The effects of spot water markets on the economic risk derived from variable water supply

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Abstract

Water availability in semiarid regions commonly exhibits patterns of extreme variability. Even in basins with large infrastructure development, some users are subject to low levels of water reliability, incurring economic losses during periods of scarcity. More flexible instruments, such as voluntary exchanges of water among users, may help users reduce their risk exposure. Recent changes in the Spanish water Law have given an initial impulse to allow for lease-out contracts of water use rights. This paper analyses, from theoretical and empirical standpoints, the effect that establishing water markets has on the economic risk caused by water availability variations. The empirical study is performed on an irrigation district of the Guadalquivir Valley (Spain) with fair levels of average water availability but a high probability of periods of extreme scarcity. A non-linear programming model is used to simulate irrigators' behaviour and derive water demand functions. Another spatial equilibrium model is used to compute market exchange and equilibrium. These programming models are combined with statistical simulation techniques. It is shown that the probability distribution of profits for a representative irrigator is modified if water exchanges are authorised, resulting in unambiguous risk reductions. Results also suggests that if the market would be extended to several irrigation districts and users, each characterised by different hydrological risk exposure, the occurrence of extremely low benefits events would become more unlikely. In sum, it is shown that exchanging water in annual spot markets allows for the reduction of farmers' economic vulnerability caused by the variability of water supply across irrigation seasons.

JEL codes: Q12, Q25, D80.

Keywords: water markets, economic risk, water availability, irrigated agriculture.

1. Introduction

Many authors have analysed the economic outcomes of water markets, simulating water exchanges and evaluating profit and welfare improvements for water users. However, most studies are static or pay little attention to the temporal variability that profits present as a consequence of variations in water availability.

In semi-arid climates, where inter-annual variations in the resource availability are extreme, the development of large water infrastructures has proved insufficient to mitigate the economic effects of scarcity periods. Traditional policies to mitigate these losses have usually been either of a preventive nature (development of new infrastructures or improvement of irrigation technologies) or a compensatory one (drought compensation schemes for farmers, such as the ones in Australia, Spain or Israel, consisting basically on tax exemptions and lump sum payments). Market based water policies may reduce the economic losses that users suffer in scarcity years, fostering other policies' economic efficiency. Establishing water market schemes is not only compatible with other policy measures, but can also create economic incentives to stimulate their development making water's opportunity cost more explicit to users.

The potential welfare gains from the reallocation of water resources through voluntary exchange have been shown to be substantial (Vaux and Howitt, 1984; Rosegrant and Binswanger, 1994; Hearne and Easter, 1995; Becker, 1995; Garrido, 2000). These benefits are specially high when supplies are reduced by the occurrence of a drought, mitigating its economic impact (Miller, 1996). Howitt (1998) shows that spot water markets are better than water rights markets as a means to stabilise water availability. From the point of view of the buyer, the sale of permanent rights may sometimes cause an inefficient excess of water available in normal years (Miller, 1996).

Annual spot and option water markets allow for a more efficient distribution of risk among the exchanging parties (Howitt, 1998).

The main hypothesis of this study is that, as water exchanges allow for profit increases in scarcity periods, the possibility of taking part in a water market does necessarily lead to a reduction in the economic risk that derives from variations in the annual level of water availability. In this sense, the main objective of the present research is to analyse the effect of establishing water markets on the variability of profits derived from inter-annual variability in water supply.

In the next section we develop a simple analytical representation of the problem, and discuss its basic assumptions. Then the shape of the probability distributions of market profit for both a water buyer and a water seller are derived. Once theoretical results are obtained, an empirical application is carried out simulating a hypothetical competitive spot water in an irrigation district of the Guadalquivir Valley (South Spain).

2. Defining the conceptual framework

The amount of water available to which a right holder is entitled is distributed as a random variable with a certain density function. The profits derived from its productive use are therefore distributed as another random variable with a different density function. It is assumed that such probability distribution of profit can be characterised by its mean, variance, coefficient of asymmetry and "Value at Risk". Value at Risk can be defined as the level of profit that leaves at its left a probability mass equal to 1-α, being α a given level of confidence (Manfredo and Leuthold, 1999).

Empirical evidence suggests that water markets are active mainly in scarcity situations. If profits are greater than in the absence of trading, it can be assumed that the probability of experiencing low profits is reduced when water trading is allowed.

Below we develop a graphical analysis of the shape of the restricted profit functions, denoted as $\pi(w)$, for two profit-maximising producers that enter a market for water (a buyer and a seller). From such functions we derive the probability distributions of profit achievable by those users. Function $\pi(w)$ denotes the profit that can be achieved using w water units and is a restricted profit function, with a negative second derivative (Chambers, 1988). It is assumed that profit function, $\pi(w)$, only depends on the amount of water used, being the optimal allocation of inputs other than water implicit in the amount of water used.

Short-term profit functions and profit-maximising behaviour are assumed. The first of these assumptions implies that the probability distribution of profit represents the probability of profit in any year assuming that no long-run adjustment of fixed assets is allowed. Such assumption would therefore result in an underestimation of the potential for economic risk reduction, as long-term adjustment would certainly reduce profit's riskiness due to the Le Châtelier principle. The profit-maximising assumption implies that production decisions are taken with perfect knowledge of the allotment that corresponds to a producer. Uncertain water availability would result in different production decisions aiming to reduce the adverse effect of such uncertainty. Therefore, the profit-maximisation assumption also results in an underestimation of the risk-reducing potential of water exchanges.

For the analysis below, we assume that when the water market is active, the allotment of a water user is below an arbitrary level denoted as D_1. For larger allotments the market is not active. For D_1 profit is $\pi(D_1)$. When water trading is initiated, the probability distribution of the water that a right holder is entitled to does not change. However, the probability distribution of water used and profits are modified.

In addition to $\pi(w)$, we define another profit function denoted by $\Pi(D)$, whose argument is the water allotment, D, to which the user is entitled. We use subscript m to denote where a function corresponds to a situation in which water trading is allowed. For a given allotment, D, profit achievable through the market, π_m, depends on the amount of water used (and, therefore, on the amount of water sold or bought), being given as the sum of profit derived from production activities and the revenue or cost derived from selling or buying water, that is:

$$\pi_m(w) = \pi(w) + (D\text{-}w)P_m \qquad [1]$$

A producer receives an allotment D and chooses between using it all for production, selling some and using the rest, or selling it all. Her decision will be given by the profit-maximising point in the new situation. The profit function $\Pi(D)$, when the producer operates in the water market is given by:

$$\Pi_m(D)=\{max_w\ \pi_m(w);\ \forall (D, P_m=h(D))\} \qquad [2]$$

which is the envelope function of [1]. We do not impose restrictions on the curvature of market price equilibrium function, $h(D)$.

When there is no possibility of selling or buying water on a market, profit as a function of allotment, $\Pi(D)$, is equal to profit as a function of water used for production, $\pi(w)$, assuming, of course, that the producer uses all water available. Further, price P_m is exogenous, being determined by market equilibrium when the producer's allotment is equal to D. That means that P_m is related to D, by means of function $h(D)$. To further simplify, it is also assumed that agents are not subject to institutional volumetric tariffs.

3. Effect of spot water markets on the PDF of profit: the case of a water seller.

The restricted profit function in presence of trading (π_m) is above or coincides with the restricted profit function in absence of trading (π), for any level of water used (Dinar y Letey, 1991), as market participation is, by definition, voluntary. Under our assumptions, function π_m is above function π ($\pi_m > \pi$) for any water level below allotment D_1, as in figure 1. Above this point, π_m coincides with π, and market is not active. Now we derive function Π_m from function π_m. As commented before, function Π coincides with function π.

In figure 1, revenue from water sold is given by the straight line $(D\text{-}w)P_m$ (Dinar y Letey, 1991); w^* is the optimal amount of water used that maximises profit in a market situation; and $(D\text{-}w^*)P_m$ is revenue from non-used water. Profit would be given by expression [1] for $w=w^*$. For a different allotment D', market price for water[1] is P'_m, and revenue from water sold is $(D'\text{-}w')P'_m$, being w'^* the optimal amount of water used (figure 2). If we calculate such optimum for each possible allotment level below the generic allotment D_1 we obtain a maximum profit function in a water market setting, Π_m, for a water seller, function that is defined by [2].

The probability distribution of a potential water seller's profit changes when water trading is allowed, with respect to the non-market situation. Depending on the size of her gains-from-trade, we can identify three possible cases relating to the shape of function Π_m, that are analysed below.

Case 1) Function Π_m takes values always below $\pi(D_1)$ (figure 3).

In this case, only the probabilities associated to profit values below $\pi(D_1)$ change. Consequently, probability mass above profit level $\pi(D_1)$ remains unchanged. Below that point, the probability of lower levels of profit decreases and the probability of upper levels of profit increases (figure 4). As a result, the variance of profit decreases, while mean, coefficient of asymmetry and "Value at Risk" of profit increase.

Figure 4 shows how the probability distribution of profit changes. For any value

[1] Clearly, equilibrium price will change with D provided that the allotments of many potential market participants also change. If only the allotment of the seller changes, then P_m remains unchanged (Dinar y Letey, 1991; Weinberg et al., 1995).

of Π, the probability mass to the left of the distribution with water market (f_2) is less than the probability mass to the left of the distribution without market (f_1). It can be stated that Π_m first-order stochastically dominates Π, as $F_2(.) \leq F_1(.) \ \forall \Pi$, what implies a higher mathematical expectation (Anderson et al., 1977) and second-order stochastic dominance (the reciprocal is not certain) (Wolfstetter, 1999). This means that Π_m is unambiguously preferred by any producer, regardless of her attitudes towards risk.

Case 2) Profit function Π_m takes values above $\pi(D_1)$ and below π_{max} (fig. 5).

Function Π_m for D values below D_1 takes a maximum value $\pi(D_2)$ that is lower than π_{max}. In this case, not only the probabilities of profit levels below $\pi(D_1)$ are increased, but also that of profit levels below $\pi(D_2)$ (figure 6). Now it is the probability mass above profit level $\pi(D_2)$ that remains unchanged. Below that point, probabilities of lower levels of profit decrease, while that of upper profit levels increase. The variance of profit is reduced, while kurtosis, mean, coefficient of asymmetry, and "Value at Risk" of profit all increase. As in case 1, Π_m first-order stochastically dominates Π (as $F_2(.) \leq F_1(.) \ \forall \Pi$), therefore Π_m is preferred by any producer, regardless of her risk preferences.

Case 3) Profit function Π_m takes values above π_{max} (figure 7).

It is possible that profits resulting from market participation become larger than non-market profits with the largest possible allotment, D_{max}. In such a case, probability mass shifts to the right, increasing the probability of upper profit levels (figure 8), in a way it is no longer possible to assert that a profit variance reduction occurs, nor that negative asymmetry is reduced. However, mean and "Value at Risk" of profit are unambiguously increased. Yet, Π_m stochastically dominates Π (as $F_2(.) \leq F_1(.) \ \forall \Pi$), and then again it is the preferred option for any producer acting as a water seller.

4. Effect of spot water markets on the PDF of profit: the case of a water buyer.

For a water buyer, profit function π_m is never above profit function π. As depicted in figure 9, for levels of water use below allotment D, profit function is not modified, as all water is used in the production process. Entering the market as a buyer, in order to have more than D units available for production, modifies the profit function, that now lies below profit in absence of market for water values greater than D (figure 9), as the agent would always be better-off with a desired granted allotment for free instead of acquiring extra units in the market. If the producer can buy water up to an amount equal to w^*, earned profit is equivalent to π_m^*, given by expression [1] for $w=w^*$. $(D-w^*)P_m$ is now the cost of buying the water. Market allows a buyer to use more water but at a higher cost than if the granted allotment was given for free.

In parallel to the seller case, we assume that when the market is active, allotment is never greater than a generic value D_1, that corresponds to a profit level $\pi(D_1)$ (figure 10). Above that point D_1, π_m would be greater than $\pi(D_1)$; otherwise there is no incentive to buy water. Each allotment has a corresponding equilibrium price, an associated cost line for water, and therefore a different profit function π_m. Calculating the profit-maximising point for each allotment below D_1, we obtain the maximum profit function for a water buyer, Π_m. The probability distribution of profit for a water buyer gets modified by means of market participation as in the case of a water seller, shown in figures 4, 6 and 8. Π_m stochastically dominates Π, and then the market option is the preferred one for a producer acting as a water buyer, regardless of her risk attitudes.

5. Empirical application

In order to obtain measures of the economic risk, and to perform a stochastic dominance analysis of water markets, we use optimisations model to simulate farmers' behaviour and water exchanges, combined with statistical simulation techniques. The random variable in the model (water allotment) is represented by its probability distribution. Hypothetical values of water allotments are randomly generated from a probability distribution fitted with past recorded allotments for the area of study. Those values are used as parameters in the water market model, from which a probability distribution of profits both with and without the water market is obtained.

Several studies have simulated hypothetical water market schemes under different institutional and behavioural assumptions, generally perfect competition (Flinn and Guise, 1970; Vaux and Howitt, 1984; Saleth et al., 1991; Rosen and Sexton, 1993; Dinar and Wolf, 1994; Weinberg et al. 1993; Horbulyk and Lo, 1998; Garrido, 2000). To simulate exchanges in a water market, some authors use price endogenous models, such as those developed by Enke (1951), Samuelson (1952) and Takayama and Judge (1964) to solve the problem of equilibrium in spatially separated markets. Water price is derived as the dual value of water availability restrictions (see for instance Flinn and Guise (1970), Vaux and Howitt (1984), Booker and Young (1994) and Becker (1995)). Others introduce market equilibrium conditions to force the equality of shadow prices for water (Weinberg et al., 1993; Garrido, 2000).

The area of study is the Guadalmellato irrigation district in the Guadalquivir River Basin (Southern Spain). The district is served by a single reservoir. In normal years water availability for irrigation is abundant, but it presents a remarkable level of inter-annual variability, with a high variance and a negative asymmetry of the frequency distribution of allotments (shown in table 1). From the series of 24 year water allotment a beta PDF has been fitted to represent uncertainty in water availability. In table 1 both the statistics of the empirical and fitted distribution are shown. The beta distribution is used to randomly simulate series of water allotments. Eleven types of irrigated farms have been identified in the Guadalmellato irrigation district. They differ in size, irrigation technologies and cropping patterns.

Inverse water demand functions for the different farm types are derived from a non-linear programming model calibrated using Positive Mathematical Programming to conditions and characteristics of farms in the irrigation district. Details can be seen in Calatrava (2002). These functions are used to simulate water exchanges using an endogenous price model that maximises economic surplus derived from market participation by all users, defined as follows:

$$\text{Max } \sum_i \left[\int_0^{m_i^*} f_i(m_i)\, dm_i \right] \qquad [10a]$$

$$\text{s.t:} \qquad \Sigma_i\, m_i \leq 0 \qquad [10b]$$

$$-m_i \leq D_i \qquad \forall i \qquad [10c]$$

where $f_i(m_i)$ is the inverse excess water demand function for user i (marginal profit); $m_i=w_i–D_i$ is the amount of water bought ($m_i>0$) or sold ($m_i<0$) in the market by user i; w_i is the total amount of water used by user i. The first constraint requires that all supplied water volumes be greater or equal than the amount demanded. The second constraint impedes a user to sell more water than her allotment D_i. Market water price is derived from the dual value of the first constraint.

6. <u>Results</u>

Table 2 summarises the effect that the water market has on the probability distribution of farm profits. It reports the statistics of the series of profits simulated both with and without permission to trade. Results confirm the conclusions drawn from the theoretical analysis, and demonstrate the risk-reduction potential of water exchanges. For one thing, both average profit and the median of profit in presence of water are always greater than in the no-trade situation. An important result relates to the standard deviation of profit, that goes down significantly for all farms when trading is allowed, in a percentage that ranges from 5% to more than 36%. Similarly, the coefficient of variation is reduced significantly for all farms. The negative asymmetry of the empirical PDF of profit is slightly reduced.

Table 2 shows that Value at Risk increases remarkably for all farms. Several issues are to be highlighted. First, the relative increases in Value at Risk are much greater than relative increases in average profit for all farms, showing that the market allows for a high reduction in the levels of risk exposure in scarcity periods. Second, for citrus and olive tree farms (farm types 10 and 11, respectively, mainly buyers), increases of Value at Risk for a 0.05 level of significance are very high, both in absolute and relative terms. Increases for a 0.01 level of significance are modest. This is because the market does not allow for a complete avoidance of economic losses in extreme and unlikely scarcity periods (1% probability of occurrence), but it reduces its magnitude. However, for periods of scarcity with a 5% probability of occurrence, the market allows to completely outcast losses, and to substantially increase profits. For the remaining farms (annual crops, mainly sellers), the risk-reduction effect is greater in the most extreme scarcity situations. The reason behind could be the possibility of substitution between crops to secure profits irrigating with small amounts of water crops with low water requirements, or to choose non-irrigated crops to sell water in the market.

Regarding the whole irrigation district, the market multiplies by seven the Value at Risk of profit for a 0.05 level of significance. For a 0.01 level of significance, Value at Risk increases from a loss of 670,000 euros (average loss of 100 euros/ha) without the market to a positive profit of almost 67,000 euros with the market (10 euros/ha).

It is important to clarify some issues related to the spatial extent of the hypothetical market simulated. As all farms belong to the same irrigation district, their level of risk exposure is identical, as they all are entitled to equal water allotments per hectare. Therefore, for zero allotments, there is no possibility for welfare improves through the market as there is simply no resource to trade with. As a consequence, the PDF of profit has an equal or greater range with than without the market (as can be seen in on figure 11). If the market takes place among users with different PDF of allotment, profit when some of the users receives a zero allotment could be greater than without the market, and the most extreme levels of risk exposure would be further reduced.

Figure 11 shows the probability distribution of profit obtained with and without the water market for some of the farm types and the market as a whole. They are the empirical equivalents of the theoretical PDF. In addition to the improvement of all profits' statistical measures, it can be seen that in all cases the probability distribution of profit when trading is allowed stochastically dominates the probability distribution of profit without trading.

7. <u>Conclusions</u>

It has been shown theoretically that water markets allow users to reduce their risk exposure caused by unstable water supply. Both water sellers and buyers can operate in the market and shift their profit's probability density function in the desired direction. In general, it can be said that the variance of profit is reduced as a consequence of water trading, except for some cases of great profit increases. It is also shown graphically that the asymmetry of the probability distribution of profit becomes less negative, and Value at Risk of profit increases.

In a wider sense, it has been shown theoretically that annual spot water markets are a preferred option for any producer in context of stochastic water availability, regardless of her attitudes towards risk. Profit function when water trading is allowed second-order stochastically dominates the profit function when trading is not allowed. This implies that exchanging water in an annual spot market allows for the reduction of the economic vulnerability that users are exposed to as a consequence of variability in water supply.

The empirical results confirm those of the theoretical analysis. Specifically, several aspects related to economic risk are to be highlighted. First, water trading allows for a significant reduction of the variance of the profit of all farms in the area of study, with reductions ranging between a 10% and a 60%. Second, the negative asymmetry of profit is slightly reduced. This is because all district's farms are exposed to the same level of risk regarding their water availability due to the application of the doctrine of proportional water rights. Thus, in a larger market setting, encompassing other areas and users with different levels of risk exposure, then the probability of occurrence of extremely low values of profit would be quite reduced and asymmetry would increase.

Increases in relative terms of Value at Risk of profit are much greater than relative increases in average profit for all farm types. This highlights the large reduction in the levels of economic exposure and vulnerability to extreme scarcity situations that the market allows. Nevertheless, for farms devoted to tree crops (citrus and olives) such reduction is small for those very extreme and improbable levels of risk, as the spatial extension of the market limits water availability in extremely dry years. A larger market boundary would have the opposite effect.

For all farms, the empirical probability distribution of profits in presence of water trading stochastically dominates the probability distribution without water trading. It is shown that those farms that are more active in the market those that exhibit a greater level of stochastic dominance.

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Tables

Table 1. Statistics of the empirical and fitted distribution of water allotments.

Distribution	Mean	Median	Minimum	Maximum	Std. Dev.	Coef. of variation	Coef. de asymmetry
Original	4026.3	4821.7	0	5799.3	1796.6	0.4462	-0.986
Beta	4026.3	4821.7	0	5799.3	1796.4	0.4462	-0.959

Table 2. Statistics of the PDF of profit simulated both with and without water market.

	Water Market	Mean	Median	Standard Deviation	Coefficient of Variation	Coefficient of asymmetry	Value at Risk 5%	Value at Risk 1%
Farm 1	No	1333	1482	326	0,2448	-0,4568	615	486
Farm1	**Yes**	**1409**	**1486**	**253**	**0,1799**	**-0,3051**	**965**	**724**
Farm 2	No	1196	1370	346	0,2891	-0,5042	403	242
Farm 2	**Yes**	**1236**	**1370**	**275**	**0,2227**	**-0,4907**	**714**	**472**
Farm 3	No	4687	5517	1627	0,3471	-0,5104	939	167
Farm 3	**Yes**	**4781**	**5540**	**1467**	**0,3068**	**-0,5075**	**1773**	**927**
Farm 4	No	4424	5218	1494	0,3379	-0,5316	922	164
Farm 4	**Yes**	**4503**	**5219**	**1322**	**0,2934**	**-0,5310**	**1773**	**927**
Farm 5	No	9179	10840	3061	0,3334	-0,5424	1950	348
Farm 5	**Yes**	**9719**	**10975**	**2249**	**0,2313**	**-0,5385**	**5319**	**2783**
Farm 6	No	7545	8920	2478	0,3285	-0,5549	1637	293
Farm 6	**Yes**	**8392**	**9272**	**1529**	**0,1822**	**-0,5544**	**5319**	**2783**
Farm 7	No	76716	90973	24305	0,3168	-0,5865	17528	3147
Farm 7	**Yes**	**78655**	**90973**	**22979**	**0,2921**	**-0,5360**	**18489**	**9675**
Farm 8	No	73911	87694	23265	0,3147	-0,5924	17042	3062
Farm 8	**Yes**	**75747**	**87708**	**22099**	**0,2917**	**-0,5412**	**18489**	**9675**
Farm 9	No	243645	288824	77506	0,3181	-0,5829	55347	9935
Farm 9	**Yes**	**252316**	**289089**	**71485**	**0,2833**	**-0,5144**	**57382**	**24918**
Farm 10	No	100374	150062	109928	1,0951	-0,452	-140118	-182748
Farm 10	**Yes**	**202970**	**229452**	**69744**	**0,3436**	**-0,3797**	**67044**	**-157879**
Farm 11	No	48338	57752	18765	0,3882	-0,5016	5429	-3230
Farm 11	**Yes**	**55647**	**62063**	**14548**	**0,2614**	**-0,441**	**20040**	**-2454**
I.D.	No	4883491	5912234	1970514	0,4035	-0,522	302370	-667416
I.D.	**Yes**	**5624559**	**6371576**	**1507605**	**0,268**	**-0,4855**	**2132731**	**69962**

Profit in euros.

Figures

Figure 1

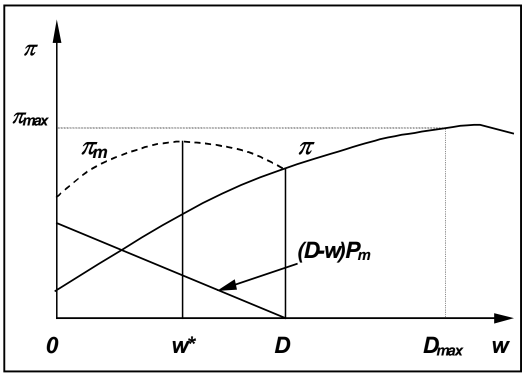
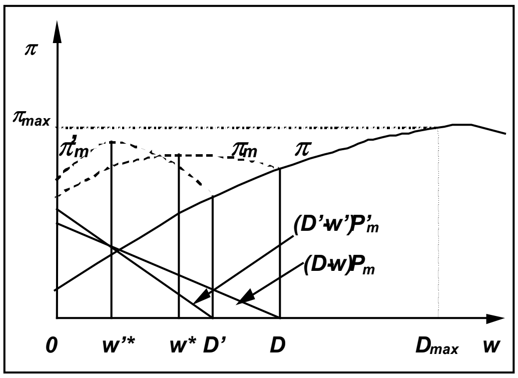


Figure 2



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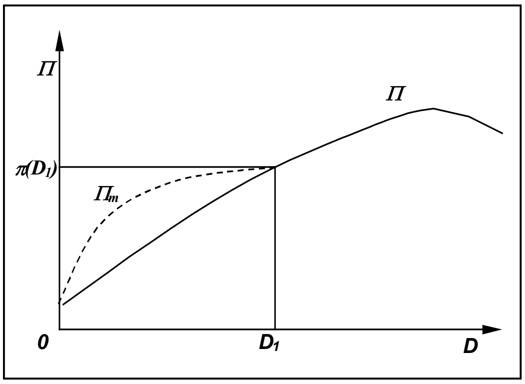

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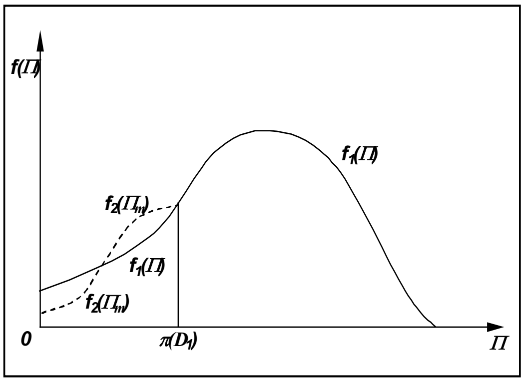

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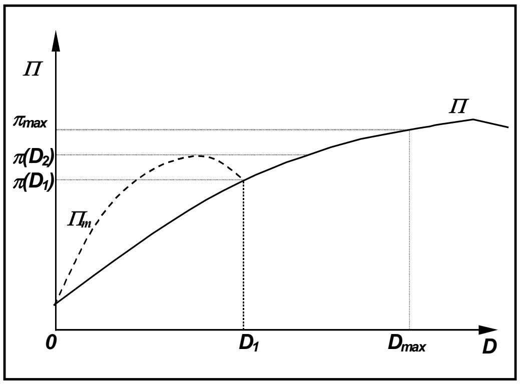

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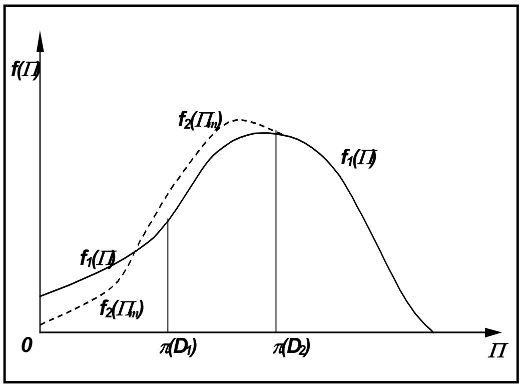

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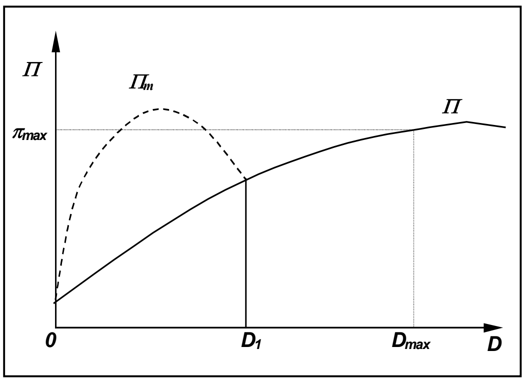
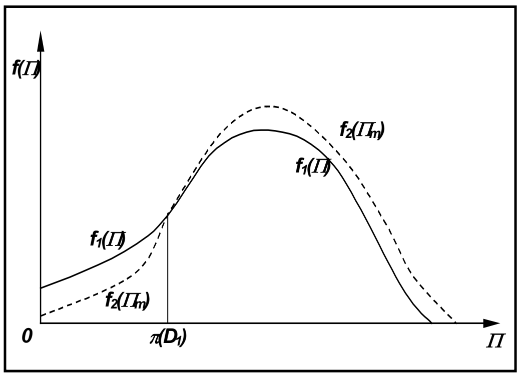


Figure 8



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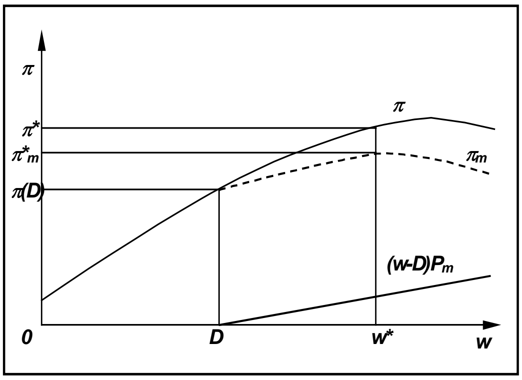
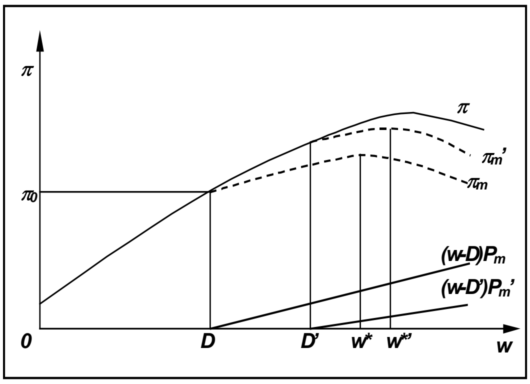


Figure 10



Figures 11. Probability distribution of profit with and without water market