Exit Timing Decisions under Land Speculation and Resource Scarcity in Agriculture

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Abstract

This paper models the impact of water scarcity in agriculture on the timing of exit decisions for farmers faced with the prospect of declining profitability in agriculture but increasing benefits from land rezoning in the future. The prospects of land rezoning are modeled as a Poisson process. The analysis highlights the role of speculative rewards in making farmers resilient to declining profitability in agriculture and also identifies the circumstances under which water prices may become an ineffective policy tool for allocating water. An empirical application is performed for the case of a drought prone region in Western Australia. Results indicate that when the chances of urbanization are low, it is more profitable to exit agriculture sooner than later as the expected rewards from urbanization are superseded by the current losses in agriculture. Also, water pricing as a mechanism for promoting efficient water use may not work in the presence of speculative rewards from urbanization.

Keywords: land rezoning, agricultural resilience, binary choice, water scarcity, Poisson process, urbanization
1. Introduction

Water scarcity, especially in agriculture, is increasingly becoming a harsh reality for Australia (CSIRO & Australian Bureau of Meteorology 2007). While water has several competing uses, agriculture has been one of the main beneficiaries of water resources historically. Increasing frequency of droughts, however, has led to curtailment of water allocation to farmers, thereby causing declining profitability in agriculture. Yet, farmers have been found to be resilient to such prolonged droughts which are believed to be related climate change (Keil et al. 2007).

Several theories have been proposed to explain farming decisions under external pressures. Farmers’ timing of entry and exit decisions has received considerable attention in the agricultural economics literature. Previous literature has found links of exit decisions with farm characteristics, farmer's age (specifically retirement and pre-retirement decisions) and the existence of potential successors (see e.g. Kimhi 1994; Pietola et al. 2003).

Pressure of urbanization on farmer’s exit decisions has been studied as well in the past. For farmers to survive rapidly rising land value from urbanization, two recommendations have been made by Adelaja et al. (1998). First, farmers must switch to high value crops that yield more profitability (e.g., herbals and vegetables). Second, institutional changes are necessary to protect farmers via mechanisms such as farm land preservation or right-to-farm acts.

Declining profitability within agriculture does not necessarily encourage exit in presence of speculative rewards from urbanization of their lands. Speculative effects and reliance of farmers on capital gains from farmland sales compromise the long-term competitiveness of farms.
as farmers are reluctant to invest in new technology, a phenomenon known as "impermanence syndrome" (Lockeretz 1989). With the prospect of selling farm lands to urban developers, farmers perceive their lands as a financial asset instead of a productive input (Lopez et al., 1988) and prefer to operate at sub-optimal efficiency and wait-it-out until land is rezoned to urbanization.

There exists an exhaustive literature devoted to understanding the linkages between land speculation from urbanization in the rural areas on efficient farming practices (see e.g. Raup 1975; Plaut 1980; Lopez et al. 1988; Lockeretz 1986, 1988, 1989; Lockeretz et al. 1987). Kottke (1966) explains the effects that farm business life cycle and urbanization have on timing of exit decision. However, to the authors' knowledge, none have formally linked urbanization pressure and water scarcity to exit decisions.

Urbanization pressure coupled with water scarcity in agriculture is increasingly becoming a reality for farmers. Notable in this regard is the current situation of agriculture in Western Australia which relies almost exclusively on groundwater resources to satisfy its urban, agricultural and environmental water needs. Prolonged droughts have resulted in a rapidly declining Aquifer Head, forcing the government to consider extreme measures such as land rezoning to free land and water out of agriculture and allocate it to urban and environmental uses. Given the speculative rewards from urbanization, it is not clear how market based approaches such as water pricing would fare in achieving the above objective. While water curtailment or water pricing might encourage water-efficient technology adoption, the uncertainty over the prospects of land rezoning discourages such investments. "How do farmers decide whether or not to exit farming at a given point in time?", is a question of significant policy relevance as it informs policy makers about the influence of urbanization pressure and
policy uncertainty on structural dynamics in agriculture. When farmers can collectively influence the land rezoning probability through their extraction rate, the situation becomes even more complicated.

Keeping in mind the above policy context, the contribution of this paper is, therefore, to model the timing of farmers' exit decisions under pressure from urbanization and water scarcity in the context of depleting groundwater resources. Less surface water leads to more groundwater use and less rainfall may lead to less recharge and overdraft of the aquifer system. We develop a theoretical model that captures farmers' exit decisions, due to either declining profitability or higher rewards from land rezoning (from rural to urban), as a binary choice problem, where the timing of urbanization is stochastic and follows a Poisson process. As long as the farmers decide to stay in agriculture they optimize over the use of water and other resources in order to reap maximum possible benefits from agriculture.

The farmer’s use of water resources may influence the possibility and timing of land rezoning. Urbanization helps improve water recharge into the aquifer, therefore, a declining water table makes it more likely that land would be rezoned to help prevent further decline. When farmers can collectively influence such rezoning possibilities, inefficient uses of water, might be promoted due to their impact on rezoning possibilities.

Whether or not the possibilities of land rezoning could be influenced, the farmer has the option of selling land out of agriculture to another farmer or a speculative urban developer. However, this option leads to a lower reward than the reward from waiting until the land has been rezoned. The timing of exit is determined by the intersection of the value function from
staying on in agriculture (which involves profits from agriculture and expected rewards from rezoning) and the one-off reward from selling out of agriculture.

Our key findings highlight the role of speculative impact from rezoning in augmenting farmers’ resilience in the presence of increasing water scarcity. The empirical analysis reveals that because the benefits from urbanization are relatively large, the use of water pricing as a tool for allocating scarce water resources may not be effective when the risk of rezoning is endogenous.

The rest of the paper is organized as follows. Section 1.2 explains the basic theoretical model that captures farming decisions, specifically on water extraction, under uncertainty of land rezoning. An optimal extraction rule is derived. This model is then applied to the case of a water challenged region in Western Australia, the city of Perth, in Section 2. Section 2.2 extends the theoretical model to incorporate the binary decision of exiting out of agriculture in the case study. Section 3 discusses the results of the empirical model and Section 4 concludes.

1.2. Model

Understanding resilience in agriculture is significant for policy purposes. Resilience has been traditionally defined in two senses; one called the engineering definition which refers to the rate at a system can revert back to its original state after an initial perturbation (Pimm 1984). The other is called ecological resilience and it refers to the amount of shock that any system can withstand before flipping into a new state (Holling and Meffe 1996). Economic resilience in agriculture can be defined as the amount of water shortage induced economic loss that can be tolerated by the farmers before they relocate or shut down. Alternatively, it could also be measured in terms of the maximum amount of reduction in water supply that the farmers could
tolerate before exiting agriculture. This, of course, would require farmers to adapt to new water saving technologies. If farmers undergo losses, and yet do not alter farming practices or are not willing to relocate, then this could possibly be due to behavioral resilience borne out of psychological, social or speculative factors. In this paper we use the term resilience to identify farmer’s persistence in agriculture despite groundwater depletion and declining profitability.

Let the output in agriculture be defined by the following production function:

\[ q(t) = A \cdot h(t)^\theta \cdot k(t)^{1-\theta} \]  \hspace{1cm} (1)

where \( q(t) \) is the output or yield (in tonnes) at time \( t \), \( A \) is an exogenous technology parameter, \( h(t) \) is the rate of water extraction (in ML) from the aquifer, \( k(t) \) is the composite of other factors of production such as capital, land and labor, and \( \theta \) is the share of water in the output. Here we assume that \( h(t) \) is inclusive of any other forms of water application including rainfall.

Let the Aquifer Head dynamics be modeled as:

\[ \dot{w}(t) = -\alpha + \beta \cdot rain(t) - h(t) \]  \hspace{1cm} (2)

where \( \alpha \) is the rate of long term decline in the Aquifer Head possibly due to the drought, \( \beta \) is the proportion of per period rainfall, \( rain(t) \), that gets recharged, \( h(t) \) is the annual harvest or water extraction rate and \( \dot{w}(t) \) is the rate of change of the Aquifer Head, measured in meters.

Consider that the farmer maximizes long term expected discounted net benefits from agriculture as:

\[ \bar{E} \int_0^\infty \{ p \cdot q(t) - (w_0 - w(t))^{c_h h(t)} - c_k \cdot k(t)^{c_k} \} \cdot e^{-rt} \, dt, \]  \hspace{1cm} (3)
where \( p \) is the price of agricultural commodity assumed constant over time, reflecting a small scale economy, \( c_k \) is the parameter for the cost of harvesting water (e.g. pumping costs), \( c_k \) & \( \gamma \) are cost of capital parameters, \( w_0 \) is the initial hydraulic head of the aquifer, \( w(t) \) is the depth of Aquifer Head at time \( t \), and \( r \) is the discount rate. Cost of harvesting, \((w_0 - w(t))^{c_k \cdot h(t)}\), increases non-linearly as the Aquifer Head decreases.

Farming decisions also involve long term planning of profitability outside of agriculture. There is an element of uncertainty in terms of future land use allocations. Hence, even though water scarcity increases, there is an expectation that future profits from higher land prices might balance out current losses. To model this we assume that the possibility of land rezoning is given by a hazard rate, \( \zeta(t) \), of land conversion which could be a function of the level of water in the aquifer. An optimal level of the Aquifer Head needs to be maintained to ensure the health of the groundwater dependent ecosystems (GDEs) in the region. When the agricultural sector extracts from the aquifer without rainfall replenishing it each year, it leads to a drop in the Aquifer Head level thereby prompting government intervention through water curtailment and subsequent rezoning of agriculture out of the area.

The methodology used to account for the risk of rezoning in this model is based on previous works of Clarke and Reed (1994), and Tsur and Zemel (2004, 2006). The risk of rezoning is modeled using a survival function, \( S(t) \), to represent the farmer’s likelihood of surviving rezoning in each time period, \( t \). Let \( T \) be the time period of rezoning. The cumulative probability distribution associated with conversion is denoted by \( F(t) \), where \( F(t) = \Pr(T < t) \). The survival function captures the probability that rezoning has not yet occurred in time \( t \), and represents the upper tail of the cumulative probability distribution:
\[ S(t) = \Pr(T \geq t) = 1 - F(t) = e^{-\zeta(t)} \], where \( \zeta(t) = \int_0^t \hat{\zeta}(t)dt \) \hfill (4)

In each time period it is assumed that, conditional upon arriving at time \( t \) without land been rezoned, the farmers face a certain probability of transition into the post-rezoning state, denoted as \( \hat{\zeta}(t) \). This conditional probability, \( \hat{\zeta}(t) \), is also referred to as the hazard rate.

As the groundwater level drops, the government would be forced to relocate farmers to other areas. This would mean land resale and possible urbanization of the existing agricultural area, thus leading to very high profits from land sales. When this happens, farmers receive a one-time benefit at the time of sale. Therefore, the revised objective function is now expressed as:

\[
\int_0^\infty \left\{ p \cdot q(t) - (w_0 - w(t))^{c_k \cdot h(t)} - c_k \cdot k(t) \cdot e^{-\zeta(t)} + N_a(t) \cdot \hat{\zeta}(t) \cdot e^{-\zeta(t)} \right\} e^{-rt} dt \hfill (5)
\]

where \( N_a(t) \) is the value of the land from selling after rezoning to urban. Due to increasing demand for urbanization, \( N_a(t) \), is projected to increase with time (as shown in equation (17) in the Appendix), thereby making the speculative rewards from waiting to sell the land higher. The first term \( (p \cdot q(t) - (w_0 - w(t))^{c_k \cdot h(t)} - c_k \cdot k(t) \cdot e^{-\zeta(t)} \) represents the expected value derived from farming in each time period until the time of rezoning, where as the second term \( N_a(t) \cdot \hat{\zeta}(t) \cdot e^{-\zeta(t)} \) represents the reward from selling land at time \( T \) when urbanization occurs.

Equation (5) is derived by taking the integral of the expected value from farming profits from time period 0 to \( T \) and adding to it the expected benefits from land sale at time \( T \), discounted to the initial time. The probability distribution of \( T \), the time at which rezoning
occurs, is given by the survival function as defined in equation (4) (see Clarke and Reed 1994; Tsur and Zemel 2006 for derivations of objective function with an exponential uncertainty distribution).

The objective function is maximized subject to constraints posed by equation (2) and the equation of motion for the hazard rate, which is given as:

$$\dot{\zeta}(t) = f(w(t), \vartheta)$$

(6)

where $w(t)$ is the level of the Aquifer Head, $\frac{\partial \zeta(t)}{\partial w(t)} < 0$ (the lower the level of the Aquifer Head, the greater the risk of land being rezoned to urban) and $\vartheta$ is an exogenous component of the hazard rate, such as urban pressure, on land rezoning. Rezoning risk depends on many factors, however, here we assume that the declining Aquifer Head has the most significant influence on land rezoning risks. The hazard rate of land rezoning is a function of the amount of water in the aquifer, thus making the risk of rezoning endogenous. In reality, the risk of rezoning may be exogenous and we consider such situations later on.

The current value Hamiltonian (CVH) is given as:

$$CVH = (p \cdot A \cdot h(t)^{\theta} \cdot k(t)^{1-\theta} - (w0 - w(t))^c) \cdot e^{-\zeta(t)}$$

$$+ N_a(t) \cdot \dot{\zeta}(t) \cdot e^{-\zeta(t)} + \gamma_1(t) \cdot (-\alpha + \beta \cdot rain(t) - h(t)) + \gamma_2(t) \cdot f(w(t), \vartheta)$$

(7)

where $\gamma_1(t)$ is the shadow price of water and $\gamma_2(t)$ is the shadow price of cumulative risk of rezoning. The first order condition with respect to water harvesting requires that the marginal change in the objective function with respect to harvesting, $h(t)$, be equal to the shadow price of water and is specified as:
\[
\frac{\partial CVH}{\partial h(t)} = 0 \Rightarrow e^{-\xi(t)} \cdot (\log(w_0 - w(t)) \cdot (w_0 - w(t)))^{c_h \cdot h(t)} \cdot c_h + \theta \cdot p \cdot A \cdot h(t)^{\theta-1} \cdot k(t)^{1-\theta} = \gamma_1(t)
\]  

The no-arbitrage condition for the shadow price of water is given as:

\[
- \frac{\partial CVH}{\partial w(t)} + \gamma_1(t) \cdot r = \dot{\gamma}_1(t) \Rightarrow e^{-\xi(t)} \cdot c_h \cdot h(t) \cdot (w_0 - w(t))^{c_h \cdot h(t)-1} + \gamma_1(t) \cdot r - \gamma_2(t) \cdot f_w'(w(t), \theta) = \dot{\gamma}_1(t)
\]  

where \( \dot{\gamma}_1(t) \) is the rate of change of the shadow price of water.

The no-arbitrage condition for the shadow price of rezoning risk is given as:

\[
- \frac{\partial CVH}{\partial \zeta(t)} + \gamma_2(t) \cdot r = \dot{\gamma}_2(t) \Rightarrow (p \cdot A \cdot h(t)^{\theta} \cdot k(t)^{1-\theta} - (w_0 - w(t))^{c_h \cdot h(t)} - c_k \cdot k(t)^{\gamma} + N_a(t) \cdot \dot{\zeta}(t)) e^{-\xi(t)} + \gamma_2(t) \cdot r = \dot{\gamma}_2(t)
\]  

where \( \dot{\gamma}_2(t) \) is the rate of change of the shadow price of risk. In a steady state, \( \dot{\gamma}_2(t) = 0 \), equation (10) yields:

\[
\frac{- (p \cdot A \cdot h(t)^{\theta} \cdot k(t)^{1-\theta} - (w_0 - w(t))^{c_h \cdot h(t)} - c_k \cdot k(t)^{\gamma} + N_a(t) \cdot \dot{\zeta}(t)) e^{-\xi(t)}}{r} = \gamma_2(t)
\]

The steady state, where \( \dot{\gamma}_1(t) = 0 \), for equation (9) implies:

\[
\frac{- e^{-\xi(t)} \cdot c_h \cdot h(t) \cdot (w_0 - w(t))^{c_h \cdot h(t)-1} + \gamma_2(t) \cdot f_w'(w(t), \theta)}{r} = \gamma_1(t)
\]

Equations (8)-(10) describes an optimal water harvesting plan for the farmer when faced with land rezoning possibilities. Equation (11) further dictates that the optimal shadow price of risk from rezoning must be equal to the discounted sum of per period expected benefits arising from
staying in agriculture and rezoning. Equation (12) dictates that the shadow price of water must equal the discounted value of increased costs of future extraction from drawing an additional unit of water out of the ground plus the added risks of rezoning from the marginal water draw down.

The following section applies the theoretical model to the case of the farmers on the Gnangara Mound of Western Australia.

2. An Empirical Application: The Gnangara Mound

2.1. The Gnangara Mound

The Gnangara Mound is a system of four loosely connected aquifers located beneath the Swan Coastal plane in Western Australia. It is the most valuable source of fresh water in the Perth Region as it provides the majority of water used for consumptive purposes in the urban area and supports the agricultural and commercial sector. The aquifer was regarded as an infinite resource in the past. However, the ongoing decline in recharge of groundwater through reduced rainfall and unsustainable water extraction have led to concerns that groundwater under the Gnangara Mound is no longer a boundless source of water. Increased frequency of droughts have caused the Aquifer Head to decline over time, thereby creating conflicts between the competing users that span, urban, environment (such as the GDEs) and agriculture. Water scarcity could have significant impact on the viability of agriculture and other water dependent sectors. Optimal allocation of water between different sectors might require curtailing of water to certain sectors, particularly those with lower economic benefit for each megalitre (ML) of water consumed.

The horticulture sector on the Gnangara Mound is the second largest user of water under the mound. It is entirely dependent upon the groundwater as its single source for irrigation. There is a current license to extract 66 gigalitres (GL) of water or 19 percent of total annual extraction
Although horticulture is a significant social and economic activity, under the current lower than average rainfall conditions and declining water table levels, there is little prospect of new water licenses and allocations being made available to enable new horticultural uses and land to be irrigated or for existing uses to expand (DPI, 2005). The timing of such curtailment becomes a crucial policy issue as it could determine whether or not adequate adaptation opportunities are provided to the affected sectors.

Farmers on the Gnangara Mound currently face the challenge of staying in agriculture with declining profits and an uncertain prospect of their land becoming urbanized in the future. However, if they must exit, they can still sell their lands to more efficient farmers, albeit at a lower price than what waiting for rezoning would offer.

The next section extends the theoretical model to incorporate additional nuances of exiting before land rezoning.

2.2. Exit Timing under Endogenous and Exogenous Rezoning Risks: A Binary Choice Extension

The theoretical model presented in Section 1.2 only captures the trade offs between staying in farming with declining farming profits and speculative benefits from urbanization which the farmer may or may not be able to influence. However, the farmer also has the option of moving out of agriculture and selling off his land to another speculative buyer at a lower price than what he would have received had the land been rezoned. In this section we extend the model to incorporate this binary choice of exiting or staying in agriculture. The farmer may also have an option to adopt water efficient technology. However, given the current situation in the study area, farmers are discouraged to adopt because of the significant uncertainties associated
with future land uses. If the farmer went ahead and invested in water efficient technology, such a capital would be made redundant upon urbanization.

The revised objective function can now be derived as:

\[
\int_0^\infty \left\{ ((p \cdot A \cdot h(t)^\theta \cdot k(t))^{1-a} - (w_0 - w(t)))^{c_k} - p_w \cdot h(t) - c_k \cdot k(t) y \right\} \cdot e^{-\gamma t}dt
\]

where \( sell(t) \) is 1 when the land is sold and 0 otherwise, \( p_w \) is the price of water (in \$/ML) imposed by the policy maker, \( N_a(t) \) is the gain from selling land after rezoning and \( N_b(t) \) is the speculative gain from selling land before rezoning, with \( N_b(t) < N_a(t) \), as shown in equations (17) and (18) in the Appendix.

The above formulation allows for exiting out of agriculture even as \( N_b(t) < N_a(t) \). Once the farmer decides to exit out of agriculture he derives a one-time reward, \( N_b(t) \). We apply the above model to the Gnangara Mound case.

### 2.3. Parameter Calibration

The Wanneroo horticultural precinct on the Gnangara Mound (see Figure 2 area JP9), is located approximately 50 kilometers north of the city centre. The precinct has been earmarked for possible urban development as it is strategically located close to the city and a major road connecting the precinct and the city already exits. As Perth is experiencing exponential growth in demand for housing due to the mining boom, there is increasing interest in land banking and speculation by property developers, investors and farmers reaching their retirement. This has contributed to non-productive use of existing rural zoned land for agriculture as farmers await for their lands to be rezoned for urban purposes.
The variety of vegetable crops grown in the Wanneroo horticultural precinct generally varies from year to year depending on market demand. In this paper, due to data constraints, an empirical analysis of the economics of only lettuce production (grown using sprinkler systems) is used. We specify a plateauing revenue function for lettuce and calibrate the parameters based on the lettuce production data from Brennan (2007):

\[ p \cdot q(t) = k_0 \cdot b \cdot (g - e^{-(a+c \cdot h(t))}) - i \cdot e^{-a_1 \cdot h(t)} + j \cdot (m - n \cdot h(t)^2) \]  

(14)

where \( k_0, b, g, a, c, i, a_1, j, m \) and \( n \) are parameters of the revenue function, the values of which are reported in Table 1 in the Appendix. The costs of water extraction are insignificant, and hence are not considered here.

Future predictions of the Aquifer Head were based upon an eight year climate change scenario, which was simulated in the Perth Regional Aquifer Modeling System (PRAMS) for 2005 to 2030 (DOE 2005). Figure 1 shows data points simulated by Perth Regional Aquifer modeling System (PRAMS) of falling aquifer head with time (DOE 2005) due to severe drought which follows a trend specified by the function below:

\[ w(t) = w_0 - \eta \cdot \frac{t^{w_1}}{t^{w_1} + w_2} - w_3 \cdot h(t) \]  

(15)

where \( w_0 \) is the initial level of the Aquifer Head, \( \eta, w_1, \) and \( w_2 \) are the parameters that capture the non-linear decline in the Aquifer Head over time, \( w_3 \) is the conversion parameter from volume (ML) to Aquifer Head height (meters). The values of these parameters are reported in Table 1 in the Appendix. In the exogenous risk case it is assumed that the risk of rezoning is a function of the declining Aquifer Head with time, due to the impact of the drought, and that it is
independent of water harvesting by the farmers. The endogenous risk case incorporates farmers’ extraction of water for agricultural production into the risk component as well. The hazard rate, \( \zeta(t) \), which is used to determine the rezoning probability is specified as:

\[
\zeta(t) = \left\{ \begin{array}{ll}
1 - \\
= w_0 - \eta \cdot \frac{t^{w_1}}{t^{w_1} + w_2} - w_3 \cdot h(t) \end{array} \right\} \cdot p_0
\]

where \( p_0 \) is the exogenous component of the hazard rate and is used as a scaling factor for numerical simulations. The maximum possible value of the hazard rate would be \( p_0 \) and would occur when the water table drops to zero. A high value of \( p_0 \) represents a severe drought scenario and thus would accelerate the rezoning probability, whereas a low value of \( p_0 \), made possible by good rainfall, would decelerate it. Figure 3 illustrates the time path of hazard rate when \( p_0 = 1 \).

When \( p_0 = 1 \), it implies that if the water table were to hit rock bottom, the probability of rezoning would become 1 in the next seven years. While it is more likely that risk of rezoning is affected by the aggregate water extraction of all farmers rather than a single farmer’s extraction, here we make the assumption that an individual farmer is a representative of an aggregate farmer acting on a smaller scale. Consequently, the farmer is aware of the total impact of all individual extractions on the risk.

Expected gain from selling land after rezoning is based on current and projected land value of urban land on Gnangara Mound. The median residential sales price in 2007 for the Wanneroo district was approximately $3 million/ha (REIWA 2007). Expected gain before
rezoning was approximated at half of this value. The projected time paths $N_a(t)$ and $N_b(t)$ as shown in equations (17) and (18) in the Appendix display the fact that the long term difference between their values is approximately $2$ million/ha.

A Mixed Integer Non-linear Programming solver (SBB) in GAMS was used to incorporate both continuous and binary choice controls for optimization of the above problem. We use a 200 period time horizon to represent a continuously lived farmer.

3. Results

We perform several numerical simulations varying the exogenous component of the hazard rate (given by $p_0$). A change in this parameter alters the risk of rezoning thereby changing the expected rewards from rezoning. We define the discounted sum of agricultural benefits and the expected rewards from rezoning as ‘beforesell’ and the discounted sum of one-time reward from selling out of agriculture before rezoning as ‘aftersell’ reward. Figure 4 compares the before sell benefits and aftersell rewards for various values of $p_0$. A farmer decides to sell when the aftersell rewards exceed the before sell benefits as shown in Figure 4 where aftersell reward for case $(p_0=.5)$ is $1.35$M at time period 5. Note that before sell benefit is highest when $p_0$ is the highest and lowest when $p_0$ is the lowest. This should be intuitive as an increase in the overall chances of rezoning increases the expected rewards. Also, note that the before sell benefit has a concave shape which is a result of two forces - the rising land prices pushing it upwards and the declining probability of land rezoning over time pushing it downwards. The probability of rezoning falls over time as the cumulative probability increases with time, thus making conversion far away in future less likely than earlier.
effect dominates the land price effect over time thus giving it the concave shape. *Aftersell* rewards are depicted as a single point dashes in the same figure. The later the exit of the farmer, the lower is the reward from selling land. This is primarily guided by the time discounting effect.

First result to note is that exit happens earlier if $p_0$ is lower (as given by $p_0 =0.5$). When the chances of urbanization are slim, it is more profitable to move out of agriculture earlier, as there is no point in waiting for rezoning to happen. Also note that the reward from selling out of agriculture is higher the sooner the farmer sells off. While most of the cases depicted in Figure 4 are with exogenous rezoning chances, we also consider one possibility (case with $p_0=1, \ p_w=0$) where the farmer is able to influence the chances of rezoning by his choice of water usage. The logic behind this assumption is that, even though it may not be possible for a single farmer to have any significant impact on the overall Aquifer Head on the Gnanagara Mound, he could still lower the Aquifer Head underneath his bore. If, all farmers have similar incentives, the risks of rezoning could be collectively influenced. Notice that the *beforesell* benefit in this endogenous case are similar to the exogenous case when $p_0 =2$. This is primarily achieved through a very high level of water extraction in the endogenous case.

Figure 5 compares water extraction levels for the exogenous case ($p_0=1$) and the endogenous case ($p_0=1$). Traditionally water has been available to farmers at a negligible cost. This is basically a case of subsidizing water for farming. A declining productivity in water discourages wasteful excessive uses in agriculture. However, our previous exercise shows that wasteful uses are still possible under perverse incentive from rezoning.
Another purpose of this exercise is to evaluate the effectiveness of market instruments, specifically, water prices in alleviating water scarcity. In the next exercise we ask, what would happen if water prices are raised significantly? Figure 6 compares the case of endogenous risk of rezoning with two water prices, $p_w=0$ and $p_w=50$ (or equivalent to 50 cents per kilolitre). In fact, we hardly find any differences in the rate of water drawdown. This is simply because the net benefits from agriculture (including higher cost of water) are negligible as compared to speculative rewards from rezoning. Figure 6 shows the differential in the agriculture benefit function for the two cases. In order to see how the different cases have an impact on the timing of land rezoning, consider Figure 7. The highest chance of rezoning is achieved through the case where $p_o=2$ and the lowest chance at $p_o=.5$. The endogenous case lies in between this range.

4. Conclusion

In this paper our key objective was to explore the factors and circumstances that may provide resilience in farming from drought induced water scarcity. It was determined that when risks are endogenous, water resources were highly discounted in the presence of speculative benefits from land rezoning. When risks are exogenous, the timing of exit from agriculture is influenced by the level of the risk of rezoning—the higher the risk the more beneficial it is to wait out. This provides for higher resilience under declining agricultural profits. Water pricing may not be an efficacious tool for encouraging the adoption of efficient irrigation technology under excessive rewards from urbanization. A better policy instrument for preventing wasteful usage could be to put a cap on allowable extraction, or water allocation limits.

While the above analysis considers only economic factors that influence exit decisions in agriculture, it does not incorporate social factors such as farmer's age and education and
psychological factors such as risk aversion and risk weighting. These factors also may have a significant influence on farming decisions. Older generation farmers are less likely to move out of agriculture due to lifestyle choices compared to the younger generation. Education level may influence acceptance and adoption of new water saving technologies. Risk weighting has been found to be significant in influencing investment and speculative actions. Farmer heterogeneity may be crucial in determining resilience to droughts for a particular region as large farmers may be better able to sustain drought related or policy shocks compared to small farmers. Inter-sectoral dynamics within the agricultural sector could also be determined by the level of farmer heterogeneity. Large farmers may buy out small farmers as the size of their holding may have an impact on the magnitude of their rewards from rezoning.

In a policy context, a long term approach to agricultural planning is needed to help maintain the economic viability of the agriculture sector under the increasing pressure from other land uses such as urbanization. Adequate protection of the agricultural sector through appropriate land zoning discourages land speculation and subdivision of land by farmers just prior to their retirement. It also encourages farmers that choose to stay in business to adopt more efficient farming practices and water saving technologies.
The integrated water supply system (IWSS) which provides potable water consumption to Perth metropolitan is the largest water user on the mound. The current extraction is 344 gigalitres/year or 48% of total extraction.

Farmers currently pay only for the cost of extraction such as the cost of sinking a bore and the cost of electricity. It has been estimated that extraction costs is $50/ML or 5 cents per kilolitre (Brennan, 2007).
### Appendix I

#### Table 1: Parameter Values

<table>
<thead>
<tr>
<th>Revenue Function (Equation 14)</th>
<th>Aquifer Head Function (Equation 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_0 = 1$</td>
<td>$w_0 = 41$</td>
</tr>
<tr>
<td>$a = -1.7$</td>
<td>$w_1 = 3$</td>
</tr>
<tr>
<td>$a_1 = -0.065$</td>
<td>$w_2 = 49000$</td>
</tr>
<tr>
<td>$b = 27000$</td>
<td>$w_3 = 0.1$</td>
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<tr>
<td>$c = 1.56$</td>
<td>$\eta = 11.7$</td>
</tr>
<tr>
<td>$g = 0.305$</td>
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</tr>
<tr>
<td>$i = 4500$</td>
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</tr>
<tr>
<td>$j = 11.8$</td>
<td></td>
</tr>
<tr>
<td>$m = 18.8$</td>
<td></td>
</tr>
<tr>
<td>$n = 1.4$</td>
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</tr>
</tbody>
</table>

#### Land Price Specifications:

\[
N_a(t) = 0.7 + \frac{0.9}{e^t + 0.19} \times 1000000
\]  
(17)

\[
N_b(t) = 0.54 + \frac{0.35}{e^t + 0.17} \times 1000000
\]  
(18)
References


Figure 1: Aquifer Head Decline with Time (where t=1=1980)

Source: Department of Environment (DOE):2005
Figure 2: Gnangara Mound Predictive Hydrograph Locations (source: DOE, 2005)
Figure 3: Time Path of the Hazard Rate (for $p_0 = 1$)
Figure 4: *Beforesell* Benefits and *Aftersell* Rewards as a Function of Time
Figure 5: Water Extraction under Exogenous and Endogenous Cases
Figure 6: Revenue ($/ha) under Different Water Prices
Figure 7: Probability of Land Surviving Rezoning Until Time $T$