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Avoiding health risks from drinking water in Moscow: An empirical analysis

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ABSTRACT. Casual observation suggests that many households in Moscow boil water, settle water in pans for some periods (e.g., overnight) before consuming, filter water, and buy bottled water. To date, there has been little empirical analysis of such avoidance behavior. Based on a recently completed survey of 615 households in Moscow, this paper investigates the types and amounts of avoidance measures that are used by households in Moscow to adjust drinking water quality. Survey results show that this is clearly the case: over 88 per cent of the sample boil water regularly due to concerns about water quality; 23 per cent filter water regularly; over 30 per cent settle water regularly; and about 13 per cent buy bottled water regularly. On the other hand, residents are generally content with their cold water supply and quality of delivery. Based on a microeconomic model of household avoidance behavior, logit regression results show how avoidance decisions relate to income, opinions of water quality, and location in the city. It is expected that this analysis from Moscow can also be used as a guide for future studies in other cities in Russia to evaluate opinions of quality, avoidance measures, and citizens' willingness to support public infrastructure projects designed to improve water supply.

1. Introduction

In a recent interview with 'Green World', which is a main ecological newspaper in Russia, the Senior State Doctor for Sanitation and Hygiene in the government states that Moscow drinking water is clear, Moscovites can

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drink it directly from the tap, but it is 'better, of course, to settle or boil tap water before consumption' (Ardabatskaya and Soboleva, 1997). Boiling water and settling water in pans over night as well as buying bottled water and filtering water are examples of avoidance measures; that is, before consuming tap water, households can undertake these various measures to improve the quality of the water, thereby avoiding some of the health risks.[1]

In Russia, casual observation suggests that many households boil water, settle water in pans, filter water, and buy bottled water.[2] However, besides casual observation, there have been no systematic data available on avoidance measures used in relation to drinking water and no analysis that helps to explain avoidance decisions. This lack of information and analysis is surprising given concerns over risks from tap water in most Russian cities. If avoidance measures are widely used, health risks from the drinking water when actually consumed may be substantially different from such risks at the tap. As a result, public health concerns based on assessment of tap water quality may substantially overstate health concerns about public water supplies.

To begin to fill this information gap, the main purpose of this paper is analyze the types and degree of avoidance measures that are used by households in Moscow based on data from a recently completed survey of 615 households in Moscow. This example from Moscow can be used as a guide for future studies in other cities in Russia to evaluate opinions of quality and the use of avoidance measures to manage health risks from drinking water.[3]

The paper is organized as follows. Section 2 discusses the basic data obtained as part of the Moscow Drinking Water Quality Survey. After a description of the survey method, information is provided on the types and frequency of use of different avoidance measures, opinions on water quantity issues (consistency of supply), and water quality. The survey data clearly show that Moscow residents regularly undertake measures to manage health risks from the public water supply: over 88 per cent of the sample boil water regularly due to concerns about water quality; 23 per cent filter water regularly; over 30 per cent settle water regularly; and about 13 per cent buy bottled water regularly. On the other hand, residents

[1] Health risks from tap water are a good example of bilateral risks. With bilateral risks, the actions of Group A create some initial risk, but Group B has some ability to alter the amount of risk it receives by undertaking various measures. Thus, with bilateral risks, policy can focus on the actions of both Group A and Group B. Chronic health risks from air pollution are a good exmaple of unilateral risk problems, except to the extent that people can physically move out of an area to avoid risks from ambient air.

[2] Another avoidance measure is to consume only water from the cold water supply and not to consume water from the district hot water system.

[3] A logical next step is to assess directly citizens willingness to accept changed water tariffs to support specific public infrastructure projects using a contingent valuation approach. Given the results of the water survey presented in this paper, it is probably better to undertake such analysis in other cities in Russia with substantially poorer water quality such as, for example, Yekaterinberg or Perm in the Urals.

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are generally content with their *cold* water supply and quality of delivery. These two results are not that surprising: consistency of cold water supply is good in Moscow and water prices are very cheap, while people have several low-cost options to improve quality from the tap prior to consumption if they so desire.

While any survey can ask about opinions, section 3 develops a simple economic framework that can be used to explain and analyze avoidance behavior. Section 3 identifies an equation that describes avoidance behavior and provides three simple testable hypotheses regarding its empirical form. If the survey responses are consistent to some degree with economic theory, there is additional evidence that the survey was able to provide reasonable information. As an approximation to the theoretical framework in section 3, section 4 uses a binomial logit statistical framework to investigate how choices of avoidance measure are related to respondents opinions of their water quality and service and other socio-economic characteristics.[4] Section 5 concludes.

2. The Moscow Drinking Water Quality Survey

A survey was completed during October 1996 to gather information on Moscow residents' opinions of the quality of the cold water services to their apartments, any actions they take to alter the quality of the water consumed, simple information on expenditures associated with these actions, and general socio-economic characteristics of the respondents. As far as we know, this was a first formal survey designed and implemented in Moscow and Russia in general to address water quality issues and avoidance behavior.[5]

[4] Of course the obvious question is to ask is: what is the quality of Moscow water? Unfortunately, there is not an objective answer to this question and it is unlikely that there will be such an answer any time soon. The public utility, Mosvodokanal (MVK), responsible for water supply and the city's Committee of State Sanitary and Epidemiological Surveillance say that Moscow drinking water meets all Russian and international standards. However, MVK does not provide public access to its water monitoring data for the public to evaluate. Given the lack of credibility of some public institutions in Russia, Moscovites do not necessarily believe the press releases of MVK. At the same time, water filter companies continue to advertise potential problems that can exist in public water supplies as a way of increasing demand for their product. During the first half of 1996, the Harvard Institute for International Development (HIID) attempted to convene a team of Russian and American scientists, along with MVK staff, to undertake an objective quantitative risk assessment at several stages of the water distribution system (intake, after treatment plant, in the distribution network, and at the tap). After initially agreeing to support such analysis, MVK decided not to participate in the study and did not provide access to their water quality monitoring data.

[5] The survey was developed by the authors, and Dr Alla Guzanova and her team at the Institute for Economic Forecasting implemented the survey. Dr Guzanova and her team (about 12 interviewers for this project) have substantial experience conducting socio-economic surveys in Moscow, including longitudinal household surveys for the Urban Institute and the World Bank. There is about 97 per cent coverage of telephones in apartments in Moscow. More details on the survey are discussed below.

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There are two main water sources for Moscow, the Volga and Moscow rivers, and four water treatment and supply stations. The distribution networks from these four stations are essentially separate. The water sources have very different implications for water quality at the source. Both sources consist of reservoirs and rivers (streams). The Moscow-source reservoirs are constructed relatively far from Moscow so that there is opportunity for water to be contaminated between the reservoir and the treatment facilities. The opposite situation occurs with the Volga source where reservoirs are located near the water treatment stations. As a result, water from the Northern and Eastern stations has several months self-purification in the Uchinskoe reservoir (Moscow Committee of Nature Protection, 1993).

Using a telephone survey format, 1,200 telephone numbers were drawn at random across Administrative Districts in Moscow. These Administrative Districts of the city were sampled proportionately to reflect the two main sources of water for the city and the four main water treatment supply facilities. An initial survey was developed in September 1996 and then pre-tested on a random sample from the 1,200. After revising several questions, the final survey instrument was developed. In total, 615 respondents agreed to participate in the survey, including 268 respondents from Moskvoretsky drinking water source (hereafter called the Moscow source) and 347 respondents from the Volga drinking water source.[6] This distribution of about 44 per cent from Moscow and 56 per cent from Volga sources is the same as the actual distribution from the water supply network for each source. With respect to the four drinking water treatment stations, the distribution of respondents is: 114 for the Rublevo station (Moscow source), 154 for the Western station (Moscow source), 167 for the Northern station (Volga source), and 180 for the Eastern station (Volga source).

The interviewers reported that most respondents were friendly, willing to talk, and gave detailed answers. The interview lasted 12 minutes on average. In the interviewers' opinions, the telephone survey worked 'as well as' their other in-home survey projects.[7]

After an introduction to the survey, based on a pre-determined format written in the interviewer questionnaire booklet, the survey was organized into five main sections: avoidance measures; opinions of water quality, opinions of cold water supply (i.e. water quantity); apartment and family characteristics; and income. In the remainder of this section, we present and discuss basic summary information on the results of the survey of particular interest for this analysis.

[6] When a potential respondent, an adult living in the apartment, refused to participate in the survey, a new telephone number was drawn from the 1,200 sample from the same Municipal District. In total, there were 63 refusals so that overall sample size was 678 with about a 10 per cent refusal rate.

[7] This is an important point for future surveys in Moscow. It is difficult and costly to conduct in-home interviews. Using the mail opens up substantial questions regarding basic reliability and timeliness of service.

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Table 1. *The use of boiling in Moscow (percentages)*

Answer	*Total sample n = 615*	*Northern n = 167*	*Eastern n = 180*	*Rublevo n = 114*	*Western n = 154*
1 always	80.7	77.2	80	88.6	79.3
2 rather often	7.8	10.8	8.9	0.9	8.4
3 seldom	4.2	3.0	6.1	2.6	4.5
4 never	7.3	9.0	5.0	7.9	7.8

Table 2. *The use of settling water in Moscow (percentages)*

Answer	*Total sample*	*Northern*	*Eastern*	*Rublevo*	*Western*
1 always	25.0	29.9	21.7	27.2	22.1
2 rather often	8.0	6.6	6.1	5.3	13.6
3 seldom	9.9	8.4	7.2	3.5	19.5
4 never	57.1	55.1	65.0	64.0	44.8

Table 3. *The use of filtering water in Moscow (percentages)*

Answer	*Total sample*	*Northern*	*Eastern*	*Rublevo*	*Western*
1 always	20.8	16.8	18.3	29.8	21.4
2 rather often	2.3	3.0	1.7	0.9	3.2
3 seldom	3.1	2.4	3.9	3.5	2.6
4 never	73.8	77.8	76.1	65.8	72.8

Table 4. *The use of bottled water in Moscow (percentages)*

Answer	*Total sample*	*Northern*	*Eastern*	*Rublevo*	*Western*
1 always	3.3	4.8	1.70	6.1	1.3
2 rather often	10.1	9.0	11.1	8.8	11.0
3 seldom	20.5	18.0	17.2	22.8	25.3
4 never	66.2	68.2	70.0	62.3	62.4

Avoidance measures

Four main types of avoidance measures were included in the survey: boiling, settling, filtering, and buying bottled water. Boiling and settling are customary and essentially no-cost options in Moscow for households.[8] Boiling is related mainly to concerns about bacteria, etc., while settling is done both for managing solids in water as well as improving taste and smell (e.g., chlorine). More recently, the availability of filters, bottled water, and 'spring water' for general use as opposed to more salty mineral water have increased. Filters and bottled water are two higher cost options.

Tables 1–4 report summary results of the survey for these avoidance measures. As expected, the lower cost alternatives are used more widely than higher cost options, with about 88 per cent boiling water regularly (answers 1 and 2 in table 1) due to health concerns, 33 per cent settling water regularly before consumption (answers 1 and 2 in table 2), about 23 per cent filter regularly (answers 1 and 2 in table 3), and 13 per cent purchase spring water regularly for consumption purposes due to concerns

[8] Stoves are mainly natural gas, and gas utility prices are low.

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Table 5. *Opinions of water quality*

	Volga source (%)	*Moscow source (%)*
Normal clearness	85.6	76.8
Good smell	61.5	55.7
Good taste	57.2	54.6
No residue	63.9	57.9
Normal color	82.1	82.2
General satisfaction	88.0	82.2

about tap water quality (answers 1 and 2 in table 4).[9] With a population of around 8.5–10 million people in Moscow, and extrapolating to the city level, these percentages add up to a substantial number of people undertaking avoidance measures in Moscow.

Given the nature of the survey as well as concerns that residents would not be able to answer more detailed questions, it was not feasible to ask more intricate questions such as how many liters per week are boiled and for how long, how many liters of bottled water are purchased, and details about filtering technology. Thus, it is probably best to think of this initial Moscow survey as a first empirical step; a step that shows substantial levels of avoidance measures being undertaken in Moscow.

It is necessary to be cautious when interpreting these answers, especially regarding boiling and buying bottled water. For example, there is the issue of 'joint production' when boiling water; that is people boil water because of health concerns but also for drinking tea and 'compote'. People can buy bottled water for 'taste' reasons as well as health reasons, and in many cases it is likely that people do it for both reasons. While the survey attempted to differentiate boiling and buying water 'due to health concerns', it is possible that households are not really able to differentiate since they are intimately related. However, whether they boil water for tea or buy water for simple preference reasons, the end result is that they still have affected the final quality of the water that they consume.

As a final point, expenditures on bottled water are generally under 20,000 rubles per week (about $3.5 per week at an exchange rate of 5,900 rubles per dollar US).[10] Depending on the brands and location of purchase, 20,000 rubles could buy about 7–10 liters per week. About 6 per cent of the sample reported weekly expenditures above 20,000 rubles and about 1.5 per cent above 50,000 rubles. Regarding expenditures on filtering water, monthly expenditures are generally under 20,000 rubles, which is enough to replace a filter cartridge each month. About 4 per cent of the sample reporting monthly expenditures above 20,000 rubles with about 1.5 per cent above 40,000 rubles.

[9] Some people also report using 'traditional' water purification measures such as, for example, putting a silver spoon in water before consumption.

[10] Based on the results of the pre-test survey, expenditure and income data were gathered as ordered-categorical data.

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Table 6. *Water quality characteristics vary significantly during the year*

	Volga source (%)	*Moscow source (%)*
Clearness	3.2	8.6
Smell	11.2	28.7
Taste	8.9	16.1
Residue	2.7	8.4
Color	2.7	7.5

General options of cold water quality

Table 5 summarizes Moscow residents opinions of their cold water quality. Moscow residents report that they are generally satisfied with the quality of their cold water (about 88 per cent from the Volga source and 82 per cent from the Moscow source). While generally satisfied with cold water quality, residents generally have lower opinions of various characteristics of water. From table 5, between 55 per cent and 65 per cent of residents report that water smells good, tastes good, and does not leave residue (calcium-like deposits) on dishes and sinks. These percentages are substantially lower in absolute terms than general satisfaction, which probably is related to a social or cultural expectation of what is considered acceptable water.[11]

The 6 per cent difference in satisfaction rates between the two sources (88 per cent for Volga and 82.2 per cent for Moscow) is statistically significant at the 5 per cent level using an approximate generalized likelihood ratio test.[12] The difference in clearness between the Moscow and Volga sources is also statistically significant at the 5 per cent level. The responses for smell, taste, and residue are not statistically significant at the 5 per cent level.[13]

While table 5 provides results for the general opinion questions, table 6 shows that there is some annual variation in water quality in Moscow, with the most annual variation being reported in terms of smell and taste. It is also noted here that the difference in opinions across the two sources is also statistically different for all characteristics reported in table 6. Combining tables 5 and 6, we conclude that opinions of quality are lower for the Moscow source, and there is more annual variation in the Moscow source as well.

Household and apartment characteristics

Table 7 summarizes self-reported total household income, which was

[11] Residents are generally content with cold water delivery, with just 6.5 per cent of the sample dissatisfied with their tap water supply. Almost the complete sample has consistent 24-hour delivery, adequate pressure, etc. While not addressed in the survey, it is probably the case that residents without consistent cold water supply have plumbing problems in their building. Thus, the 'supply' problem is not really a problem from the water distribution network *per se*.

[12] The test specified in theorem 8.4 of Larsen and Marx (1981: 335)

[13] As a side note, the best opinion of drinking water comes from residents receiving water from the Eastern water treatment station (Volga source), which is the only station in Moscow that uses ozonization instead of chlorination of the water.

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Table 7. *Reported monthly total household income*

Total monthly income (million roubles)	*Total sample %*	*Northern station %*	*Eastern station %*	*Rublevo station %*	*Western station %*	*In-home survey*
1 less than 1.5	58.9	55	60.6	68.4	53.9	59.0
2 1.5–2.5	24.2	24.6	22.8	17.5	30.5	24.5
3 more than 2.5	16.4	19.8	16.6	14.1	14.3	15.6
4 no answer	0.5	0.6	0.0	0.0	1.3	0.09

Note: The last column, 'in-home survey', is the results of a recent 2,200 direct, in home survey conducted by the survey team as part of the Moscow Longitudinal Household Survey, 1992–6, fourth round, January 1996.

designed to capture all types of formal and informal income. From the total 615 sample, three respondents did not answer this question. From table 7, about 59 per cent of household report income less than 1.5 million rubles per month (a little less than $300), about 25 per cent report income between 1.5 and 2.5 million rubles per month (about $300 to $500), about 25 per cent report income between 1.5 and 2.5 million rubles per month (about $300 to $500), and a little over 16 per cent report income levels over 2.5 million rubles. The last column in table 7 shows that the income distribution obtained in this survey is very consistent with income information derived from a larger-scale direct, in-home survey. This is another indication that the results obtained through this telephone survey format are reasonably good.

For reference, over 90 per cent of the sample live in buildings on the 12th floor or below built after 1955, which indicates the level of destruction during the Second World War and the level of reconstruction and growth after the war. Over 90 per cent of families live in apartments with three or less rooms, with about 50 per cent of the sample living in two room apartments. Over 65 per cent of the sample pay 100,000 rubles or less per month for their apartment including utility costs. This apartment payment is a relatively small fraction of total household income. About 13 per cent of households report plumbing problems that result in lost water in their apartment (either intensive drops, slight flow, or intensive flow), with some slight variation across regions of the city.

In terms of education, over 90 per cent of households contain at least one person who has completed at least secondary education, with over 54 per cent of households containing persons with post-graduate training. For reference, regarding the actual respondents to the survey, about 87 per cent completed at least secondary education and about 39 per cent had post-graduate training. About 76 per cent of respondents were female, as might be expected with a telephone survey in Moscow. About 60 per cent of respondents were 50 years old or less, with an average age of about 49 for the complete survey.[14]

[14] In terms of demographics, over 80 per cent of households have no children under eight years old living in the apartment and about 68 per cent of households have no children between eight and 18 years old. About 17 per cent of households

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3 An economic model of avoidance behavior

While the survey results discussed in section 2 show that Moscow residents undertake multiple types of avoidance measures to adjust drinking water quality, this section develops a simple economic framework for analyzing avoidance decisions. The basic idea is that households 'produce' drinking water, what Bartik (1988) calls the 'quality of its personal environment', based on water coming into the apartment at the tap along with any measures taken to adjust quality. Household production theory provides a reasonable analytical framework for investigating avoidance behavior (e.g., Becker, 1981; Singh, Squire, and Strauss, 1986).

The model

For notation, let 'x' represent the household's *perception/opinion* of the quality of water coming into the apartment at the tap. We emphasize the word perception because households never have clear, objective facts on water quality.[15]

Let a represent avoidance measures used by the household to improve tap water quality, and let p represent the price of such measures. Let z represent other consumption goods purchased at price c. In general, there are several possible measures and other consumption items, in which case a and z represent vectors with p and c being the corresponding vectors of prices. It should be noted that in some situations there are not direct market prices. For example, while bottled waters and filters are purchased in stores, settling water over night is a measure with no direct market cost. Boiling water has little cost as well in Moscow because natural gas, which is the main cooking fuel, is very inexpensive. In Moscow, both settling and boiling do require a little time, probably of a retired parent living in the apartment, but such costs are small.[16]

A household cannot spend more than its income, denoted as I, so that $pa + cz \leqslant I$. Based on perceptions x and avoidance measures a, the household produces water of perceived quality y, where $y = f(a,x)$ is the household's production function. The function f is increasing in x and a (i.e., the first partial derivatives $fx > 0$ and $fa > 0$). There is substitution between x and a, so that $da/dx|_{y\,=\,constant} = -fx/fa < 0$. And last, let $U = U(y,z;\beta)$ represent

have one child under eight living in the apartment and 22 per cent of households have one child between eight and 18 years old. Over 52 per cent of households included one or two pensioners, with about 47 per cent including no pensioners. There were some initial concerns that only pensioners would be home to participate in a telephone survey. This was clearly not the case.

[15] People can taste, smell, feel, and see water. People also receive various types of information on tap water quality provided, of example, from the water provider and city health authorities. But it should be recognized that people take such information into account in their own way. While an interesting issue for public policy research, how perceptions are formed and how information is used in the process is not the purpose of this research and is not addressed in this theoretical analysis or in the Moscow survey.

[16] Of course, in some parts of Russia and other parts of the world, the costs of boiling water using a wood stove would include fuelwood costs and time and could be substantial. This is not the case in Moscow.

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the household's utility function, where β represents other characteristics of the household (other than income), such as family size, apartment location, education, etc.[17]

Based on this notation, the household's problem of choosing avoidance measures can be modeled as

$$\max_{y,z} U(y,z;\beta)$$
$$s.t.\ E(p,y,x) + cz \leq I$$
$$\text{where } E(p,y,x) \equiv \min_a pa \ s.t.\ y = f(a,x) \tag{1}$$

In (1), the overall problem is separated into two steps. First, the expenditure function $E(p,y,x)$ is the minimum expenditure on avoidance measures needed to obtain a level of water quality y given initial quality x. And second, given the expenditure function, the optimal level of y and z are chosen, defined here as y^* and z^*, to maximize overall utility subject to the budget on constraint.[18]

The optimal level of avoidance

The solution to the problem in (1) implies an indirect utility function that can be written as $V^x = V(p,I;x,\beta)$. Using the envelope theorem, the household's optimal choice of avoidance a^*, can be written as

$$a^* = -\frac{\partial V/\partial p}{\partial V/\partial I} = \frac{\partial E}{\partial p} = a^e(p,x,y^*(p,c,I,x,\beta)) \tag{2}$$

where the function a^e is the expenditure-minimizing level of avoidance from problem (1) evaluated at the optimal level of water quality y^* from problem (1).

From equation (2), five types of variables are in general related to avoidance behavior: the price of avoidance represented by p; other prices represented by c; income represented by I; the household's opinions of tap water represented by x; and general characteristics of the household represented by β. For reference, all the basic results of consumer theory with respect to prices and income, such as homogeneity and the Slutsky matrix, hold for this model (see Varian (1984)).

The Slutsky matrix implies that

[17] It could also be possible to include the vector β directly into the production function, so that $y = f(a,x;\beta)$. When avoidance measures a represents a vector of avoidance options, then there can also be substitution across individual avoidance options as well (i.e., boiling water and buying bottled water).

[18] The formulation in (1) is a simple variation on different models of defensive expenditures (e.g., Bartik, 1988; Courant and Porter, 1981; Berking and Stanley, 1986; Harford, 1984; Harrington and Portney, 1987; and Shibata and Winrich, 1983). Since this earlier literature is focused on defensive expenditures, the expenditure minimization problem in problem (1) is not explicitly addressed in earlier literature. For example, the Bartik model is exactly the model outlined in problem (1) when $c = 1$ and prices p of avoidance measures are ignored, in which case the avoidance expenditure function is just written as $E(y,x)$.

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$$\frac{\partial a^*}{\partial p} \leqslant 0 \text{ and } \frac{\partial a^*}{\partial I} \geqslant 0 \text{ if normal good} \tag{3}$$

All else constant, higher prices of avoidance measures imply lower levels of avoidance for normal goods (higher income implies higher consumption). It is possible, however, that some avoidance measures are inferior goods so that income effects are negative. This issue is discussed in more detail in section 4 in relation to boiling water.

A more complicated issue to investigate is the relationship between basic initial quality x and the optimal level of avoidance, a^*. Using equation (2) and differentiating with respect to x yields

$$\frac{\partial a^*}{\partial x} = \frac{\partial a^e}{\partial x}\Big|_{y^* \text{ constant}} + \frac{\partial a^e}{\partial y}\frac{\partial y^*}{\partial x} \tag{4}$$

The sign of (4) depends on two main terms: the substitution effect and the final quality effect. The substitution effect in (4), the first term, is negative directly from the structure of the household's water production function because $\partial a^e/\partial x|_{y \text{ constant}} = -fx/fa < 0$. The final quality effect in (4), the second term, can be shown to be positive as follows. Since the structure of the avoidance production function implies that $\partial a^e/\partial y > 0$,[19] the sign of the final quality effect in (4) depends on the sign of $\partial y^*/\partial x$.

To determine the sign of $\partial y^*/\partial x$, it is necessary to take the total differential of the three first-order conditions to problem (1) with respect to y,z, the multiplier on the income constraint, and x, and then use Cramer's Rule to solve for the derivative.[20] After some tedious algebra, this process shows that $\partial y^*/\partial x > 0$ when $\partial^2 U/\partial y\,\partial z \geqslant 0$, and otherwise the sign of (4) could be positive or negative.[21] As it turns out, it is reasonable to assume that $\partial^2 U/\partial y\,\partial z \geqslant 0$. For example, as shown in Varian (1984, p. 135), this assumption is needed to assure that y and z are normal goods (more income, more y and z). Thus, $\partial y^*/\partial x > 0$ and the final quality effect in (4) is positive.[22]

[19] Holding x constant, more a is needed to obtain more y.

[20] It is necessary to be clear about the sign of the determinant of the bordered Hessian for problem (1), which is positive in this case. As a side note, the second-order conditions for a optimum cannot be used to sign the determinant of the bordered Hessian; the second-order conditions are just related to principle minors (see, e.g., Intrilligator (1971) for more details).

[21] For reference, this derivative is $\partial y^*/\partial x = M/N$, where $N = 2cE_yU_{zy} - U_{zz}E_y^2 - cc(U_{yy} - \lambda E_{yy}) > 0$ is the determinant of the bordered Hessian for problem (1), $M = -cE_xU_{zy} + U_{zz}E_yE_x - cc\lambda E_{yx} > 0$ and subscripts denote partial derivatives. All of the terms can be easily signed directly from the indirect objective function, the direct utility function, the expenditure function, and the production function (using the envelope theorem when appropriate), except for the term $E_{yx}\,\partial\lambda^e/\partial x$, where λ^e is the multiplier on the quality constraint in the expenditure function in problem (1). Using the same Cramer's rule process for the first-order conditions of the expenditure function, it is possible to show that $E_{yx} = \partial\lambda^e/\partial x < 0$, which intuitively makes sense because the constraint is less costly as x increases.

[22] As far as we know, the previous literature does not explicitly analyze the sign of this term. Harrington and Portney (1987) discuss this term but do not identify its sign, the rest of the defensive expenditure literature does not discuss the term. The term shows up in equation (5) in Bartik (1988) but is not analyzed. The term is not discussed in Harford (1984) and Courant and Porter (1981).

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In sum, the substitution effect in (4) is negative, the final quality effect in (4) is always positive, and it is not clear if there is more or less avoidance as perceived quality x increases (the sign of (4) can be positive or negative). Both signs could be reasonable depending on the avoidance measure being addressed. For example, consider filtering. When water is very bad quality (may be because of biological concerns), filtering technologies may not work adequately and households would need to boil water or buy bottled water. But if quality was improved, especially in relation to biological risks, the filtering technologies may begin to work well enough and the household could now use filtering more often with perhaps less boiling of water and buying of bottled water. In this example, the sign of (4) is positive for filtering and negative for boiling water and buying bottled water.

In principle, the avoidance equation (2) along with the optimal demand for other goods z^* can be estimated using multivariate regression methods.[23] The results in (3) and (4) provide testable hypotheses reading avoidance behavior. However, the exact regression approach will have to vary depending on the nature of the data available (time series, cross-section, panel data). These econometric issues are discussed below in section 4.

4. Logit regression analysis of avoidance behavior

The basic survey results reported in section 2 show that Moscow residents commonly use avoidance measures to adjust their water quality. Section 3 provides a theoretical representation of the avoidance choice and a discussion of how prices, income, and initial water quality are expected to be related to avoidance choices. Section 4 uses a binomial logit regression framework to estimate these relationships.

The Moscow survey did not acquire data directly on exact quantities of avoidance measures used (liters of bottled water, liters of filtered water, etc.). Instead, the survey asked questions in an ordered categorical form (never, sometimes, most of the time, always). In principle an ordered logit framework can be used to handle the four possible answers to each avoidance question. However, for some answers to each avoidance question, there are very few positive responses so that the degrees of freedom in the analysis are too small for statistical interpretation. As a result, given the four choices for each question (always, most of the time, some of the time, never), a new binary variable for each measure was defined as 1 if the response was always or most of the time and 0 if sometimes or never. With this binary choice variable, a logistic (logit) regression framework is used to model the probability that a given respondent uses a specific avoidance measure (boil, settle, filter, buy bottled water).[24]

The theoretical model from section 3 provides the following hypotheses

[23] In a time series context, (3) implies that the use of avoidance measures should increase as such measures become less expensive, income grows, and if perceptions of quality decline.

[24] Each of these four avoidance measures are not technically linked so that individual logit regressions for each measure can be estimated (there is no nesting or jointness issues).

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regarding the logit analysis. For filtering water and buying bottled water, which involve market expenditures, higher-income households are expected to have higher probabilities of choosing the measure than lower-income households. For boiling water or settling water, which involve essentially no cost involved for households, higher-income households are not expected to have higher probabilities of choosing the measure than lower-income households. Since the income constraint in (1) would not affect choices of boiling or settling, it would be expected that income is not related to these decisions.[25] And from (4), the model suggests that households may undertake more avoidance behavior when basic water quality is considered to be worse.[26] The empirical results related to each of these theoretical implications are discussed below.

Table 8 provides the parameter estimates for one basic model for each avoidance measure, where income and proxies for perceived water quality are included as explanatory variables. All explanatory variables in the model are 0/1 variables. In the survey, there are two possible proxies for the household's perceived water quality (the variable x in section 3). One proxy is the location in the city, which defines the water source and supply station (Rublevo, North, East, and West in tables 1–4). Another proxy is the direct opinion of water quality (good, OK, bad). The basic survey results discussed in section 2 show that there is a strong correlation between water delivery station and overall opinion of quality. Such correlation causes multi-colinearity problems in estimating a model that includes both proxies. Given that these variables are largely addressing the same issue in the survey, just one proxy is used in each logit regression for each avoidance measure. The direct opinion of quality provided better results for the settle and boil regressions (the no-cost measures), while the location proxy provided better results for filter and bottle regressions (the higher-cost measures).

The base case for all four regressions presented in table 8, as represented by the constant, is for low-income households living in the Rublevo water supply region who consider their water quality to be good. The estimated parameter coefficients show the change in the probability of choosing an avoidance measure as this base case changes in terms of income (from low to medium and high) and initial water quality proxy (from Rublevo water supply station to the North, South, or East station for the filter and boil regressions and from the good quality to either OK or bad quality for the settle and boil regression). The estimate b of the variable B is reported next

[25] As explained earlier, water and natural gas are provided at no marginal cost to households. There is some nominal time involved with boiling water, but it is almost zero given gas stoves commonly used in apartments in Moscow. Time could be a much more serious issue in certain parts of Russia and other parts of the world where heating water is a much more time consuming and costly activity. In this context, it could be appropriate to add a direct time constraint into problem (1) to consider labor and leisure choices as part of the analysis (see, e.g., Singh, Square, and Strauss (1986) for examples of time-constrained models).

[26] With the cross-section survey data, basic prices for avoidance measures do not really vary for each household, so it is not possible to estimate the 'price' effect from (2).

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to each coefficient in table 8, with an estimate b greater than 1.96 being statistically significantly different from zero at the 5 per-cent level for a two-tailed test.[27]

Income effects

For purchasing bottled water and using filters, table 8 shows that the parameter for income medium and income high are statistically significant at the 5 per cent level, the parameters have a positive sign and the parameter for income high is greater than that for income medium as would be expected in economic theory. For example, from the estimated regression, the probability of low-income households in Rublevo region choosing bottled water is about 8 per cent. This number increases to about 30 per cent for high-income households. Income growth over the next few years in Moscow could have a rather strong impact on the bottled water market.

For settling water, the income parameter is not statistically different from zero for both medium and high levels of income. This result is also consistent with theory because settling involves essentially no cost in Moscow. With no expenditures, the income constraint does not matter for that avoidance measure in (1).

Regarding boiling, from table 8, the parameter on the medium level of income is not significantly different from zero, as might be expected because boiling does not involve any real cost in Moscow so that the income constraint is not a binding factor in the choice of boiling. However, in table 8, the parameter on the highest level of income (income *H*) is statistically significant at the 5 per cent level and is *negative*. These empirical results indicate that boiling water has the characteristics of an 'inferior' good. High-income households tend to buy bottled water anyway, which reduces the need for boiling.[28]

Water quality effects (location or direct opinion)

As shown in relation to equation (4), economic theory does not suggest an unambiguous answer regarding initial water quality and the level of avoidance. As a result, the relationship between initial water quality and avoidance is an empirical question. In table 8, as discussed above, water delivery station is used as the proxy for initial water quality for the models of filtering and bottling, while direct opinion of initial quality is used for settling and boiling.

In table 8, the location variables are not statistically significant for purchasing bottled water. For bottled water, income matters the most, which indicates that other factors beside water quality could be wrapped up in the decision to buy bottled water. For filtering water, the North and East

[27] The variable B is distributed as standard normal (mean 0, variable 1).

[28] If boiling has essentially no cost, then the negative income effect on boiling must come from the underlying structure of the household water production function or the structure of household preferences. Either are possible. As a reviewer points out, if the opportunity cost of time is positively correlated with income, it is also possible that boiling 'costs' higher-income households more than lower-income households, which would result in less boiling with higher income.

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Table 8. *Bionomial logit regressions for use of avoidance measures (1 = use measure all the time or regularly, 0 = use measure never or seldom)*

n = 612	*Settle*		*Filter*		*Bottle*		*Boil*	
	Coefficient	*b*	*Coefficient*	*b*	*Coefficient*	*b*	*Coefficient*	*b*
Constant	−0.85	−5.8	−1.09	−4.9	−2.41	−7.7	2.19	2.9
Income M	−0.09	−0.5	0.71	3.1	1.44	4.8	−0.05	−0.2
Income H	−0.17	−0.7	0.92	3.6	1.66	5.2	−0.94	−3.1
North			−0.71	−2.5	−0.37	−1.0		
East			−0.66	−2.3	−0.33	−0.9		
West			−0.39	−1.4	−0.43	−1.1		
Qual. OK	0.65	3.2					0.54	1.6
Qual. bad	−0.08	−0.4					−0.26	−0.9

locations are statistically different from 0 at the 5 per cent level and the signs on the parameters are negative, indicating that there is less filtering of water in the North and East locations as compared to Rublevo and West. This result is consistent with the summary survey results in tables 5 and 6 where residents receiving water from the Volga source (the North and East stations) are generally more satisfied with their water quality and report less annual variation than residents receiving water from the Moscow source.

Regarding settling choices, with quality good as the base case (i.e., dummy excluded from the regression), the dummy for quality OK is statistically different from 0 at the 5 per cent level and is positive. The parameter for quality bad, however, is not statistically different from 0. It seems plausible that households with OK water quality consider it reasonable to settle water to improve its quality, while households with bad water quality conclude that settling will have no benefit since the water is so bad. In the first case, there is some perceived benefit from settling while in the second case there is no perceived benefit from settling. Some other measure would be needed to improve quality.

For boiling decisions, basic opinion of water quality is not related to boiling decisions. Given this result, it seems likely that the boiling decision is driven more by household characteristics (the parameter β in section 3) than simple quality, location, and income variables.

5. Conclusions

Drinking water health risks are a combination of basic quality at the tap (the variable x in the model in section 3) and any avoidance measures that households use to affect final water quality (the variable y^*). It is very possible that the level of risk at y^* may be acceptable for city health officials even though risks at x would be unacceptable. In this sense, public health concerns associated with tap water quality could be overstated in policy debates and city-level financial priority setting.

As far as we know, the Moscow survey used in this paper provides the first relevant data for understanding levels of avoidance. While obtaining detailed quantity and quality data needed to estimate precisely initial quality x and final quality y^* is a clear topic for future research, the basic empirical findings reported in section 2 show that a substantial portion of Moscow households boil, filter and settle water, and buy bottled water. As reported in section 4, these decisions are systematically related to household income and information on initial water quality. These results are also consistent with an economic model of avoidance behavior developed in section 3. As a result, final health risk related to water consumption in Moscow could be substantially less than initial risks at the tap.

There is substantial need for further analysis of drinking water health risks and avoidance behavior in Russia at this time. Practical applications of quantitative health risk assessments regarding drinking water supplies have begun in Russia, but to date avoidance decisions are not being included in the analysis. For example, if there are concerns about biological contaminants in drinking water mainly during the spring rainy season (and fields are spread with manure before planting during the winter and

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spring), then the least-cost approach may be just to recommend publicly (e.g., radio, newspapers) that it is the 'boiling' season.

Understanding avoidance decisions is also central to questions of improving public water supplies and expecting households to pay higher water charges as a result. As in Moscow, if residents are basically content with their water supply, and use relatively low-cost avoidance measures to improve water quality, it is very likely that residents will not be willing to pay higher water charges to self-finance water infrastructure improvements. To investigate these issues further, it is clear that direct valuation methods (i.e., contingent valuation) should be used. There are many opportunities to use such valuation methods in Russia to inform public decision making regarding water infrastructure improvement, and such work could be easily included in pre-feasibility studies for infrastructure projects.[29]

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[29] See Malzubris, J., S. Senkane, and R. Ready (1997) for an example from Latvia, which was part of the former Soviet Union.

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