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The Economics of Curiosity

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We develop the hypothesis that an individual can get some value of information, even if they do not use the information for his subsequent decision, contrary to the expected utility theory. Curiosity is associated with the direct utility from information and is defined formally by using the concept of entropy. We can measure an agent's curiosity level by the maximum amount of money that he is willing to pay in order to obtain the information thereby reducing the entropy. We test the hypothesis from lab experiments and obtain the empirical evidence that people are actually willing to pay a positive amount of money to obtain payoff-irrelevant information. Also, the comparison of the coefficients of variation for our curiosity measure and the IPI (Imaginal Processes Inventory) curiosity measure which is widely used in psychology suggests that our measure is more informative.

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I. Introduction

Many people obtain utility from learning something they did not know. Some often pay significant costs simply to learn something they want to know. For example, we have fun for quiz games, are excited by news about a movie star, have interest in the culture of other countries, enjoy reading about history, science, art etc. or observing flowers, insects, stars, etc. We sometimes even struggle to find out a solution for a puzzling mathematical problem without any reward, and some explore the unknown land at the risk of the life. These behavior can be explained by

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the notion of "curiosity."

In this paper, we define curiosity in a formal way. In plain English, curiosity is defined by someone's propensity to learn something unknown to him.[1] The motive of learning something may be various,[2] but we distinguish mainly between two motives; one is to avoid risks associated with an uncertain monetary outcome and the other is purely to want to know it without any monetary concerns.[3] In the former case, information gives indirect utility, while it gives direct utility in the latter case. We will call only the latter motive curiosity. For instance, if a person is eager to know the answer for a quiz question "What is the oldest existing firm in the world?" or "What is the highest mountain in Europe?," it must be out of curiosity, but if a person who is thinking of investing in stocks wants to know "What will be the interest rate next month?," it is not.

Curiosity is a personal characteristic, so the intensity of curiosity can vary across individuals.[4] Insofar as curiosity is associated with an individual's utility obtained from some information, it is natural that each individual attaches a different value to given information. Then, what can be used as an index for an individual's curiosity? How can we measure his valuation for information? For the purpose, the information theory can provide a useful index of curiosity.

Entropy is a measure of disorder or a measure of the uncertainty. It quantifies information (usually in bits). For example, a fair coin has an entropy of one bit. However, if an agent knows that the outcome of the coin toss is Head, the entropy is zero, because there is no further information necessary to communicate. A fair dice

[1] Litman (2005) defines curiosity by the "desire to know, to see or to experience leading to exploratory behavior directed towards the acquisition of new information." Here, seeing and experiencing are both to acquire new information, i.e, to know it. Therefore, in a broad sense of the word "know", the phrase "to see or to experience" may be considered as redundant, although psychologists distinguish sensory curiosity (perceptual curiosity) for sensing experience from cognitive curiosity (epistemic curiosity) for knowing experience. See Berlyne (1954), Loewenstein (1994) and Litman and Spielberger (2003).

[2] Berlyne (1960) believes that curiosity is a motivational prerequisite for exploratory behavior. The term curiosity is used both as a description of a specific behavior as well as a hypothetical construct to explain the same behavior. Exploration refers to all activities concerned with gathering information about the environment. This leads to the conflict and question of whether exploratory behavior should be defined in terms of the movements that an animal or human performs while exploring or in terms of the goal or purpose of the behavior observed. A clear distinction between these two may not always be possible.

[3] Condry (1977) distinguishes curiosity as "intrinsic" and "extrinsic." While extrinsic curiosity is to receive an external reinforcement, intrinsic curiosity is independent of external reward, such as play, imaginative behavior etc. Thus, intrinsic curiosity corresponds with our latter motive. Also, Wohlwill (1981) calls it *affective* curiosity (or exploration) whose examples include children's high level play for the pure joy of it and adults' philosophizing.

[4] It is reported that the intensity of curiosity is both inherited and acquired. While Saxe and Stollak (1971) found some evidences for the social learning theory that both parental reinforcement and modeling foster children's curiosity, the characteristic of curiosity is recently found in genomes. See Fidler *et al.* (2007).

has a higher entropy than a fair coin, because it has more equally likely outcomes.

If an agent does not know the value of a random outcome, curiosity indicates that he wants to know it. This means that he has a valuation for the information. Note that the value of information can be measured by entropy.[5] This implies that learning the value of a random outcome by obtaining information is a process of reducing entropy,[6] and naturally we can conclude that *curiosity is a biological mechanism to lower entropy.*[7]

Learning an unknown value can be done by spending some resources in acquiring the information. The more curious he is of the random outcome, the more resources he will be willing to invest. Thus, we can use the maximum amount of money that an agent is willing to pay in order to obtain information as the proxy for his intensity of curiosity. In analogy with risk preference, we will say that an individual is curious if he is willing to pay a positive amount of money to obtain given information, or otherwise he is incurious.[8] Also, we will say that an individual is more curious than another if he is willing to pay more to acquire given information.

If it is too costly to obtain full information, people may alternatively want to acquire noisy, partial information in a less costly way in order to satisfy their curiosity at least partially thereby reducing their entropy. The information theory predicts that people will be willing to pay more to obtain a more informative signal for the information.

To test the hypothesis that people may get positive utility simply from learning the value of a payoff-irrelevant random outcome, we perform a laboratory experiment. After recruiting about 40 subjects in a random and public way, we provide 40 questions which may arouse their curiosity and ask them to respond by mouse-clicking which is costly in terms of their reward they will be paid after the experiment. The questions are categorized into two groups (interpersonal questions and impersonal questions)[9] à la Imaginal Processes Inventory (IPI) measure which

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[5] The attempt to interpret entropy as the value of information was begun by Kelly (1956) and then has been succeeded to Bellman and Kalaba (1957), Marschak (1959) and Arrow (1972).

[6] The view of curiosity from an information-gap perspective dates back to William James (1890 [1950]). Also, see Kreitler, Zigler, and Kreitler (1974) for an interesting view on the entropy-interpretation of curiosity.

[7] Erwin Schrödinger (1944), in his famous book "What is Life?", used the concept of negative entropy. By the concept, he meant that a living system exports entropy in order to maintain its own entropy as a low level. It is an interesting analogy that information entropy is reduced by a flow of energy which can be initiated by curiosity.

[8] This case includes that an individual is reluctant to know something, i.e., he even wants to pay a positive amount of money in returns for leaving him ignorant of the information. For example, some patients may not want any information about their fatal medical conditions.

[9] The importance of this categorization is widely recognized in psychology. For example, Glambra *et al.* (1992) show that "women showed an increase in impersonal-mechanical curiosity and a decline in interpersonal curiosity ... men were unchanged on both curiosity measures." We ignore sensory

has been widely used in psychology.[10]

The experimental results suggest that people are actually willing to pay a positive amount of money to obtain payoff-irrelevant information, and that their willingness-to-pay (WTP) for full information is on average higher than their WTP for partial information. Both results seem to support the hypothesis and the explanation of curiosity based on entropy. We also find that the curiosity level of an individual for persons (interpersonal questions) is positively correlated with his curiosity level for objects (impersonal questions). In addition, we compare our curiosity measure (WTP) of an individual with Imaginal Processes Inventory (IPI) measure which has been widely used in psychology since Singer and Antrobus (1970) invented it. The distributions of WTP and IPI over subjects seem to suggest that our measure is more informative than IPI measure in the sense that the former tends to have a higher coefficient of variation than the latter, that is, its distribution is more disperse across individuals. Interestingly, our experimental result also show that the difference in curiosity level between males and females is rejected in all cases at a 5% significance level.

While curiosity is considered as one of the most important motivations for learning in schools, little about its effect on the economic behavior has been explored so far. However, curiosity indeed has a deep potential for explaining lots of human (economic/social) behavior that has been unexplored. For example, many youngsters start adolescent deviance including smoking and drug use simply out of curiosity.[11] In South Korea, it is reported that "almost one in every two female smokers was found to have started smoking out of simple curiosity."[12] This implies that their choices are made heavily based on the consideration of curiosity rather than simply based on expected utility. Also, gossip magazines featuring scandalous stories about the personal lives of celebrities have been flourishing. Most of such magazines are designed mainly for catering to the curiosity of people. These days, there are nearly 400 magazines including *People* and *Us* related to gossip sold in the U.S. news stand.

The paper is organized as follows. In Section 2, we formally introduce the concept of information entropy and define curiosity in terms of entropy. In Section 3, we consider the effect of noisy information to satisfy curiosity partially. In Section 4, we test the hypothesis that people can direct utility from information by using

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curiosity here just as IPI measure does.

[10] Psychologists use measures of curiosity which are outcomes of responses to pencil-and-paper questionnaires. They include the Novelty Experiencing Scale (NES; Pearson, 1970), the Academic Curiosity Scale (ACS; Vidler and Rawan, 1974), the Sensation Seeking Scale (SSS; Zuckerman, 1979, 1994) and the Melbourne Curiosity Inventory (MCI; Naylor, 1981) etc. For example, Zuckerman (1994) contains items like "I would like to try parachute jumping."

[11] See Green (1985), Mizner *et al.* (1970) and Ormian (1975).

[12] See Byun (2003).

laboratory experiments. In Section 5, we discuss some economic applications. In Section 6, we compare our theory with the expected utility theory. Concluding remarks follow in Section 7. Instrictions and questionaires used in the experiments are provided in the Appendix.

II. Entropy and Curiosity

Let X be a random variable. If we want to define uncertainty $H(X)$ associated with X, $H(X)$ is to be a function only of the probability distribution of X. In 1948, Shannon proposed a concept of information entropy as a measure of uncertainty. He started from three axioms that a sensible definition of uncertainty $H(X)$ should satisfy;

Let X be a random variable with values x_i and probabilities $p_i = Prob(X = x_i)$, $i = 1,\ldots,n$. Then, $H(X)$ must satisfy

Axiom 1
H is continuous in p_i.

Axiom 2
If all the p_i are equal, $p_i = 1/n$, then H is a monotonic increasing function of n.

Axiom 3
H of a composite choice is the weighted sum of the individual values of H.
Then, a well known theorem follows.

Theorem 1 (Shannon) *The only H satisfying Axiom 1 --- 3 is of the form*

$$H(X) = -k\sum_{i=1}^{n} p_i \log p_i, \tag{1}$$

where k is a positive constant.

Proof. See Shannon (1948).

$H(X)$ is called Shannon value or information entropy. It is also well known that the value of entropy is maximized if $p_i = 1/n$ *for all* i.

Suppose one tosses a fair coin and tell you the outcome *Head* of the experiment. Now, suppose one tosses a biased coin and tell you the outcome *Head* when the probability of *Head* is 0.99. Then, in the latter case, considerably less information is provided than in the former case, since the outcome is already expected. This example suggests that the information of an event $X = x_i$ should be defined as

$$I(X = x_i) = -\log p_i. \tag{2}$$

This implies that the entropy of a random variable is the expected value of the information content of events $X = x_i$. Therefore, we can say that entropy measures the average information content of an observation of X.

Now, we can define curiosity in terms of entropy. Consider an agent and a variable X that yields an uncertain outcome but whose value is irrelevant to his monetary income. We normalize the utility when he knows the value of a random outcome to zero, i.e., $\bar{U} = U(X = x_i) = 0$ for any x_i. If he does not know the value, this yields him disutilty. Our hypothesis is that this disutility can be measured by the entropy, that is, $U = U(X) = -H(X) = k\sum_{i=1}^{n} p_i \log p_i$. Assume that the utility is the (monetary) value to the agent, accordingly measured in the monetary unit. Then, his value of the information ($X = x_i$) is $\Delta U \equiv \bar{U} - U(X) = H(X)$. Therefore, this agent will be willing to pay the price up to $p = \Delta U = H(X)$ to obtain the information. This implies that $p = H(X)$ can be viewed as a measure of curiosity.[13] The maximum amount of money that an agent is willing to pay to eliminate uncertainty (not risk) can be called *uncertainty premium*. It has the exact analogy with risk premium in the case of payoff-relevant information. Also, given X, $\Delta U = H(X)$ can differ across agents. We can think of the difference as coming from a difference in k. In fact, high $H(X)$ is associated with high k. Thus, k can be also used as a measure of curiosity.

To elaborate, consider two agents A and B. Let U_A and U_B be the utility levels of the respective agents when they have no information. If $U_A < U_B$, it means that $k_A > k_B$, or equivalently, $H_A(X) > H_B(X)$, in turn implying that agent A is willing to pay a higher price than agent B to learn the value. Thus, we can say that agent A is more curious than agent B. If $\Delta U = H(X) = 0$ for some agent, that is, he wants to pay nothing to learn the value of X, we can say that he is incurious, which corresponds to the case that $k = 0$.

To contrast our measure of curiosity with the measure of the usual expected utility, let us define a generalized lottery by a generalized random variable that yields values x_i for $i = 1, \ldots, m$. This is generalized in the sense that the values may not be real. For example, it may be "Mt. Everest" or "Mt. Baekdoo". Let us denote the set of generalized lottoeries by L. Then, an individual's curiosity for X is formally defined by the entropy function $H : L \rightarrow R$ such that $H(X) = -k\sum_{i=1}^{n} p_i \log p_i$, whereas the utility function is defined by $U(X) = \sum_{i=1}^{n} p_i u(x_i)$. If it is known that $X = x_i$, the curiosity $H(x_i) = 0$, whereas the expected utility is $U(x_i) = u(x_i)$ in this degenerate case.

[13] We are implicitly assuming that all agents get the same utility from money.

III. Noisy Signal

When an agent wants to know the value of X, he may have a chance to obtain a noisy signal of X instead of directly learning the value of X.

Let Y be a noisy signal of X with values y_j for $j=1,\dots,m$ and $P(X=x_i \mid Y=y_j)$ be the conditional probability. Unless X and Y are independent, i.e., $P(X=x_i \mid Y=y_j)=P(X=x_i)$, we can say that Y is informative. Then, the conditional entropy of X given $Y=y_j$ can be defined by

$$H(X \mid Y=y_j) = -\sum_{i=1}^{n} P(X=x_i \mid Y=y_j)\log P(X=x_i \mid Y=y_j)$$

and the conditional entropy of X given Y is defined as the weighted average of the entropies $H(X \mid Y=y_j)$ for $j=1,\dots,m$, i.e.,

$$\begin{aligned} H(X \mid Y) &= \sum_{j=1}^{m} P(Y=y_j) H(X \mid Y=y_j) \\ &= -\sum_{j=1}^{m}\sum_{i=1}^{n} P(Y=y_j) P(X=x_i \mid Y=y_j)\log P(X=x_i \mid Y=y_j). \end{aligned}$$

Conditional entropy measures the average uncertainty of a random variable X given observations of a random variable Y, averaged over all values that Y can take.[14]

Let us take a simple example of $n=m=2$. Suppose X can take only two values of x_1 and x_2 with equal probabilities. Let Y be a noisy signal of X, so that if $Y=y_1$, $X=x_1$ with probability $\rho(\geq 1/2)$ and if $Y=y_2$, $X=x_1$ with probability $1-\rho$. If $\rho=1/2$, X and Y are independent, and as ρ increases, Y is a more informative signal of X. We know that $H(X)=k\log 2$. Now, compute $H(X \mid Y)$. We have

$$H(X \mid y_1) = H(X \mid y_2) = -k\left[\rho\log\rho + (1-\rho)\log(1-\rho)\right],$$

implying that

$$H(X \mid Y) = -k\left[\rho\log\rho + (1-\rho)\log(1-\rho)\right].$$

Let $\psi(\rho) \equiv \rho\log\rho + (1-\rho)\log(1-\rho)$. Note that $\psi'(\rho) = \log\dfrac{\rho}{1-\rho} > 0$. This

[14] Conditional entropy should be distinguished from relative entropy. The latter is a measure of the distance between two probability distributions.

means that $H(X|Y)$ is decreasing in ρ. In other words, $H(X|Y)$ becomes lower as Y is a more informative signal of X. To generalize, we have

Theorem 2 *$H(X|Y) \le H(X)$ with equality if and only if X and Y are independent.*

The proof is standard in information theory. So, we omit the proof here. Note that this is true averaging across all possible values of Y. It does not necessarily hold for every realization of Y, i.e., it is not always the case that $H(X|Y=y_j) \le H(X)$ for all j.

How much is an agent willing to pay to acquire the value of a signal Y? The gain he obtains by paying the price is $\Delta = H(X) - H(X|Y)$, which must be the maximum price that he is willing to pay. If X and Y are independent, Y is not informative at all, so he will not pay any positive price. As Y is more informative, he will be willing to pay more. Also, as far as $H(X)$ and $H(X|Y)$ are linear in k, a more curious agent will be willing to pay more to have access to a given signal.

Now, let us formally define more informativeness. Let Y and Z be two signals of X where $|Y| = m$ and $|Z| = l$. Also, let $P_Y = [P(Y = y_j | X = x_i)]$ $n \times m$ (conditional probability) matrix and $P_Z = [P(Y = z_h | X = x_i)]$ $n \times l$ matrix each of which specifies a probability distribution over a set of signal values for each x_i. Then, à la Blackwell (1951), we can say that Y is more informative than Z if there exists an $m \times l$ matrix M with $P_Y M = P_Z$. The matrix M plays the role of stochastically transforming Y to Z, and it must itself satisfy the usual conditions of a conditional probability distribution in the sense that the entries in each row sum up to one. In this case, Z is referred to as a "garbling"[15] of Y since it is as if Z were generated from Y using a stochastic transformation. Each realization z_h can be interpreted as being obtained from Y by adding some noise through a process of randomization. Now, we have

Theorem 3 *If Y is a more informative signal of X than Z, then $H(X|Y) < H(X|Z)$.*

The proof is omitted, since the proof is also standard.[16] The intuition is clear. If one can obtain a better information generator in the sense that it yields a more informative signal, he can reduce the entropy more. So, he will be willing to pay a higher price for the signal to learn the value of X.

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[15] Marschak and Miyasawa (1968) used this term of "garbling."

[16] All the proofs of the theorems can be found in the earlier version of this paper which can be obtained from the authors upon request.

IV. Experimental Evidences

In this section, we test the hypothesis that people obtain utility from the probability distribution as well as from the reward by using laboratory experiments. Since they will be willing to pay nothing if and only if they obtain no such utility, it is equivalent to show that they are willing to pay some positive price to obtain information even if the information does not affect their monetary income. Also, we use an individual's willingness-to-pay (WTP) as a measure of curiosity, and compare it with Imaginal Processes Inventory (IPI) curiosity measure which is widely used in psychology. IPI, which was first developed by Singer and Antrobus (1970), consists of 28 subscales and 4 of them are to measure curiosity motivations. Among them, two subscales (Interpersonal Curiosity and Impersonal Curiosity) are to measure information-seeking motives of curiosity, while the other two subscales (Boredom and Need for External Stimulation) are to measure the stimulation-seeking motives. For our purpose, we used only the two subscales measuring information-seeking motives and selected 10 questions each from interpesonal questions and impersonal/mechanical questions.[17] The Cronbach α, which is a measure of internal consistency for a set of questions, was 0.559 for interpersonal questions and 0.774 for impersonal questions.[18]

4.1. Experimental Design

The experiments were conducted at the Laboratory of the economics department at Kyung Hee University on October 8, 2008. Subjects were recruited by the announcements in the community website in Kyung Hee University and Hankuk University of Foreign Study which is located within a walking distance from Kyung Hee University. The announcements were posted on October 3, 2008. We pre-excluded the students from the economics department of Kyung Hee University to avoid a possible demonstration effect.[19]

The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). 42 students participated in the experiment. To make participants clearly understand the experimental rules, we explained the instructions one more time by illustration after asking them to read the instructions

[17] Some of impersonal questions were slightly modified or newly invented by the authors (#3, 9, 13, 15, 20), since many of the questions in this scale are more or less mechanical ones that have little to do with curiosity for objects, for example, "I have always liked to take things apart to see what makes them work" or "I know relatively little about the mechanical operation of an automobile."

[18] As a rule of thumb, social scientists say that the consistency of the questions is reliable if the value of Cronbach α exceeds 0.7 and that it is acceptable if the value is about 0.6 or higher.

[19] By the demonstration effect, we mean the psychology that students want to look good to their professor.

carefully.

To test that subjects are willing to pay some monetary amount to obtain full or partial information regarding uncertain outcomes, we used a set of 40 questions.[20] In Part A consisting of 20 questions, subjects are supposed to choose whether or not they are interested in obtaining the full answer for each question at the price of 100 won (roughly 10 cents). We set this price by considering the price for the alternative information source which is the information usage fee in the Internet. If they choose to obtain the full answer, the correct answer is provided; otherwise, it is not provided. In part B consisting of the remaining 20 questions, they are supposed to choose whether or not they are interested in obtaining hints (noisy information) about the correct answer at the price of 50 won.[21] If they choose to see the hints, two possible candidates for correct answers are provided.[22] In this part, the correct answer is never provided. We allocated 10 interpersonal questions and 10 impersonal questions in each Part in a random order so that the subjects cannot realize that they are being tested on curiosity for interpersonal matters or impersonal matters.

When a subject chose not to obtain information, it could mean either "he/she is really uninterested" or "he/she already knows the answer." To distinguish between the two and to measure the pure curiosity intensity, we asked subjects to provide the answer in the beginning of each question. Only when he/she failed to provide the correct answer, was it programmed so as for him/her to proceed the binary choice.

On average, the experimental session lasted about 40 minutes. The participants were paid their respective earnings including the showup fee of 15,000 won ($15) and the initial endowment of 3,000 won ($3) on October 9 after we completed the calculations of their earnings.

4.2. Empirical Results

We examine the correlation among several measures of curiosity for interpersonal questions (persons) and impersonal questions (objects) respectively from individual data. Then, by averaging the values of individual measures across subjects, we show that the willingness-to-pay (WTP) for payoff-irrelevant information, that is, people obtain direct utility from information which does not yield any monetary reward.

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[20] One author made 142 questions, and the other two authors selected 40 questions of which they were most curious. This selection procedure was to maximize the entropy value for the regression purpose.

[21] Most of the content usage fee including today's luck, today's weather etc. is 100 won. Also, the website of "Curiosity Paradise" was managed at http://joybox.co.kr either on a membership basis (5000 won per year) or at the price of 100 won per request.

[22] The binary choices were provided as a pair of one correct answer and the other which most students are likely to choose. This is again to maximize the entropy value.

Also, we examine the correlation between the given curiosity measures for interpersonal questions and impersonal questions, and compare those measures of males and of females.

Table 1 provides the summary statistics. To see the correlation between WTP for full information and WTP for partial information, we plot the pairs of the two WTP as in Panel A, of Figure 1. Similarly, to see the correlation between WTP for full information and IPI measure, we plot the pairs as in Panel B of Figure 1. As Panel A suggests, there seems to be a strong correlation between WTP for full information and WTP for partial information both in cases of interpersonal questions and impersonal questions.[23] This implies that WTP can be used as a reliable measure of curiosity. On the other hand, Panel B suggests that the correlation between WTP for full information and IPI measure seems to be weak or nonexistent, which implies that it is meaningful to resort to WTP as a measure of curiosity in addition to IPI.[24] Futhremore, we know that a strong correlation betweeen WTP for full and WTP for partial is useful and consistent to reflect a subject's curiosity. Figure 2 graphically shows the correlation between an individual's curiosity for interpersonal questions and curiosity for impersonal questions. We find a strong positive correlation between person and object curiosities in terms of WTP.[25]

Now, let us denote the average curiosity level over all subjects by μ_{WTP}. Then, for our purpose, we consider the following null hypothesis; $H_0 : \mu_{WTP} = 0$. A hypothesis test shows that the null hypothesis is rejected at a 5% significance level, that is, people are willing to pay a positive amount of money to obtain payoff-irrelevant information. This result is summarized in Table 2. Then, in order to compare the WTP for full information and that for partial information, we denote the respective WTP by μ_{Full} and $\mu_{Partial}$. Since we obtain two observations for a

[Table 1] Summary Statistics

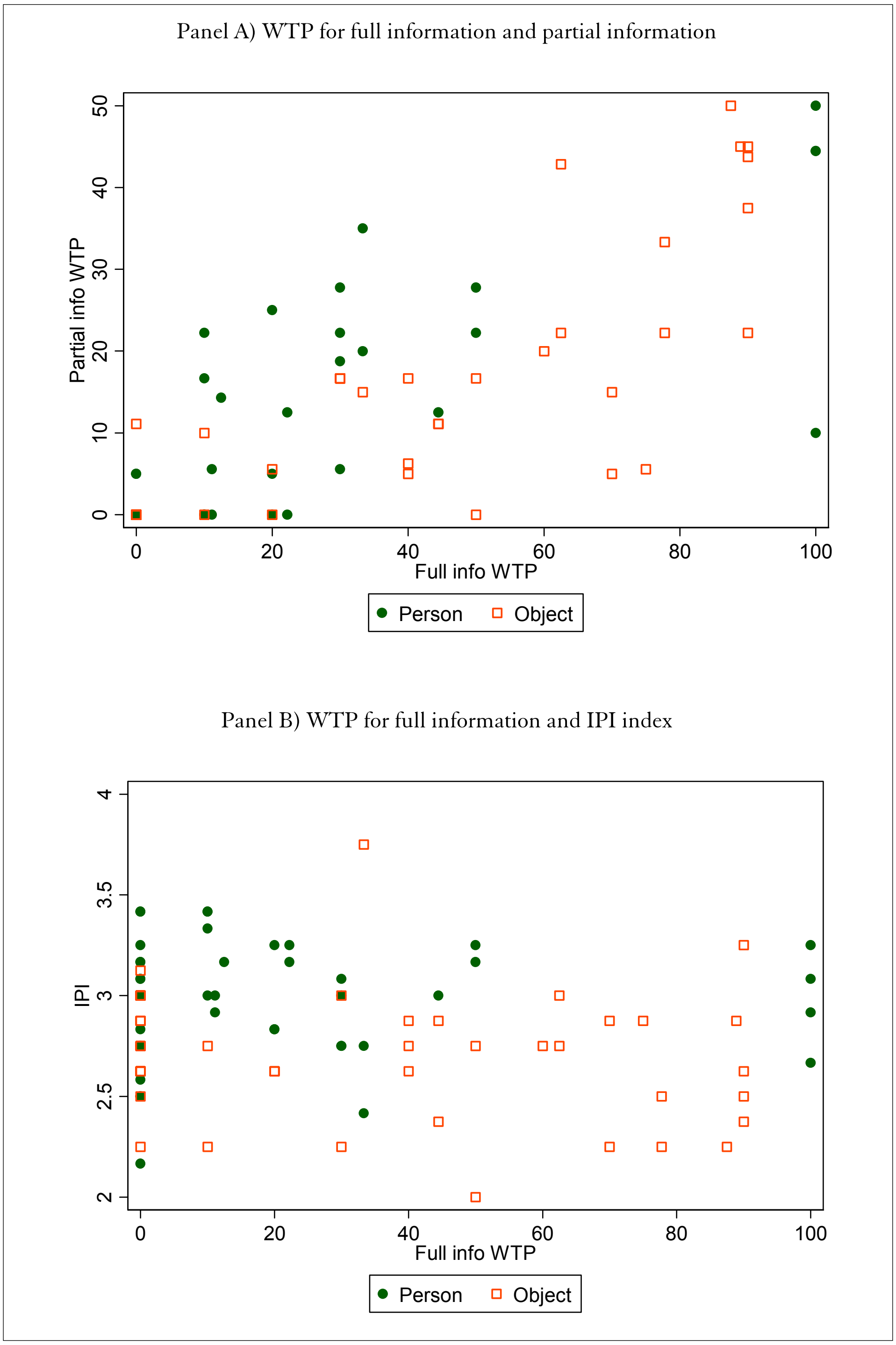
		obs	mean	s.d
WTP for Full	Person	42	21.67	29.65
	Object	42	33.87	33.87
WTP for Partial	Person	42	14.18	14.18
	Object	42	15.33	15.33
IPI measure	Person	42	3.21	0.31
	Object	42	2.82	0.28

[23] The correlation coefficients between full WTP and partial WTP are 0.795 (Person) and 0.816 (Object) and they are signficantly different from zero at a 5% significance level.

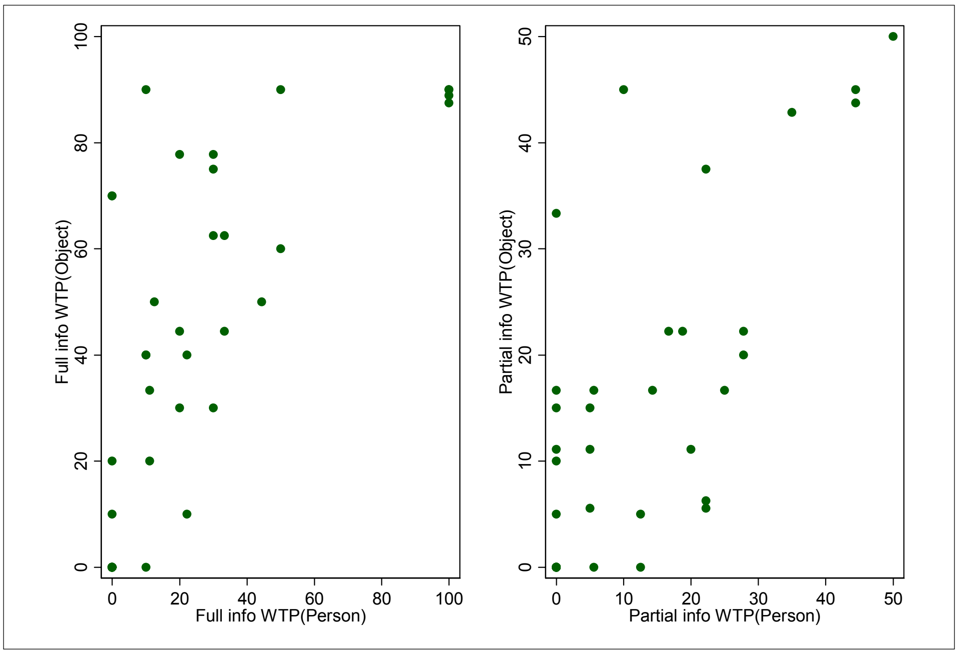
[24] The correlation coefficients between full WTP and IPI are 0.047 (Person) and 0.183 (Object) and they are not significantly different from zero at a 5% significance level.

[25] The correlation coefficients between person and object curiosities are 0.720 (WTP for full) and 0.752 (WTP for partial).

[Figure 1] Scatter plots between curiosity measures



[Figure 2] Scatter plots between person and object curiosities



[Table 2] Confidence interval for μ_{WTP}

		Mean	95% CI	Decision
WTP for Full	Person	21.67	(12.43, 30.91)	Reject $H_0 : \mu = 0$
	Object	33.87	(26.44, 47.55)	Reject $H_0 : \mu = 0$
WTP for Partial	Person	14.18	(6.34, 15.17)	Reject $H_0 : \mu = 0$
	Object	15.33	(8.35, 17.90)	Reject $H_0 : \mu = 0$

* For the hypothesis test, we use a 5% significance level.

given subject, we use a paired sample t-test. Table 3 shows that people are willing to pay a higher price for full information than for partial information. This result is consistent with Theorem 3, which states that one is willing to pay more when he can obtain more information. Also, out of simple curiosity, we test various hypotheses that males and females are equally curious. Although Table 4 seems to suggest that males are more curious for both interpersonal questions and impersonal questions, interestingly none of the hypotheses is rejected at a 5% significance level.[26]

[26] Only one hypothesis that their WTP for partial information are same is rejected at a 10% significance level.

[Table 3] Mean comparison t-test

	Mean WTP		t-value (p-value)	Decision
	Full info	Partial info		
Person	21.67	10.76	3.487 (0.000)	Reject $H_0 : \mu_{Full} \leq \mu_{Partial}$
Object	37.00	13.11	6.691 (0.000)	Reject $H_0 : \mu_{Full} \leq \mu_{Partial}$

[Table 4] Comparison between curiosities of men and women

		Mean (Male)	Mean (Female)	t-value (p-value)	Decision
WTP for Full	Person	24.88	16.45	0.891 (0.377)	Do not reject $H_0 : \mu_m = \mu_f$
	Object	37.59	36.04	0.142 (0.887)	Do not reject $H_0 : \mu_m = \mu_f$
WTP for Partial	Person	13.74	5.90	1.784 (0.085)	Do not reject $H_0 : \mu_m = \mu_f$
	Object	13.91	11.85	0.416 (0.678)	Do not reject $H_0 : \mu_m = \mu_f$
IPI measure	Person	2.98	2.97	-0.071 (0.480)	Do not reject $H_0 : \mu_m = \mu_f$
	Object	2.71	2.69	-0.396 (0.639)	Do not reject $H_0 : \mu_m = \mu_f$

* For the hypothesis test, we use a 5% significance level.

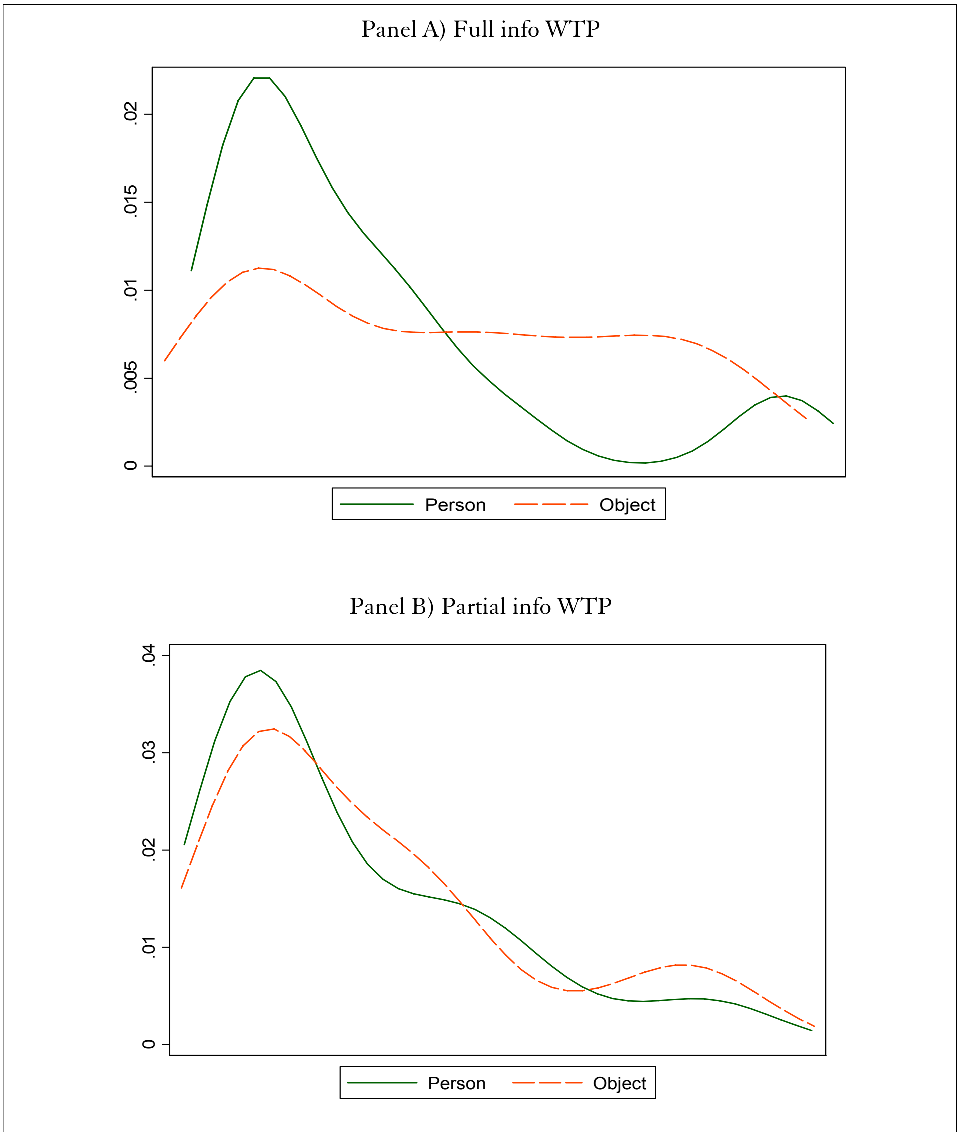
Figure 3 shows the distributions of various curiosity measures. For each graph, Y-axis represents nonparametric kernel densities and X-axis indicates each subject's curiosity measure defined by WTP and IPI. Figure 3-A suggests that some people have extremely high curiosity for interpersonal questions, while all people have moderate curiosity for impersonal questions. Also, Figure 3-A and 3-B show that the distributions are all long-tailed, right-skewed which is different from a normal distribution, whereas IPI measures seem to follow a normal distribution as shown in Figure 3-C. This is consistent with the psychological finding that personal characteristics are likely to follow non-normal distributions.[27]

Finally, we provide the coefficient of variation (CV) for the dispersion comparison. This statistic is to compare the dispersion of two distributions when the means substantially differ. In our experiment, the means of WTP and IPI measures are so different that it is not appropriate to compare the dispersion of the two measures simply by standard deviations. As Table 5 shows, the dispersion of IPI is

[27] See Burt (1963) and Leonardelli (2003).

relatively small. Most of the subjects chooose the values around 3. On the other hand, the CV of WTP is more than 10 times larger than that of IPI. Consequently the curiosity index measured by WTP is much more disperse and has a wide range of curiosity level. We just conjecture a subject's curiosity level is located in the middle when the distribution of curiosity is less disperse and concentrated around the mean in Figure 3-C. In terms of dispersion, we can argue that WTP is a more informaitve measure of curiosity than IPI because WTP captures various aspect of curiosity.

[Figure 3] Distribution Plots



Panel C) IPI

[Table 5] CV comparison

	WTP for Full		WTP for Partial		IPI measure	
	Person	Object	Person	Object	Person	Object
CV	1.36	0.91	1.31	1.16	0.10	0.10

* The coefficient of variation is defined as CV = sd/mean.

V. Economic Applications

In this section, we apply this line of thought to human economic behavior and attempt to understand the behavior that could not be explained within the framework of the traditional expected utility theory.

1. **Curious-Related Market**

People keep watching soap operas because they are just curious of what will be the next story. Children could not stop reading Harry Potter series simply because of curiosity.

Besides, clearly there is a market for information that can satisfy people's curiosity, for example, newspaper, gossip magazines, books, films etc. People are willing to pay prices in returns for obtaining the information they wanted out of curiosity. As the information provided by this channel is more accurate, people will be willing to pay more for the information channel. That is, newspaper, gossip magazines and so on can serve as a noisy signal. However, the market often goes further. There are some businesses whose tactic is to pique curiosity. In our framework, this tactic can be interpreted as giving people the misleading impression that there are more plausible possibilities than they thought. This can increase the entropy so as to induce them to pay more for their information products.

2. Curiosity-Inducing Marketing

In Korea, the placard saying “I love you, Sunyoung.” that appeared from street to street in 2000 made people curious about what it is for, and after all, it turned out to be an advertising for www.miclub.com. This is an example of so-called teaser marketing. Teaser advertising sends cryptic ad messages by veiling the brand or deliberately omitting the explanation about the brand in order to induce consumers' curiosity. A typical example is Sony's ad campaign for Rolly, a commercial featuring a man dancing with the Rolly device, which was initially launched on August 20, 2007. Also, the number marketing that uses numbers in the name of the brand so as to arouse consumers' curiosity for what the numbers mean or the initial marketing that expresses the brand only by its alphabetical initials are often in use. The common feature of such marketing techniques is to pique curiosity about the advertising brand so as to give consumers a stronger desire to try the brand.

Only in the thin marketing literature has the effect of the marketing technique arousing curiosity been discussed. Krugman (1965) asserted that the curiosity-inducing advertising has the effect of making consumers search for information, possibly leading to purchase. Menon and Soman (2002) argued that consumers tend to remember the curiosity-inducing brand better.

3. Policy to Reduce Curiosity

The juvenile delinquency like smoking and drug use is often started out of simple curiosity. This is partly because a certain class of behavior is too strictly regulated, which makes the value of information too high. As a consequence, juveniles tend to experience such behavior even at the expense of significant risks or monetary prices.

If the government believes that it is socially desirable to discourage such behavior caused mainly by curiosity, the policy can be either to raise the cost of engaging in the behavior even higher, for example, by increasing the penalty, or to reduce the value of information. The latter policy can be enforced by offering chances to experience other alternatives yielding noisy signals. Since this is similar to boosting immunity to a specific disease by introducing a vaccine or a serum into the human body, it is called the *inoculation effect* in social psychology. For example, the sex education can have the inoculation effect of reducing the adolescence's high curiosity about sexes. The inoculation technique, which was first discovered by Lumsdaine and Janis (1953) and formulated by Papageorgis and McGuire (1961), can be also effective in preventing adolescent smoking. McAlister *et al.* (1980) reports that middle schools which offer the class of teaching the good sides and bad sides of smoking has much lower smoking rates than those schools which do not.

VI. Relation with the Expected Utility Theory

Measuring the value of information has been studied by many authors including Kelly (1956), Bellman and Kalaba (1957), Marschak (1959), La Valle (1968), Hirshleifer (1971) and Arrow (1972) etc.

To the best of our knowledge, all of them measure the value of information in terms of the difference between the maximum expected payoffs resulting from the decision maker's optimal decision when he is informed of the information and not. So, their models all implicitly assume that the decision maker attaches some value to the information to the extent that it increases its expected payoff, implying that their measure of the value of information is based on the expected utility theory. In our model, however, an individual gets the value of the information not because it helps him make a better decision thereby increasing his expected utility, but because he enjoys acquiring the information itself.

We will take Arrow's model to elucidate the contrast. Arrow considers an individual who bets on the occurrence of states of nature. As before, let p_i be the prior probability that $X = x_i$ for $i = 1,\ldots,n$, and a_i be the amount bet on the occurrence of state i. Also, let $u(x)$ be his utility function where x is his monetary income. Assume that he invests all his resources which is equal to 1. The individual will then face the problem:

$$\max_{a_i} \sum_i p_i u(a_i x_i)$$
$$s.t. \sum_i a_i = 1.$$

If we assume $u(x) = \log x$, the optimal bet is $a_i^* = p_i$ and thus the maximized utility is $U_0 \equiv \sum_i p_i \log p_i + \sum_i p_i \log x_i$. On the other hand, if he can get to know the state of world, for example, by installing (purchasing) an information generator which shows a perfect signal, he can bet all his resources on the true value. This will yield him the utility of $\log x_i$, thus his expected utility is $U_1 \equiv \sum_i p_i \log x_i$. Therefore, the value of the information (signal) is

$$\Delta = U_1 - U_0 = -\sum_i p_i \log p_i = H(X).$$

Note that Arrow's interpretation of $H(X)$ as the value of information is possible only under the assumption that the utility function is logarithmic, while our interpretation requires no such assumption.

Since we empirically confirmed that people get direct utility from information which is not captued in the expected utility theory, we argue that the proper form of the utility function under uncertainty should be modified, and furthermore, we propose the following generalized expected utility function;

$$U(X)=\sum_{i=1}^{n}p_i u(x_i)+k\sum_{i=1}^{n}p_i \log p_i . \tag{3}$$

The first term is the indirect utility from information and the second term is the direct utility from information (disutility from lack of information).[28] Note that the proposed utility function *cannot be unique up to affine transformations*.

VII. Conclusion

In this paper, we defined curiosity in terms of information entropy by Shannon and empirically showed that people have curiosity in the sense that they get direct utility from information contrary to the expected utility theory. We also interpreted Shannon constant as a degree of personal curiosity and proposed a measure of individual curiosity which is the individual's willingness-to-pay to obtain information. This measure is methodologically distinguished from various measures developed in psychology which rely on pencil-and-paper questionnaires. Moreover, we show that this method of measuring the individual curiosity level in terms of his willingness-to-pay is more informative than particularly IPI curiosity measure used in psychology in the sense that the distribution is more disperse. However, we think that our measure is still not completely satisfactory in the sense that the concept implicitly assumes that all individuals have the same utility from money. If it is not the case, we cannot say that an individual who is willing to pay 100 won for some information is more curious than another who is willing to pay 50 won. Thus, in this case, WTP cannot be a proper measure of curiosity and we need more refined method. One possible alternative method without resorting to some value intermediary such as money would be to use fMRI to compare the image

[28] Some authors, for example, Hofbauer and Sandholm (2007), also used the entropy function to characterize the best response dynamics in the perturbed payoff environment. Although (boundedly rational) agents use a similar form of payoff incorporating the entropy term to the form given in (3) in their paper, the role of the entropy is entirely different. In our model, a decision-maker can control the entropy (uncertainty) by obtaining some information, while the entropy level is exogenously given in their model. Entropy is just a representation of perturbation (disorder) in payoffs in their model.

reflecting the individual's utility level directly. We will take up this approach in a different paper.

Although all the concepts offered in this paper are rudimentary and need to be further refined, we believe that the overall perspective should deserve attention and that it can be fruitfully applied to many economic situations. We look forward to future research along this line.

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Appendix A

Oct 8, 2008

Instructions

This experiment is about decision making in Economics, sponsored by the Korea Research Foundation. Everyone who participates in the experiment will be provided with a show up fee of 15,000 won and additionally with an initial endowment of 3,000 won. The final payment will depend on your choice of decision making in the experiment.

The experiment is divided into two parts, the first part is the "main experiment", and the second is the "questionnaire".

The main experiment is a composition of 40 problems. After reading each problem, it is requested to type in the answer, but if you do not know the answer for the problem type in "do not know". Do not type any spaces between the answer, and if you make the wrong answer do not try again and just type in "do not know". If you know the right answer, you will be automatically going to the next stage, but if you do not know the answer in part A, you will be seeing the following in the monitor 1) Not interested in the answer 2) Would like to know the answer. In part A, if you click 2), then 100 won will be subtracted from the initial endowment which has been given in the beginning period. Thus, 100 won would be the information cost for knowing the answer of the question. If you do not know the answer in part B, you will be seeing 1) Not interested in the answer 2) Would like to look at the hint. If you choose 2), then you would be provided with 2 hints, and 50 won will be subtracted from the initial endowment. (The experiment recommends each problem has the time limit of 15 seconds, although this is a recommendation, it is allowed to go over the time limit.)

After the 40 questions, the experiment will continue with the second part: the questionnaire. Also by using the same computer, the questionnaire has 20 questions. You are requested to choose the most appropriate answer for each specified question. This questionnaire will not give any influence in your final payment. It is just a simple questionnaire.

After finishing the main experiment and the questionnaire, and after getting the permission from the instructor, you are allowed to leave the room.

The payment will be made tomorrow (Oct 9) from 6:00 to 7:30 in the Political

Science department unit 301. **If you cannot make it to the time above, please give me an email or a call. To get the final payment, it is essential for you to know the your computer's number, please write down the computer's number below, and hand in this paper to get the final payment.**

Computer Number	

Rules

1. Need to answer all the questions that are in the experiment
2. Cannot discuss or talk with other experimenters until the end of the experiment
3. If you have a question, ask before the experiment starts, and if you do not you may start the experiment.

Appendix B

Questions

Part A

1. Who is the South Korean soccer player to make a first goal in the World Cup? [person]
   Answer: Park Chang Sun
2. How many Japanese Nobel Laureates are there? [person]
   Answer: 12 people
3. Which country has the longest life expectancy? [object]
   Answer: Andorra
4. What does “yahoo” mean in the novel “Gulliver’s Travel”? [object]
   Answer: Human
5. What is the most important invention in human history that The Independent published in the United Kingdom had chosen? [object]
   Answer: Abacus
6. In which Olympiad did the South Korean soccer team made the first victory? [person]
   Answer: 1948 London Olympiad against Mexico 5:3
7. How many moons does the Mars have? [object]
   Answer: 2
8. Which is the oldest corporation in South Korea? [object]
   Answer: Dusan or DongWha (1896)
9. What is the last state of the United States? [object]
   Answer: Hawaii
10. Where is blood made in the human body? [object]
    Answer: Inside the human bones
11. Who is the first South Korean athlete to win the first gold medal in Olympiads? [person]
    Answer: Yang Jung Mo
12. Which is the highest mountain in Korea after Baek Du San? [object]
    Kwan Mo Bong (2540 meters)
13. What is the highest located capital in the world? [object]
    La Paz
14. Which capital has the most population? [object]
    Answer: Tokyo
15. What is the occupation of the Einstein’s son? [person]
    Answer: Professor of University of California, Berkeley
16. Who is the first comedian to perform in Sejong Center for the Performing Arts?

[person]
Answer: Lee Joo Il
17. Who is the first prosecutor in Korea? [person]
Answer: Lee Joon
18. Who is the famous son of Seo Dong Yo? [person]
Answer: King EuJa
19. Who is the first person to discover the existence of the irrational number? [person]
Answer: Hippasus
20. What is the family name that comes from the Royal family of BaekJe Dynasty? [person]
Answer: Booyeo Seo

Part B

1. How long will it take to Mars by using the current technology? [object]
Answer: 10months / Hint: ⓐ 3 months ⓑ 10 months
2. Who is the soccer player who made a goal in the Barcelona Olympic preliminary match against Japan? [person]
Answer: Kim Byung Soo / Hint: ⓐ Noh Jung Yoon ⓑ Kim Byung Soo
3. Which company has the most revenues in the world? [object]
Answer: Wal-mart / Hint: ⓐ MS ⓑ Wal-mart
4. Which country has the highest per capita GDP? [object]
Answer: Luxemburg / Hint: ⓐ Luxemburg ⓑ Sweden
5. Who is the baseball player who is a Korean resident in Japan to win the first "Perfect Game" in the Japanese Professional League Baseball? [person]
Answer: Lee Pal Yong / Hint: ⓐ Kaneda ⓑ Lee Pal Yong
6. What is the name of the automobile first made in South Korea (in 1955)? [object]
Answer: Sibal / Hint: ⓐ Saenara ⓑ Sibal
7. Which country has the shortest life expectancy? [object]
Answer: Swaziland in Africa / Hint: ⓐ Ethiopia ⓑ Swaziland
8. Who has the highest batting average in the Korean Major League Baseball? [person]
Answer: Baek In Cheon (.335) / Hint: ⓐ Chang Hyo Jo ⓑ Baek In Cheon
9. What is the most important invention that scientists have chosen over the past 2000 years? [object]
Answer: Glasses / Hint: ⓐ Automobile ⓑ Glasses
10. What university did Park Kun Hae's sister Part Kun Rung graduate? [person]
Answer: College of Music, Seoul National Unversity / Hint: ⓐ Seoul National University ⓑ Ewha Women's University

11. Who is the first western-style medical doctor in South Korea? [person]
Answer: Seo Jae Pil / Hint: ⓐ Seo Jae Pil ⓑ Park Esther
12. Which is the first elementary school in South Korea? [object]
Answer: Kyodong Elementary School (1894) / Hint: ⓐ Kyodong ⓑ Jaedong
13. How many prime numbers are there from 1 to 100? [object]
Answer: 25 / Hint: ⓐ 20 ⓑ 25
14. Who is the Chaebol(plutocrat) who got into a scandal with the singer Ha Choon Hwa? [person]
Answer: The founder of Samsung Group, Lee Byung Chul / Hint: ⓐ Lee Byung Chul ⓑ Jung Joo Young
15. What does Kim Tae Hee's father do for a living? [person]
Answer: CEO of the Korean TongWoon Corporation / Hint: ⓐ CEO ⓑ teacher
16. What is the name of the elementary school Bae Yong Joon graduated? [person]
Answer: Myung-Il Elementary School / Hint: ⓐ Myung-Il ⓑ Jaedong
17. Who is the singer that is regarded as one of the two best vocalists (with Kim Choo Ja) in Shin Joong Hyun's music band and sang the famous "Beautiful rivers and mountains"? [person]
Answer: Kim Jung Mi / Hint: ⓐ Bang Eui Kyung ⓑ Kim Jung Mi
18. What is the job of the movie director Shin Sang Ok's son? [person]
Answer: Policeman / Hint: ⓐ policeman ⓑ professor
19. Which country has the lowest population density? [object]
Answer: Mongolia / Hint: ⓐ Mongolia ⓑ Kongo
20. How many countries meet with China's border? [object]
Answer: 14 / Hint: ⓐ 11 ⓑ 14