that considers individuals' WTP for a marginal decrease in their risk to life. Most studies calculate an estimate of the value of a statistical life (VOSL) in a static setting, i.e., one period only. This is inadequate for studying an environmental problem associated with varying degrees of latency as latency affects the valuation of risk (Alberini et al., 2002).

Hammit and Liu (2004) and Alberini et al (2004) estimated the effect of latency on people's WTP for a small improvement in the risk to life. Hammit and Liu (2004) used a contingent valuation (CV) approach which considers the effect of a given disease and the latency on people's WTP to reduce mortality risk in Taiwan. In this case, the WTP is elicited with regard to protecting everyone in a household from four different environmental health risks which varied in terms of their latency and disease type. Interestingly, they find out that the WTP to reduce the latent risk is about one-fourth smaller than WTP to reduce acute risk, indicating that respondents discount for latency at about 1.5% per year. Additionally, they point out that while WTP declines with age by 2.3% per year, more educated respondents value risk reduction more compared to less educated individuals. In another study, Alberini et al (2004) also applied a state preference valuation approach using a North American population sample to explore how latency affects the WTP to reduce a risk of mortality and found that the current health status, future health status and subjective probability of surviving until the age of 70 are significant determinants of individuals' WTP to reduce risk of mortality. The model estimates were then used to calculate respondents' implicit (constant) utility discount rates. These turned out to be around 8% and 4.5 % for the Canadian and US subsamples, respectively.

Here we address the trade-off between latency and risk of developing arsenicosis from groundwater contamination. The focus is on estimating how much a given risk would have to be postponed to make it acceptable to individuals. A decrease in the latency period may be associated with an implicit willingness to accept (WTA) approach for increasing the risk of developing arsenicosis. Hence, one could, in principle, determine the marginal rate of substitution (MRS) of risk for latency provided that individuals' values are assumed to be commensurable. In this paper we argue that individuals are aware of the problem and accept the possibility of making trade-offs which require the substitution of risk of developing arsenicosis for its associated latency period. Thus, strong commensurability is assumed throughout the analysis in to be able to estimate people's perceived trade-offs using a random utility model.[3]

A simple conjoint (analogue to a choice experiment) analysis that elicits information directly from potentially affected individuals is used to estimate the marginal rate of substitution of risk for latency. The choice experiment is designed to minimise cognitive problems. The alternative hypothetical choices that individuals are confronted with under the field experiment are associated with two different hypothetical tube-wells: a

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[3] It is acknowledged that lexicographic preferences may arise in stated preference valuation methods due to cognitive problems by respondents when confronting hypothetical scenarios, especially when they are poorly informed and show ignorance about the issue being valued (Spash and Hanley, 1995; Rekola, 2003). In order to avoid excessive cognitive problems, the design of the conjoint analysis is greatly simplified to make the experiment as tractable as possible from the respondents' point of view. A pilot study was also used for this end.

near well that is assumed to be contaminated with arsenic (at varying degrees and with varying latency) and a far-off tube-well assumed to contains arsenic-*free* (safe) water.

The way that risk and latency influence the probability of choosing the arsenic contaminated tube-well is based on a random utility model. The information from the model can then be used to interpret the trade-off between how many lives in a given number of years time is equivalent to one life in the present following the standard 'value of statistical life' (VOSL) approach (Cropper et al 1990, 1991, 1992; Poulos and Whittington, 2000). Additionally, following Alberini et al. (2004) this information is used to estimate exposed individuals' (implicit) RTP. Such rate ought to be understood as a pure time preference rate which reflects the individuals' psychological motives to place preference weights on the future. As it is the individuals' reflection of such weighs, it is expected that various socio-economic factors such as age, gender and income may also determine them.

3. The case study

The Chandpur district is one of the worst arsenic affected districts in Bangladesh. 90% of the tube-wells in this district are contaminated by arsenic (Bibi et al., 2006). Arsenic contamination is coupled with high levels of extreme poverty and acute problems of food insecurity, especially by landless farmers (IFID, 2006). 29% of the population that is considered moderately poor own a small plot of land and have some livestock (IFID, 2006). This segment of the rural population is at risk of sliding deeper into poverty as a result of health problems or natural disasters (WHO, 2000, 2004). In this context, communities are mostly affected by arsenicosis due to high levels of arsenic contamination in the drinking water. Typically, when poor rural households with inadequate savings are affected by arsenicosis, they need to borrow in the informal market at high interest or sell their valuable assets such as domestic animals, land property and trees to meet the cost of medical treatment.

The case study is based on five villages in the Matlab *thana*[4] in the Chandpur District of southeastern Bangladesh, i.e. *Shilmondi, Shuvonkardi, Munsubdi, Udumbdi*, and *Babur Para*. The villages are all located in a shallow water table area and are representative of Matlab *thana* in terms of exposure to arsenic contamination, access to alternative water sources and patterns of water consumption.[5] Matlab *thana* has an area of nearly 410 km^2, and a population of around 445,000 people. The population of all five villages is about 6,254 people.

The five villages were selected by a random sampling approach based on a list of villages obtained from the ICDDR-B office (International Centre for Diarrhoeal Disease Research, Bangladesh, previously known locally as the Cholera Hospital). Within each village households were randomly selected using interval based random sampling. The number of household was initially ascertained for each village. The ratio of the number of the households to the number of total households in the sample was taken as the interval to be used for selecting family dwellings.

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[4] Divisions are the highest administrative unit in Bangladesh. There are six divisions, which are disaggregated into 64 districts. Each districts has an average of eight counties (*Thanas*). There are about 500 *Thanas* in the country, each of which holds a number of unions — a grouping of several villages or urban wards. Within the units, one can further distinguish hamlets (*Para*) at the local level.

[5] In Bangladesh the depth of water tables varies from less than a meter to more than 30m. The shallowest water table occurs in the coastal region (south Bengal). The depth to the water table moves seasonally with annual recharge and discharge conditions. Here, the water table is shallowest towards the end of monsoon and deepest in April-May. In recent years there is a declining trend in the deepest water table due to larger amount of groundwater withdrawal, particularly for irrigation.

A pilot study of 30 questionnaires was first employed in December 2005 and after some moderation of the design of the choice experiment to reduce the cognitive demand on respondents, the finalised survey was implemented between March and April 2006, and 240 household heads were finally interviewed, each interview lasting about 20 minutes.[6]

From the sampled households, 55% of them were living below the national poverty line of 1.3$/per capita/day (at 2005 purchasing power parity).[7] The average household in the sample consists of five members, one of them earning cash income (an average of about Tk. 6,000 per month). While the primary source of income is farming, about 50% of households had a variety of other sources of income, including activities in the business and service sector (21%), poultry and fish farming (8%), self employment (5%) and the production of handicrafts (11%).

As regards sampled households' water collection activities, almost all (97%) collected water for drinking, cooking and washing about five times a day using a *kalshi*[8]. The source of water is mainly from wells that are privately owned (92% of households), followed by public wells (5%), or a mix of both types of wells (3%). Water is free for all regardless of its source (private or public) and it is mainly collected from a near well

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[6] Responses to follow up questions indicate that the majority of household heads did not feel "nervous" or "uncomfortable" with the questions (96%) and the local enumerators expressed that in the majority of cases (97%) respondents were believed to have understood the questions and revealed truthful information. In addition, the overall quality of the survey was deemed good (70%) or fair (30%). In light of this information the whole sample consisting of 240 households were used in the analysis.

[7] Here we define households with a per-capita daily expenditure level below 23.1 *Taka* as very poor 23.1 *Taka* following Zeller et al (2005).

[8] A *kalshi* is a water vessel made usually of fired unglazed clay used as a reservoir for drinking water by 85% of the people in Bangladesh. *Kalshis* are also made of steel and bronze. Local artisans make a variety of shapes of *kalshis* of which a narrow mouth and round bottom with a volume of 20 liters can be used well.

usually by the spouse of the household head or by children. 32% of respondents perceived that the water they used for drinking is contaminated with arsenic.[9]

In the case study area the ICDDR closed down the wells which were contaminated and new wells had been with an increased depth between 190-350 feet (with assured arsenic-free water at 350 feet deep). However, it was observed that households in Shuvonkardi and Munsubdi were dissatisfied with the quality of the water. In addition, in Babur Para while two new public wells were opened and considered safe by the local government, households complained that they are located at a large distance, implying a relatively large investment in time to fetch water form them.

In terms of awareness of arsenicosis, 5% of the surveyed individuals responded that they or someone in their household were suffering from arsenicosis, and 13% stated that they knew someone in heir neighbourhood with arsenicosis. 80% also reported that they were familiar with the health impacts with 75% stating that arsenic causes skin pigmentation. Interestingly, however, only 1% of the surveyed individuals acknowledged that advanced stages of arsenicosis could lead to development of internal cancer.

While all the households consume water directly from the tube-wells, only 3% use arsenic mitigation technology. This low share of households attests to the relatively high operational and maintenance cost of the technology, the difficulty in getting the necessary chemicals, and not having enough understanding of how the technology works. Lastly, with regard to households' capacity to meet the cost of treatment of arsenicosis, household heads reported that they could hardly afford such costs (averaging about Tk. 5,000 per year).

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[9] The majority of the respondents stated that all the tube wells were tested for arsenic by ICDDR while most of the tube-wells in the five villages had been tested, a sizeable portion still remained to be investigated.

4. The model

As mentioned above, given the relatively complex framing and cognitive issues involved in experimental valuation models in poor rural areas of developing countries, a simple conjoint design which could be well understood by the respondents is used. The experiment involved asking household heads to choose between two hypothetical tube-wells: (A) a far-off well, 30 minutes walk away, that is uncontaminated and (B) the status quo, described broadly as a nearer well 5 minutes walk away, that is contaminated with arsenic. The latter scenario is then associated with varying degrees of risks to human health and latency, resembling the current situation. Each respondent was asked to choose between scenario A and a hypothetical one with a combination of risk and latency (B1, B2, B3 or B4) as summarised in table 1.

[TABLE 1]

The hypothetical scenario associated with the distance to the free-arsenic tube-well was chosen taking into account individuals' range of experiences regarding the distance to the nearest tube-well. In most cases, it was indicated by respondents that it takes about five minutes to walk to the nearest tube-well. However, 10% of households stated that they spend at least 15 minutes each time to walk to collect water from their nearest tube-well, not necessarily being arsenic-free. In order to recreate the scenario that individuals could choose to collect uncontaminated water at a higher cost than actually incurred, the time needed to reach the uncontaminated tube-well (15 min) was doubled. Hence, without making the scenario unrealistic, respondents were made to think that in a hypothetical case, in order to be able to collect arsenic-free water they would need to incur some additional effort associated with a greater opportunity cost of the household's time.[10] The alternative choice of water source is defined so that in scenario A (the far off well), the latency may readily be interpreted as being infinite with mortality risk being zero.[11] With regards to the hypothetical attribute levels associated with risk and latency in each scenario B_i ($i=1,2,3,4$), it is a maintained assumption of this experiment, as in any other conjoint analysis, that the attribute levels per se do not alter the estimated parameters of the indirect utility function (Hensher et al., 2005).

A given hypothetical scenario is described in the following way, e.g., scenario B_i (for $i=1$): *"Suppose that you have a choice between two tube-wells from where to fetch drinking water everyday. The first well means a 30 minute trip (walk) and it supplies uncontaminated water. The second well means only a five minute trip (walk) but it is contaminated by arsenic. For every 100 people who drink from this well one would develop arsenicosis and die of cancer in 5 years time as a consequence. Which well would you choose?"* (see table 1 for the different combinations of levels and attributes).

The experiment is based on the assumption that if the individual chooses the distant well, his survival probabilities are not affected and thus her discounted life years are unchanged. However, if an individual chooses the near well, her risk of death increases

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[10] Information from focus revealed that women face a significant opportunity cost of time due to (i) the need to walk long distances to find uncontaminated water, (ii) overcoming rain and mud in the monsoon, and (iii) crowding and waiting in line at the clean water source. For some women to obtain water from clean wells, the extra time is considerable, when balanced against their other tasks/responsibilities within the household. The recreated hypothetical scenario about the contaminated nearest well (5 min.) vs. the uncontaminated well (30 min), somewhat reflects the range of individuals' experiences.

[11] The following basic information about the effect of arsenicosis was provided to all respondents: "*Many scientists have studied the effect on people's health of consuming arsenic contaminated water over a period of years. They now agree that drinking arsenic contaminated water can cause cancer in some people. I now want to ask you some questions about whether you would change your behaviour in order to avoid the risk of contracting cancer, even if it meant spending more time collecting water from more distant wells*".

and her discounted life years falls. The change in her expected discounted life years depends on the increased risk and the latency described in the scenario that the respondent is asked. It follows that when confronted with this simple choice experiment, the individual can be modelled as choosing between two different sets of expected discounted life years. The far well choice represents the unchanged expected discounted life years and the near well choice represents a decreased expected discounted life years due to the increase in risk.

It is also worth noting that that questions were answered by household heads and that only 11% of sampled household heads were women. However, women are mostly responsible for collecting water from the tube-wells (96% of households). We thus follow the unitary household modelling approach, which assumes that the household's allocation decisions is governed by optimisation on the part of one member who can be regarded as a "first mover with a take-it-or-leave-it opportunity in a negotiated household by assuming that he has the habit of taking each member's well-being into account" (Dasgupta, 1993: 233). Hence, the RUM model assumes that the preference about the trade-off between risk and latency reflects that of a unitary household (i.e., all the members in the household drink from the same water) and not just the preference of the head of the household.[12]

After various functional forms for the random utility model (RUM) were tried, the final model used is based on an additive functional form as it provides the best fit and in addition it has useful properties for estimation and interpretation purposes. The two main variables are related to disutility, i.e., risk (x) and the inverse of latency ($1/y$). The latter

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[12] Notwithstanding this fairly strong assumption, modelling the intra-household resource allocation mechanism given potential heterogeneous preferences among household members is beyond the scope of this paper. For a discussion about bargaining theory as a framework for household choice, especially due to gender differentials see Dasgupta (1993), chapter 11. This is an area that merits further research and we are grateful to one of the reviewers for pointing this out.

transformation is useful since in instances of no risk whatsoever the latency of the impact is infinite. In addition, the variables are not transformed into logs since by construction x is zero in scenario A.

$$U_i = \alpha_0 - \alpha_1 x - \alpha_2 (1/y) + e_i \tag{1}$$

where 'x' and 'y' denote risk and latency, respectively, for individual i, and e_i is a standard normally distributed white noise disturbance term. The parameter vector that can be estimated from the data is given by $\boldsymbol{\alpha}$. The marginal rate of substitution (MRS) between risk and latency can be determined by estimating the vector of structural parameters, $\boldsymbol{\alpha}$. From (1):

$$MRS_{x,y} = -y^2 (\alpha_1 / \alpha_2) \tag{2}$$

The RUM is based on the assumption that individuals make their choices on the basis of observable attributes of the choices and an unobservable element (the random component), the latter potentially arising from incomplete information or from the randomness in the preferences of individuals.

It is assumed that an individual would choose scenario A if the utility gained from this scenario is greater than the utility obtained from scenario B, i.e. $U_A - U_B > 0$. The probability of choosing scenario A (the free arsenic tube-well), i.e., $Pr (U_A - U_B > 0)$ or $Pr (Y=1)$ is

$$Pr\,(Y=1) = \Phi\,[\alpha_0\, ASC_A - \alpha_1\,(x_A - x_B) - \alpha_2\,[(1/y_A) - (1/y_B)] \tag{3}$$

where ASC_A is the alternative specific constant representing the propensity of individuals to choose one alternative over another regardless of its attributes. Ideally the alternative specific constant would be zero, indicating both that people are not psychologically drawn to selecting choice A. Further, since by construction, $y_A \rightarrow \infty$ and $x_A=0$, the probability of choosing the arsenic-free tube-well is given by

$$Pr\,(Y=1) = \Phi\,[\alpha_0\, ASC_A + \alpha_1 x_B + \alpha_2\,(1/y_B)] \tag{4}$$

Risk (latency) is negatively (positively) associated with overall utility. Hence, equation (4) captures individuals' choice of alternatives (A and B) based on the relative contribution of risk and latency. Hence, it is possible to estimate the part-worth or marginal rate of substitution between risk and latency.

Of course, the underlying assumption is that individuals' stated choices depend on the varying attributes they are confronted with. For instance, it is expected that the likelihood associated with any given individual of choosing to drink water from the arsenic-free tube-well increases when the mortality risk (latency) of the alternative contaminated tube-well increases (decreases).

The part-worth is given by $MRS_{x,y}>0$ since x and y are a 'bad' and a 'good' respectively, implying that $MRS_{x,1/y}<0$. It also follows that the part-worth should be evaluated at different levels of latency. If latency is fixed at just one year then the part worth becomes α_1/α_2. That is, an individual would be willing to accept an increase of risk of dying from arsenicosis of 1 in 1,000 if the risk is postponed by $(0.001\alpha_1)/\alpha_2$ years. If latency instead is set at five years ($y_B = 5$), according to (2), the part-worth increases non-linearly to $25(\alpha_1/\alpha_2)$, implying that the same individual would be willing to accept an increase in risk of 1 in 1,000 if she were compensated by postponing the development of arsenicosis by $0.025\alpha_1/\alpha_2$ number of years.

The simplest RUM assumes that that the choices made are independent of the socio-economic characteristics of the respondents. Socio-economic information from the sample needs to be interacted with the main attributes in order to determine their effect on the probability of choosing any of the two hypothetical alternatives. In this case, *z* is the vector of exogenous independent covariates interacted with the *risk* attribute at its varying levels according to the scenarios in case B:

$$Pr\,(Y=1) = \Phi[\,\alpha_0\,ASC_A + \alpha_1 x_B + \alpha_2\,(1/y_B) + \sum \alpha_j\,(x_B\,z_j)] \qquad (5)$$

$MRS_{x,y} = -\,y_B^{\,2}\,(\alpha_1 + \sum\alpha_j z_j)/\alpha_2$, were z_j can be evaluated at the sample mean. The variables that are assumed to control for the individuals' idiosyncratic choices include average household age, household income, level of formal education, the degree of knowledge of arsenicosis, and the household's demographic structure.

5. Results

The individuals from the sample were confronted by a random draw of risk and latency combinations as regards scenario B, i.e., the arsenic contaminated tube-well. The share of individuals that chose scenario B (the nearer contaminated well), given each of the four combinations (risk and latency) are: [(0.0001, 5): 18%], [(0.0001, 30): 65%], [(0.01, 5): 16%], [(0.01, 30): 20%] (table 1). That is, respectively, 18%, 65%, 16% and 20% of households confronting each of the risk and latency combinations for the scenarios B_i (i=1, 2, 3, 4), associated with the contaminated tube-well, would chose to collect contaminated water rather than arsenic-free water.

The data also indicate that under a relatively high risk of arsenicosis (1% risk of developing cancer) and a short latency period (5 years) larger households, associated with a higher proportion of females and with higher average education levels would prefer to collect uncontaminated water from the more distant tube-wells (c.f. Table 2). Interestingly, for the same level of risk exposure, when latency increases to 30 years, households with more children would prefer to collect water from the nearer (even if contaminated) well. This may indicate that rearing children makes the opportunity cost of time to be significant enough to prefer bearing such health risk and trade it for a significantly longer latency period. In addition, even when risk diminishes to just 0.01% the more educated households prefer to incur the higher opportunity cost of time for collecting arsenic-free water.

5.1. The MRS between risk and latency

Given model (4) a multinomial logit RUM model is run with risk and (the inverse) of latency as the two attributes and with the dependent variable being 'one' if the individual chooses scenario A (free-arsenic far-off tube-well) and 'zero' if the choice is the near contaminated well at the (randomly) specified risk/latency mix. Table 3 shows the results of the RUM model (c.f. equation 4).

[TABLE 3]

As expected, the likelihood of choosing the far-off arsenic free tube-well increases with a higher health risk and a lower latency period. The alternative specific constant is statistically significant, indicating that individuals choose between the two alternatives not only on the basis of their attributes but also based on some unobservable preference regarding the tube-well, that may be correlated with their socio-economic characteristics.[13] As a whole the multinomial Logit model performs relatively well and the null hypothesis that the two attributes are jointly significant cannot be rejected according to a likelihood ratio test.

The basic RUM model (c.f. equation 4) can be extended by including interactions between the risk attribute and variables that are a priory thought to have an effect on the stated choice between the two alternative scenarios (c.f. equation 5). It is reasonable to assume that the households' socio-demographic structure would impact the household head's expressed trade-off between risk and latency. Table 4 describes the socioeconomic independent covariates that are included as part of the *z* vector of independent variables.

[TABLE 4]

[TABLE 5]

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[13] The reason may be due to near wells currently being labelled as contaminated' thus causing individuals to affect their hypothetical choice thus adding a psychological factor in addition to the purely hypothetical scenario based on the different risk and latency values.

Table 5 presents the results of the extended RUM model to add insights about the effects of age, education, income, knowledge of arsenicosis and household structure on household head's stated trade-off between risk and latency. This model also shows a relatively good fit. After controlling for the village dummies, the data indicate that the likelihood of choosing the far-off arsenic-free well is determined by the level of education, the share of females in the household, its size, knowledge about arsenicosis and the number of children in the household. These results complement those that appear in Table 2.

Given the potential increase in risk in scenario B (x_B) for the given level of latency, y_B, the part-worth (PW) is given by $PW = y_B{}^2(\alpha_1 / \alpha_2)x_B$. It can readily be interpreted as the number of years the risk of developing the health hazard due to arsenic contamination needs to be postponed in order for the average individual in the sample to be willing to accept an increase in such risk. Alternatively, it can also be interpreted as how individuals trade-off the health hazard in the present *viz-a-viz* the future, with the latency period identifying the time frame of such inter-temporal choice. When risk is interacted with the household's characteristics (vector z), $PW = y_B{}^2\left(x_B(\alpha_1 + \sum \alpha_j z_j)\right)\Big/\alpha_2$ is evaluated at the mean level of z_j.

Table 6 presents the estimated part-worths at different latency periods taking an exogenous small increase in risk. As expected, when the actual period of latency of arsenicosis increases, respondents are willing to accept the increased level of risk only if is postponed further into the future. The implicitly stated part-worth (WTA to accept such risk) increases non linearly from 0.34 years to 12.13 years when latency of arsenicosis is increased from five to 30 years. This information can be used to determine the implicit rate of time preference of individuals when evaluating their future health risks.

[TABLE 6]

5.2. Time varying rates of time preference

Implicit rates of time preference can be inferred from the part-worths of risk of arsenicosis in terms of different periods of latency. As the part-worth describes the minimum number of years, *t,* the increase in risk, e.g., 1 in 1000 (0.1%), has to be postponed for an individual to accept such risk (Cropper, et al., 1991, 1992; Poulos and Whittington, 2000), it can also be interpreted as the equivalency between the present value of 1001 lives ($A=1001$) in τ years time and 1000 lives ($V=1000$) in the present (Alberini et al 2004). Under this alternative interpretation τ is the part worth based on the MRS between risk and latency. It follows that $V=A.D(r,\tau)$, where now $D(r,\tau)$ stands for the discount factor r being the individual's rate of time preference. The discount factor can be approximated in continuous time, i.e., $D(r, \tau) = e^{-r\,\tau}$. Hence, once the part-worth, τ, for different periods of latency is estimated, the associated RTP (r) can be calculated. For example, table 3 shows different part-worths (τ) for each latency period ($y_B = 1, 5, 10, 30$ years). Each part-worth is associated with a different RTP for a given increase in risk of for example 1 in 1000, i.e., $1000/1001= e^{-r\,\tau}$. The RTP for each latency period, associated with a given part-worth, can be calculated as: $r_1=7.7\%$, $r_5=0.3\%$, $r_{10}=0.07\%$, $r_{30}=0.01\%$. This implies that:[14]

$$1000/1001= e^{-(0.0769)(0.013)} = e^{-(0.0029)(0.337)} = e^{-(0.00074)(1.348)} = e^{-(0.00008)(12.128)} \tag{6}$$

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[14] It can be easily observed that for small increases in risk, equation (6) generalizes to: $x_B = (1+r)^{yB}-1$.

As the risk/latency trade-off is increasingly delayed the RTP falls suggesting that individuals' implicit discount rates are not constant over time, but declining—a pattern often referred to as hyperbolic discounting (Henderson and Bateman, 1995; Frederick *et al.* 2002). According to experimental studies when people are asked to compare a smaller/sooner reward to a larger/later one, people's implicit RTP over longer time horizons is lower than over shorter time horizons (Thaler, 1981).[15]

Experimental studies also suggest that the value of a later reward decreases as the delay to its receipt increases, in other words, preferences between two delayed rewards can reverse in favor of the more proximate reward as the time to the rewards is shortened (Green et al., 1994; 1996; Pender, 1996; Frederick et al, 2002). For instance someone may prefer to obtain $100 in two years time over $50 next year, but at the same time she may also prefer $50 now over $100 tomorrow. The choice of the more immediate, but smaller reward may be interpreted as implying that the value of the later reward is discounted.[16] It has also been argued that the inverse relationship between the RTP and the size of the delay (or latency in the present case) may not be a function of relative location in time but of the size of the time delay (Read, 2001).

Interestingly, Cropper et al. (1992) estimated the discount rate from experiments based on individuals being asked to value programmes that could save other people's

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[15] Whether such observation reflects some other form of present-bias in intertemporal choice or directly supports for hyperbolic discounting continues to be an open debate (Fernández-Villaverde and Mukherji, 2002). In addition, much of the debate has centred on the way time-varying discount rates can result in time-inconsistency (see: Groom et al., 2005).

[16] This pattern has also been found in animals that tend to choose a more immediate but smaller reward than a more delayed, though larger reward. In experimental sessions it has been shown that predators accept a smaller prey item, instead of continuing to search for a larger one, despite the option maximising the rate of energy intake for the predator. This may be due to increased risk of loosing the prey if having to wait longer (Green et al., 1996).

lives.[17] The study found that the discount rate declined over time. Similarly, Poulos and Whittington (2000), using data from developing countries, have also found that a constant exponential function is inadequate for explaining the way that individuals discount future lives saved.

Our result shows time-varying (declining) average annual RTPs over a 30 year time horizon, which can be used to calibrate a hyperbolic function. Following Ainslie (1975), such RTP function can be represented by $r(t) = \frac{\lambda}{t}$, where λ is a parameter associated with how steep the discounting curve of future rewards or payoffs is. The parameter λ can be readily calibrated using non-linear estimation procedures, such as NLSQ. Other popular hyperbolic discount function is that of Mazur (1987) where $r(t) = \frac{1}{1+\lambda t}$ A more robust discounting function based on Weitzman's (2001) gamma-distribution: $r(t) = \frac{\lambda_1}{1+tv}$ with $v = \frac{\lambda_2^{\ 2}}{\lambda_1}$ representing the 'convergence velocity' parameter that in turn reflects how fast the RTP declines; t denotes time, and the λ-s are parameters that can be estimated.[18] It can be noted the constant exponential discount rate is a special case when $\lambda_2=0$. We calibrate this gamma-RTP function which follows a rectangular hyperbola to estimate discount rates within the 1-30 year time frame.

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[17] Cropper et al (1992) carried out a survey that asked respondents to choose between two programmes. Programme A saves X number of people today and programme B saves Y number of people in 10/25/50/100 years time. They found a surprisingly large number of individuals had lexicographic preferences so they always chose the present lives saved over the future lives saved, no matter the numbers involved.

[18] Another more general discount function is that of Loewenstein and Prelec (1992), $r(t) = 1/(1+ \lambda_1 t)^{\lambda_1/\lambda_2}$. However this functional form cannot be estimated as there are not sufficiently enough degrees of freedom.

The choice of the 10 years and 30 years of latency is based on the fact that the latency for induced internal cancers is at least 30 years and for less acute health effects, such as skin lesions is approximately 10 years from first exposure to visible symptoms (Smith et al, 2000). Further the average sampled respondent is about 50 years old.

[FIGURE 1]

[TABLE 7]

Figure 1 presents the relationship between MRS (latency, risk) and the hyperbolic RTP. Using the extended RUM without village dummies, and parameterising λ the resulting time varying RTPs are also shown in table 7. As it can be observed, Mazur's (1987) hyperbolic form provides the highest RTP. However, the three RTP functional forms provide a similar insight. The implicit RTP is relatively high when latency is very short (e.g., one year), with estimates ranging between around 3% to around 7%, with a mean of about 5%. However, for a latencies of around five years a sharp decline in the RTP is seen (around 1%), 0.5% for a latency of 10 years and then rapidly converging towards zero for longer latencies of around 30 years.

We hypothesize that after very short term latencies, people discounting expected losses (i.e., increased health risk) less than gains (reduced health risk), as it has been observed in different experimental studies (e.g., Frederick et al, 2002) also echoing the observed asymmetry between WTA and WTP estimates in environmental valuation studies. Further, it is important to note that while the economic literature suggests that individuals discount heavily in instances where economic growth is rapid (Dasgupta and Heal, 1979;

Groom et al, 2005), in Bangladesh per capita incomes are stagnant and the calculated discounts should be interpreted as only reflecting pure time preference rates.

6. Conclusions

This paper addresses the question of how people trade-off risk and latency from health hazards regarding groundwater contamination. Using a straightforward conjoint and random utility modelling approach adapted to the idiosyncrasy of the Ganges Delta of Bangladesh, the empirical results suggest that such trade-offs do exist and that individuals are willing to accept an increase in health risk so long as such increase is postponed for a certain amount of time. In addition, we find that the socio-economic characteristics affect the strength (or part worth) of such trade-off.

Individuals exposed to arsenic contamination in the Ganges Delta of Bangladesh employ a rate of time preference regarding their future health risks above the market interest rate only at very short time horizons. The same level of risk further into the future appears to be discounted at significantly lower rates, rapidly converging at zero rates of time preference. While this finding concurs with recent evidence from similar studies in developed countries, the difference is that such decline is observed quite early and that after just about five years, the rate of time preference approximates to zero rather quickly.

This information is important for current decision-makers facing the arsenic crisis in the Ganges Delta. We suggest that policy makers apply a rather low discount rate for public health programmes aimed at solving the arsenic crisis, programmes which in fact have most of their benefits in the medium to distant future. This also calls to a revision of recent estimates (Maddison et al., 2005) regarding the value of the arsenicosis crisis in

Bangladesh. It can be argued that even with a pure time preference set close to zero given sensible latency periods of about 30 years, the opportunity cost of the capital component in a typical discount rate may not be necessarily zero, thus still allowing for positive discounting. However, in regions such as the one studied here where economic growth is quite stagnant, it is questionable whether the capital component of the discount rate should really have an important effect.

The results complement those by Ahmad et al's (2005) who find that people in Bangladesh value little arsenic free drinking water. We go further to suggest that those values, albeit small, should not be discounted with due care if used to evaluate alternative policy interventions. As a rule of thumb applied to evaluate policy alternatives with benefit cost analysis, we favour the use of rather low discounting rates, especially in stagnant economies affected by ecological crisis of the magnitude of the Ganges Delta of Bangladesh.

The issues in this paper merit further research. External validity tests applying approaches based on revealed preference data may allow a higher degree of confidence in our results. One such approach may involve the use of travel cost approach where the time invested in gathering water from alternative (both from contaminated and arsenic free) tube-wells is recorded and the opportunity cost of time, e.g., in terms of competing household activities, carefully evaluated.

Last by not least, a further development of the presented analysis may involve extending the unitary household random utility model and test the potential differential gender effects regarding intra-household water collection decisions. This is because in certain societies and cultures the roles of women and male household heads may differ when deciding about competing chores, e.g., water collection and other productive activities. Hence, developing models accounting for a more explicit intra-household resource allocation bargaining approach is likely to refine the results presented in this paper. This may prove to be a challenging modeling task, especially when dealing with rural households where due to cultural reasons women's voices are not easily allowed to be heard by either local or outside analysts. However, we find that this to be one of the most fertile grounds that would shed additional light about the trade-offs between latency and health risks from contaminated drinking water to the rural poor in developing countries.

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Table 1: Description of the hypothetical scenarios

Scenarios	Risk	Latency	Share of respondents confronting choice	Share of respondents choosing B_i (i=1,2,3,4) vs. A
A	0	infinite		
B_1	1 in 100	5 years	A vs. B_1: 25%	16%
B_2	1 in 100	30 years	A vs. B_2 30%	20%
B_3	1 in 10,000	5 years	A vs. B_3 25%	18%
B_4	1 in 10,000	30 years	A vs. B_4 20%	65%

Number of observations: 240 households.

Table 2. Group mean comparison test about choices made according to household characteristics

Scenario A vs. B_i (i=1,2,3,4)	**Variable**	**Mean value Choice A**	**Mean value Choice B**	**P value**
B_1	Household size	5.06	4.00	0.056
	% females	0.51	0.39	0.049
Risk: 0.01,	Number of children	0.38	0.30	0.661
Latency: 5 years	Formal education	2.50	1.62	0.003
B_2	Household size	5.83	4.44	0.032
	% females	0.45	0.43	0.900
Risk: 0.01,	Number of children	0.33	0.67	0.070
Latency: 30 years	Formal education	2.31	1.82	0.005
B_3	Household size	4.86	5.10	0.550
	% females	0.46	0.41	0.786
Risk: 0.0001	Number of children	0.32	0.40	0.631
Latency: 5 years	Formal education	2.54	1.66	0.005
B_4	Household size	5.04	5.22	0.612
	% females	0.53	0.47	0.580
Risk: 0.0001	Number of children	0.61	0.47	0.397
Latency: 5 years	Formal education	2.43	2.10	0.067

Number of observations: 240 households.

Table 3: The marginal effect coefficients of the basic latency/risk random utility (logit) model

Variable	Coefficient[a]	|T-stat|
Constant	-0.139**	2.454
Risk	-24.832***	3.814
Latency (inverse)	1.843***	4.933

[a] The coefficient reflects the partial derivatives of probabilities with respect to the vector of characteristics calculated at the mean levels. Goodness of fit: Log likelihood function: - 129.72. Restricted log likelihood: -151.33. LR stat. (Chi squared): 43.22. Pseudo R-squared: 0.14. N: 240.

Table 4: Descriptive statistics of socio-economic variables interacted with the level of environmental risk in the RUM

Variable	**Mean**	**Std.Dev.**	**Min.**	**Max.**
z_1: Household size	5.100	1.511	2	11
z_2: Number of children in the household	0.412	0.571	0	3
z_3: Share of female members in the household	0.474	0.167	0	0.86
z_4: Degree of formal education[a]	2.297	0.788	1	5.6
Dummy variables				
z_5: If household lives in the village 'Shilmondi'	0.250		0	1
z_6: If household lives in the village 'Babur'	0.166		0	1
z_7: If household lives in the village of 'Munsubdi'	0.166		0	1
z_8: If household lives in the village of 'Shuvonkardi'	0.250		0	1
z_9: If household or neighbours have been affected by *arsenicosis*	0.154		0	1
z_{10}: If household is below the poverty line (1.3US $/day). [b]	0.545		0	1

[a] Education: Categorical variable, i.e: 1 if iliterate; 2 if School up to class V (primary education); 3 if school up to class X (secondary education); 4 if school up to class XII (higher secondary education); 5 if XII completed and 6 if graduate.

[b] The level of extreme poverty is set at 23.1 taka per capita/day (PPP). The dummy identifies those households that live below the average income level of the sample (1.3US $/day). N: 240.

Table 5. Extended latency/risk RUM (multinomial logit)

Variable	**Coefficient**	**|T-stat|**
Constant	-0.001***	4.272
Risk	-0.832***	3.590
Latency (inverse of)	0.012***	5.803
Household size	0.060**	2.176
Number of children (< 5 years) in the household	0.102*	1.628
Share of female members in the household	0.414**	2.288
Degree of formal education	0.293***	3.843
Affected by *arsenicosis*	0.166*	1.674
Below income poverty line	-0.066	0.802
Shilmondi village	-0.182*	1.847
Babur village	10.937***	2.543
Munsubdi village	-0.177	1.659
Shuvonkardi village	-0.059	0.542

Log likelihood function:-101.75. Restricted log likelihood: -151.33. LR stat. (Chi squared): 99.17. Pseudo R-squared: 0.33. The coefficient reflects the partial derivatives of probabilities with 4espect to the vector of characteristics calculated at the mean level. Note: all socio-economic variables are interacted with the risk attribute. N: 240.

Table 6: Part-worth estimates and implicit discount rates at different levels of latency

	Latency			
	1 year	5 years	10 years	30 years
Logit RUM (model 4)				
Part worth of increase in risk (1 in 1000)	0.013	0.337	1.348	12.128
RTP (Ainslie)	7.669%	0.297%	0.074%	0.008%
Logit RUM (model 5)				
Part worth of increase in risk (1 in 1000)	0.021	0.515	2.062	18.555
RTP (Ainslie)	4.77%	0.19%	0.05%	0.01%

Table 7. Comparison of time varying implicit rates of time preference

Latency **RTP (%)**	**1 year** **(95% conf. int.)**	**5 years** **(95% conf. int.)**	**10 years** **(95% conf. int.)**	**30 years** **(95% conf. int.)**
Ainslie (1975): $r(t) = \frac{\lambda}{t}$	4.77 (3.14, 6.39)	0.19 (0.13, 0.26)	0.05 (0.03, 0.06)	0.01 (0.00, 0.01)
Mazur (1987): $r(t) = \frac{1}{1+\lambda t}$	4.74 (3.49, 7.38)	0.99 (0.72, 1.57)	0.50 (0.36, 0.79)	0.17 (0.12, 0.26)
Weitzman (2001): $r(t) = \frac{\lambda_1}{1+(\lambda_2^2/\lambda_1)t}$	4.77 (3.64, 6.05	0.95 (0.73, 1.21)	0.36 (0.12, 0.48)	0.20 (0.16, 0.60)

Note: The 95% confidence interval is shown in brackets. The confidence interval for Weitzman's gamma function is based on the confidence interval for λ_1 due to not sufficient amount of degrees of freedom in the NLSQ model.

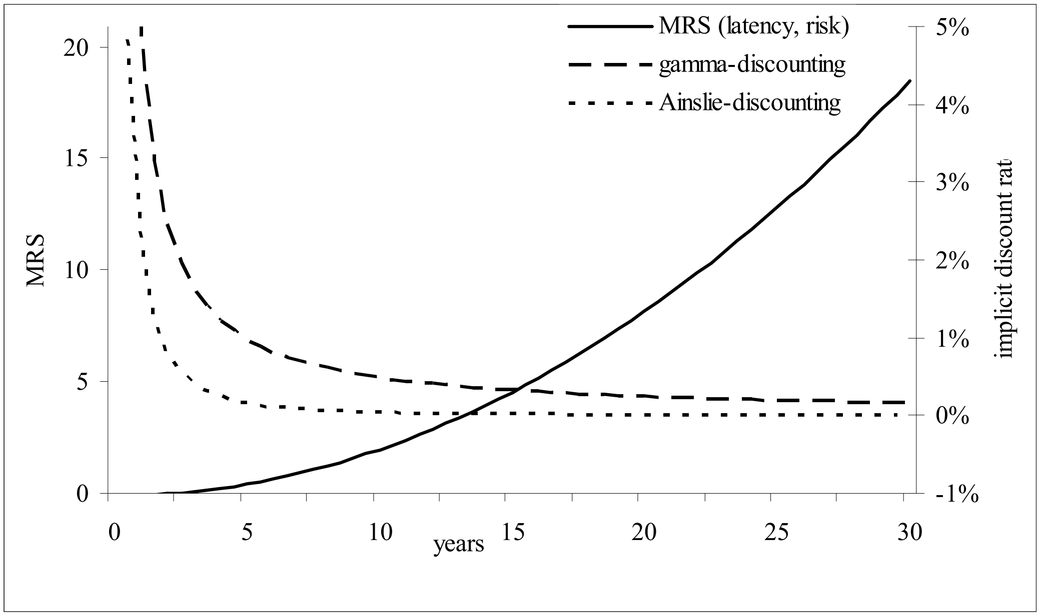

Figure 1. Time-varying implicit discount rates and the MRS between risk and latency