

CrossRef DOI of original article:

Short and Long Term Effects of Water Markets

Received: 1 January 1970 Accepted: 1 January 1970 Published: 1 January 1970

Abstract

Index terms—

1 INTRODUCTION

In several countries having limited water resources, water is being sold cheaply, which encourages water wasting behaviour. The design of an adequate pricing to urge users to take water scarcity into account, implying necessarily a substantial rise of prices, would probably meet resistance from users and would moreover require accurate information on demands. Water markets have been precisely suggested to manage more efficiently water resources while ensuring traditional users' approval, without requiring information on demands. Each user is given a water use right on the basis of his/her historical use at the historical price. An exchange of these rights is allowed, which should lead to a new water price better revealing the water value as it results from a balance of water offer and demand. It should be expected that water markets would result in a more efficient use of water, an improvement of farmers' situation, an improvement of total production thus in an improvement of social welfare. In this paper, we aim to check whether these expectations are always theoretically founded, taking into account the transaction cost of water markets and the social cost due to the inactivity of some farmers that may result from water markets.

In several countries and regions around the world, although water provision requires high costs, water is being attributed through quotas to farmers at very low prices. Some farmers are using water inefficiently (with regard to its real value) while other more efficient farmers are not being satisfied with the quantities received. A water market would result in a balance between offer and demand, thus avoiding the rationing of farmers, and in water transfer from the least to the most efficient farmers (Lahmandi-Ayed and Matoussi, 2003). When the efficiency difference between farmers is sufficiently high, some farmers among the most inefficient ones would stop production activity. This very advantage in terms of water use may have highly negative socio-economic impacts. First inefficient farmers becoming inactive, are very likely to move to cities with all the related families thus increase the number of rural exoders with all their urban, social, political and economic problems mainly in the developing countries. Second they are unemployed persons. The possibility of conversion to another activity is only theoretical for the major part of farmers who are poorly educated thus hardly convertible. Third from the viewpoint of junior farmers, the introduction of a water market results in the introduction of an intermediary in water sale, thus in a rise of water prices. Within a short period, junior farmers will become themselves "senior", and may dislike that a difference remain, which may result in a tenseness in farmers' relationship. Finally people may not think acceptable that a resource involving high public costs, be offered graciously to inefficient farmers that will live on its sale or rent. Hence there is a real cost to put some farmers outside the productive sector which is taken simply into account in this paper.

In the long run water markets are expected to urge farmers to invest in water saving technologies to sell the water saved, which would mitigate at least some of the short term drawbacks. The few empirical observations on the question are contradictory. According to Hearne and Easter (1995), concerning the Chilean water market experience, farmers sell in general a part of their use rights, which allows them to invest in new irrigation techniques that conserve better the resource and results in improving the global production without requiring new mobilizations harmful to the environment. However, according to Bauer (1997) concerning the same experience, "despite expectations on the contrary, there has been almost no private investment in irrigation technology for the purpose of selling rights to the water saved". In Most of Chile, the author observes that water use efficiency remains at its traditional level and that flood irrigation remains the dominant practice. Therefore the question

of whether water markets foster private investments in water saving technologies, needs to be explored from a theoretical viewpoint.

We consider a simple model involving unequally efficient farmers. We suppose that water resources are being rationed. In the short run farmers have only the possibility of exchanging water. We prove that in the short run water markets improve farmers' profits thus production efficiency but do not necessarily improve total production. Taking into account the transaction cost of water markets and the social cost due to the inactivity of some farmers which may result from water markets, we prove that water markets do not necessarily improve social welfare. In the long run farmers have the possibility of investing in water saving technologies before exchanging water rights. We prove that water markets do not always foster private investments when compared to the status quo (situation without water market). exists compelling to deal separately with each sort of problem: a pollution permit is not an input as it is the case for water rights. Malueg (1989) and Milliman and Prince (1989) prove that the introduction of tradeable pollution permits may actually decrease some firms' incentives to adopt more effective pollution control technologies. But both papers examine the question at the firm's level. Jung, Krutilla and Boyd (1996) extend Milliman and Prince's approach from the firm to the industry level. They prove that auctioned permits provide the most incentive effects to promote the development and adoption of advanced pollution abatement technology. But Jung et al. model the pollution permits price mechanism only roughly while in our model the water price is function of the investment decisions since the demand of each farmer is function of his/her level of investment. The more recent paper of Requate (1998) examines the incentives to innovate (adopt a cleaner technology) within a polluting industry under emission taxes and tradeable permits. Requate proves that "there is no unique ranking between those tools, i.e. neither does one of the two tools provide a higher incentive to adopt a new technology in all cases". His conclusion is close in spirit to our own one in that tradeable rights do not necessarily provide higher incentives to innovate. His model is richer than the previous ones in that he models more richly the pollution price mechanism and takes the feedback on the output market into account. The weakness of the previous paper lies nevertheless in the hypothesis that only one firm has the possibility of adopting the new cleaner technology, while the possibility of investing in water saving technologies is given in our paper to all inefficient farmers. The paper is organized as follows. Section 2 describes the model. Section 3 deals with the short term effects of water markets. Section 4 deals with their long term effects mainly in terms of private investment. Section 5 concludes. An appendix contains the proofs.

Consider n farmers ($i = 1, \dots, n$) producing a homogenous farm good sold at an exogenous price p . This is a simplifying but reasonable hypothesis as a water market is local while the output trade may be made at a national or international level. The model accounts for the effect of a local switch to water market within a given group of farmers sharing a given water resource, which thus has a negligible effect on the output price.

The limiting factor is supposed to be water thus the produced quantity and costs may be expressed function of the quantity of water used. More precisely, when the quantity of water x_i is applied by farmer i , $f_i(x_i)$ is the quantity of farm good produced, while $C_i(x_i)$ is the total cost stemming from inputs other than water (fertilizers, labor, chemicals...). Functions f_i and C_i are naturally supposed to be increasing. We suppose that they are twice continuously differentiable with $f''_i(x_i) < 0$ hence f_i is concave, while $C''_i(x_i) > 0$ hence C_i is convex,

and that at least one among the two inequalities is strict.

Denote by \bar{x} the total exogenous offer. The authority assigns a given quota q_i to each farmer i . We have $\sum_{i=1}^n q_i = \bar{x}$.

2 II. THE MODEL

3 The general framework

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We refer to status quo the situation without water market. In this situation, each farmer may buy a quantity of water up to his/her quota q_i , at the historical price $p_h = 0$. Hypothesis $p_h = 0$ supposed for simplicity is close to reality in several developing countries as Tunisia or Egypt for instance. Farmer i 's profit in the status quo is given by: $\pi_i(x_i) = p f_i(x_i) - C_i(x_i)$.

The solution of the first order condition $\pi'_i(x_i) = p f'_i(x_i) - C'_i(x_i) = 0$ is denoted by x_{s_i} . The demand of farmer i if he/she were not constrained by his/her quota is: $x_{s_i} = \max(x_{s_i}, 0)$.

Taking farmer i 's quota into account, his/her actual demand d_{s_i} is given by: $d_{s_i} = \begin{cases} x_{s_i} & \text{if } x_{s_i} < q_i \\ q_i & \text{if } x_{s_i} \geq q_i \end{cases}$. We suppose that $\sum_{i=1}^n x_{s_i} > \bar{x}$. (1)

This inequality means that the total desired quantity is not satisfied, which would be natural in a scarcity context. It will also ensure as we will see the existence of a price equilibrium when a water market is introduced. This implies that there exists necessarily some rationed farmers, i.e. such that $x_{s_i} > q_i$. In the welfare analysis, we focus on the implied group of farmers and the authority who organizes the water market (who is inactive in the status quo). This partial analysis is a first step to have an idea on the effect of water markets on the agricultural sector taking into account their direct costs. The explicit consideration of interests outside the group of farmers and the organizing authority would require at least to model adequately the output market thus for instance to deal with water market within the other groups of farmers and to have information on the demand side. This would be a more complete treatment of the subject and may be a further step of the present

109 research. However the demand side is implicitly dealt with through the examination of the effect of water market
110 on total production. The social welfare in the status quo is given by $W^s = \sum_{i=1}^n u_i(d_i)$.

111 Suppose now that a water market is introduced. We suppose that this involves a transaction cost T , often
112 mentioned in the literature. The transaction cost T is a global cost corresponding to all the costs incurred by the
113 organizing authority to set up the water market and make it work. In this paper, we suppose that farmers do
114 not pay fees to the organizing authority when they participate in the water market. In order to promote water
115 markets. Indeed when a new practice is introduced, even if it is expected to do only good, the mere mentioning
116 of a fee to be paid may give rise to suspicion thus may discourage the adhesion of farmers. Thus we think that
117 the transaction cost should be incurred entirely by the organizing authority at least for some period of time if it
118 wants to promote water markets. If farmers were to pay fees, the sharing of the transaction cost is not a simple
119 issue and the conclusions of the paper may change substantially depending on the way those fees are calculated,
120 another issue which can be dealt with in a next work. Section 3 deals with the short term effects of water markets.
121 Farmers have only the possibility after receiving their quotas to exchange water, which results in a new price p
122 e . We suppose that they are price-takers.

123 Under some conditions water markets result in the inactivity of some farmers. We suppose that this inactivity
124 involves a social fixed cost S per each inactive farmer. Cost S may be viewed as the cost necessary to solve all
125 the problems implied by the inactivity of one farmer (rural exodus, conversion to another activity...) 1.

126 1 See the introduction for a more detailed explanation.

127 Section 4 deals with the long term effects of a water market. We suppose that in the long run farmers have
128 the possibility of making investments to "improve their productivities" before water exchange. To deal simply
129 with the long run, we choose a particular specification of the relevant functions.

130 We suppose that all farmers produce with the same cost function $C_i(x_i) = cx_i^2$

131 i and that the n farmers are divided into two homogeneous groups. The first group involves q "inefficient
132 farmers" ($q \geq 2$), $i = 1, \dots, q$, i.e. that have the same function $f_1(x) = \alpha_1 x$, thus the same low
133 "productivity" α_1 . The second group involves m "efficient farmers", $i = q + 1, \dots, q + m$, "up-to-date"
134 i.e. that have the best possible productivity α_2 , implying function $f_2(x) = \alpha_2 x$. Parameters α_1 and α_2
135 correspond to the quantity of

136 4 A specification of the model for the long run

137 output obtained per unit of water used, respectively by inefficient and efficient farmers. The unit of the farm good
138 is chosen such that $\alpha_2 = 1$.

139 In order to check whether the long term effects of water markets mitigate the short term ones, the difference
140 between the two productivities is chosen such that only the efficient farmers would remain productive in the short
141 run if a water exchange were to take place 2. For simplicity, we consider a specific numerical case: $c = mp = 1/4$
142 and $\alpha_1 = 1/3$; and we take the case of farmers having the same quota: $q_i = q$. Hence, the relation $c = mp = 1/4$
143 becomes $c = p = m^2/(m + q)$. (2)

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145 In the long run the inefficient farmers have the possibility of improving their productivities. To move from
146 productivity α_1 to some productivity μ with $\alpha_1 < \mu < 1$, an inefficient farmer must invest $I(\mu) = a(\mu - \alpha_1)$.
147 Parameter $a > 0$ may be called the intensity of investment and measures how intensive an investment must be
148 to move from the initial productivity to some given new one. We suppose that efficient farmers cannot improve
149 their productivities, they have the best available one.

150 Inefficient farmers are involved in a non-cooperative game in which they choose simultaneously their investment
151 levels (or equivalently the level of their new productivities). In the second step or the "exchange" step, after
152 observing the choices of the first step, with the new productivities, a water exchange occurs between farmers,
153 supposing that farmers have a competitive behaviour.

154 In this section we compare the status quo with a water market in the short run from the following viewpoints:
155 the profit of each farmer and production efficiency, total production and social welfare. We prove that a water
156 market always improves each farmer's profit thus production efficiency but does not necessarily improve total
157 production and social welfare.

158 When a water market is introduced, the profit of farmer i is given by: $\pi_i = p e (q_i - x_i) + p f_i(x_i) - C_i(x_i)$
159 i).

160 5 III.

161 THE SHORT RUN III.

162 THE SHORT RUN $p e (q_i - x_i)$ is the part of the profit coming from the exchange (to be further referred
163 to as "exchange profit") which may be either positive if the farmer is globally a water seller or negative if the
164 farmer is globally a water buyer; while $p f_i(x_i) - C_i(x_i)$ is the profit coming from production (to be referred
165 to as "production profit").

166 Denote by $x_i(p e)$ the solution of the first order condition: $p f_i(x_i) - C_i(x_i) = p e$.

167 The demand of farmer i is given by $d_i(p e) = \max(x_i(p e), 0)$. A price equilibrium $p^* e$ satisfies: $\sum_{i=1}^n d_i(p^* e) = ?$.

169 Result 1 is needed to ensure that the demonstrated properties have cases of application. It holds for general
170 specifications of f_i and C_i under the general hypotheses supposed in the model.

171 Result 2 (Profits, Production efficiency) Under the general framework of the model, the water market improves
172 each farmer's profit thus improves production efficiency Result 2 is a natural one for, with a water market each
173 farmer has the possibility of applying exactly quantity d_{si} (his/her demand in the status quo), which gives
174 him/her a production profit equal to his/her profit in the status quo, and selling the difference $q_i - d_{si}$ at
175 price p_e , which gives him/her an additional exchange profit. Water markets offer indeed more possibilities to
176 farmers by releasing the constraint on demands, which necessarily improves the situation of each one of them.
177 Consequently, if they are given the choice, farmers have always interest to participate in the water market.

178 Denote by A the difference between the sum of profits with a water market at price equilibrium and the sum of
179 profits in the status quo. Necessarily $A > 0$. Hence in terms of production, a water market improves production
180 efficiency in the sense that it improves the profit of the whole sector as it improves each farmer's profit.

181 However the improvement of production efficiency is not synonymous of the improvement of total production.
182 This is illustrated through the following simple example.

183 Result 3 (Total production) Suppose that there are two farmers $i = 1, 2$. Farmer i has function $f_i(x_i) = \mu_i x_i$
184 x_i , the cost function $C_i(x_i) = c_i x_i^2$

185 i and the quota $q_i = q/2$. Let $\mu_1 = 1, \mu_2 = 3, c_1 = 0.5, c_2 = 2.9$ and $p = 1$. With these values of the
186 parameters, the switch to water market decreases total production relative to the status quo.

187 Note that we consider the case of two farmers for exposition simplicity. But the same type of result may
188 be proved for two groups of homogenous farmers. The reason that total production decreases with the chosen
189 example is that the most productive farmer has also the highest cost. Thus there is a shift to more production
190 by the farmer with lowest productivity and lowest cost. Obviously the result is not a general one. An anonymous
191 referee is thanked for this remark. The result is provided only to say that it is a possible case. As cost C_i
192 corresponds to the costs implied by the inputs other than water (labor, fertilizers...), the quantities to be used
193 with a given amount of water thus the implied cost C_i may depend on several parameters as the land's slope or
194 the soil's nature. Thus all combinations are a priori possible (high productivity with high costs, low productivity
195 with low costs, high productivity with low costs...) including the given example.

196 Although a water market always increases the profit of each farmer thus always increases total profit (which is
197 true in particular with the chosen example), this does in no way imply an increase of total production. In short
198 terms, the example provided by Result 3 together with the general Result 2 show that the sector may end up
199 earning more and producing less after setting up a water market!

6 London Journal of Research in Science: Natural and Formal

200 Finally, in terms of welfare, if only the welfare of incumbent farmers is considered, it is obvious that a water
201 market improves the social surplus, since it improves the profit of each one of them. But if the transaction and
202 the inactivity costs are considered, a water market has an ambiguous effect on social surplus.

203 If equilibrium involves h inactive farmers, the surplus difference between both situations $W_w - W_s = A - hS$
204 $-T$.

205 The water market improves the social welfare only if: $A - hS - T > 0$

206 The last inequality allows to see simply the advantages and disadvantages of water markets, as far as only
207 farmers and the organizing authority are concerned. A water market improves the farmers' profit but involves
208 costs and may result in the inactivity of some farmers. A net benefit would result only if the gain outweighs the
209 losses.
210

211 But number h is endogenous. The consideration of a specific example allows to calculate that number and
212 derive conclusions on whether a water market improves welfare, depending on exogenous parameters.

213 Lahmandi-Ayed and Matoussi (2003) studied the case of linear functions $f_i(x_i) = \mu_i x_i$, μ_i being the
214 productivity of farmer i , and a quadratic cost function $C(x_i) = c x_i^2$. Farmers are supposed to have the same
215 cost function and to differ only by their functions f_i . Thus a farmer with a higher productivity is more efficient
216 than a farmer with a lower productivity. Suppose that farmers are ordered as follows: $\mu_1 \geq \mu_2 \geq \dots \geq \mu_n$.
217 And denote by $(u_i)_{i=1}^n$ defined by: $u_i = \sum_{j=i+1}^n (\mu_j - \mu_i)$

218 At equilibrium "Productive" farmers are those who produce a positive quantity of the farm good and "non-
219 productive" farmers those who make profit only from water resale. Lahmandi-Ayed and Matoussi (2003) proved
220 Proposition 1 stated below.

221 What is particular here is that the water market improves not only production efficiency as we defined it,
222 but total production, as water is transferred from the least to the most efficient farmers in terms of production.
223 Moreover in the first case where the difference in productivities is small enough, all farmers remain active.

224 Consider now the specification of the model adopted for the long run which is a particular case of the above
225 one. The parameters of the example have been chosen such that only the efficient farmers are active in the short
226 run if a water market is set up (thus $h = q$). After calculations, the improvement of the sum of profits due to
227 the water market is equal to $A = (5/12) q p^2 m + q$. The water market improves the social welfare only if 5 :

$$(5/12) q p^2 m + q - T - q S > 0. \quad (4)$$

228 Denote by $\theta = (5/12) p^2$. Inequation 4 is equivalent to $\theta q < q = -T - mS + [(-T - mS)^2 + 4ST m]^{1/2} / 2S$,
229 which may also be written as: $S < 1/q [(5/12) q p^2 m + q - T]$.

231 Therefore there is an overall benefit in the short run from a water market only if inefficient farmers are not too
 232 numerous and/or the cost due to inactivity of a farmer is not too high. Otherwise, the social welfare worsens with
 233 a water market relative to the status quo. Indeed in the opposite case, the improvement of the farmers' profit
 234 implied by a water market is not enough to outweigh the too high social costs due to those inactive farmers.

235 We now suppose that farmers have the possibility of investing in water saving technologies as in the specification
 236 described in the model for the long run. As in the 5 Note that Inequality 4 involves now only exogenous
 237 parameters.

238 7 IV. THE LONG RUN

239 short run case, it is easy to check that a water market improves each farmer's profit thus production efficiency.
 240 Hence each farmer has interest to participate in the water market if he/she is given the choice. However we prove
 241 that a water market does not always encourage private investments relative to the status quo.

242 Result 4 (Long run, farmers' profits and production efficiency) Under the specification for the long run, a
 243 water market improves each farmer's profit thus production efficiency.

244 Each farmer has always the possibility within a water market to keep his/her initial productivity, apply
 245 the same quantity of water as the status quo and sell the remaining quantity, which gives him/her a profit at
 246 least equal to his/her profit in the status quo. The improvement of each farmer's profit naturally implies the
 247 improvement of the sector's profit.

248 8 London Journal of Research in Science: Natural and Formal

249 It remains now to check whether a water market encourages investments. We consider the investment decisions
 250 respectively in the status quo then with a water market. Then the investment decisions in both situations are
 251 compared.

252 Proposition 2 (Investment decisions in the status quo) Under the specification for the long run, in the status
 253 quo, -If $p > a$ all inefficient farmers choose $\mu = 1$.

254 -If $p < a$ all inefficient farmers choose $\mu = 1/3$, i.e., no investment is made.

255 Suppose now that a water market is set up. Proposition 3 provides the investment decisions of farmers in such
 256 conditions. Before doing so, we need the following lemma.

257 Lemma 1 Under the specification for the long run, an inefficient farmer necessarily chooses productivity $\mu =$
 258 $1/3$ or productivity $\mu = 1$. Thus after the investment choice, productive farmers have necessarily a productivity
 259 equal to 1.

260 Lemma 1 states that an inefficient farmer actually makes his/her choice between keeping his/her initial
 261 productivity and moving to the best one. He/she never makes intermediary decisions. This is because the
 262 investment is linear w.r.t. the difference between productivities. This result allows to simplify the comparison
 263 between the water market and the status quo in terms of private investment, as it amounts to the comparison of
 264 the number of investing farmers in both situations.

265 Proposition 3 (Investment decisions with a water market) Under the specification for the long run, let (u_t)
 266 $m_t, m_t + q - 1$ be the sequence defined by: $u_t = (3/2)mp / (1 + 2t(t + 1) + (m + q)4(t + 1)^2)$ (5)

267 Three cases are possible:

268 - $u_m > a$, there is a unique Nash equilibrium in which all inefficient farmers keep their productivity at its
 269 initial level.

270 - $a < u_{m+q-1}$, there is a unique Nash equilibrium in which all inefficient farmers move to productivity 1.

271 - Otherwise, there exists some integer h such that $u_{m+h} > a < u_{m+h-1}$, in which case the set of Nash
 272 equilibria involves all the q -uples in which there are exactly h investing farmers who move to productivity 1 and
 273 $(q - h)$ farmers that keep their initial productivity.

274 From Result 5 the consideration of the effects of water markets in terms of private investments turns out to
 275 be more complicated than expected by a rough intuitive approach. In some cases water markets may dissuade
 276 farmers from investing while the same farmers would invest if no water market is set up. These findings which
 277 could not be easily guessed in advance, may be explained as follows.

278 With a water market, the profit of an (initially) inefficient farmer comes from production and water resale.
 279 The decision of investing in new technologies will be taken only if water resale is not very profitable. Water
 280 markets result in two contradictory effects. First a water market better reveals the value of water through the
 281 water equilibrium price, thus urges farmers to save water through adequate investments. At the same time,
 282 the possibility of water resale may dissuade farmers from production and investment. Without a water market,
 283 inefficient farmers make profit only from production. The decision of investment is taken if it is profitable in
 284 terms of production only.

285 In the first case ($q < m < 5/3 + 10/3m + 2/3m^2$), the proportion of initially inefficient farmers is relatively
 286 low, then the second effect is always the winner. Indeed in this case water being scarce because provided by
 287 few farmers, water resale is profitable and inefficient farmers are more willing to rely on water resale than on
 288 production, to make profit. The existence of a water market always reduces the number of investing farmers
 289 when compared to the status quo.

In the second case ($q_m > 5/3 + 10/3m + 2/3m^2$), the number of inefficient farmers is relatively high, the choice between water resale and investment-production becomes more complicated. The two effects have comparable consequences. Hence a priori the number of investing farmers with a water market may be greater or smaller than that number in the status quo. For sufficiently intensive investments and/or sufficiently low output or quota ($p^? < a < u_m$), it appears that the first effect is stronger than the second one. This can be explained in a double way. Considering the production and investment side, a high intensity of investment and/or a low output price have two contradictory effects. Investment and production are not profitable as production is costly w.r.t. entries, reducing the incentive for investment. This direct effect raises water offer, lowers the water price thus making the water resale less profitable and production more attractive! An equilibrium between the two effects occurs when some farmers among the inefficient ones invest and the remaining ones continue to sell their water rights. The explanation is simpler when we view the result in terms of quotas. When the quota is low, the available water is scarce, which makes its resale interesting and lowers the incentives for investment and production within a water market.

To conclude, the claims made about the effects of water markets in the short and long run, are not always theoretically founded. Several concluding remarks and perspectives for future research may be driven from the analysis.

Water markets improving each farmer's profit thus the whole sector's profit, ensure traditional farmers' support and are likely to improve the agricultural sector's situation in countries where farmers are among the poorest people, without increasing the water offer thus without harming the environment. The same amount of water is used more efficiently through water markets. However only traditional farmers are considered in the model. The results may change if "potential farmers" are considered. A water market may even dissuade new farmers from entering in the sector as it results in a rise of water prices, while they would be younger, more highly educated, thus more aware of the modern techniques than traditional farmers. A further interesting step to this research would be to deal with the effects of water markets considering a group of farmers of two types: traditional farmers with historical use rights and potential ones with no use rights.

However the improvement of production efficiency does not necessarily imply an improvement of total production. We indeed prove that a water market may not improve total production, which may be problematic in a scarcity or poverty context or when the considered farm good has a strategic or food security role (for instance some kinds of cereals in Tunisia).

Taking into account the transaction cost of water markets and the social cost due to the inactivity of the least efficient farmers, we prove that a water market does not necessarily improve social surplus. The welfare analysis would be more complete if the price of the farm good is endogenized and the demand side of the farm good properly taken into account. This would be another possible further research step.

Finally, a water market sometimes discourages private investments. This last result, contrary to the roughly intuitive expectations but consistent with some observations on water market experiences, proves that the short term drawbacks of a water market are not always mitigated by its long term effects.

9 APPENDIX: PROOFS

Proof of Result 1. First note that $x_{si} = d_i(0)$. Inequality (1) is then equivalent to $\sum_{i=1}^n d_i(0) > ?$. Equation $pf_i(x_i) - C_i(x_i)$

$= p_e$ defines implicitly $x_i(p_e)$ as a continuous decreasing function of p_e . d_i is then a continuous non-increasing function of p_e , and so is $\sum_{i=1}^n d_i$. On the other hand there exists p such that for all $p_e > p$, for all $i = 1, \dots, n$, $pf_i(0) - C_i(0) - p_e < 0$, then $x_i(p_e) < 0$ for all $x_i \geq 0$, which implies $d_i(p_e) = 0$, so Proof of Result 2. As $d_i(p_e)$ maximizes the profit of farmer i with a water market, it ensures to him/her a better profit than d_{si} his/her demand in the status quo, which is written as $pf_i(d_i(p_e)) - C_i(d_i(p_e)) + p_e(p_e - d_i(p_e)) \geq pf_i(d_{si}) - C_i(d_{si}) + p_e(p_e - d_{si})$.

As $p_e(p_e - d_{si}) \geq 0$ since $d_{si} \geq 0$, we have $pf_i(d_{si}) - C_i(d_{si}) + p_e(p_e - d_{si}) \geq pf_i(d_{si}) - C_i(d_{si})$, implying $pf_i(d_i(p_e)) - C_i(d_i(p_e)) + p_e(p_e - d_i(p_e)) \geq pf_i(d_{si}) - C_i(d_{si})$,

which says that the profit of farmer i is better under water market than in the status quo.

Summing these inequalities, together with $\sum_{i=1}^n d_i(p_e) = \sum_{i=1}^n ?_i$, we prove that a water market improves the profit of the whole sector.

Proof of Result 3. With these values, we have first: $x_{si} > ?_i$, so that in the status quo $d_{si} = ?_i = ?/2$ and total production equals $P_s = (?_1 + ?_2)/2$.

With a water market, we have $?_2 - ?_1 < 2c_2 ?_p$, which ensures the activity of both farmers at equilibrium. Demands of farmers are respectively given by the following:

London Journal of Research in Science: Natural and Formal $d_1 = p_1 - p_2 + 2c_2 ?_2 / (2(c_1 + c_2))$ and $d_2 = p_2 - p_1 + 2c_1 ?_2 / (2(c_1 + c_2))$.

Total production is then given by $P_w = ?_1 d_1 + ?_2 d_2 = p_1(?_2 - ?_1) / 2 + 2?(c_2 ?_1 + c_1 ?_2) / (2(c_1 + c_2))$. $P_w < P_s$ is equivalent to $?_2 - ?_1 < ?(c_2 - c_1)$

p , which holds with the chosen values of the parameters.

Proof of Result 4. Denote by $d_i(\mu_i, \mu_{-i})$ the farmer i 's demand of water when he/she chooses μ_i and the other farmers choose μ_{-i} . Denote by μ^* the q -uple of productivities chosen by farmers at equilibrium. We have the following: $pf_i(d_i(\mu^*_i, \mu^*_{-i})) - C_i(d_i(\mu^*_i, \mu^*_{-i})) - I(\mu^*_i) + p_e(p_e - d_i(\mu^*_i, \mu^*_{-i})) \geq pf_i(d_i$

352 $(\mu^*, \mu^*) - C_i(d_i(\mu^*, \mu^*)) + p e_i(d_i(\mu^*, \mu^*))$ (6) $\mu^* p f_i(d s_i) - C_i(d s_i) + p e_i(d s_i)$
 353 $(7) \mu^* p f_i(d s_i) - C_i(d s_i)$. (8)

354 Inequality 6 holds as μ^* is a best reply to μ^* thus is better than the initial productivity μ^* . Inequality
 355 7 holds as quantity $d_i(\mu^*, \mu^*)$ is chosen to maximise farmer i 's profit within a water market thus is better
 356 than $d s_i$ the farmer's demand in the status quo.

357 This proves that a water market improves each farmer's profit. Now summing the inequalities $p f_i(d_i(\mu^*, \mu^*)) - C_i(d_i(\mu^*, \mu^*)) - I(\mu^*) + p e_i(d_i(\mu^*, \mu^*))$ $\mu^* p f_i(d s_i) - C_i(d s_i)$, we obtain
 358 $\sum_{i=1}^n p f_i(d_i(\mu^*, \mu^*)) - C_i(d_i(\mu^*, \mu^*)) - I(\mu^*) + p e_i(d_i(\mu^*, \mu^*))$ $\mu^* \sum_{i=1}^n p f_i(d s_i) - \sum_{i=1}^n C_i(d s_i)$.

359 Proof of Proposition 2: Denote by μ the productivity chosen by an inefficient farmer. His/her profit when he
 360 allocates quantity x to production, is given by: $\mu x - c x^2 - a(\mu - 1/3)$

361 His profit is maximum at $x = ?$. Indeed, first order condition yields: $x^* = \mu/2c - p/6c$, to be compared to
 362 $?$. But relation (2) equivalent to $? = pm/4c(m + q)$ together with inequation (3), implies $x^* > ?$. $?$ being the
 364 sum of productivities of all the other productive farmers. The productive quantity is given by:

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366 $x = p t / (2(t + 1)c \mu - p / (2(t + 1)c) + ?$

367 The total profit of the considered farmer is given by: $\pi(\mu) = [p e_i(x) + \mu x - c x^2] - a(\mu - 1/3)$

368 The coefficient of μ^2 has the same sign as $1 - t + 2 / (2t + 2)$ which is non negative for all $t > 0$.

369 Hence, the profit of the farmer is a continuous function that is linear decreasing then convex. It reaches its
 370 maximum at $1/3$ or at 1 .

371 Proof of Proposition 3: Consider an inefficient farmer $i \in \{1, \dots, q\}$. Let t be the number of productive farmers
 372 (in the first and the second group other than the considered one). According to Lemma (1), they have necessarily
 373 a productivity equal to 1. Farmer i makes his/her choice between $\mu_i = 1/3$ and $\mu_i = 1$.

374 If $\mu_i = 1/3$, then the equilibrium water price is equal to $p e = p t t - 2c t = p - 2c t$.

375 The corresponding profit is given by: If $\mu_i = 1$, the equilibrium water price is equal to $p(1/3) = (p - 2c) p e =$
 376 $p - 2c t + 1$,

377 and the productive quantity is equal to $x_i = t + 1$.

378 The corresponding profit is equal to After calculations, the profit is given by: Using Equality (2), this profit
 379 is equal to $\pi(1) = p^2(1 - m / (2(t + 1))) + p^2(m / (4(t + 1)^2)) - (2/3)a$.

380 The difference is then given by: $\pi(1) - \pi(1/3) = m p^2 / (2t(t + 1)) + m p (m + q) / (4(t + 1)^2) - (2/3)a$.

381 Farmer i moves to productivity $\mu_i = 1$ if $a < u t$.

382 Note that $(u t) / (m + q - 1)$ is a decreasing sequence. Three cases are then possible:

383 If $u m > a$, then for all t , $u t > a$. This implies that whatever the number of other investing farmers, Farmer i
 384 has no interest to invest.

385 If $a < u m + q - 1$ then for all t , $a < u t$. This implies that whatever the number of other investing farmers,
 386 Farmer i invests.

387 Otherwise, there exists some integer h such that $u h > a < u h - 1$. In this case the best reply of Farmer i is
 388 to move to productivity 1 if the number of other productive farmers is less or equal to $h - 1$, and to keep his/her
 389 productivity if this number is greater or equal to h .

390 Proof of Result 5.

391 1) When $q m < 5 / 3 + 10 / 3 m + 2 / 3 m^2$, we have: $u m + q - 1 < u m < p$.

392 $?$ When $a < p$ all farmers invest in the status quo. However with a water market all of them invest only
 393 when $a < u m + q - 1$. The number of investing farmers with a water market is at most equal to $q - 1$ when $u m + q - 1 < a$.

394 $?$ When $a > p > u m > u m + q - 1$, whether or not a water market is implemented, no farmer invests.

395 2) When $q m > 5 / 3 + 10 / 3 m + 2 / 3 m^2$, we have: $u m + q - 1 < p < u m$.

396 Denote by n_{wm} the number of investing farmers with a water market and by n_s the number of investing
 397 farmers in the status quo. Results are summarized in the table below: a n_{wm} Comparison $n_s < p > ? > q > q$
 398 $p? < a < u m > 0 > 0 a > u m 0 = 0$ ^{1 2 3 4 5 6}

¹ This is a consequence of a result obtained by Lahmandi-Ayed and Matoussi (2003) recalled in Proposition 1 later in this paper.

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Figure 1:



Figure 2: n



Figure 3:



Figure 4:

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Figure 5: ?(1)

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- 401 [Provencher and Burt ()] ‘A Private Property Rights Regime for the Commons: the case for Groundwater’. B
402 Provencher , O Burt . *American Journal of Agricultural Economics* 1994. 76 p. .
- 403 [Provencher ()] ‘A Private Property Rights Regime to replenish a groundwater aquifer’. B Provencher . *Land*
404 *Economics* 1993. 69 p. .
- 405 [Bechtel-Scet Tunisie (ed.) ()] *A water sector study*, Bechtel-Scet Tunisie (ed.) 1998. Ministry of agriculture of
406 Tunisia.
- 407 [Burness and Quirk ()] ‘Appropriative Water Rights and the Efficient Allocation of Resources’. H Burness , J P
408 Quirk . *The American Economic Review* 1979. 69 p. .
- 409 [Bauer ()] ‘Bringing water markets down to earth: the political economy of water rights in Chile, 1976-95’. C
410 Bauer . *World development* 1997. 25 (5) p. .
- 411 [Bohm ()] ‘Comparative analysis of alternative policy instruments’. P Bohm , RusselC . *Handbook of Natural*
412 *Resources and Energy Economics*, Sweeney Kneese (ed.) 1985. Elsevier Science Publishers B. V.
- 413 [Eau 21: Stratégie à long terme du secteur de l’eau en Tunisie ()] *Eau 21: Stratégie à long terme du secteur de*
414 *l’eau en Tunisie*, 2000. 2030. Ministry of agriculture of Tunisia.
- 415 [Burness and Quirk ()] ‘Economic Aspects of Appropriative Water Rights’. H Burness , J P Quirk . *Journal of*
416 *Environmental Economics and Management* 1980. 7 p. .
- 417 [Matoussi (ed.) ()] *Economics of Water Management in Short and Long term Effects of Water Markets Developing*
418 *Countries: Problems, Principles and Policies*, Lahmandi-Ayed R Matoussi , M S . Koundouri P, Pashardes
419 P, Swanson T and Xepapadeas A (ed.) 2003. Edward-Elgar Publishers. (Selection through water markets)
- 420 [Malueg ()] ‘Emission Trading and the Incentive to Adopt New Pollution Abatement Technology’. D Malueg .
421 *Journal of Environmental Economics and Management* 1989. 16 (1) p. .
- 422 [Milliman ()] ‘Firm Incentives to Promote Technological Change in Pollution Control’. S Milliman , PrinceR .
423 *Journal of Environmental Economics and Management* 1989. 17 (3) p. .
- 424 [Gleik ()] P Gleik . *The world’s water: the biennial report on fresh water resources 98/99*, 1998. Island Press. p.
425 17.
- 426 [Jung et al. ()] ‘Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation
427 of Policy Alternatives’. C H Jung , K Krutilla , R Boyd . *Journal of Environmental Economics and*
428 *Management* 1996. 30 (1) p. .
- 429 [Requate ()] ‘Incentives to innovate under emission taxes and tradeable permits’. T Requate . *European Journal*
430 *of Political Economy* 1998. 14 p. .
- 431 [Howe et al. ()] ‘Innovative approaches to water allocation: the potential for water markets’. C W Howe , D
432 Schurmeier , Douglas Shawwjr . *Water resources research* 1986. 22 (4) p. .
- 433 [Issue 10 | Compilation 1.0 © 2023 Great Britain Journal Press Short and Long term Effects of Water Markets]
434 *Issue 10 | Compilation 1.0 © 2023 Great Britain Journal Press Short and Long term Effects of Water*
435 *Markets*, 36.
- 436 [Hearne and Easter ()] *Water allocation and water markets: an analysis of gains from trade in Chile*, R Hearne
437 , K W Easter . 1995. (World Bank technical paper. No 315)