Proceedings of the 2023 Winter Simulation Conference
C. G. Corlu, S. R. Hunter, H. Lam, B. S. Onggo, J. Shortle, and B. Biller, eds.

EQUITY-DRIVEN MANAGEMENT OF ESSENTIAL ENVIRONMENTAL RESOURCES UNDER PRICE-BASED CONSUMPTION

Shai Amouyal
Noa Zychlinski

Faculty of Data and Decision Sciences
Technion – Israel Institute of Technology
Haifa 3200003, ISRAEL

ABSTRACT

The global climate crisis and population growth restrict the availability of essential environmental resources such as water and energy and a solution for this situation remains elusive. If and when conditions become extreme, only the well-offs will have access to these valuable resources. With that in mind, we look for ways to achieve equity within societies while preserving, to the degree possible, natural resources. We suggest a method for setting differential pricing for each population stratum so that each spends a relatively similar percentage of their income on these basic commodities, without depleting valuable resources. Our method optimizes the prices while simultaneously estimating the unknown consumption–price relationship. We show the effectiveness of our method based on data from Israel and through extensive simulation experiments reflecting different levels of income inequality within societies, different consumption–price relations, and resource availability. Our study shows that equity and resource preservation can go hand-in-hand.

1 INTRODUCTION

Essential environmental resources such as water are becoming scarce due to climate changes and population growth. This is especially prominent in semi-arid to arid region countries (i.e., areas with hot and dry climates and relatively low precipitation) such as Africa, Asia and the Middle East (Bozorg-Haddad et al. 2020). Moreover, global warming is decreasing the amount of rainfall in certain areas, thus reducing water availability. Forecasts for the Middle East estimate that water availability may fall under $1,000$ m^3/person/year, the worldwide threshold signifying water scarcity, by 2050 (Rijsberman 2006).Desalination efforts, adopted in some countries such as Israel, can help deal with the shortage. They, however, are still very expensive and increase environmental pollution.

Under such shortfall conditions and without regulatory interventions, water prices will inevitably become prohibitive, blocking access to this fundamental commodity for people unable to pay market prices. With this problem in mind, we seek a way to set equity-driven prices so that all levels of society have access to basic resources. In this paper, we focus on household water consumption, which comprises 40% of the overall consumption in Israel (Portnov and Meir 2008), with the intention of ensuring that everyone can afford to have running water. The other 60% of water usage in Israel is primarily for agricultural purposes.

Income inequality (Dabla-Norris et al. 2015) prevails in many countries around the world and is the focus of intense study designed to understand its sources and remedies. Experts associate this phenomenon with factors over which people have little or no control; for example, gender, ethnicity, geographic location, and occupation. Income inequality is implicated in a variety of circumstances, mainly vis-à-vis the inability to maintain a certain standard of living. Various ways to measure income inequality exist. The Gini Index (or Gini coefficient) (Gastwirth 1972), a well-known metric, measures the income distribution within a population. It ranges between 0 to 1 (or 100%), where 0 represents perfect equality and 1 represents perfect inequality. Some of the world's poorest countries have the world's highest Gini coefficients, e.g., South

979-8-3503-6966-3/23/$31.00 ©2023 IEEE

Africa with a coefficient of 60, while many of the lowest Gini coefficients are found in wealthier European countries, e.g., Denmark, with a coefficient of 27 (Gini Index). The calculation uses each country's Lorenz curve, which in economics represents the distribution of income or wealth. Israel is among the countries with a relatively high Gini index (38.9) due to its income inequality. The Gini Index was used in previous literature such as in the paper by Eisenhandler and Tzur (2019), as a part of a method aimed to address a resource allocation problem, with the goal of maintaining equitable allocations aligned with the Gini Index.

We suggest a pricing method for essential environmental resources that can help achieve social "equity". The term "equity" refers to fairness and justice and should not be confused with equality. Whereas equality means providing the same to all, equity means recognizing that we do not all start from the same place and that we must acknowledge and make adjustments for imbalances (equity-definition).

Under the existing pricing method in Israel, water is priced uniformly for everyone, without considering individual income levels. Consequently, although each household pays the same price, the proportion of their income allocated to water expenses varies greatly. In our proposed model, we seek to address this issue. Recognizing water as a fundamental and indispensable necessity, we believe that a higher degree of fairness is essential. Therefore, to align the model with the broad and varied income levels in the population, we chose to utilize income deciles. Income deciles divide the population into ten layers, where each layer i includes all households whose average income is less than the i-th percentile in the population and greater than the (i-1)th percentile.Although our main motivation concerns water prices and consumption, our method can also be used to find equity for other basic commodities such as energy, power, and essential nourishment.

The equity we wish to achieve is within the ten income deciles of the population – each characterized by a monthly average income, average household size, and monthly water consumption of m^3 per person. Figure 1 presents data from Israel (2018-2019) – specifically, the average income per decile (A), average household size (B), and average monthly water consumption per person (C).

The measure we consider for each income decile is the average household water expense vs. income (the expense–income ratio, in short). The current expense–income ratio, which is based on a fixed unified price for all deciles, is presented in plot D of Figure 1. This plot demonstrates the heterogeneity within society in terms of the average income, household size and consumption. Under a fixed water pricing, we get the inequality presented in Figure 1D, where the percentage that the lower deciles spend on water relative to their income is significantly higher than the upper deciles. Taking this into account, our goal is to set different decile prices so that the difference between the largest and smallest ratios is minimized. Once modified, however, the new prices will likely change the resource consumption, which is an unknown future variable.

We show the effectiveness of our method under different price–consumption relations, different levels of inequality income, and different resource availability.

1.1 Brief Literature Review

Throughout history, the various aspects of equity has been studied, particularly in relation to equality. To the best of our knowledge, the oldest theory is Aristotle's equity principle (Bertsimas et al. 2011) that asserted that a fair distribution of resources should consider the prior rights or entitlements that each individual has to those resources.

Due to its complexity, equity has been defined in a variety of ways depending on the specific field of study. including interpretations from psychology, politics, economics, and sociology. As a social behaviorist, Walster et al. (1973) investigated equity and defined it as a term aimed to anticipate individuals' perception of fair treatment and their response when they encounter unfair situations. In psychology, Adams (1965) defined equity as an individual's understanding that the ratio of their inputs to outcomes is equal to that of their peers. The "justice as fairness" theory, in political philosophy, is another theory developed by Rawls (1971) who claimed that equity is equivalent to justice. He believed that equity can be achieved in two

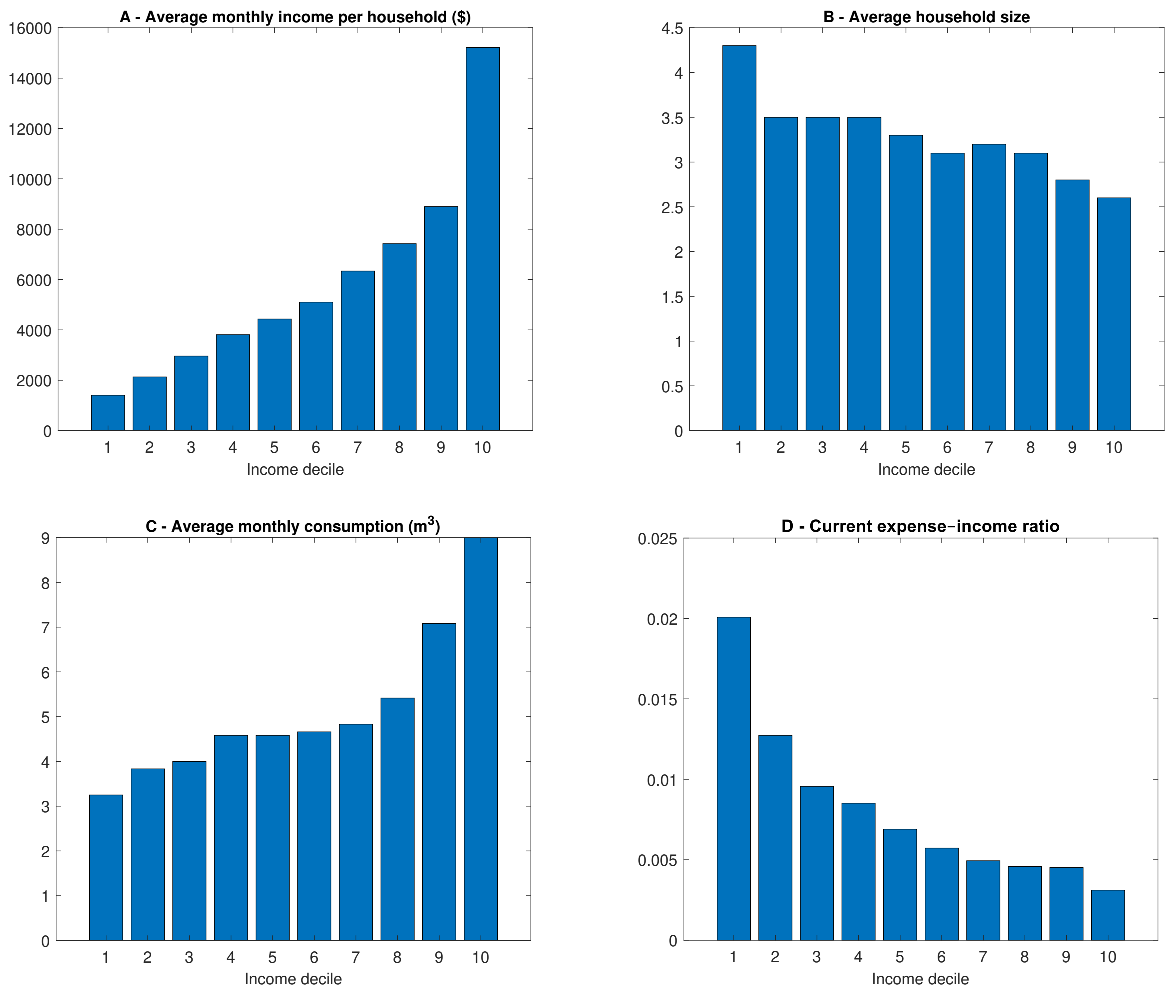

Figure 1: Average income, household size and consumption per income decile in Israel, 2018–2019 (Sources: The Knesset – Research and Information Center; Israel Central Bureau of Statistics, Israel Water Authority).

different ways: first, by following the principle that all are equal, and second, by taking into account the initial wealth of each individual and trying to maximize that of those with the fewest advantages.

Our paper views equity in the framework of basic resource consumption. The two issues – equity and resource preservation – are, by nature, intertwined. Johansson et al. (2002) predicted that by 2050, given the forecast world population growth and the fact that the Earth's renewable freshwater resources are finite, we will face a severe shortage in any context.

In light of the various water shortage predictions, authorities around the world are seeking to carry out forward planning for the allocation of water. Establishing accurate prices, in alignment with this goal, is one way to equitably allocate water; how to accomplish this remains a debatable issue. One example of the positive results that can be achieved through equitable-like pricing methods is the system developed for Ding et al. (2019) in South Africa, a country with severe water scarcity problems. There, to prevent exacerbation of these problems, two methods for imposing fines for excessive use of the scarce resource were examined using simulations. Qaisar et al. (2018) focused on Pakistan, a water-stressed country, as a platform to explore humane water restrictions. They suggested a hybrid approach that combines aged-based modeling and system dynamics. Ozik et al. (2014) and Rasoulkhani et al. (2017) used agent-based simulation to examine water consumption and preservation.

Since water is a necessary commodity, we believe fairness must be ensured in its allocation. Suggestions for different water distribution methods appear in the literature. For example, Bakker (2001) studied the efficiency of and equity in water distribution by exploring the shift away from price policies prioritizing social equity, toward policies prioritizing economic efficiency. Several studies focused on equity in regard to water prices.For example Rogers et al. (2002) argued that the conventional wisdom is incorrect; in their opinion, increasing prices could improve equity. They claimed that by setting a price policy that accurately reflects the cost of water, it is possible to ensure sustainable use of the resource. This, they claimed, will enable efficient resource utilization.

Our paper uses a different approach for achieving equity via pricing methods focusing on domestic use. We consider an unknown price-dependent consumption function and suggest a method to reveal it and achieve the desirable equity. Given a broad range of income among a certain population (or looking at its Gini index), our method sets differential prices, making fairness the basis for water pricing. This approach ensures that everyone has access to this essential commodity at a cost they can afford, as well as helps preserve the resource in a time of crisis.

2 THE MODEL

Our model takes into consideration the ten income deciles of a population (fifteen years old and over), i.e., $i = 1,\ldots,10$ deciles. Each decile is characterized by its mean income I_i and mean household size N_i. We allow different prices x_i for each decile i; these prices are the decision variables we wish to set to achieve equity. Throughout the paper we refer to prices as the price per one consumption unit – a cubic meter of water and a kilowatt of energy. The prices in each decile i can vary between zero and M_i, the maximal price allowed. The average consumption in each decile is normally distributed with price dependant expectancy; namely, $C_i(x_i)$ is the expected consumption in decile i when the price is x_i. Let $C(x) = (C_1(x_1),\ldots,C_{10}(x_{10}))$, $x_i \in [0,M_i]$ denote the vector of consumption function in each decile.
The true consumption function is unknown; the method we suggest attempts to estimate it while setting the optimal prices for each decile. To determine the actual consumption, however, a survey must be conducted to reveal the consumption level for each price. The assumption for the consumption function is presented below. We also assume that there is no government intervention to assist in funding water consumption. Given a price x_i, we define the expense–income ratio for each income decile i thus:

Assumption 1 (price dependent consumption function)**.** *The price-dependent consumption function $C_i(\cdot)$ for each decile i, $i = 1,\ldots,10$, is non-increasing in price. (i.e., the higher the price, the smaller the consumption). Moreover, there is a finite minimum and a finite maximum consumption level in each decile.*

$$R_i = N_i\; x_i\; C_i(x_i)/I_i, \tag{1}$$

where $N_i\; x_i\; C_i(x_i)$ is the expected outlay per household for water/energy. To achieve our goal of equity, we want to set the income decile prices such that the ten expense–income ratios are relatively close to one another. To this end, we aim to minimize the difference between the maximal and minimal ratios. Formally, the non-linear optimization problem we are interested in is

$$\begin{aligned} &\min_{(x_1,\ldots,x_{10})} \quad \max_i\{R_i\} - \min_j\{R_j\} \\ \text{s.t.}\; &\sum_{i=1}^{10} C_i(x_i) \le T; \\ &x_i \le x_{i+1}, \quad i = 1,\ldots,9; \\ &0 \le x_i \le M_i, \quad i = 1,\ldots,10, \end{aligned} \tag{2}$$

where T is the total available amount of the resource. Unlike other products, here we consider an environmental resource whose consumption we wish to restrict rather than increase. The total available amount of the resource can also be the total current consumption (under a unified price) of this resource or some percentage of it. The second and third constraints assure that the decile prices are non-decreasing and that their range will be between zero and a predefined maximal price. The challenge in solving (2) lies in the fact that the consumption functions $C(\cdot)$ are a priori unknown.

3 THE ITERATIVE OPTIMIZATION ALGORITHM

The problem we tackle is twofold. First, we need to reveal the consumption functions given a certain price in each decile. Second, we need to find the optimal prices that achieve the equity we seek in terms of the ratio between water/energy expenses and income. These problems are co-dependent and thus must be solved simultaneously. To this end, we develop the iterative Algorithm 1. The algorithm approximates the consumption function of each decile by a piecewise linear function. The initial approximation includes two parts and is constructed by three price points: consumption when the price is zero, the current consumption for the current price, and consumption when the maximal price is allowed. Note that the minimal consumption is determined by 4/5 of the first decile's consumption, assuming this is the consumption required for basic needs. Each iteration assumes a piecewise linear approximation of the unknown consumption function and solves the optimization problem for the approximated consumption function. Then, the consumption at the optimal prices and the associated value function are estimated. We stop when the value function becomes smaller than a predefined threshold α or if the value function converges and does not keep improving by more than β. Otherwise, we add a new price-consumption point to each decile's approximated consumption function. To demonstrate the estimation of the consumption for each price and decile, we use different predefined consumption functions. We elaborate on this in Section 4.

Recall that $C(x) = (C_1(x_1), \ldots, C_{10}(x_{10}))$, $x_i \in [0, M_i]$ denotes the vector of consumption functions for each decile. For each iteration j, we denote by $\tilde{C}^j(x) = \left(\tilde{C}_1(x_1), \ldots, \tilde{C}_{10}(x_{10})\right)$ the vector of approximated piecewise consumption functions for each decile. Lastly, $x^{(0)}$ denotes the current unified price for all deciles and $C\left(x^{(0)}\right)$ denotes the current consumption at the current price for each decile.

Algorithm 1. *(Optimizing prices and revealing the consumption function)*

1. *Set $j = 0$. For each decile i, assume a two-piece consumption function, $\tilde{C}_i^j(x_i)$, $x_i \in [0, M_i]$ based on the consumption at the two boundaries $x_i = 0$ and $x_i = M_i$ and at the current price–consumption point $x^{(0)}$*
2. *Solve the optimization problem (2) for $\tilde{C}^j(x)$ and set the optimal price for each decile, $x^j = (x_1^j, \ldots, x_1^j)$*
3. *Estimate the actual consumption $\hat{C}(x^j)$ for the optimal prices x^j, and calculate the value function $V^j(\hat{C}(x^j))$*
   (a) *If $V^j(\hat{C}(x^j)) \leq \alpha$ or $|V^j(\hat{C}(x^j)) - V^{j-1}(\hat{C}(x^{j-1}))| \leq \beta$, stop*
   (b) *Otherwise, add another point $(x^j, \hat{C}(x^j))$ to each approximated piecewise consumption function. Set $j \leftarrow j+1$ and return to step 2*
4. *Return the prices x^j and the estimated consumption functions $\hat{C}(x^j)$*

To illustrate the algorithm's steps we first introduce two examples of consumption functions:

Example 1. *For each income decile i,*

$$C_i(x_i) = a_i + b_i e^{-c_i x_i}, \quad i = 1, \ldots, 10,$$

where

Table 1: Parameters for Example 1.

Income decile i	1	2	3	4	5	6	7	8	9	10
a_i	2	2.1	2.2	2.3	3	3.5	3.9	4.4	5.4	6.8
b_i	5	5.4	5.8	6.2	6	6	6.1	6.1	5.6	5.2
c_i	0.18	0.15	0.15	0.14	0.17	0.2	0.24	0.24	0.16	0.12

Example 2. *For each income decile i,*

$$C_i(x_i) = \tilde{a}_i + \tilde{b}_i \frac{e^{-0.5(x_i/\tilde{c}_i)^2}}{\sqrt{2\pi}\tilde{c}_i}, \quad i = 1,\ldots,10,$$

where

Table 2: Parameters for Example 2.

Income decile i	1	2	3	4	5	6	7	8	9	10
$\tilde{a}_i$	2	2.5	2.8	3.3	3.5	3.6	3.9	4.4	5.5	7.5
$\tilde{b}_i$	60	60	60	60	60	60	60	60	60	60
$\tilde{c}_i$	4.8	4.8	4.6	4.5	4.4	4.2	4	4	4.5	5

Figure 2 illustrates the algorithm's steps on Income Decile 8 and the two consumption function examples. The left plots show the first iteration, which starts from a two-piece-wise linear function. The threshold point between the two pieces indicates the current price and consumption. The right plots show the approximation after two iterations – there are three points now, which constitute a three-piece-wise linear approximation. The approximation is quite accurate in both examples after two iterations. In Section 4 we demonstrate the solution achieved by the algorithm and compare the algorithm's solution to the optimal solution for the actual consumption function.

4 RESULTS

We now demonstrate the algorithm's solution for the two examples of consumption functions. Figure 3 presents an illustration of the functions for three representative deciles. Each decile function crosses the current price and consumption.

Next, we compare the algorithm's solution for Iterations 1–3 to the optimal solution achieved when the consumption function is known and does not need to be estimated through approximation. The top plots of Figure 4 present the decile prices achieved by each algorithmic iteration as well as the optimal prices. The bottom plots of Figure 4 present the expense-to-income ratio. The prices and ratios converge to the optimal ones after two iterations. Table 3 compares the value function generated by each iteration and the optimal value function when the consumption function is known. Note that in both examples, a significant improvement in terms of equity is achieved after a single iteration. In Section 5, we analyze the algorithm's solution through extensive simulation experiments.

Table 3: Comparing the VF* achieved in each algorithmic iteration and the optimal VF when the consumption function is known.

	Current VF	Optimal VF	1st Iteration	2nd Iteration	3rd Iteration
Example 1	0.017	3.5e-04	0.0022	7.8e-04	3.5e-04
Example 2	0.017	0.0013	0.0029	0.0014	0.0014

* Value Function

In this paper, we address the implementation of the suggested model based on data from Israel for the years 2018–2019. Israel's Gini index rank is 27, which means that the presented results may characterize

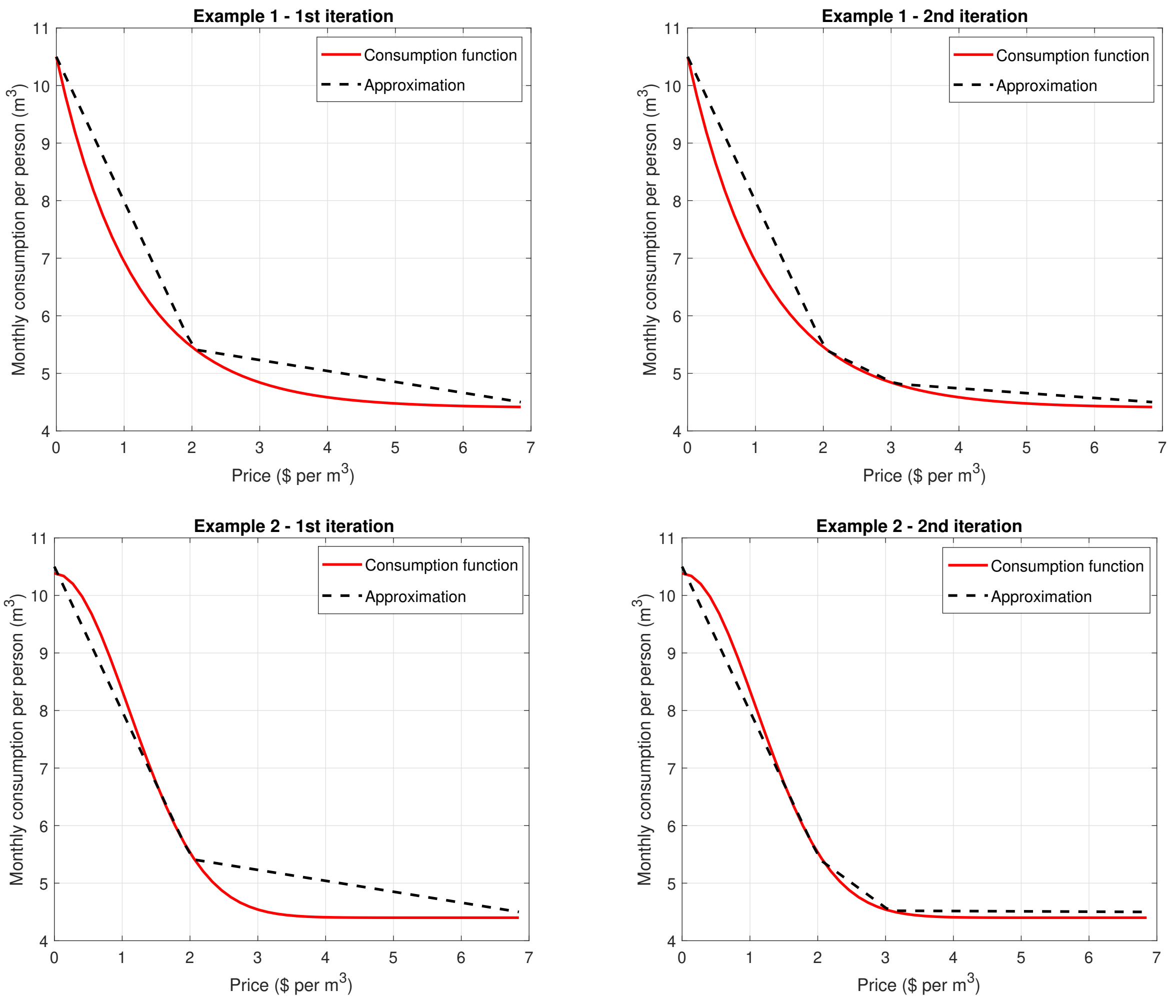

Figure 2: Illustration of consumption function approximation via Algorithm 1.

other countries with a similar rank. The data required to fit the model to other places include average and variance of monthly income, per capita consumption, and household size for each decile. Thereafter, we can apply our suggested method.

The results demonstrate that through our model, significantly greater equity can be achieved compared to the current situation. Moreover, the model helps ensure a reasonable consumption of a limited resource is maintained by adjusting prices accordingly.

The implications of this model in social and economic aspects are significant. The model drives a policy where prices are not uniform across different segments of the population, allowing for the reduction of socioeconomic disparities among these segments. According to this policy, the less privileged segments would be required to allocate a smaller percentage of their monthly income toward fulfilling their essential resource requirements. This would allow them to utilize the freed-up budget to enhance their fundamental living conditions, including areas such as nutrition and education.

5 SIMULATION EXPERIMENTS

In this section we use simulation to evaluate the performance of our approach on different populations in terms of income inequality and consumption. We also examine the results on different levels of total resource availability. We start by simulating populations with different income decile levels. Each population was

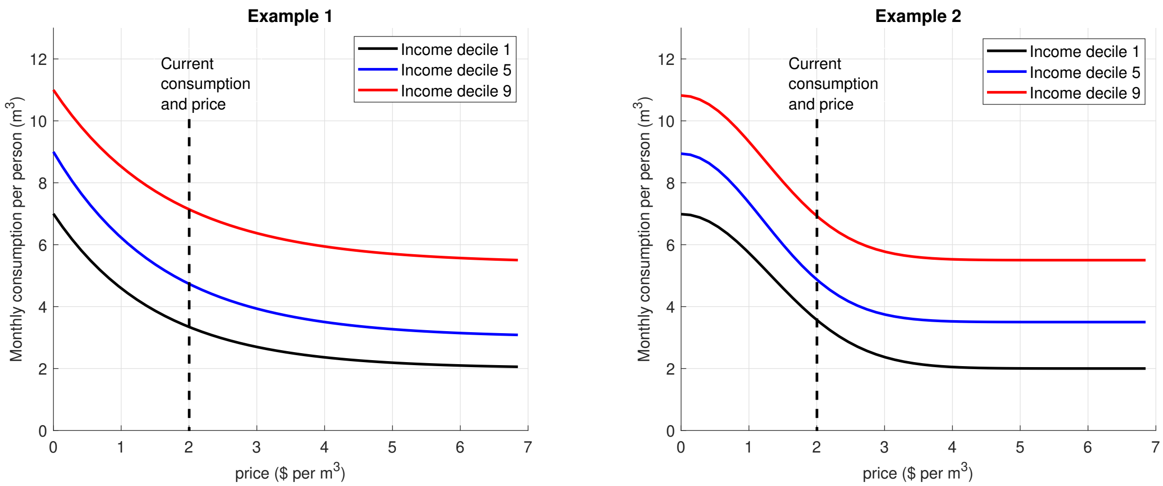

Figure 3: Two examples of consumption functions.

generated randomly with a different income variability rule, which is aligned with the Gini coefficient index. We consider two population groups with low and high income variability. The low income variability group includes relatively homogeneous population segments in terms of income. The high income variability includes heterogeneous population segments with significant income inequality, where most income is concentrated in the upper deciles. Each group includes 50 different population segments and here we report the average income and its distribution among these segments. To keep the comparison fair, we assume the same total economic wealth for both populations. The distribution, however, across population segments varies in both populations.

To be more specific, the level of population's homogeneity was determined by an income range $[3000, 100000]$, from which we uniformly generated ten income levels in each simulation iteration. For the homogeneous population, the range was much smaller compared to the heterogeneous population $[10000, 20000]$, ensuring smaller differences between the deciles. To keep the comparison "fair", we normalized the income levels to ensured a fixed total capital in each iteration. Based on the sorted income levels, we derived the prices for each decile according to Algorithm 1.

Figure 5 presents the distribution of the deciles' prices set by the algorithm for each of the two simulated population groups. We observe that the algorithm works extremely well for heterogeneous populations; indeed, the prices set vary across deciles to achieve the desired equity. For the homogeneous population, however, the prices set are relatively close to one another. In this case, the pricing method should include a lower price for the first decile and a uniform price for all other deciles.

Table 4 presents the average value function generated in each iteration for each population group. Recall that our goal is to achieve fairness by narrowing the gaps between deciles' expense-to-income ratios. The value function, therefore, is the difference between the maximal and minimal ratios. The optimal value (first column in Table 4) is achievable when the consumption function is known. The other columns show the value function achieved after each algorithm iteration (when the consumption function is known). Although there is a slight improvement with each iteration, even the performance after the first iteration is very good.

Table 4: Comparing the average VF achieved in each algorithm iteration.

	Optimal VF	1st Iteration	2nd Iteration	3rd Iteration
Low income variability	0.0017	0.0020	0.0019	0.0018
High income variability	0.0025	0.0040	0.0040	0.0038

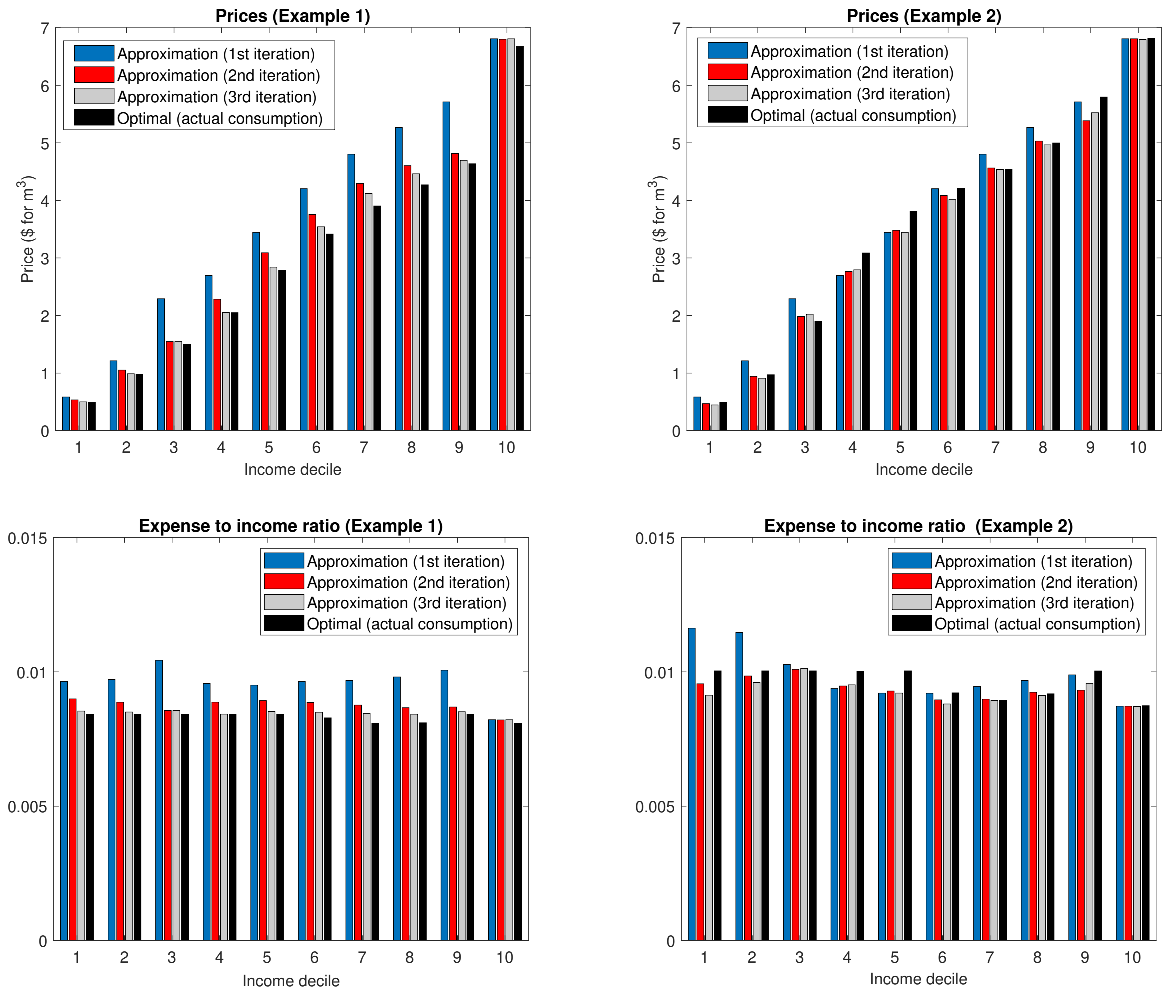

Figure 4: Prices and expense to income ratios for each decile.

5.1 Limited Resource Availability

We now examine our model under resource constraints. With the global climate crisis that may cause water scarcity across the globe in mind, we use simulation to assess how the availability of this resource will affect the prices and consumption under three different water constraints – scarcity, average, and surplus.

Figure 6 illustrates the prices determined by the algorithm for 75%, 100%, and 120% availability, respectively, of the resource (i.e., water) for each population. We see that as availability decreases, the prices increase accordingly, which can easily be related to the supply and demand principle. In addition, it can be noticed that the algorithm adjusts the prices for non-homogeneous populations, while almost identical prices across all resource levels are fixed for homogeneous populations. Therefore, it can be inferred that the algorithm performs well on non-homogeneous populations and is able to adapt prices for each existing resource constraint.

Furthermore, it can be observed that when resources are limited and scarce, the algorithm sets almost identical prices for all income deciles. Here too this result is consistent with the principle of supply and demand – when a resource is limited, we want to reduce its usage. Therefore, the consumption–price dependency influences the algorithm and directs it to set a high price, so that there will be lower demand for the resource and thus there may be a sufficient amount for everyone. Accordingly, the value function

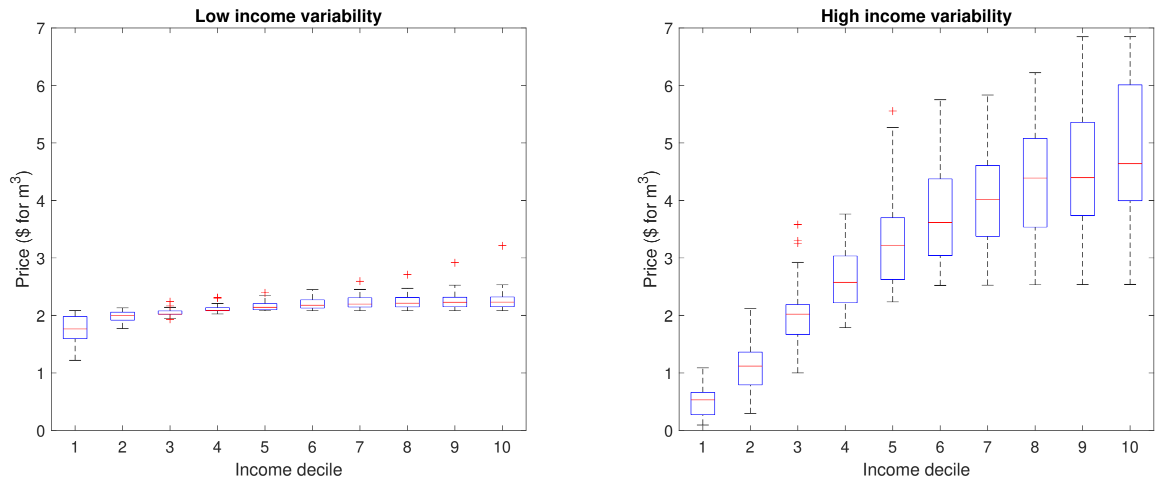

Figure 5: Average prices for each population group.

is slightly higher than when there is no scarcity because there is very limited flexibility to balance the expense–income ratios when almost all prices are the same.

Table 5 displays the objective function, which represents the difference between the maximal and minimal ratios for each resource level in the algorithm's second iteration. As shown, When there is a scarcity of the available resource, the algorithm achieves a higher-than-usual minimum gap, whereas when there is an abundance of the resource, the algorithm is able to achieve a minimal gap between the ratios similar to the case where there is an average amount of the resource.

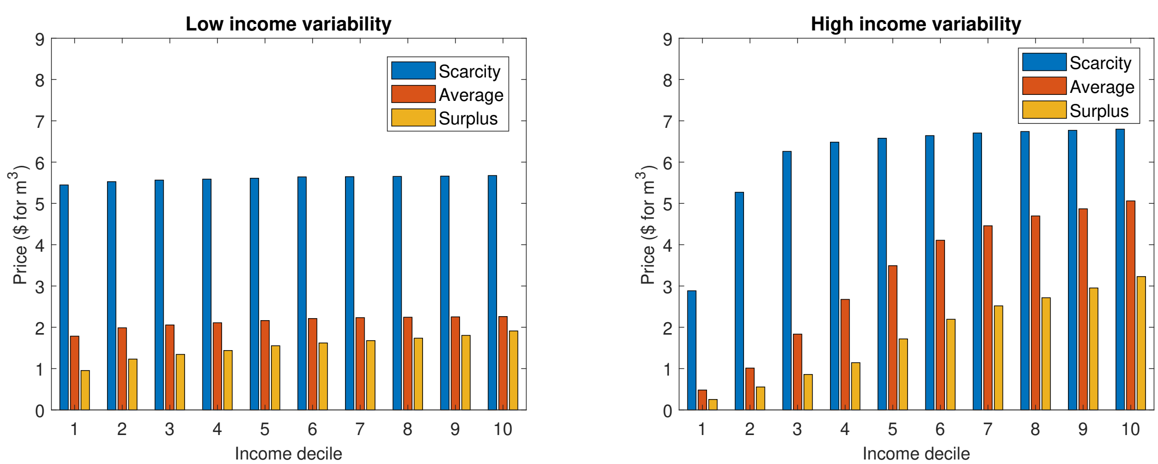

Figure 6: Prices for different resource availability levels.

Table 5: Comparing the average VF achieved in each algorithm iteration based on 100 simulation replications.

	75% Availability	100% Availability	120% Availability
Low income variability	0.0052	0.0020	0.0019
High income variability	0.0226	0.0040	0.0021

6 CONCLUSIONS AND FUTURE DIRECTIONS

This paper suggests a method for setting prices for essential environmental resources such as water under price-dependent consumption in order to achieve equity within a population. The fact that the consumption function is a priori unknown imposes a challenge – the current consumption of each income decile is known for the current price but is likely to change when the price changes. Moreover, under resource scarcity due to the global climate crisis and population growth, the resources need to be allocated efficiently to ensure that everyone can afford to pay for this basic resource.

We measure equity as the ratio between total average cost of water per household and the average household income. Our goal is to set the prices for each income decile so that the ten decile expense–income ratios are relatively close to one another. The method we suggest is based on an iterative algorithm that sets the prices for each decile income while revealing the unknown consumption function. We used extensive simulation experiments to study the performance of our method for different populations with low or high income variability and under different resource constraints. The simulation results demonstrate that the method works well for populations with high income variability: the prices set for each income decile achieve the desired equity. For populations with low income variability, the prices set for each income decile are very similar. In this case, equity can be achieved by setting the same price for all nine income deciles and a lower price for the first decile, without the need to run the model. Under resource scarcity, the algorithm sets high prices, thereby reducing consumption, which helps preserve the resource and prevents it being squandered. Furthermore, the model provides evidence that it is feasible to reduce disparities and can, potentially, help narrow the socioeconomic gaps among population segments. When each segment of the population allocates an equal percentage of its income to acquiring the resource, it allows them to allocate higher proportions of their remaining income toward obtaining additional basic needs, thus elevating the overall standard of living.

We identify three directions for future research. The first includes conducting a survey of the correlation between price and consumption. In this work, we made a number of assumptions about this unique relation. To reduce the number of assumptions that must be made and make the methodology more precise, a comprehensive survey of the target population regarding price and consumption should be conducted, which would enable a more accurate dependency function of consumption and price to be built. The second direction is to broaden the model to incorporate a penalty or tax on excessive consumption. Recognizing that the limited resource must be available to the entire population and fairly distributed among the segments, the concept of a penalty or tax on consumption beyond a certain threshold may be incorporated into the model. This threshold can be fixed or dynamic, based on the income percentile. By doing so, we can enforce and discourage excessive consumption. The third direction is to extend the method to different resources whose prices are set simultaneously where the objective is to gain equity with respect to all basic commodities.

REFERENCES

Adams, J. 1965. "Inequity in Social Exchange". In *Advances in Experimental Social Psychology*, Volume 2, 267–299. Elsevier.

Bakker, K. 2001. "Paying for Water: Water Pricing and Equity in England and Wales". *Transactions of the Institute of British Geographers* 26(2):143–164.

Bertsimas, D., V. Farias, and N. Trichakis. 2011. "The Price of Fairness". *Operations Research* 59(1):17–31.

Bozorg-Haddad, O., B. Zolghadr-Asli, P. Sarzaeim, M. Aboutalebi, X. Chu, and H. Loáiciga. 2020. "Evaluation of Water Shortage Crisis in the Middle East and Possible Remedies". *Journal of Water Supply: Research and Technology-Aqua* 69(1):85–98.

Dabla-Norris, E., K. Kochhar, N. Suphaphiphat, F. Ricka, and E. Tsounta. 2015. *Causes and Consequences of Income Inequality: A Global Perspective*. International Monetary Fund.

Ding, K., J. Gilligan, and G. Hornberger. 2019. "Avoiding" day-zero": a Testbed for Evaluating Integrated Food-Energy-Water Management in Cape Town, South Africa". In *Proceedings of the 2019 Winter Simulation Conference*, edited by N. Mustafee, K.-H. G. Bae, , S. Lazarova-Molnar, C. S. Markus Rabe, P. Haas, and Y.-J. Son, 866–877. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Eisenhandler, A., and M. Tzur. 2019. "The Humanitarian Pickup and Distribution Problem". *Operations Research* 67(1):10–32.

Gastwirth, J. 1972. "The Estimation of the Lorenz Curve and Gini Index". *The review of Economics and Statistics* 54(3):306–316.

Johansson, R., Y. Tsur, T. Roe, R. Doukkali, and A. Dinar. 2002. "Pricing Irrigation Water: A Review of Theory and Practice". *Water Policy* 4(2):173–199.

Ozik, J., N. Collier, J. Murphy, M. Altaweel, R. Lammers, A. Prusevich, A. Kliskey, and L. Alessa. 2014. "Simulating Water, Individuals, and Management Using a Coupled and Distributed Approach". In *Proceedings of the 2014 Winter Simulation Conference*, edited by A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. J. Buckley, and J. A. Miller, 1120–1131.

Portnov, B. A., and I. Meir. 2008. "Urban Water Consumption in Israel: Convergence or Divergence?". *Environmental Science & Policy* 11(4):347–358.

Qaisar, A., S. Muhammad, I. Mahmood, F. Javed, A. Malik, and H. Sarjoughian. 2018. "Dynamic Behavioural Modeling, Simulation and Analysis of Household Water Consumption in an Urban Area: A Hybrid Approach". In *Proceedings of the 2018 Winter Simulation Conference*, edited by M. Rabe, A. A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson, 2411–2422.

Rasoulkhani, K., B. Logasa, M. Reyes, and A. Mostafavi. 2017. "Agent-Based Modeling Framework for Simulation of Complex Adaptive Mechanisms Underlying Household Water Conservation Technology Adoption". In *Proceedings of the 2017 Winter Simulation Conference*, edited by V. W. Chan, A. D'Ambrogio, G. Zacharewicz, N. Mustafee, G. Wainer, and E. H. Page, 1109–1120.

Rawls, J. 1971. *A Theory of Justice: Original Edition*. Cambridge Massachusetts: Harvard University Press.

Rijsberman, F. 2006. "Water Scarcity: Fact or Fiction?". *Agricultural Water Management* 80(1-3):5–22.

Rogers, P., R. De Silva, and R. Bhatia. 2002. "Water is an Economic Good: How to Use Prices to Promote Equity, Efficiency, and Sustainability". *Water Policy* 4(1):1–17.

Walster, E., E. Berscheid, and G. W. Walster. 1973. "New Directions in Equity Research". *Journal of Personality and Social Psychology* 25(2):151.

AUTHOR BIOGRAPHIES

SHAI AMOUYAL is an undergraduate student at the Faculty of Data and Decision Sciences at the Technion – Israel Institute of Technology. Currently, she is also working in a student position as a project manager performing data analysis and process optimization at a high tech company. Shai served as a psycho-technical officer as part of her IDF compulsory service. Equity and advocacy are values according to which she was raised from childhood. Her email address is shai.amouyal@campus.technion.ac.il.

NOA ZYCHLINSKI is an Assistant Professor in the Faculty of Data and Decision Science at the Technion – Israel Institute of Technology. Noa completed her postdoctoral fellowship in the Division of Decision, Risk, and Operations at Columbia Business School. Her research interests focus on service and healthcare operations management, the analysis of queueing networks and their applications, the theory of stochastic process approximation, and data analysis of large service systems. Her email is noazy@technion.ac.il.