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IRRIGATION PRICING POLICY AIMED AT THE ENHANCEMENT OF WATER SAVING INNOVATION AT FARM LEVEL. A CASE STUDY[§]

G. Gatta *, G. Giannoccaro **, M. Monteleone *, M. Prosperi ** and G. Zanni **
* Department of Agro-Environmental Sciences, Chemistry and Crop Protection (DiSACD),
Via Napoli 25, 71100 Foggia, Italy
** Department of the Science of Production, Engineering, and
Economics for Agricultural Systems (PrIME),
Via Napoli 25, 71100 Foggia, Italy

SUMMARY – In this study we analyze the price inducement effect of a generalized water tariff increase in the adoption of water saving innovation at farm level. We apply a linear programming decision making model to analyze the determinants affecting the adoption of two types of innovation: a process innovation, consisting on a crop mulching practice, and a management innovation, based on a voluntary water seasonal pricing scheme, differentiated according to a peak and off-peak periods. According to our results, the mulching practice is not affected by the tariffs that are still lower than the water marginal productivity, while they exert a negative effect when they become higher. On the contrary, the adoption of the voluntary water seasonal pricing scheme is affected by the tariffs increase only if the latter induce an excessive concentration of water demand during the peak.

Key words: water pricing policy, water saving, adoption of innovation

RESUME *– Dans cette étude nous présentons une recherche relative à la possibilité que l'augmentation de tarif de l'eau est capable d'induire l'agriculteur de adopter une innovation adressée à l' épargne de l'eau. Notre modèle de programmation linéaire nous a permis de analyser le procès de décision de l'agriculteur et d'entendre les causes déterminantes de l'adoption de deux typologies d'innovation: une innovation de procès, relative à une technique de paillis, et une innovation de management, relative à l'introduction d'un plan volontaire, avec des tarifs différentes entre les periodes de intense et de normale utilisation de l'eau. Nos résultats montre que l'augmentation de tarif de l'eau n'est pas une mesure sufficiente pour stimuler les agriculteurs à adopter la technique de paillis, lorsque le tarif de l'eau est inférieur à sa productivité marginale. Ou contraire, quand le tarif est plus grand que la productivité marginale de l'eau, l'augmentation de tarif freine l'adoption de l'innovation. L'introduction des tarifs différentes entre les periodes de intense ed de normale utilisation de l'eau est encouragée par l'augmentation de tarif seulement quand la demande de l'eau est plus concentrée dans la la periode de intense utilisation de l'eau.*

Mots-clés*: politique de prix de l'eau, épargne de l'eau, adoption de l'innovation*

INTRODUCTION

In the last decades, an increasing awareness on water scarcity, occurred either at international organizations and European Union levels. Water is a renewable natural resource available in limited quantities and essential to civil uses, production activities, and environmental needs. According to the economic theory, the optimal allocation of an input is achieved when its market price equals its marginal productivity. However, since under certain conditions, water cannot be substituted by other production factors, other allocation criteria are followed in order to pursue not only the maximum economic efficiency, but the achievement of some basic social objectives, such as equity, justice,

[§] Although the paper is the result of a common effort of the authors, the introduction is edited by G.Zanni, the description of the agronomical aspects related to water saving innovations (first part of the second paragraph) is described by G.Gatta and M.Monteleone, while the economic methodology (second and third parts of the second paragraph) is written by G.Giannoccaro. The empirical analysis, the results discussion (third paragraph), and the mathematical appendix are edited by M.Prosperi. Concluding remarks are the result of common efforts.

income distribution, resource conservation, public consensus (Boland and Whittington, 2000; OECD, 1987).

Therefore, the debate about water allocation strategies is still quite intense, especially with regard to strength and weakness of alternative water pricing schemes and their possible impacts on the economic sector and the social welfare.

Another important issue is represented by the Directive 2000/60/EC, the so-called Water Framework Directive (WFD), enacted by the EU to solicit member countries the pursuing of a ‘good status’ for all water bodies, to be achieved by the year 2015. In order to promote the enhancement of the water quality the E clearly recommends the adoption of the ‘full recovery’ of the costs for water services. Environmental costs should also be considered, consequently to the application of another basic principle, the so-called ‘polluter-pays principle’. In addition, the EU suggests member states to adopt a water pricing policy, as the most preferable measure, suitable for encouraging the conservation and optimizing the allocation of water resources (WATECO, 2003).

This new approach implies a sudden change into the allocation of the water resource, often distributed by public agencies at very low tariffs, and causing relevant impacts especially for the agricultural sector, which is responsible for the consumption of 50-60% of the available water. Farmers and water agencies are concerned about the effects of an eventual water tariffs increase, and foresee difficulties either for the ability of farmers to pay back for the water services, and the ability of the water agencies to supply a sufficient amount of water to offset the distribution costs. The impact of the WFD on European irrigated agriculture might probably be severe especially in the Mediterranean region where irrigated agriculture, while covering only 20-25% of the total cultivated area, accounts for about 50% of total agricultural production and over 60% of the total water demand (Berbel and Gutierrez, 2005).

In this study, we attempt to test if water pricing policy exerts a positive effect on the adoption of water saving innovation, enabling the increase of the water use efficiency and the compensation of eventual negative effects due to water tariffs increase. In particular, we focus on the so-called price-inducement effect, where it is supposed that higher water tariffs may induce farmers to adopt water-saving technologies, similarly to the approach proposed by Caswell and Zilberman (1985; 1990). Furthermore, the analysis aims to test the ability of farmers to adapt their management to water policy changes, and their ability to maintain adequate levels of income and to agricultural added value.

We investigate about the price inducement effect referred to two types of innovation: i) a process innovation, enabling farmers to gain an increase in terms of water use efficiency, and ii) a management innovation, based on a voluntary water seasonal pricing scheme, differentiated according to a peak and off-peak periods.

The farm decision making process was assessed by means of a linear programming model. The role of the water tariffs increase was analyzed on a theoretical basis, and empirically by presenting the results from a case study, referred to the Capitanata area (Apulia region, Italy).

METHODOLOGY

Water saving innovations

In a broad sense, there are two basic, hypothetical approaches to improve irrigation water use:

a) the first strategy is directly meant to consume less water, by improving the irrigation efficiency along the distributive irrigation scheme, from the reservoir to the field, and by implementing all the technical procedures to reduce the irrigation water consumption without affecting the yield;

b) the second strategy is indirectly related to the water consumption but is strictly linked to the water use; it pertains to the effectiveness of irrigation and is intended to gain the higher yield with the minimum amount of irrigation water supplied to the crop, especially in condition of limited water availability.

A very simple equation could be useful to outline the overall productive water performance (or 'water use efficiency', WUE) with respect to these two different, but complementary, approaches:

$$WUE = \frac{Y}{W_{\sup}} = \frac{W_{abs}}{W_{\sup}} * \frac{Y}{W_{abs}} \qquad (1)$$

Mathematically the aforementioned equation is an "identity" and is useful to describe the two terms engaged in the determination of the effect of water on yield (Y/W_{sup}). The first term represents the water irrigation efficiency, that is, the ratio of the amount of water absorbed by the crop (W_{abs}) over the total water supplied (W_{sup}). The second term denotes the water irrigation effectiveness, that is, the ratio of the yield achieved (Y) over the amount of water actually absorbed by the crop (W_{abs}). Both of these different terms are considered in the economic model and they are indicated as ρ and ε, respectively.

A technical innovation could be able to improve only one of the considered terms independently or both at the same time. In the latter case, more emphasis could be given to the first (higher yield, with the same water consumption), or the second term (same yield, but with lower water consumption). Among the most important advancement in the irrigation techniques it's worth to mention the transition from the gravimetric irrigation methods to micro-irrigation, via the sprinkler irrigation method. This is one of the best example of upgrading in the irrigation efficiency. Differently, the improvement in the timing of crop watering, according to several technical procedures in irrigation scheduling, can be considered as the uppermost example to achieve the highest irrigation effectiveness, because avoiding even the smallest crop water stress, while ensuring the maximum crop yield.

In this research, two kinds of water saving innovations are considered and their consequences are directly compared with respect to increasing water pricing scenarios. The first is a process innovation in tomato cropping practice consisting in the use of a bio-plastic soil cover as a mulching system; the second pertains to a management innovation carried out through a "shifting" of the irrigation season, allowing to avoid the period of maximum climatic crop water requirement (full summer) according to an alternative option on the species to crop.

Plastic mulching

Mulching is the partial, more or less extended soil covering, performed in strips along the rows of the plants. It is a largely diffused cropping practice, particularly in horticulture. Plastic films are the more frequently used covering materials today. There are several advantages and positive effects related to mulching, specifically in relation to crop water use and water savings: the reduction of direct soil evaporation; a successful weed control along the plant rows that prevents the use of herbicides and reduces soil water losses from weed evapotranspiration; an improvement in the soil structure, allowing good air and water circulation and preventing soil crusting. Due to a general increase in the soil temperature regime, a most relevant effect of mulching is the shortening of the crop cycle. A further reduction in irrigation water supply is expected as a result of an earlier harvesting time. Another indirect effect of mulching on water use is related to a general increase in yield relatively to the water consumption, and implying an increase of the water productivity.

Several works confirmed these effects and the general suitability of mulching as an innovative cropping practice (Vofsi, 1989, La Mantia, 1990a and 1990b; Candido *et al.*, 2003; Magnani *et al.*, 2005) in conditions that other important improvements were satisfied, such as micro-irrigation systems and, preferentially, fertirrigation.

In regard to tomato cultivation, the mulching practice significantly reduces both seasonal irrigation volumes and irrigation frequencies, thus decreasing the total number of watering. As a broad estimate, a 20-30% of reduction on soil evaporation together with a 20-30% of increase in plant transpiration can be achieved, thus resulting in a overall limited although still significant water savings as well as an important decrease on water consumption per unit of yielded production.

Nevertheless, the use of traditional plastic film exhibits several problems: the mechanical placement of the film on the soil is still a difficult operation (Silvestri *et al.*, 1990); the mulching removal at the end of the crop cycle needs a specific and expensive operations; the mechanization of harvest is hampered; the disposal of the plastic residues creates environmental impact (Picuno and Scarascia Mugnozza, 1994). In this regard, it becomes convenient to use bio-degradable innovative films that goes trough a progressively and complete degradation along the crop cycle thus solving the majority of the problems related to traditional plastic films.

Shifting of the irrigation season

The climatic conditions of the Capitanata plain are signed by an irregular distribution of rains, both during the year and among the years, with frequently marked drought periods. Another characteristic feature is an arid or semi-arid condition in the spring-summer period. For this reasons, irrigation is essential in order to promote agricultural productivity.

Farming systems, notwithstanding a considerable variability from zone to zone, are mainly characterized by autumn-winter crops (such as wheat or sugar beet) in annual or biannual rotation with spring-summer crops. Wheat is usually a rain fed crop while sugar-beet benefits of supplemental irrigations. In areas where irrigation water availability is mostly reliable, tomato is the principal summer crop, widely diffused together with other horticultural crops. Differently, under uncertain water availability conditions, sunflower or other drought tolerant crops prevail.

The period in witch the highest irrigation needs are requested (peak-period) usually starts the last decade of June and ends the first decade of July, accordingly with the prevailing daily climatic condition (high temperature, great radiation load and a few or no rains at all). Any crop that in this period goes trough a fast vegetative growth or a critical reproductive phase (flowering and fruit setting) clearly requires frequent and large irrigation amounts. At the whole district level, this condition produce great management difficulties such as a drop in the hydraulic head and sometimes even a forced stop in water delivery due to a simultaneously massive request. It is not rare the case in which the total water availability is insufficient to respond to the irrigation needs of the farms. A significant reduction in irrigation water requirements could be obtained by narrowing the land totally devoted to summer irrigated horticultural crops and correspondently extending the land dedicated to different horticultural crops, with a shifted crop cycle from the peak to the in an off-peak irrigation period, corresponding to the end of the summer until the late autumn season. A lot of horticultural crops can be considered in this respect, such as broccoli (*Brassica oleracea var. itakica* Plenck), cauliflower (*B. oleracea var. botrytis* L.), cabbage (*B. oleracea var. capitata* L.), broccoli rab (*B. rapa* L.), spinach (*Spinacia oleracea* L.), lettuce (*Lactuca sativa* L.) and many others.

All the aforementioned crops are characterized by lower seasonal irrigation volume with respect to summer crops, for two different reasons: the first is related to the lower evapotranspiration rate due to different climatic conditions (lower temperature and radiation load), while the second is due to the large amount of rain generally recorded in this time of the year, not only contributing to sustain plant transpiration but also allowing soil water recharge.

Economic modelling of the adoption of a process innovation

There is a considerable theoretical and empirical literature about the determinants playing a role on the adoption of a certain innovation at the firm level. Among the several approaches, we focus on the price induced innovation effect (Hicks, 1932; Thirtle and Ruttan, 1987). The basic hypothesis underlying this approach rely on the assumption that the change of the relative factor prices is sufficient to induce a firm operating in a purely competitive environment, to seek for improvements aimed at saving the more expensive factor (Fellner,1967).

As follows we develop a methodology to estimate the effects of exogenous and endogenous aspects that may determine the adoption of a water saving innovation, with emphasis on the role played by an increase of water tariffs. We follow the neoclassical paradigm of the firm behaviour, in order to model the decision making process of a generic irrigation farm, involved in the choice of adopting the innovation or maintaining the current technology. The evaluation of the shadow price of a generic dichotomous variable, expressing the opportunity cost of the adoption of the innovation, is calculated by solving the farmer's profit maximization function. We develop a theoretical analysis referred to the two types of innovation, a process and a management innovation. The first implies a change into the input-input and/or input-output ratio, and refers to the crop mulching practice. The second relies on a departure from the traditional management principles, processes, and practices that significantly alters the way the work of management is performed, and refers to the shifting of the irrigation season.

Economic modelling of the decision to adopt a process innovation

The farmer decision making model is based on the traditional profit function ($\pi = PY - C$), in which the profit is calculated as the difference between the gross return (sells of the output Y multiplied per the corresponding market price P), and the production cost (C). The market price is an exogenous variable, while the output derives from the combination of the inputs, according to a generic Cobb-Douglas production function, that we assume to be concave and twice differentiable ($Y{=}a \cdot T^t \cdot L^l \cdot Z^z \cdot W^{(\varepsilon.\rho)}$). The output is function of a generic coefficient a, and the combination of land (T), labour (L), other variable inputs (Z), and water (W). The productivity of irrigation water is represented by the water use efficiency (*WUE*), that is, the product of the water irrigation effectiveness (ε) and the water irrigation efficiency (ρ). The cost function ($C{=}re \cdot T{+}s \cdot L{+}v \cdot Z\ \tau \cdot v_w \cdot W + I$) is linear and corresponds to the sum of the purchases for all the variable inputs, multiplied by their market price (rent *re*, wage *s*, water tariff v_w, unit cost v for the other variable inputs) and the fixed costs (I), including those related to the irrigation system. The water tariffs surcharge factor (τ, for $0 < \tau < \infty$) represents the exogenous policy variable, enabling the enforcement of full recovery cost principle, and from which we expect a positive effect on the adoption of the innovation.

In the case of the choice between the current technology and the water saving innovation, we consider the combination of both profit functions ($\pi°$ for the current technology, and π' for the innovation), and we introduce a generic dichotomous variable α, such that its value equals to 0 or 1 (with α=0 in case $\pi°$ is more convenient, while α=1 in case π' is more convenient), in order to exclude linear combinations of the two functions. Consequently, the objective function of the farmer is given as follows:

$$MAX\ \pi = (1-\alpha)\ \pi° + \alpha\ \pi'$$

subject to the constraints of resources availability
(the mathematical notations are reported in the appendix of this paper).

For our purposes, we solve the problem of the profit maximization, and we determine the value of the α shadow price (λ_α), that is, the increment of the profitability of the farm, in terms of the objective function, consequent to the adoption of the process innovation. After solving the problem by means of the Lagrange multipliers method (the demonstration is reported in the appendix), we found the following equation:

$$\lambda_\alpha = \tau \cdot v_w [(1+\lambda_k)(\sum_j x_j^\circ w_j^\circ - \sum_j x_j' w_j')] + CONST' \quad , \qquad (2)$$

where:
CONST' is a constant, that is not directly affected by changes of τ.

This equation shows that the innovation adoption is encouraged by the application of water tariffs surcharge τ , only if the new technology allows the reduction of the overall water demand, at a farm level, with respect to the current technology. In addition, we notice that the effect of τ also depends on the opportunity cost for the capital (λ_k) and the current water tariff level (v_w).

Economic modelling of the decision to adopt a management innovation

We adopt a similar framework, based on the maximization of the profit function, in order to evaluate the opportunity of the farmer to adopt a different type of management for the water resource. In particular, we focus on the possibility to disaggregate the overall water availability according to a peak and an off-peak periods, for which different tariffs are applied.

In this case, the Cobb-Douglas production function (changed into: $Y=a \cdot T^{t} \cdot L^{l} \cdot Z^{z} \cdot Ws_1^{(\varepsilon,\rho)} \cdot Ws_2^{(\varepsilon,\rho)}$) takes into account of the water demand during the peak and off-peak periods (Ws_1 and Ws_2, respectively). We assume a surcharge factor (δ, for $0 < \delta < 1$) of the seasonal water tariff related to the peak period results surcharged by a factor δ, while the off-peak tariffs are discounted of the same amount ($1/\delta$).

Therefore, the cost function ($C=re \cdot T+s \cdot L+r \cdot Z+ \tau \cdot \delta \cdot v_w \cdot Ws_1+ \tau \cdot 1/\delta \cdot v_w \cdot Ws_2 + I$) is basically similar to the previous case, but takes into account of the two different tariffs, applied to the water consumed during the two different periods.

We define β as another generic dichotomous variable, such that its value equals to 0 or 1 (with $\beta=0$ in case $\pi°$ is more convenient, while $\beta=1$ in case π'' is more convenient), in order to exclude linear combinations of the two functions. Therefore, we model the farmer's decision problem about applying to the water seasonal management scheme, by means of the following profit maximization function:

$MAX\ \pi = (1- \beta)\ \pi° + \beta\ \pi''$

subject to the constraints of resources availability
(the mathematical notations are reported in the appendix of this paper).

By solving through the Lagrange multipliers method, we determine the value of the β shadow price (λ_β), meaning the profitability of the farm, in terms of the objective function, of adopting the management innovation. We found the following equation:

$$\lambda_\beta = \tau \cdot v_w (1+\lambda_K) \left\{ \sum_j x_j^{''} (1+\delta^2 \frac{w_{s1,j}}{w_{s2,j}}) - \sum_j x_j^{\circ} (w_{s1,j} + w_{s2,j}) \right\} + CONST'' \quad , \qquad (2)$$

where:
CONST'' is a new constant, that does not have a direct relationship with τ.

Farmers will find convenient the water seasonal management scheme, if the technical coefficient of water consumption related to each season, for any crop (the ratio w_{s1}/w_{s2}) increases more than δ^2. This may easily occur in those situations where seasonal tariff discrimination is adopted to correct very unbalanced water uses across seasons, while may not be very effective if the water use is already balanced.

Other technical specifications

The simulation was applied with respect to a representative farm of the South Fortore, in the Capitanata plain (Apulia region, South Italy). It is a relatively homogeneous area in terms of climate, soil quality, water infrastructures, crop yields and farming structure. The area is characterised by a Mediterranean climate, with wet, mild winters and dry, hot summers. Rainfall varies from less than 400 mm/year to more than 700 mm/year, mostly distributed in autumn and winter.

The water district covers 143,000 ha, of which about on third is regularly irrigated. The water totally distributed by the farmers' consortium amounts to about 86 millions m^3, while the overall consumption, including wells and other sources (pounds, recycled waters) is estimated to about 112 millions m^3. Water resource, at present, is provided to single farms with restrictions in volume according to a fixed area base criterion. The water pricing scheme is based on increasing tariff blocks, with three successive levels: 0.09 Euro/m^3 (from 0 to 2,040 m^3/ha), 0.18 Euro/m^3 (2,040-3,000 m^3/ha), and 0.24 Euro/m^3 (over 3,000 m^3/ha). Farmers usually draw groundwater from wells and they are able to cover about one third of the annual crop water needs, either during the peak season (July and August), or during the period in which the consortium is not operating (from November to March).

The district water delivery system is set up with pressure pipes, while irrigation systems at farm level are recently evolved from sprinklers or mobile rain guns, to micro-irrigation systems (like drip irrigation). Cropping patterns are mostly characterized by winter cereals (50%), and highly profitable crops, such as tomato (19%) and other vegetables (21%). Orchards cover about 10% of farmland, while the remaining area is occupied by annual set-aside.

The case study is referred to a farm where the basic production factors are conferred by the farmer (10.21 ha of land, 1.5 labour units, capital for 20,600 Euro, 14,376 m^3 of water from the Consortium and about 4,300 m^3 from other sources). Additional labour is hired only during specific seasons, corresponding to the harvest of the fruits and vegetable crops.

In regard to the plastic mulching innovation, we considered its applications only for the tomato crop, with an increase of its variable costs for 857 Euro/ha, due to the purchase of plastic film, in comparison with the standard cultivation technique. In addition, we also considered an increase of the annual fix cost of 300 Euros, related to the depreciation of the investment in machineries necessary for the plastic film setting and its disposal before the harvest. We assumed an increase of about 10% of yields, due to the higher water use efficiency, and about 10% of the market price, due to a higher quality of the harvest. We also considered some differences in the schedule of the cultural operations and irrigation, in order to consider that the mulching practice may reduce the tomato crop cycle of about 10 days. Finally, we considered 20% lower water consumption than the traditional technique.

In regard to the shifting of the irrigation season, we have defined a first so-called ‘peak season’, corresponding to the period from April to July, and a second ‘off-peak season’, corresponding to the period from August to October. The overall increasing block water tariffs corresponding to the peak season have been increased uniformly (10%, 25%, 50%), while those of the off-peak season have been reduced of the same amount.

The simulations were performed through a linear programming technique, employing the GAMS software (General Algebraic Modelling System, distributed by the GAMS Development Corporation, Washington, D.C.). We assumed that, by following the WFD recommendations, tariffs were raised of 10%, 25%, and 50%.

RESULTS AND DISCUSSION

The first stage of the analysis considers the simulation on the actual technical conditions under the hypothesis of a water tariffs increase (*Table 1*). First of all we obviously notice negative effects on the farm profit. Income and product added value are not notably affected by small tariffs increase (+10% and +25%), but they decrease when the tariffs are increased by 50%.

A slight reduction of the irrigated area is observed as far as water tariffs are getting higher. However, with respect to water volume consumption, reductions appear only with higher tariffs, while with limited increases the situation remains unchanged. It’s quite evident that until water tariffs are below the water marginal productivity, the farmer continues to use all the available water. According to other studies (Nardone *et al.*, 2007a; Nardone *et al.*, 2007b), the marginal productivity in the Capitanata area is estimated between 0.15-0.18 Euro/m^3. Therefore, an increase in the water tariffs above the marginal productivity, induce the farmer to adapt the cropping pattern in order to pursue a higher water marginal productivity. In other words, higher tariffs cause an increase of the water use efficiency. A reduction of the volumes of water used per unit of irrigated area is also observed (from 4,039 to 3,258 m^3/ha).

After a small tariffs increase, the Consortium revenue will increase, although with higher tariffs there are relatively lower increments, due to the reduction in the overall water demand.

Finally, it is worth to mention that the area allocated to the tomato crop is not affected by the tariffs change. In fact, tomato is the most profitable crop, and it represents the most important irrigated crop of this area.

Table 1. Simulations of the water tariffs increase according to the actual technical conditions

	Current	Changes due to water tariff increase		
		+10%	+25%	+50%
Objective Function (Euro/ha)	-117	-128	-145	-168
Income (Euro/ha)	1,721	1,721	1,721	1,464
Added Value (Euro/ha)	1,537	1,537	1,537	1,268
Irrigated area (ha)	0,35	0,33	0,33	0,32
Water use (m^3/ha)	1,408	1,408	1,408	1,056
- peak season	604	604	803	355
- off-peak season	605	605	406	502
Water use, on irrigated area (m^3/ha)	4,039	4,305	4,305	3,258
- peak season	1,731	1,845	2,455	1,095
- off-peak season	1,736	1,850	1,240	1,547
Consortium revenue (Euro/ha)	109	120	136	116
Tomato cropping surface (% of total farmland)	12%	12%	12%	12%

Water saving innovation based on plastic mulching.

The optimal solution of the farmer's decision making problem reveals that the mulching practice is always more convenient than the traditional technology. As shown on *Table 2*, the shadow price (λ_α) of αcorresponding to the current situation is positive and equal to 150 Euro/ha. This value remains constant also when tariffs increase of 10% and 25%, that is, while their values are still below the water marginal productivity. However, in the case of higher tariffs (+50%), the innovation is still profitable but, in relative terms, the value of λ_α tends to be lower.

In order to explain this phenomenon, it is worth to refer to equation (2), that describes the relationship between λ_α, the tariffs increase rate (τ), and the difference on the overall water demand ($\Sigma x^0 w^0$-$\Sigma x'w'$). The results prove that until all the available water is completely consumed, τ does not have any effect on λ_α. However, once τ raises tariffs to a value higher than the current water marginal productivity, the mulching technique increases also the water efficiency, implying an increase of the marginal productivity, that causes an increase of the overall water demand (at farm level). Paradoxically, a more efficient technique allows the water saving referred to one hectare of irrigated land, but at a farm level, we observe an overall increase of water demand. Therefore, in this case, τ exerts a negative effect on λ_α. In particular, we observed that the profitability of the mulching technique starts to decline for τ equal to 50%.These findings seems to be consistent with the theoretical demonstration previously shown in this paper.

If the increase of water tariffs is pursued in order to reduce the water demand, we observe that the introduction of the technical innovation cancels this effect, while the only visible effect is the increase of the consortium revenue.

Finally, the increase of the tomato cropping area is easily explained by considering that the mulching technique, at the present time, is applied to this crop that, in relative terms, becomes more profitable than other crops.

Water saving innovation based on the shifting of the irrigation season.

In general, we found results proving that the adoption of this innovation is positively affected by water tariffs increase (τ) and the profitability of introducing the innovation (λ_β). These findings are consistent with the theoretical representation of equation (3).

The effect of τ also depends on the value of the tariffs differentiation rate (δ), but it varies according to the overall ratio between the water consumption of the peak period, relatively to that of the off-peak period. Therefore, if τ causes a relevant shift on water consumption from the peak to the off-peak season, then the effect of δ becomes lower, and there will be a certain reduction in the profitability adopting the innovation.

Table 2. Effects consequent to the introduction of the bio-plastic mulching innovation (expressed in relative terms with respect to the corresponding actual condition)

	Current	Changes due to water price increase		
		+10%	+25%	+50%
α shadow price (Euro/ha)	150	150	150	144
Income	9%	9%	8%	26%
Added Value	-30%	-30%	-29%	-14%
Irrigated area	-19%	-13%	-11%	-8%
Water use	0%	0%	0%	33%
- peak season	86%	84%	36%	240%
- off-peak season	-86%	-83%	-70%	-100%
Water use, on irrigated area	23%	15%	12%	45%
- peak season	129%	111%	52%	271%
- off-peak season	-82%	-81%	-67%	-100%
Consortium revenue	0%	0%	0%	41%
Tomato cropping surface	106%	104%	102%	96%

In addition, we observe that for low values of τ, a higher water consumption is concentrated during the peak season. Therefore, the introduction of the innovation is suitable to correct this phenomenon. However, for higher values of τ (+50%), we got higher consumption during the off-peak season, therefore the profitability of introducing the innovation becomes relatively lower.

With respect to the economic performances, higher levels of income and product added value are observed consequently to the introduction of the innovation. On the contrary, we observed that the reduction of the overall water demand was possible in only two cases (the combination τ = +25%; δ=+25%, and τ = +25%; δ=+50%). Finally, we conclude that this innovation might be more effective to reduce the total water demand, in respect to the innovation based on the mulching technique.

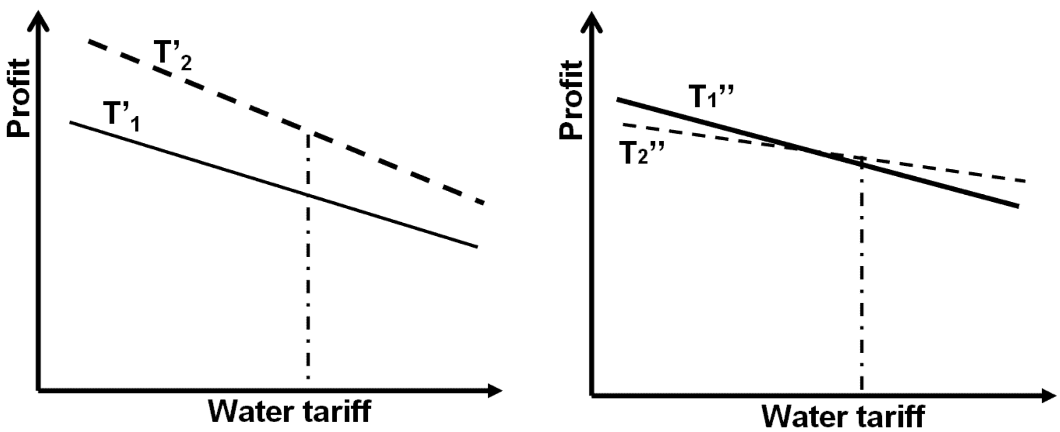

Fig. 1. Simplified scheme of the water pricing policy effects on the profitability of the farm,
Here, two different trends are shown. In the first case the innovation (T'_2) is already profitable, therefore as far as water tariff are raised, the profitability tends to be lower, but will still be more profitable until the irrigation itself will not be dismissed. In the second case, we observe a typical price-induced innovation, although there is only a little difference in the profitability between the two technologies.

In conclusion of our analysis, we attempt to compare the effects of τ on the adoption of the two types of innovation. According to the results of our simulations, we draw Fig. 1, in which we represents the relationship between water tariffs and profit achievement. In the first case (left side), the increase of the water tariffs is not effective to determine the adoption of the innovation, since the point of intersection between the two lines may not occur. In the second case (right side), the increase of the water tariffs may exert a positive role, although the magnitude of this effect might be too small to be perceived by farmers.

Table 3. Effects of the shifting of the irrigation season (expressed in relative terms with respect to the corresponding actual condition)

	Current	Changes due to water price increase		
		+10%	+25%	+50%
10% interseasonal tariff difference				
β shadow price (Euro/ha)	0.29	0.29	0.39	0.78
Income	3%	3%	3%	0%
Added Value	6%	6%	6%	0%
Irrigated area	-7%	0%	0%	0%
Water use	0%	0%	0%	0%
- peak season	-23%	-23%	-42%	0%
- off-peak season (Consortium)	23%	23%	83%	0%
Water use, on irrigated area	8%	0%	0%	0%
- peak season (Consortium)	-17%	-23%	-42%	0%
- off-peak season (Consortium)	33%	23%	83%	0%
Consortium revenue	-1%	-1%	-1%	-1%
Tomato	-17%	-17%	-17%	0%
25% interseasonal tariff difference				
β shadow price (Euro/ha)	2.25	2.15	2.74	2.94
Income	4%	4%	-1%	13%
Added Value	7%	7%	1%	19%
Irrigated area	-9%	-3%	-3%	-2%
Water use	0%	0%	-11%	13%
- peak season (Consortium)	-26%	-26%	-66%	-28%
- off-peak season (Consortium)	26%	26%	93%	48%
Water use, on irrigated area	10%	3%	-8%	15%
- peak season (Consortium)	-19%	-24%	-65%	-27%
- off-peak season (Consortium)	39%	31%	99%	50%
Consortium revenue	-3%	-3%	-17%	12%
Tomato	-25%	-25%	-25%	-33%
50% interseasonal tariff difference				
β shadow price (Euro/ha)	10.87	10.77	11.75	9.21
Income	4%	4%	4%	22%
Added Value	7%	7%	8%	31%
Irrigated area	-18%	-13%	-18%	-15%
Water use	0%	0%	-6%	24%
- peak season (Consortium)	-66%	-66%	-78%	-49%
- off-peak season (Consortium)	66%	66%	132%	86%
Water use, on irrigated area	22%	15%	14%	46%
- peak season (Consortium)	-58%	-61%	-73%	-41%
- off-peak season (Consortium)	102%	90%	182%	118%
Consortium revenue	-17%	-15%	-20%	15%
Tomato	-25%	-25%	-33%	-33%

CONCLUDING REMARKS

This research proves that the introduction of the full recovery cost principle may play a different role in regards to the adoption of water saving innovation, at farm level. Although this effect is obvious and immediate in the case of analysis referred to one unit of irrigated area, unexpected outcomes may occur if we try to assess the effect at a farm or district scale. In the case of a broader analysis, involving the management of a multi input-multi output firm, we recommend a more accurate analytical framework, in order to consider some relevant aspects that may be of interest for problem of the water management (e.g. opportunity cost of the capital; overall water consumption at farm level; ratio between demand in the peak and off-peak period).

In fact, we found that the mulching technical innovation, although has been proved to be economically convenient for every tariff, it is not suitable to save water. On the contrary, the increasing in the tomato cropping surface at the farm level, determines higher water demand per hectare, mostly concentrated in the peak period.

In this regard, we conclude that whatever innovation aimed at improving the water use efficiency, will not be effective to reduce the overall water demand (at farm level), since the amount of water made available consequently to the water efficiency enhancement may be easily devoted to increase other production activities undertaken in the same farm. This may easily occur in arid areas (e.g. Mediterranean region), where water is a very limiting factor of intensive agriculture. The exception is represented by the case in which some other production factors will constraint the expansion of the irrigated crops (e.g. land, labour, capital).

Relatively to the shifting of the irrigation season, we found that consequently to the adoption of the seasonal water pricing scheme, it might be more suitable to save water, in comparison with the mulching practice. The most important advantage of adopting this innovation, not for the single farm but for the agricultural district, would be a remarkable relief in irrigation water requirements during the peak period. This may allow for a more rational and efficient management of the Consortium, with some savings in the water distribution costs, from the water source to the farm. Furthermore, this innovation would allow a more precise water use planning, especially in case of drought, since it would be possible to avoid an excessive cultivation of irrigated crops during the peak season.

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MATHEMATICAL APPENDIX

We consider a general case of a standard Cobb-Douglas production function, concave and twice differentiable:

$$Y = aT^{t}L^{l}Z^{z}W^{(\varepsilon \cdot \rho)}$$

With:

0< ε <1 , the crop specific yield water use efficiency;
0< ρ <1 , the irrigation system water distribution efficiency, and

According to the neoclassical theory, farmer's decision making is modeled on the basis of the profit achievement. The profit is given by the difference between the sells of outputs (*PY*) and the production cost (*C*):

$$\pi = PY - C \quad ,$$

where:

$$C = reT + sL + vZ + v_{w}W + I_{w} + I$$

meaning the sum of rent, wages, acquisition of other variable inputs, water purchase, the specific fixed costs due to the irrigation system, and the remaining fixed costs.

Adoption of the process innovation. In the case of the application of the generic technology *H*, the profit equation is written as:

$\pi^{H} = PY^{H} - C^{H}$, and considering a multi output farm with *j* crops, we obtain:

$$\pi^{H} = \sum_{j} x_{j}[(p_{j}(a_{j}t_{j}^{tH}l_{j}^{lH}z_{j}^{zH}w_{s,j}^{(\varepsilon_{j}\cdot\rho H)}) - (re_{j} + sl_{j}^{H} + vz_{j}^{H} + \tau \cdot v_{w}\sum_{s} w_{s,j}^{H})] - (I_{w}^{H} + I) ,$$

provided that τ is representing the exogenous water policy variable, enforcing the full recovery cost principle and, therefore, inducing an increase of the basic water tariff v_w.

The decision about the choice between maintaining the current irrigation technology or introducing a new technology, may be modeled as follows:

$$MAX \ \pi = (1-\alpha)\,\pi^{\circ} + \alpha\,\pi^{'} \qquad (5)$$

$$\text{s.t.} \ \sum_{j} x_{j}^{\circ} + \sum_{j} x_{j}^{'} \leq T \qquad (6)$$

$$(1-\alpha)(\sum_{j} x_{j}^{'}l_{j}^{\circ}) + \alpha(\sum_{j} x_{j}^{'}l_{j}^{'}) \leq L \qquad (7)$$

$$(1-\alpha)[\sum_{j} x_{j}^{\circ}(re_{j} + sl_{j}^{\circ} + vz_{j}^{\circ} + \tau \cdot v_{w}\sum_{s} w_{s,j}^{\circ}) - I_{w}^{\circ}] +$$

$$+\alpha[\sum_{j} x_{j}^{'}(re_{j} + sl_{j}^{'} + vz_{j}^{'} + \tau \cdot v_{w}\sum_{s} w_{s,j}^{'}) - I_{w}^{'}] + I \leq K \qquad (8)$$

$$(1-\alpha)(\sum_{j}\sum_{s} x_{j}^{\circ}w_{s,j}^{\circ}) + \alpha(\sum_{j}\sum_{s} x_{j}^{'}w_{s,j}^{'}) \leq W \qquad (9)$$

$$\alpha = 0 \ or \ 1 \qquad (10)$$

When the dichotomous variable α equals to 1, it indicates the adoption of the innovation, while whenα equals to 0, it indicates the maintaining of the current technology. By calculating the shadow price (λ_α) of α, we are able to find the profitability of adopting the innovation. This can be easily done by means of the Lagrange multipliers method:

$$L = \pi \; - \lambda_T T(T) - \lambda_L L(L) - \lambda_k K(K) - \lambda_W W(W) - \lambda_\alpha (\alpha - 1)$$

with:

$$\pi \;= (1-\alpha)\left[\sum_j x_j^\circ [(p_j (a_j t_j^{t^\circ} l_j^{l^\circ} z_j^{z^\circ} w_j^{\varepsilon j\cdot\rho^\circ}) - (re_j + sl_j^\circ + vz_j^\circ + \tau \cdot vw_j^\circ)] - (I_w^\circ + I)\right] +$$

$$+ \alpha\left[\sum_j x_j^{'} \; [(p_j \; (a_j t_j^{t'} l_j^{l'} z_j^{z'} w_j^{\varepsilon j\cdot\rho'}) - (re_j + sl_j^{'} + vz_j^{'} + \tau \cdot vw_j^{'})] - (I_w^{'} + I)\right]$$

$$T(T) = (1-\alpha)\sum_j x_j^\circ + \alpha \sum_j x_j^{'} - T$$

$$L(L) = (1-\alpha)\left[(\sum_j x_j^\circ l_j^\circ)\right] + \alpha \left[(\sum_j x_j^{'} l_j^{'})\right] - L$$

$$K(K) = (1-\alpha)\left[\sum_j x_j^\circ (re_j + sl_j^\circ + vz_j^\circ + \tau \cdot v_w w_j^\circ) - (I_w^\circ + I)\right] +$$

$$+ \alpha\left[\sum_j x_{j\,j}^{'} (re_j + sl_j^{'} + vz_j^{'} + \tau \cdot v_w w_j^{'}) - (I_w^{'} + I)\right] - K$$

$$W(W) = (1-\alpha)\sum_j x_j^\circ w_j^\circ + \alpha \sum_j x_j^{'} w_j^{'} - W$$

Therefore, by assuming the first order condition, and by solving the first derivative of the Lagrangean function in respect of α, at the optimum we find its shadow price (λ_α):

$$\lambda_\alpha = \sum_j x_j^{'} [(p_j \; a \, t^{t'} l^{l'} z^{z'} w^{\varepsilon j\cdot\rho'}) - (re_j + sl_j^{'} + vz_j^{'} + \tau \cdot v_w w_j^{'})] - I_w^{'} +$$

$$- \sum_j x_j^\circ [(p_j \; a \, t^{t^\circ} l^{l^\circ} z^{z^\circ} w^{\varepsilon j\cdot\rho^\circ}) - (re_j + sl_j^\circ + vz_j^\circ + \tau \cdot v_w w_j^\circ)] + I_w^\circ +$$

$$- \lambda_T (\sum_j x_j^{'} - \sum_j x_j^\circ) - \lambda_L (\sum_j x_j^{'} l_j^{'} - \sum_j x_j^\circ l_j^\circ) +$$

$$- \lambda_K [\sum_j x_j^{'} (re + sl_j^{'} + vz_j^{'} + \tau \cdot v_w w_j^{'}) - \sum_j x_j^\circ (re + sl_j^\circ + vz_j^\circ + \tau \cdot v_w w_j^\circ)] +$$

$$- \lambda_W (\sum_j x_j^{'} w_j^{'} - \sum_j x_j^\circ w_j^\circ)$$

By rearranging terms in order to evidence τ, we demonstrate its direct relationship with α's shadow price. Put a generic function $CONST'$, such as:

$$CONST' = +\sum_j x_j^{'}[(p_j(a_j t_j^{t'} l_j^{l'} z_j^{z'} w_j^{\varepsilon j \cdot \rho'}) - (re - sl_j^{'} - vz_j^{'})] +$$

$$-\sum_j x_j^{\circ}[(p_j(a_j t_j^{t^\circ} l_j^{l^\circ} z_j^{z^\circ} w_j^{\varepsilon j \cdot \rho^\circ}) - (re - sl_j^{\circ} - vz_j^{\circ})] + I_w^{\circ} - I_w^{'} +$$

$$-\lambda_T(\sum_j x_j^{\circ} - \sum_j x_j^{'}) - \lambda_L(\sum_j x_j^{\circ} l_j^{\circ} - \sum_j x_j^{'} l_j^{'}) +$$

$$+\lambda_K[(\sum_j x_j^{\circ}(re + sl_j^{\circ} vz^{\circ}) - (\sum_j x_j^{'}(re + sl_j^{'} vz^{'}) - I_w^{\circ} + I_w^{'}] +$$

$$-\lambda_W(\sum_j x_j^{\circ} w_j^{\circ} - \sum_j x_j^{'} w_j^{'})$$

we finally find:

$$\lambda_\alpha = \tau[\frac{v}{\delta}\sum_j x_j^{\circ} w_j^{\circ} - \frac{v}{\delta}\sum_j x_j^{'} w_j^{'} - \lambda_k \cdot v_w(\sum_j x_j^{'} w_j^{'} - \sum_j x_j^{\circ} w_j^{\circ})] + CONST' \quad ;$$

$$\lambda_\alpha = \tau[(\sum_j x_j^{\circ} w_j^{\circ} - \sum_j x_j^{'} w_j^{'}) + \lambda_k(\sum_j x_j^{\circ} w_j^{\circ} - \sum_j x_j^{'} w_j^{'})] \cdot v_w + CONST' \quad ;$$

We found that the following relationship between the tariff increasing measure and the adoption of the innovation:

$$\lambda_\alpha = \tau[(1 + \lambda_k)(\sum_j x_j^{\circ} w_j^{\circ} - \sum_j x_j^{'} w_j^{'})] \cdot v_w + CONST' \qquad (12)$$

Adoption of the management innovation. Similarly to the above demonstration, we suppose that the farmer is choosing between two alternative management schemes. He would choose according the profit function:

$\pi^H = PY^H - C^H$, and considering a multi output farm with *j* crops, and the current technology, we obtain:

$$\pi^{\circ} = \sum_j x_j[(p_j(a_j t_j^t l_j^l z_j^z w_{s,j}^{(\varepsilon j \cdot \rho)}) - (re_j + sl_j + vz_j + \tau \cdot v_w \sum_s w_{s,j})] - I \, ,$$

However, in the case of the seasonal irrigation shifting, we define the peak-season water tariff as resulting from the product of the basic water tariff ($\delta\ v_w$) with a seasonal index , while the off-peak tariff is the result of the discounted value of the water tariff ($1/\delta\ v_w$), with $0 < \delta < 1$.

$$\pi^{'} = \sum_j x_j[(p_j(a_j t_j^t l_j^l z_j^z w_{s1,j}^{(\varepsilon j 1 \cdot \rho)} w_{s2,j}^{(\varepsilon j 2 \cdot \rho)}) - (re_j + sl_j + vz_j + \tau\,\delta\, v_w w_{s1,j} + \tau \frac{v_w}{\delta} w_{s2,j})] - I$$

Therefore, the farmer will choose between two different profit equations:

$$MAX\ \pi = (1 - \beta)\,\pi^{\circ} + \beta\,\pi^{"} \qquad (13)$$

$$\text{s.t.}\ (1-\beta)\sum_j x_j^{\circ} + \beta\sum_j x_j^{"} \le T \tag{14}$$

$$(1-\beta)(\sum_j x_j^{\circ} l_j) + \beta(\sum_j x_j^{"} l_j) \le L \tag{15}$$

$$(1-\beta)[\sum_j x_j^{\circ}(re_j + sl_j + vz_j + \tau\, v_w w_{s1,j} + \tau \cdot v_w w_{s2,j})] +$$

$$+\beta[\sum_j x_j^{"}(re_j + sl_j + vz_j + \tau\,\delta\, v_w w_{s1,j} + \tau \cdot \frac{v_w}{\delta} w_{s2,j})] + I \le K \tag{16}$$

$$(1-\beta)[\sum_j x_j^{\circ}(w_{s1,j} + w_{s2,j})] + \beta[\sum_j x_j^{"}(w_{s1,j} + w_{s2,j})] \le W \tag{17}$$

$$\beta = 0\ or\ 1 \tag{18}$$

Also in this case β is a dichotomous variable by which we select the adoption of the innovation or the maintenance of the current technique. By solving with the Lagrange multipliers method we define:

$$L = \pi\ -\lambda_T T(T) - \lambda_L L(L) - \lambda_k K(K) - \lambda_W W(W) - \lambda_\alpha(\alpha - 1)$$

with:

$$\pi = (1-\beta)\sum_j x_j^{\circ}[(p_j(a_j t_j^t l_j^l z_j^z w_{s1,j}^{(\varepsilon j1\cdot\rho)} w_{s2,j}^{(\varepsilon j2\cdot\rho)}) - (re_j + sl_j + vz_j + \tau \cdot v_w(w_{s1,j} + w_{s2,j}))] +$$

$$+\beta\sum_j x_j^{"}[(p_j(a_j t_j^t l_j^l z_j^z w_{s1,j}^{(\varepsilon j1\cdot\rho)} w_{s2,j}^{(\varepsilon j2\cdot\rho)}) - (re_j + sl_j + vz_j + \tau\,\delta\, v_w w_{s1,j} + \tau\frac{v_w}{\delta} w_{s2,j})] - I$$

$$T(T) = \sum_j x_j^{\circ} + \sum_j x_j^{"} - T$$

$$L(L) = (1-\beta)(\sum_j x_j^{\circ} l_j) + \beta(\sum_j x_j^{"} l_j) = L$$

$$K(K) = (1-\beta)\sum_s x_j^{\circ}[(re_j + sl_j + vz_j + \tau \cdot v_w w_{s1,j} + \tau \cdot v_w w_{s2,j})] +$$

$$+\beta\sum_j x_j^{"}[(re_j + sl_j + vz_j + \tau\,\delta\, v_w w_{s1,j} + \tau \cdot \frac{v_w}{\delta} w_{s2,j})] + I - K$$

$$W(W) = (1-\beta)[\sum_j x_j^{\circ}(w_{s1,j} + w_{s2,j})] + \beta)[\sum_j x_j^{"}(w_{s1,j} + w_{s2,j})] - W$$

Assuming the first order condition, and by solving the first derivative of the Lagrange function in respect of β, we find that at the optimum, its shadow price (λ_β) is equal to:

$$\lambda_\beta = \sum_j x_j^{"}[p_j(a_j t_j^t l_j^l z_j^z w_{s1,j}^{(\varepsilon j1\cdot\rho)} w_{s2,j}^{(\varepsilon j2\cdot\rho)}) - (re_j + sl_j + vz_j + \tau\,\delta\, v_w w_{s1,j} + \tau \cdot \frac{v_w}{\delta} w_{s2,j})] +$$

$$-\sum_j x_j^{\circ}[p_j(a_j t_j^t l_j^l z_j^z w_{s1,j}^{(\varepsilon j1\cdot\rho)} w_{s2,j}^{(\varepsilon j2\cdot\rho)}) - (re_j + sl_j + vz_j + \tau \cdot v_w(w_{s1,j} + w_{s2,j}))] +$$

$$-\lambda_T(\sum_j x_j^{"} - \sum_j x_j^{\circ}) - \lambda_L(\sum_j x_j^{"} - \sum_j x_j^{\circ} l) +$$

$$- \lambda_K [\sum_s x_j^{\circ}(re_j + sl_j + vz_j + \tau \cdot v_w w_{s1,j} + \tau \cdot v_w w_{s2,j}) +$$

$$+ \sum_j x_j^{''}(re_j + sl_j + vz_j + \tau\, \delta\, v_w w_{s1,j} + \tau \cdot \frac{v_w}{\delta} w_{s2,j})] +$$

$$- \lambda_W [\sum_j x_j^{''}(w_{s1,j} + w_{s2,j}) - \sum_j x_j^{\circ}(w_{s1,j} + w_{s2,j})]$$

If we define a new constant $CONST''$, such that:

$$CONST'' = -\sum_j x_j^{''}[p_j(a_j t_j^t l_j^l z_j^z w_{s1,j}^{(\varepsilon j1 \cdot \rho)} w_{s2,j}^{(\varepsilon j2 \cdot \rho)}) - (re_j + sl_j + vz_j)] +$$

$$- \sum_j x_j^{\circ}[p_j(a_j t_j^t l_j^l z_j^z w_{s1,j}^{(\varepsilon j1 \cdot \rho)} w_{s2,j}^{(\varepsilon j2 \cdot \rho)}) - (re_j + sl_j + vz_j)] +$$

$$- \lambda_T (\sum_j x_j^{''} - \sum_j x_j^{\circ}) + \lambda_L (\sum_j x_j^{''} - \sum_j x_j^{\circ} l) +$$

$$+ \lambda_K [\sum_j x_j^{''}(re_j + sl_j + vz_j) - \sum_s x_j^{\circ}(re_j + sl_j + vz_j)] +$$

$$- \lambda_W [\sum_j x_j^{''}(w_{s1,j} + w_{s2,j}) - \sum_j x_j^{\circ}(w_{s1,j} + w_{s2,j})]$$

and, rearranging in order to evidence τ, we obtain:

$$\lambda_\beta = \tau \{ \sum_j x_j^{''}(\delta\, v_w w_{s1,j} + \frac{v_w}{\delta} w_{s2,j}) - \sum_j x_j^{\circ}(v_w w_{s1,j} + v_w w_{s2,j}) +$$

$$+ \lambda_K [\sum_j x_j^{''}(\delta\, v_w w_{s1,j} + \frac{v_w}{\delta} w_{s2,j}) - \sum_j x_j^{\circ}(v_w w_{s1,j} + v_w w_{s2,j})] \} + CONST'';$$

$$\lambda_\beta = \tau \{ \delta(\sum_j x_j^{''} v_w w_{s1,j} + \lambda_K \sum_j x_j^{''} v_w w_{s1,j}) + \frac{1}{\delta}(\sum_j x_j^{''} v_w w_{s1,j} + \lambda_K \sum_j x_j^{''} v_w w_{s1,j}) +$$

$$- (1 + \lambda_K) \sum_j x_j^{\circ}(v_w w_{s1,j} + v_w w_{s2,j}) \} + CONST'' \quad ;$$

$$\lambda_\beta = \tau \{ v_w (1 + \lambda_K) \sum_j x_j^{''}(1 + \delta^2 \frac{w_{s1,j}}{w_{s2,j}}) - (1 + \lambda_K) \sum_j x_j^{\circ}(v_w w_{s1,j} + v_w w_{s2,j}) \} + CONST''$$

We obtain the final equation, where we specify the role of tariff increase for the adoption of the innovation:

$$\lambda_\beta = \tau\, v_w (1 + \lambda_K) \{ \sum_j x_j^{''}(1 + \delta^2 \frac{w_{s1,j}}{w_{s2,j}}) - \sum_j x_j^{\circ}(w_{s1,j} + w_{s2,j}) \} + CONST''$$