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# On the Implementation and Performance of Water Rights Buyback Schemes

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## Abstract

Governments are increasingly reliant on the reacquisition of water rights as a mechanism for recovering overexploited basins. Yet, serious concerns have recently been raised about the efficacy and operational dimensions of existing programs. Water buyback is typically implemented as the purchase of a *fixed* quantity of water rights from the agricultural sector at the price set by the Water Authority. This paper seeks to analyze whether the use of water buyback in its *current form* represents a sensible means of recovering overexploited basins. The results – which are particularly relevant to contexts characterised by poor enforcement regimes and widespread illegal water use – highlight the need for greater scrutiny of current programs and call for additional work to improve the *design* of reacquisition policies in the context of water resource management.

**Key words:** Water buy-back; Water rights; Illegal water use; Enforcement.

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# 1 Introduction

Over the last few decades, groundwater resources have become increasingly important for agricultural development especially in countries characterized by arid and semi-arid climates. According to United Nations (2003), agriculture accounts for approximately 70% of groundwater use worldwide and groundwater irrigation is responsible for over 90% of total water use in many arid and semi-arid regions.

The effect of the large-scale expansion of groundwater irrigation has been twofold. On the one hand, it has triggered significant social and economic benefits to many rural areas (Moench 2003; World Bank 2005). On the other hand, an increasing number of aquifers worldwide is now overexploited or under severe stress with adverse consequences for both the environment and the long-run economic development of regions. At the root of the problem in many countries lies the fact that groundwater development has been carried out by individual farmers with little management and planning on the part of governmental authorities (Llamas and Martinez-Santos 2005). In particular, the expansion of groundwater-based agriculture has not been accompanied by a simultaneous evolution of the property rights regime. This has, in turn, resulted in uncontrolled water abstractions and inequitable distribution of the resource (Meritxell et al. 2004; Kemper 2007).

The case of the Upper Guadiana Basin, in the La Mancha region of central Spain, is emblematic and will be used throughout this paper as an illustrative example. The process of allocation of water rights started in the Guadiana at the end of the 1980s

when groundwater use for agriculture was already widespread. In the initial phase of this process, water rights were allocated on the basis of historical uses, with little regard to the availability of groundwater resources and the long-run recharge capacity of the aquifer. As a result, the Guadiana system is now largely overallocated, in that the total volume of water that can be abstracted by entitlement holders exceeds the sustainable level of abstraction for the system (Bromley et al. 2001; Llamas 2005).<sup>1</sup> These problems are common to many other basins worldwide, from Mexico to Australia, China, North Africa and the Arabian Peninsula (Melville and Broughton 2004; Kemper 2007; Nevill 2009).

Against this backdrop, policy-makers and researchers have come to acknowledge that a revision of water rights regimes is an essential step for achieving the sustainable management of water resources. Within this context, water buy-back schemes - i.e., the direct purchase of water rights by governmental authorities - have become an increasingly popular approach. Yet serious concerns have recently been raised about the efficacy and operational dimensions of such schemes. According to recent studies, for example, only a third of the water purchased under the Living Murray buy-back program has actually made its way into the rivers as "real" water (Breckwoldt 2008; Crase et al. 2009; Foerster 2011). Predictions of similar outcomes have been made in the case of recently approved buy-back initiatives in other settings, including the Upper Guadiana basin (Blanco et al., 2007).

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<sup>1</sup>According to recent estimates (CHG 2005), total legal rights over groundwater amount to about 600Mm<sup>3</sup>/yr. This contrasts with the aquifer's estimated 300Mm<sup>3</sup>/yr renewable resources.

This paper offers a theoretical framework to analyze whether the use of water buy-back in its current form represents a sensible means of achieving structural adjustments in the water sector. The results provide theoretical support for some of the concerns voiced about existing programs, and shed light on the incentive mechanisms through which these programs operate. In particular, the analysis suggests that the design and implementation features of current programs may disregard the complexities of many real-world situations, and the interaction with other water policy initiatives, thus potentially leading to perverse effects.

The predictions of the model should not be taken to imply that water buy-back has no role as a means of recovering overexploited basins. Rather, the paper highlights the need for greater scrutiny of current programs and urgently calls for additional work to improve the design of water buy-back.

The paper is organized as follows: Section 2.1 provides a brief overview of the nature and workings of water buy-back schemes, while 2.2 discusses the associated challenges of illegal water use. Section 3 introduces the theoretical framework for analysing water buy-back schemes. The effectiveness of such schemes and key issues associated with their implementation and interaction with enforcement policies are considered in sections 4 and 5, respectively. The paper concludes in section 6 with a discussion of the key findings and the wider implications of the model.

## 2 Water buy-back schemes in context

### 2.1 Applications and rationale

Initially demonized as the ‘policy of last resort’, the direct purchase of water rights by governments is now being proposed in numerous basins as a means of "putting water back into rivers" (Thoyer 2006; Wong 2008). The Special Plan for the Upper Guadiana basin - approved in January 2008 - allocates more than 800 Million Euros to the implementation of a buy-back program within the basin (CHG 2008). In Idaho, USA, the National Water Resources Board has recently decided to engage in an important operation of re-acquisition of water entitlements from the Eastern Snake River Plain Aquifer. The re-purchase of water access rights has also been a central feature of the National Plan for Water Security of the Murray-Darling Basin, released in January 2007 (Freeman 2005; Crase et al. 2009). Similar policies have been considered in Cyprus, Morocco, and various regions of Mexico (Kemper 2000; Ansink and Marchiori 2009).

The idea behind the buy-back approach, as it has been proposed in real-world contexts, is to induce a certain reduction in water consumption by purchasing an equivalent amount of water rights from water-intensive sectors - in particular agriculture - and re-allocating this to the ‘environment’. Re-acquisition is typically defined on the basis of a *fixed-quantum* of water rights. For example, in the Upper Guadiana basin, the Water Authority has agreed to buy-back a total of 144 Mm<sup>3</sup> of water rights (GHC 2008). Following current empirical examples, in this paper we model water buy-back

as the acquisition of a fixed quantity of water entitlements from irrigators at a price set by the Water Authority.

As previously mentioned, notwithstanding the increasing enthusiasm for water buy-back, there are many reservations about the efficacy and operational dimensions of current programs. In the Guadiana context, motivated by the observed inefficacies of the enforcement regime, serious concerns have been raised by local environmental groups about the environmental outcomes that the proposed operation of reacquisition of water rights might deliver. These concerns are supported by recent simulation studies, predicting that a buy-back approach would induce only marginal reductions in water consumption in farms where legal and illegal wells coexist (Blanco et al., 2007; Martinez-Santos et al., 2008; Varela-Ortega, 2007).

This, in turn, suggests that any meaningful analysis of the efficacy of water buy-back needs to explicitly take into account the interaction between buy-back programs and enforcement policies. Indeed, as the economics and policy literature indicates, enforcement plays an important role in defining the success of any rights-based approach (Baldwin and Cave, 1999). Within the context of the present analysis, enforcement becomes even more crucial given the coexistence of overallocation and intensive illegal water use observed in many river basins worldwide.

## **2.2 Illegal water use**

‘Illegal water use’ refers to uses of water that fall outside the limits established by the law. These include wells and surface water intakes that are exploited without previously

applying for authorization from the River Basin Authority, as well as situations in which licenced holders abstract greater volumes of water than they are entitled to. The data available on illegal water use are generally fragmented and incomplete, and they are normally based on estimates. This is a first indication of how difficult it is for water authorities to tackle such problems.

Yet, recent studies indicate that illegal water use is common to many basins around the world and has intensified in recent years (UN 2003; Kemper 2000). The widespread use of illegal water is certainly a key feature of the Upper Guadiana basin. Official sources estimate that nearly 50% of existing wells in the region are unlicensed. In addition to that, most of the water withdrawn from authorized wells is not metered. Inadequate monitoring and enforcement have been recognised as an important factor underlying illegal water use in the basin (Garrido et al., 2006). In response to this situation, the Guadiana Water Authority has proposed a series of policy measures aimed at enhancing the stringency and effectiveness of the enforcement regime. Particular emphasis has been given to increasing the fine rates for illegal water usage, and improving monitoring through the expansion of remote sensing and the installation and control of water meters (Llamas 2005; CHG 2008; Carmona et al. 2011).

The current status of the enforcement regime, as well as policy measures to address its shortcomings, have potentially important implications for the effectiveness of buy-back schemes and the costs associated with their implementation. Yet these aspects are often neglected in practice by designing such policies in isolation (Blanco et al., 2007).



In this paper, we seek to analyse the suitability and performance of reacquisition programs 'in context' - that is, by taking explicitly into account the effectiveness of the enforcement regime under which such programs operate; the relationship between legal and illegal water use; and the impact that policies aiming at improving the efficacy of the enforcement regime may have on the price of water rights.

The analysis shows that although the purchase of a fixed amount of water rights induces a reduction in water consumption, such reduction is always *smaller* than the amount of water rights purchased back at a given price. This is due to the fact that farmers tend to respond to the policy by increasing their use of illegal water.<sup>2</sup> From a policy perspective, this result suggests that there is a tendency to publicly overstate the magnitude of water buy-back and that governments need to guard against the risk of paying a premium for 'solutions' to over-allocation that later require additional interventions. These conclusions seem in line with what Crase et al (2009) observe in the context of the Murray-Darling Basin and offer theoretical support for some of the concerns raised about the buy-back operation proposed in the Upper Guadiana.

The model also predicts that while investments in monitoring and enforcement might enhance the effectiveness of buy-back programs, they may also have perverse effects on the price of water rights, thus increasing the costs of implementing water

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<sup>2</sup>This tendency has been observed in some instances within the context of the Murray-Darling basin where irrigators have been encouraged to construct 'winter fill' storage which can then be accessed in summer to offset the limitations on extraction resulting from the sell of water rights (Cruse et al. 2009)

buy-back.

### 3 Definitions and assumptions

Consider a generic farmer with an initial endowment of water rights  $\bar{w} > 0$ , and assume the very simple production function:  $q = w^F$ , where  $q$  is crop output and  $w^F$  is the amount of water used for farming. Crop output is sold at the market price  $p$ . Production costs are denoted by  $C(w^F)$  and satisfy the following conditions:

$$(A.I) \quad C'(w^F) > 0, C''(w^F) > 0, \lim_{w^F \rightarrow 0} C'(w^F) = 0, \lim_{w^F \rightarrow \infty} C'(w^F) = \infty$$

Assumption (AI) guarantees that the function  $[pw^F - C(w^F)]$  always admits an interior optimum.

If the amount of water used for farming is higher than the initial endowment of water rights, then a farmer is using some water illegally. Let  $w^{IL} \equiv w^F - \bar{w}$  denote illegal water consumption. If caught using water illegally, a farmer has to pay a fine  $\mathcal{F}$ , which is defined as follows:

$$\mathcal{F} \equiv \varphi \times G, \text{ with } G = \begin{cases} 0 & , \text{if } w^{IL} \leq 0 \\ g(w^{IL}) & , \text{if } w^{IL} > 0 \end{cases}$$

In the above definition,  $\varphi$  represents the fine rate, while the function  $g(w^{IL})$  governs how quickly the per unit fine increases with total violation. It is assumed that  $g(w^{IL})$  satisfies the following properties:

$$(AII) \quad g'(w^{IL}) > 0, g''(w^{IL}) > 0, \lim_{w^{IL} \rightarrow 0} g'(w^{IL}) = 0$$

(*AI*) implies that the punishment increases more than proportionally with respect to illegal water use. Moreover, if a farmer uses a very small amount of illegal water, the punishment will be insignificant.<sup>3</sup>

Finally, let  $\sigma$  be the probability of being caught. Then, a farmer's expected cost of using water illegally is:  $\sigma \times \varphi \times G$ . To ease notation, let  $\rho \equiv \sigma \times \varphi$ , so that the expected cost of using illegal water can be written as:  $\rho G$ . The coefficient  $\rho$  can be interpreted as a measure of the enforcement severity.<sup>4</sup>

## 4 Optimal water consumption in the *status quo*

Let  $\widehat{\Pi}$  denote farmer's payoff in the *status quo*; that is, before the introduction of any buy-back scheme. Then, the following optimization problem can be defined:

$$(1) \quad \max_{w^F} \widehat{\Pi} = pw^F - C(w^F) - \rho G(w^{IL})$$

To derive the first order conditions for problem (1), the following two cases must be considered: (*I*)  $\bar{w} \geq w^*$ , and (*II*)  $\bar{w} < w^*$ , where  $w^* \equiv \arg \max_{w^F} [pw^F - C(w^F)]$ . The quantity  $w^*$  can be interpreted as the solution to problem (1) when the cost of using illegal water is zero. Note that, under (*AI*),  $w^*$  is always strictly positive.

If the farmer's initial endowment of water rights is large enough so that her payoff is maximized without using any illegal water - case (*I*) - then she will set her water

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<sup>3</sup>This assumption seems to reflect fairly well the structure of the fine system in the Guadiana region, as well as in many other basins worldwide (see, for example, Stratton et al. 2008).

<sup>4</sup>In the remainder of the paper, we will talk about increasing (decreasing) the enforcement severity without specifying whether we are increasing (decreasing)  $\sigma$  or  $\varphi$ .

consumption equal to  $w^*$ . Consider now the second case; that is:  $\bar{w} < w^*$ . Due to  $\lim_{w^{IL} \rightarrow 0} g'(w^{IL}) = 0$  in (AII), there always exists an incentive to use some illegal water. Therefore, farmer's optimal water consumption will be given by the following first order condition:

$$(2) \quad p - C'(w^F) = \rho g'_{w^F}(w^{IL}) \Rightarrow \hat{w}^F$$

Equation (2) simply states that, at the optimum, the net marginal return  $[p - C'(w^F)]$  must equate the expected marginal cost of farming with illegal water  $\rho g'_{w^F}(w^{IL})$ .

As an example, let us assume that:  $C(w^F) = c \times (w^F)^2$  with  $c > 0$ , and  $g(w^{IL}) = [w^F - \bar{w}]^2$ . Under this specification,  $w^* = \arg \max_{w^F} [pw^F - c \times (w^F)^2] = p/2c$  and farmer's optimal water consumption in the status quo is given by:

$$(3) \quad \hat{w}^F = \begin{cases} \frac{p+2\rho\bar{w}}{2(c+\rho)} & , \text{if } \bar{w} < \frac{p}{2c} \\ \frac{p}{2c} & , \text{if } \bar{w} \geq \frac{p}{2c} \end{cases}$$

For  $\bar{w} < p/2c$ , the optimal water consumption exceeds the initial endowment of water rights; that is, a farmer optimally chooses to use some water illegally. This case is highly representative of the current situation in many overexploited basins, which are often affected by serious problems of illegal water use (UN 2003; Kemper 2000). In the Guadiana, for example, despite the fact that a large amount of rights has been allocated, the vast majority of authorized properties are characterized by the coexistence of legal and illegal wells (CHG 2007; Garrido et al. 2006). The widespread use of illegal water can be explained by the high rates of return of groundwater-based agriculture, the intrinsic difficulties of monitoring groundwater resources, and poor

enforcement regimes. In the remainder of the paper, we will thus focus on the case in which the status quo water consumption exceeds the initial endowment of water rights; that is, some water is used illegally.<sup>5</sup>

## 5 Introduction of a water rights buy-back scheme

In this section, we analyze how the introduction of a buy-back scheme affects farmer's optimal decisions. In the new set-up, the representative farmer is given the opportunity to sell some of her rights to the Water Authority at a price  $p^w$  set by the Authority.

Farmer's payoff is given by:

$$\Pi = pw^F - C(w^F) + p^w w^S - \rho G(w^{IL})$$

where  $w^S$  is the amount of water rights sold at the given price  $p^w$ , and  $w^{IL} = w^F - \bar{w} + w^S$ .

Farmer's optimization problem can be written as:

$$(4) \quad \max_{w^F, w^S} \Pi = pw^F - C(w^F) + p^w w^S - \rho G(w^{IL}), \text{ s.t. } 0 \leq w^S \leq \bar{w}$$

The inequality constraint in (4) simply states that a farmer cannot sell an amount of water rights higher than her legal endowment.

Appendix A.1 shows that  $G(w^{IL})$  can be simplified as  $g(w^{IL})$ . The Lagrangian for

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<sup>5</sup>It can be easily shown that the main results of the paper do not crucially depend on this particular assumption and that the incentive-mechanism created by the introduction of a buy-back policy is still in place when  $\bar{w} \geq w^*$ .

problem (4) can therefore be defined as:

$$L = pw^F - C(w^F) + p^w w^S - \rho g(w^{IL}) - \lambda_1 \times (w^S - \bar{w}) + \lambda_2 w^S$$

The Kuhn-Tucker conditions are:

$$(a1) \quad L'_{w^F} = 0 \Rightarrow p - C'(w^F) - \rho g'_{w^F}(w^{IL}) = 0$$

$$(a2) \quad L'_{w^S} = 0 \Rightarrow p^w - \rho g'_{w^S}(w^{IL}) - \lambda_1 + \lambda_2 = 0$$

$$(b1) \quad \lambda_1 \geq 0, \quad w^S - \bar{w} \leq 0, \quad \text{with complementary slackness}$$

$$(b2) \quad \lambda_2 \geq 0, \quad w^S \geq 0, \quad \text{with complementary slackness}$$

We refer to appendix A.2 for a formal description of the procedure used to solve the above system of first-order conditions. The solutions to (4) are summarized below:

$$(5) \quad \left\{ \begin{array}{l} \text{for } p^w \leq \underline{k} \Rightarrow \left\{ \begin{array}{ll} p - C'(w^F) = \rho g'_{w^F}(w^{IL}) & 5(a) \\ w^S = 0 & 5(b) \end{array} \right. \\ \\ \text{for } p^w \in (\underline{k}, \bar{k}) \Rightarrow \left\{ \begin{array}{ll} p - C'(w^F) = \rho g'_{w^F}(w^{IL}) & 5(c) \\ p^w = \rho g'_{w^S}(w^{IL}) & 5(d) \end{array} \right. \\ \\ \text{for } p^w \geq \bar{k} \Rightarrow \left\{ \begin{array}{ll} p - C'(w^F) = \rho g'_{w^F}(w^{IL}) & 5(e) \\ w^S = \bar{w} & 5(f) \end{array} \right. \end{array} \right.$$

where,  $\underline{k} = \rho g'_{w^S}(w^{IL})|_{w^S=0}$  and  $\bar{k} = \rho g'_{w^S}(w^{IL})|_{w^S=\bar{w}}$ .

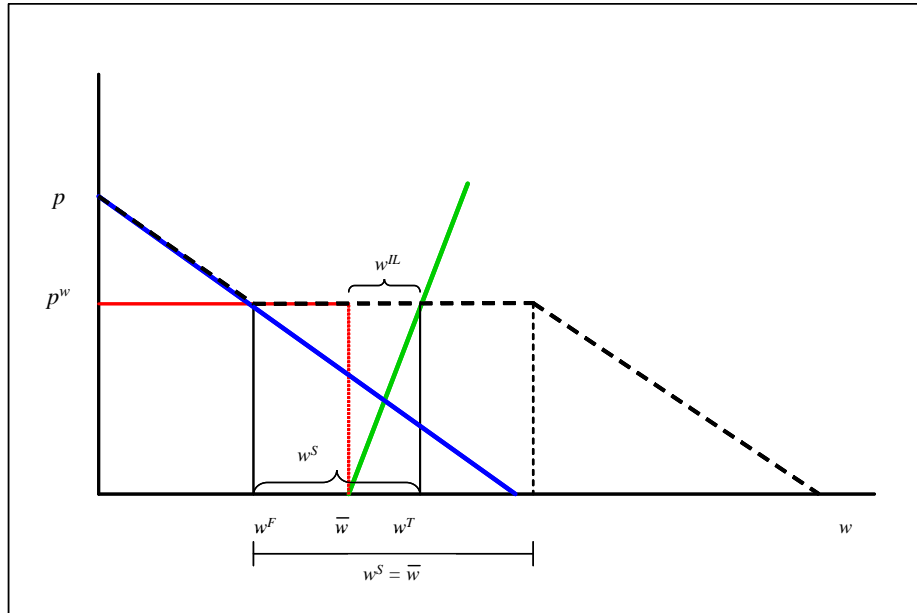
If the Authority sets  $p^w \leq \underline{k}$ , the farmer will not find profitable to sell any positive amount of water rights. Therefore,  $\underline{k}$  is the minimum value for  $p^w$  above which a

buy-back scheme can effectively take place. Notice that,  $\underline{k}$  can be interpreted as the expected marginal cost of using illegal water at  $w^S = 0$ , for a given  $w^F$ . To clarify the intuition behind threshold  $\underline{k}$ , let us consider the trade-off that a farmer faces when deciding whether or not to sell some of her water rights. For simplicity, let us imagine that the farmer wishes to sell one unit of legal water. By doing so, she will have to increase her illegal water consumption by one in order to keep the amount of water used for farming constant. Increasing illegal water use, in turn, implies that she will incur in a higher expected punishment. Therefore, the farmer will sell some of her water rights only if the price  $p^w$  offered by the Authority is sufficiently high so as to compensate the increase in the expected cost of using illegal water (threshold  $\underline{k}$ ). If  $p^w = \bar{k}$ , a farmer's optimal response will be to sell all her rights. For  $p^w > \bar{k}$ , the farmer would like to sell even more water but she hits the constraint in (4). Notice that, for  $p^w \geq \bar{k}$ , the optimal conditions in (5) do not depend on  $p^w$ . Consequently, the optimal amount of water used for farming is independent of  $p^w$ . The reason is simple: if at  $p^w = \bar{k}$  a farmer is already selling all her water rights, then any further increase in the price will simply increase farmer's payoff, but will not affect her water consumption.

Figure 1 provides a graphical representation of the farmer's optimal water use for intermediate values of  $p^w$ .<sup>6</sup>

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<sup>6</sup>In order to keep the picture simple, we have assumed that both the net benefits from farming  $[pw^F - C(w^F)]$ , and the expected fine  $\rho g(w^{IL})$  are quadratic, so that their slopes are linear. This is the case, for example, when  $C(w^F) = c(w^F)^2$  and  $g(w^{IL}) = (w^{IL})^2$ , as in the example previously introduced.



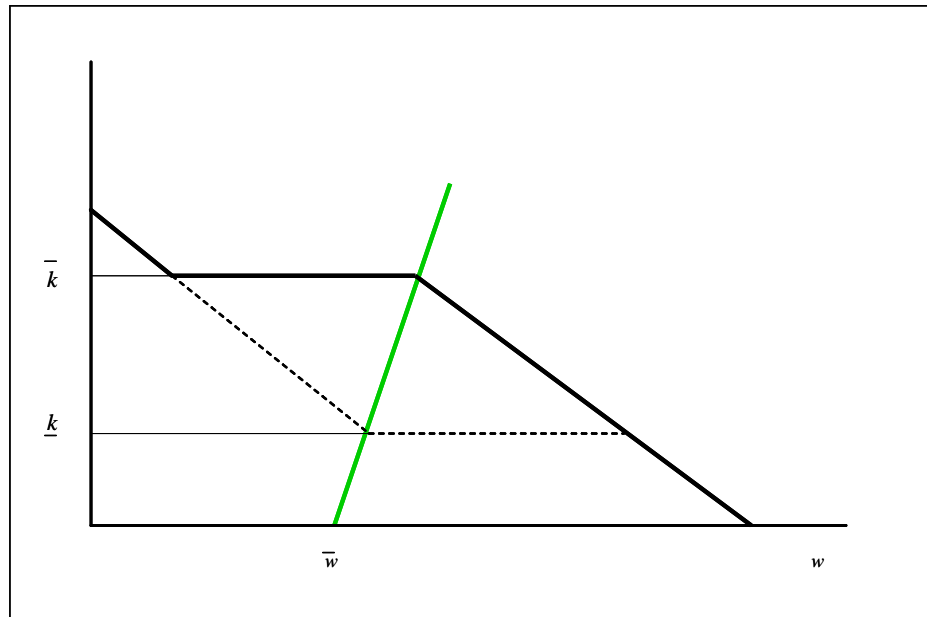
**Figure 1: Farmer's optimal conditions for intermediate values of  $p^w$**

The blue line in figure 1 represents the net marginal benefit of water used in farming (i.e. the left hand side of Eq. 5(c)). The green line represents the expected marginal fine. Since the marginal fine is the same whether additional water is used for farming or sold, this line represents the right hand side of both 5(c) and 5(d). The slope of this curve depends on the coefficient  $\rho$ , which is a measure of the enforcement severity. The red line identifies the price  $p^w$  set by the Water Authority (i.e., the left hand side of 5(d)). The point  $w^T$  represents the sum of water consumed for farming ( $w^F$ ) and water sold ( $w^S$ ). We refer to this point as the total amount 'used'. The aggregate marginal benefit of water 'used' is thus given by the kinked, dashed black line, which incorporates both constraints. When the water price is below the net marginal benefit of farming at the extreme left of the figure, water is used for farming and not sold. When the water price exceeds the net marginal benefit of farming, water is sold until the water



right constraint is hit. Once the farmer has sold the maximum amount of water she is legally entitled to sell, her aggregate net benefit is parallel to the net benefit from farming, but shifted to the right by an amount equal to the water sales. The point  $w^T$  (and consequently the quantities  $w^F$  and  $w^S$ ) is determined by the intersection of this aggregate marginal benefit curve with the expected marginal fine. In Figure 1, this intersection occurs at a point where the farmer sells some water, but not all that she is legally entitled to sell. In other words, it illustrates an equilibrium of the type embodied in Eqs. 5(c) and 5(d).

Figure 2 provides a graphical representation of thresholds  $\underline{k}$  and  $\bar{k}$ . The lower bound ( $\underline{k}$ ) occurs at the intersection of the net marginal benefit of farming and the expected marginal fine. A price below this threshold is not sufficient to induce the farmer to sell any water because the return from farming is higher. The upper bound ( $\bar{k}$ ) occurs at the point where the water price is just high enough to induce the farmer to sell all her water. This figure implies the existence of three types of equilibria, as in equation (5).



**Figure 2:** A graphic representation of thresholds  $\underline{k}$  and  $\bar{k}$

The results derived in this section will be used below to analyze the environmental effectiveness of water buy-back.

## 6 Environmental effectiveness of water buy-back

As previously mentioned, water buy-back is typically designed as the purchase of a fixed quantity of water rights from the Agricultural sector at the price set by the Water Authority. For any given price, the 'environmental effectiveness' of current programs is measured in terms of the amount of water rights acquired at that price. This is clearly stated, for example, in the latest version of the Special Plan for the Upper Guadiana (CHG 2008, Part V, page 4).

This section shows that, for any initial degree of severity of the enforcement regime,

the purchase of an amount  $x$  of water rights always induces a reduction in water consumption *smaller* than  $x$ . This, in turn, suggests that the 'declared' effectiveness of water buy-back in its current form tends to overestimate its actual effectiveness.

To illustrate this result, let us assume that the Water Authority wishes to purchase an amount of water rights  $x$ , with  $x \in (0, \bar{w})$ . This implies that the price of water  $p^w$  must lie within the interval  $(\underline{k}, \bar{k})$ . More precisely, from (5) we have that a farmer will sell an amount of water rights  $w^S = x$  if and only if the following conditions hold:

$$\left\{ \begin{array}{l} p - C'(w^F) = \rho g'_{w^F}(w^{IL}) \\ p^w = \rho g'_{w^S}(w^{IL}) \\ \text{with } w^{IL} = w^F - \bar{w} + w^S, \text{ and } w^S = x \end{array} \right.$$

The derivatives of  $g$  with respect to  $w^F$  and  $w^S$  can be written more explicitly as:

$$\begin{aligned} g'_{w^F}(w^{IL}) &= \partial g / \partial w^{IL} \times \partial w^{IL} / \partial w^F \\ g'_{w^S}(w^{IL}) &= \partial g / \partial w^{IL} \times \partial w^{IL} / \partial w^S \end{aligned}$$

From the definition of  $w^{IL}$ , it follows that:  $\partial w^{IL} / \partial w^F = \partial w^{IL} / \partial w^S = 1$ . Thus, farmer's first-order conditions can be restated as:

$$(6) \quad \left\{ \begin{array}{l} p - C'(w^F) = \rho g'(w^{IL}) \\ p^w = \rho g'(w^{IL}) \\ \text{with } w^{IL} = w^F - \bar{w} + x \end{array} \right.$$

Using the above conditions we will now prove that for any given  $\rho > 0$  the following lemma holds:

**Lemma 1**  $\frac{dx}{dp^w} > 0$ ,  $\frac{dw^F}{dp^w} < 0$ , and  $\left( \frac{dx}{dp^w} + \frac{dw^F}{dp^w} \right) > 0$ .

**Proof.** By contradiction.

By differentiating the equations in (6) with respect to  $p^w$  we have:

$$(I) \quad 0 = C''(w^F) \frac{dw^F}{dp^w} + \rho g''(w^{IL}) \left( \frac{dw^F}{dp^w} + \frac{dx}{dp^w} \right)$$

$$(II) \quad 1 = \rho g''(w^{IL}) \left( \frac{dw^F}{dp^w} + \frac{dx}{dp^w} \right)$$

(i) Suppose  $\frac{dw^F}{dp^w} + \frac{dx}{dp^w} = 0$ . Then, conditions (I) and (II) are trivially contradicted.

(ii) Suppose  $\frac{dw^F}{dp^w} + \frac{dx}{dp^w} < 0$ . Then (II) would lead to  $g''(w^{IL}) < 0$ , which contradicts assumption (AII).

(iii) Suppose  $\frac{dw^F}{dp^w} + \frac{dx}{dp^w} > 0$  and  $\frac{dw^F}{dp^w} > 0$ . Given assumptions (AI) and (AII), this implies:  $C''(w^F) \frac{dw^F}{dp^w} + \rho g''(w^{IL}) \left( \frac{dw^F}{dp^w} + \frac{dx}{dp^w} \right) > 0$ , which in turn contradicts (II).

(iv) Hence, it must be that  $\frac{dw^F}{dp^w} + \frac{dx}{dp^w} > 0$  and  $\frac{dw^F}{dp^w} < 0$ ; which, bearing in mind that  $w^{IL} = w^F - \bar{w} + x$ , implies:  $0 < \frac{dw^{IL}}{dp^w} < \frac{dx}{dp^w}$ . ■

The implications of the above discussion are summarized in proposition 1.

**Proposition 1** *For any given  $\rho > 0$ , the reduction in water consumption that can be achieved at a given price is always smaller than the amount of water rights purchased back at that price.*

The intuition behind proposition 1 is simple. When a farmer is given the chance to sell some of her water rights, the opportunity cost of farming with legal water relative to illegal increases. As a consequence, a farmer will tend to use more water illegally. This partially erodes the effect of the buy-back policy on total water consumption.

## 7 Implementation and enforcement: key interactions

As previously mentioned, many basins in the world are not only ‘over-allocated’, but also affected by serious problems of illegal water use (UN 2003; Kemper 2000). This is particularly important in the light of the incentive mechanism identified in the previous section.

One way of addressing illegal water consumption is to enhance the efficacy of the enforcement regime through increasing the fine rates for illegal water usage and investing in monitoring measures such as the installation and control of water meters or the expansion of remote sensing.

Of particular interest here is the potential impact that such policies may have on the implementation and performance of water buy-back when this is designed as the purchase of a fixed quantum of water rights.

In the context of the present model, the degree of severity of the enforcement regime is represented by the parameter  $\rho$ . As  $\rho$  increases, the expected cost of using water illegally increases. As a consequence, a farmer will try to reduce her consumption of illegal water ( $w^{IL}$ ). There are two channels through which a farmer can reduce  $w^{IL}$ :

- (i) pumping less – that is, reducing the amount of water used in farming ( $w^F$ );
- (ii) substituting illegal for legal water – by selling less water rights.

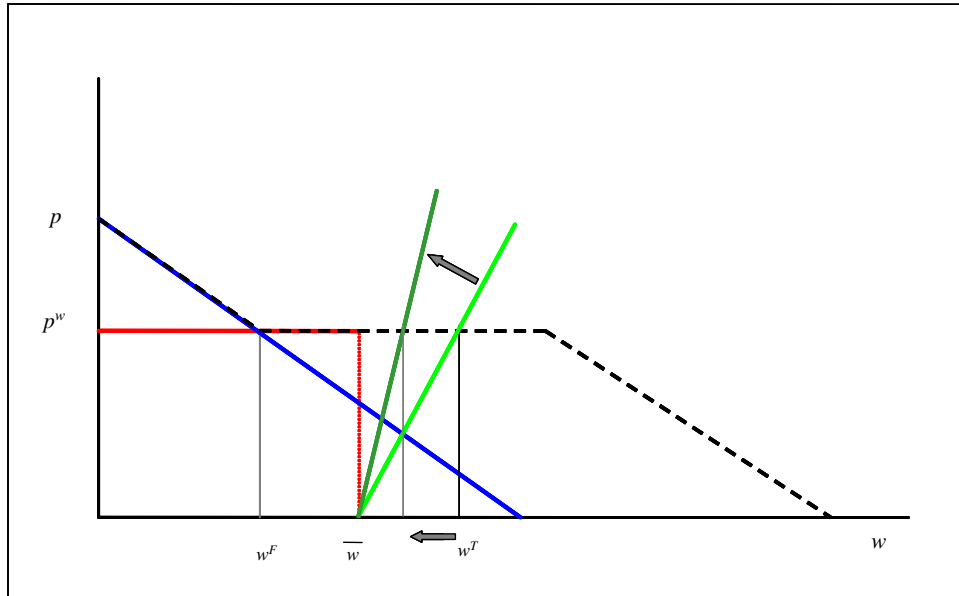
It can be shown that, for a given  $p^w \in (\underline{k}, \bar{k})$ , an increase in  $\rho$  such that  $p^w$  is still a feasible price, has no effect on water consumption. In other words, a farmer responds to

an increase in  $\rho$  by adopting the second channel only; that is, by *perfectly* substituting illegal water for legal without varying the amount of water used for farming.

From (6), farmer's first-order conditions can be expressed as follows:

$$(7) \quad \begin{aligned} (I'') \quad p - C'(w^F) &= p^w \Rightarrow w^{F*} \\ (II'') \quad p^w &= \rho g'(w^{IL}) \Rightarrow w^{IL*} \end{aligned}$$

Consider equation  $(II'')$  in (7). For a given  $p^w$ , as  $\rho$  increases  $g'(w^{IL})$  must decrease in order to restore the equilibrium. Since  $g'(\cdot)$  is an increasing function of  $w^{IL}$ , then as  $\rho$  increases  $w^{IL}$  must decrease. Assume that, in order to reduce her illegal water consumption, a farmer decides to cut down the total amount of water used for farming,  $w^{F*}$ . If  $w^F$  decreases, the marginal cost of pumping  $C'(w^F)$  will decrease. Condition  $(I'')$  says that, if  $C'(w^F)$  decreases, then the net return from farming is higher than the return from selling water rights (since  $p^w$  is constant). This implies that for any  $w^F < w^{F*}$ , a farmer will find it profitable to pump more water. From  $(I'')$ , in equilibrium:  $\partial w^F / \partial \rho = 0$ . As previously discussed, assumption *AII* and equation  $(II'')$  imply that:  $\partial w^{IL} / \partial \rho < 0$ . Combining these results with the definition of  $w^{IL}$ , we have:  $\partial w^{IL} / \partial \rho = \partial w^S / \partial \rho$ . Therefore, for a given  $p^w \in (\underline{k}, \bar{k})$ , if the degree of enforcement increases, farmer's response will be to *perfectly* substitute illegal for legal water by selling less water rights. Thus, the optimal amount of water used in farming will remain unchanged. Figure 3 provides a graphic illustration for this result. As rho increases, the expected marginal fine line becomes steeper and  $w^T$  falls. At the same time,  $w^F$  remains constant because the amount of water sold adjusts to keep the expected marginal fine equal to the water price.

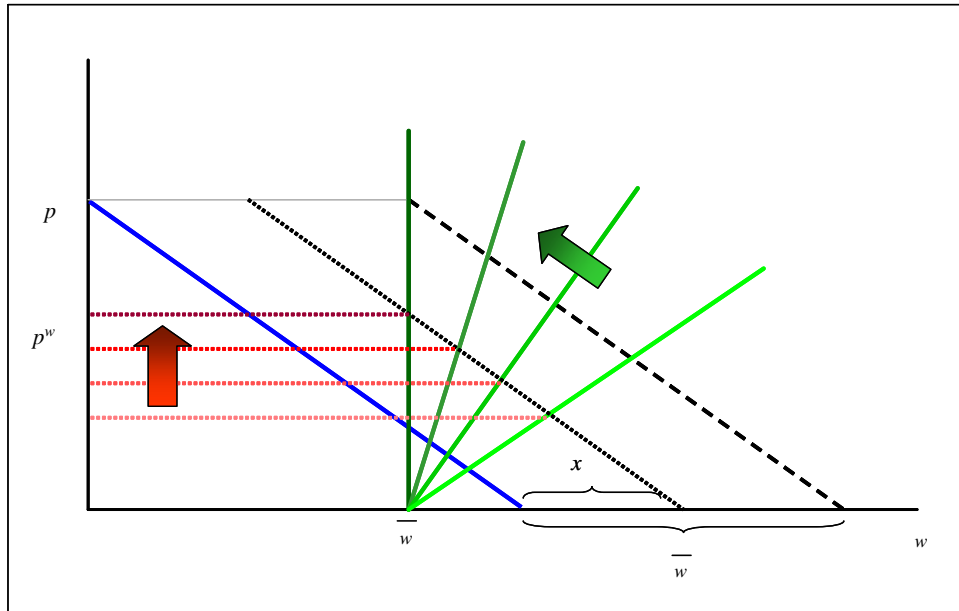


**Figure 3: Substitution of illegal for legal water**

From the above discussion it follows that:

**Proposition 2** *Given  $\rho > 0$ , the higher  $\rho$  (that is, the more stringent the enforcement regime), the higher the price required to secure the purchase of a given quantum of water rights.*

Figure 4 provides a graphic illustration of proposition 2.



**Figure 4: A graphic illustration of proposition 2**

As before,  $x$  refers to the volume of water rights that the Water Authority wishes to purchase. For the amount of water sold to be equal to  $x$ , the intersection between farmer's aggregate water benefit curve and the marginal fine must lie a constant horizontal distance  $x$  from the marginal farming benefit curve. In figure 4, this implies that the intersection must lie on the black line with round dots. The figure shows that, as the enforcement severity increases from the lighter to darker green lines, the necessary price also rises from the lighter to darker red lines.

## 8 Conclusions

Governments are increasingly reliant on the reacquisition of water rights as a mechanism for recovering over-exploited basins. Yet, serious concerns have recently been



raised about the efficacy and operational dimensions of current buy-back programs.

Water buy-back is typically being implemented as the purchase of a *fixed* quantity of water rights from the agricultural sector at the price set by the Water Authority. This relatively simple goal belies the complexities of many real-world situations, where over-allocation problems tend to coexist with poor enforcement regimes and the widespread use of illegal water. Our analysis showed that, due to these complexities, the current approach to water buy-back may not be the most sensible one. More precisely, the model proposed in this paper predicts that the purchase of a fixed quantum of water rights always induces a reduction in water consumption *smaller* than the amount of rights purchased back at a given price. The intuition for this is that when farmers are given the chance to sell some of their water rights, the opportunity cost of farming with legal water relative to illegal increases. Consequently, farmers tend to optimally increase their use of illegal water. This result provides theoretical support for some of the concerns raised about existing programs, and highlights the need for greater scrutiny since there is a strong tendency to publicly overstate the magnitude of buy-back while securing water purchases that amount to limited environmental gains.

The second part of the analysis showed that the difference between the acquired volume of rights and the actual reduction in water consumption is smaller the more stringent the enforcement regime. At the same time, the higher the degree of severity of the enforcement regime, the higher the price required to secure the purchase of a given quantum of rights. This result is especially important when a basin is not only over-allocated but also affected by problems of illegal water use and poor enforcement

regimes – as it is the case in many real-world situations. In such contexts, water buy-back will not be capable of making any genuine progress towards reduction in water consumption without enhancing enforcement capacity. However, investments in monitoring and enforcement may have perverse effects on the price of water rights. In other words, more public funds will be required to secure a given quantum of rights where buy-back is accompanied by investments in enforcement capacity.

To avoid these perverse effects, re-acquisition and enforcement policies must be coupled, with consideration for how they interact. This has not been the case in the Upper Guadiana basin, where policy interventions have largely overlooked the complex relationship between legal and illegal water use. The tendency to develop buy-back programs in isolation has been observed also in other settings, and in relation to other policies. In the Murray Darling Basin, for example, water buy-back has been introduced without much consideration for its potential interaction with the sustainable diversion limit (SDL) established under the Commonwealth *Water Act 2007*. As shown by Horne et al. (2011), however, the interaction between these two measures may have significant implications for their implementation and effectiveness, again reinforcing the importance of considering water buy-back in context. In the light of our findings, Horne et al. (2011)'s conclusion is even more relevant when transparency in property rights is not guaranteed due, for instance, to inefficiencies of the enforcement regime.

Pairing the purchase of water entitlements with other relevant policies is a challenging task, which may require a revision of current programs in terms of design, goal specification and implementation strategies. Designing water buy-back as the

purchase of a *fixed-quantum* of water rights at a price set by the water authority does not seem very sensible in the light of the incentive mechanisms identified in this paper and the complex relationship with other policies.<sup>7</sup> The formation of a more consistent and effective approach to water resource exploitation would benefit from a governance framework that sets the overarching policy goal in terms of *water-use* rather than *water-rights* reduction targets, and flexibly uses the purchase of water entitlements and the increase of fine rates or the installation of water meters as complementary tools of adjustment.

From an implementation perspective, one way to couple reacquisition and enforcement policies may be by linking farmers' participation to the buy-back program with an agreement to install water meters and accept higher fines. This approach would imply devolving partial decision-making responsibility to local stakeholders. In a recent study, Marchiori et al. (2012) showed that an additional benefit of this approach is that it might be able to better take account of equity issues associated with the distribution and reallocation of water rights. Equity considerations are particularly important in light of the fact that in many real-world settings water resource expansion has essentially followed the 'rule of capture'; that is, the current allocation of water rights is the result of the order of arrival of sectors or users rather than long term planning on the part of governmental authorities (Ansink and Marchiori, 2009). In this paper, we focused exclusively on issues related to cost-efficiency and effectiveness of buy-back

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<sup>7</sup>In a different setting, Dixon et al. (2011) similarly point to the potential problems of defining buy-back schemes on the basis of a fixed quantity of water rights.

schemes. An interesting extension for future research would be to explicitly model distributional aspects.

## Appendices

### A.1 Farmer's optimal consumption of illegal water

This appendix shows that, when the initial endowment of water rights,  $\bar{w}$ , is smaller than  $w^* \equiv \arg \max_{w^F} [pw^F - C(w^F)]$ , it is never optimal for a farmer to set her consumption of illegal water at  $w^{IL} \leq 0$ .

To prove this, let us study farmer's optimization problem under the case  $w^{IL} \leq 0$ .

From (4), this can be written as:

$$\begin{aligned} \max_{w^F, w^S} \Pi &= pw^F - C(w^F) + p^w w^S \\ \text{s.t.} \quad &0 \leq w^S \leq \bar{w} \end{aligned}$$

The Lagrange function for the above problem is:

$$L = pw^F - C(w^F) + p^w w^S - \lambda_1 \times (w^S - \bar{w}) + \lambda_2 w^S$$

The Kuhn-Tucker conditions are:

- (a1)  $L'_{w^F} = 0 \Rightarrow p - C'(w^F) = 0$
- (a2)  $L'_{w^S} = 0 \Rightarrow p^w - \lambda_1 + \lambda_2 = 0$
- (b1)  $\lambda_1 \geq 0$ ,  $w^S - \bar{w} \leq 0$ , and  $\lambda_1 \times (w^S - \bar{w}) = 0$
- (b2)  $\lambda_2 \geq 0$ ,  $w^S \geq 0$ , and  $\lambda_2 \times w^S = 0$

Looking for the 'active constraint', the following four cases can be identified:

(I)  $w^S - \bar{w} = 0$ , and  $w^S = 0$ , which implies:  $\bar{w} = 0$ . This, however, cannot be since by definition the farmer is endowed with a *strictly positive* amount of water rights, that is:  $\bar{w} > 0$ .

(II)  $w^S - \bar{w} = 0$ , and  $w^S > 0$ . Under this case, and from the definition of  $w^{IL} = w^F - \bar{w} + w^S$ , we have:  $w^{IL} = w^F$ . Since we are considering the hypothesis  $w^{IL} \leq 0$ , the previous equality implies:  $w^F \leq 0$ . This violates condition (a1).

(III)  $w^S - \bar{w} < 0$ , and  $w^S = 0$ . The complementary slackness condition implies:  $\lambda_1 = 0$ . Consequently, (a2) becomes:  $p^w = -\lambda_2$ . From (b2), we have:  $\lambda_2 \geq 0$ . Since water price cannot be negative, it must be:  $p^w = 0$ . This corresponds to the status quo case when the farmer does not use any positive amount of illegal water. However, due to assumption *III*, this case does not represent an optimal solution when  $\bar{w} < w^*$ .

(IV)  $w^S - \bar{w} < 0$ , and  $w^S > 0$ , so that:  $\lambda_1 = \lambda_2 = 0$ . From (a2), we have:  $p^w = 0$ . However, if the price offered by the Water Authority is zero, a farmer will not sell any positive amount of water rights. Therefore, it cannot be  $w^S > 0$ .

From the above analysis, we can conclude that, when  $\bar{w} < w^*$  there is no solution to problem (4) such that at the optimum  $w^{IL} \leq 0$ .

## **A.2 Resolution of farmer's optimization problem under a buy-back scheme**

Appendix A.1 showed that, under a buy-back policy and for  $\bar{w} < w^*$ , it is never optimal for a farmer to set her consumption of illegal water at  $w^{IL} \leq 0$ . This allows us to write  $G(w^{IL}) = g(w^{IL})$  and to define the Lagrangian for farmer's optimization problem as:

$$L = pw^F - C(w^F) + p^w w^S - \rho g(w^{IL}) - \lambda_1 \times (w^S - \bar{w}) + \lambda_2 w^S$$

The Kuhn-Tucker conditions are:

$$(a1) \quad L'_{w^F} = 0 \Rightarrow p - C'(w^F) - \rho g'_{w^F}(w^{IL}) = 0$$

$$(a2) \quad L'_{w^S} = 0 \Rightarrow p^w - \rho g'_{w^S}(w^{IL}) - \lambda_1 + \lambda_2 = 0$$

$$(b1) \quad \lambda_1 \geq 0, \quad w^S - \bar{w} \leq 0, \quad \text{and} \quad \lambda_1 \times (w^S - \bar{w}) = 0$$

$$(b2) \quad \lambda_2 \geq 0, \quad w^S \geq 0, \quad \text{and} \quad \lambda_2 \times w^S = 0$$

Conditions  $\lambda_1 \times (w^S - \bar{w}) = 0$  and  $\lambda_2 \times w^S = 0$  in (b1) and (b2) yield the following four cases:

(I)  $w^S - \bar{w} = 0$ , and  $w^S = 0$ . This case can, in fact, be disregarded because it implies  $\bar{w} = 0$ , while a farmer's initial endowment of water rights is, by definition, strictly positive.

(II)  $w^S - \bar{w} = 0$ , and  $w^S > 0$ , so that  $\lambda_2 = 0$ . Condition (a2) becomes as follows:

$$p^w - \rho g'_{w^S}(w^{IL} | w^S = \bar{w}) = \lambda_1$$

Therefore, for  $\lambda_1$  to be greater than or equal to zero as (b1) requires, it must be:

$$p^w \geq \rho g'_{w^S}(w^{IL} | w^S = \bar{w})$$

Under this condition, the system admits the following solution:

$$\begin{cases} p - C'(w^F) = \rho g'_{w^F}(w^{IL}) \\ w^S = \bar{w} \end{cases}$$

(III)  $w^S - \bar{w} < 0$ , and  $w^S = 0$ , so that  $\lambda_1 = 0$ . In this case, condition (a2) is as follows:

$$p^w - \rho g'_{w^S}(w^{IL} | w^S = 0) = -\lambda_2$$

Therefore,  $\lambda_2 \geq 0$  if and only if the following holds:

$$p^w \leq \rho g'_{w^S}(w^{IL} | w^S = 0)$$

Under the above condition on  $p^w$ , the whole system is satisfied and the solution to farmer's optimization problem is:

$$\begin{cases} p - C'(w^F) = \rho g'_{w^F}(w^{IL}) \\ w^S = 0 \end{cases}$$

(IV) Finally,  $w^S - \bar{w} < 0$ , and  $w^S > 0$ , so that  $\lambda_1 = \lambda_2 = 0$ . From (a1) and (a2),

we have that the solution to the problem is defined by the following conditions:

$$\begin{cases} p - C'(w^F) = \rho g'_{w^F}(w^{IL}) \\ p^w = \rho g'_{w^S}(w^{IL}) \end{cases}$$

It can be easily observed that the above results correspond to the solution summarized in (5).



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