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Should I farm or should I not?

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Should I farm or should I not?

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Abstract

In this paper we use stochastic dynamic programming for modelling the investment decision of a landowner contemplating the conversion of idle land to farmland. The landowner may, by investing, develop land for active farming counting, whenever farming is not profitable, on the support secured by the CAP for land kept in good agricultural and environmental condition, i.e. land "passively" farmed. We determine, under the current CAP frame, the optimal capital intensity and the optimal investment timing and show that, if compared to a scenario where no support is provided, land development occurs earlier in expected terms and the associated capital intensity is lower. Our results contradict arguments against the support paid to farmers that passively manage their land and show that the current policy frame allows maintaining land in good state at limited cost in terms of excess capacity.

KEYWORDS: Real Options, Land development, Capital Intensity, Passive Farming.

JEL CLASSIFICATION: C61, Q15, R14.

1 Introduction

The Common Agricultural Policy (CAP) is one of the oldest and more dynamic policies of the European Union. It was first launched back in 1962 in order to guarantee food security for the consumers and market stabilization for the farmers. Since then, the CAP has changed radically. The 1992 reform, the Agenda 2000 and especially the 2003 reform attempted to improve the competitiveness of the European farmers ensuring at the same time, budget control and rural development.¹ As of today, the CAP has two main components: Pillar 1, that deals with direct payments to farmers and Pillar 2, that the Member States use to fund rural development programmes. Prior to the 2003 CAP reform, the farmers in EU received direct payments per hectare of crops through Pillar 1, a policy that affected both their individual cropping decisions and, consequently, the overall production of agricultural commodities making the farming industry less market-oriented than intended. The 2003 CAP reform addressed this distortion by introducing the decoupled Pillar 1 payments. Farmers can choose not to grow crops and still receive support conditional on the fulfilment of the so called cross-compliance requirements that consist of statutory management requirements (SMRs) (i.e. public, animal and plant health, environmental and animal welfare requirements) and

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¹For a detailed description of the mission and the historical development of the CAP one can refer to the website of the European Commission: http://ec.europa.eu/agriculture/cap-history/index_en.htm.

land maintenance according to Good Agricultural and Environmental Condition (GAEC) standards which are defined by the EU Member States.²

It is true that farmers are still adjusting to the 2003 CAP reform and as a result, it is too early to observe the true effects of the decoupled payments. Nevertheless, the implementation of the reform gave rise to a debate concerning the actual environmental, industrial and financial consequences of the policy. Some parties within the EU, perceived the decoupling as a measure that encourages land abandonment or might jeopardize the food security and the raw material autonomy in areas with few economic alternatives.³ Further, according to Ciaian et al. (2010), evidence from several countries suggests that decoupled payments might, by hindering farm exit and increasing part-time farming, prevent structural change in the agricultural industry.

An issue related to the 2003 CAP reform that is currently debated in Sweden is the so-called "passive farming". As grass-sown fallow land meets the GAEC standards, some landowners have in fact chosen not to produce any commodities and manage their land as fallow in order to qualify for the CAP payments. The Federation of Swedish Farmers has taken a clear position against passive farming practices arguing that active farming is crucial for rural development and that land managed passively is a lost resource (see e.g. Brady et al., 2015).⁴ Further, active farmers stress that, due to the capitalization in land values of the support secured to passive farmers, buying or leasing land has become expensive.⁵ This in turn deters active farmers from aiming at the expansion of their farm business (see Björnsson, 2011).

In this paper, we attempt to address the issues presented above focusing particularly on the linkage between support to passive farming and land development. We consider a landowner who contemplates the opportunity to invest in the conversion of a plot of idle land into farmland. Once invested, the landowner will, whenever farming is profitable, sell the crop yield on the market and cash, as active farming automatically secures that GAEC standards are met, the subsidy. In contrast, whenever farming, due to commodity price fluctuations, is not profitable, the landowner may suspend farming operations keeping the option to restart as soon as farming becomes again profitable. In the meanwhile, by maintaining land in GAEC, s/he can qualify for the subsidy.

The problem that the landowner faces is twofold. Firstly, the landowner must determine the level of capital intensity, i.e., the capital-land ratio, taking into account that profits from agriculture are random and that s/he has, by holding the options to suspend and to restart, some operational flexibility. Secondly, the landowner needs to decide when the investment should be undertaken. These decisions are affected by the sunk investment cost that such an investment requires as well as the price volatility of the produced commodities. Additionally, the potential farmer keeps in mind that s/he will be able to mothball the project whenever the harvest price is lower than the unit cost of production and restart it whenever active farming starts to pay off. Using the real option approach, we show that decoupled subsidies actually encourage land development since they act as a buffer for the farmer in the periods when, because of low profitability, the project is laid up. Our result clearly confirms the appropriateness of decoupled subsidies as a measure that encourages rural development and contradicts the main statement against passive farming subsidization.

The remainder of the paper is organized as follows. In Section 2 we present the model set-up,

²The main argument in favor of decoupling is that the direct payments need to support farmers' incomes and not the production itself. See for instance Keenleyside and Tucker (2010, pp. 31). A discussion on cross-compliance is presented in Ciaian et al. (2010).

³See for instance Renwick et al. (2013).

⁴The support to passive farmers is also questioned by the Swedish Agricultural Leaseholders Association and by the Dairy Association who are concerned about its impact on the land rental market. Further, concerned about the difficult promotion of energy crops, also the Swedish Bioenergy Association has been critical (see Trubins, 2013).

⁵See Ciaian et al. (2010) on this specific issue.

in Section 3 we introduce our model and determine the optimal capital intensity, in Section 4 we study the value and the timing of investment. Section 5 concludes. The Appendix contains the proofs omitted from the text.

2 The basic set-up

Consider a landowner contemplating investment for the development of idle land. The decision involves the choice of both the timing and the capital intensity of the investment. The land parcel considered has a surface which is normalized to 1.

Denote by $\alpha \in [0, 1]$ the capital-land ratio or capital intensity⁶ that the landowner may choose for developing idle land (see Capozza and Li, 1994). The initial sunk investment cost, $I(\alpha)$, associated with the project takes the following functional form

$$I(\alpha) = k_1 + k_2\alpha, \quad k_1 \geq 0 \text{ and } k_2 > 0 \quad (1)$$

where k_1 and k_2 are dimensional parameters.⁷ The term k_1 includes any fixed cost associated with the mere land conversion while the term $k_2\alpha$ considers any cost associated with a higher capital-land ratio.

Assume that a subsidy $s > 0$ is paid to the landowner (i.e., the single farmer payment) if developed land is kept in Good Agricultural and Environmental Condition (GAEC, hereafter). Keeping land in GAEC requires periodic maintenance⁸ costing $m \geq 0$ which means that a periodic net amount $s - m \geq 0$ accrues to the landowner.⁹

Once invested in a land development project characterized by a generic intensity level α , the following two post-investment scenarios are considered

- **active farming**: the land is cultivated and the corresponding yield is increasing and concave in the selected capital intensity α . Consequently, we assume that the yield is equal to:

$$q(\alpha) = \frac{\alpha^\gamma}{\gamma} \text{ with } \gamma \in (0, 1) \quad (2)$$

Unit production costs are constant and equal to c . We assume that the unit market price for the commodity¹⁰ produced, x_t , is stochastic and fluctuates according to the following geometric Brownian motion:

$$\frac{dx_t}{x_t} = \mu dt + \sigma dL_t \text{ with } x_0 = x$$

where μ is the drift parameter, $\sigma > 0$ is the instantaneous volatility of the market price and dL_t is the standard increment of a Wiener process (or Brownian motion) uncorrelated over time satisfying $E[dL_t] = 0$ and $E[dL_t^2] = dt$.

Summing up, under active farming, the periodic total profits are

$$\pi_t^a = \frac{\alpha^\gamma}{\gamma}(x_t - c) + s - m \quad (3.1)$$

⁶Note that, at no loss, we have normalized our frame by setting the maximum intensity level equal to 1.

⁷Note that we could have allowed for a more general functional form such as $I(\alpha) = k_1 + k_2 \frac{\alpha^\omega}{\omega}$, with $\omega \geq 1$. This would have, however, no impact on the quality of our results.

⁸Note that, for the sake of simplicity, we abstract from the consideration of maintaining efforts that the landowner may, in any case, undertake.

⁹We implicitly assume that the farmer would never apply for a subsidy paying $s < m$.

¹⁰Note that our frame may be easily extended to the consideration of several farm outputs and prices.

- **passive farming**: once invested, the farmer, when not actively using the land, may secure the maintenance needed for keeping the land in GAEC which again allows cashing the subsidy. Hence, under passive farming, the periodic total profits are

$$\pi_t^p = s - m \quad (3.2)$$

Once invested, the actual profitability of farming depends on the margin between the price x_t and the unit production costs c . If the margin is positive then active farming is profitable whereas, if it is negative, then active farming would generate losses and the landowner decides to temporally stop farming. Summing up, the gains associated with the investment are as follows

$$\pi_t = \begin{cases} \frac{\alpha^\gamma}{\gamma}(x_t - c) + s - m, & \text{for } x_t > c \\ s - m, & \text{for } x_t \leq c \end{cases} \quad (3.3)$$

As a positive payoff is associated with passive farming, the active farmer may be viewed as holding the option to suspend her/his activities whenever farming is not profitable. Similarly, a passive farmer may be viewed as holding the option to restart the agricultural activity as soon as farming becomes profitable. In this respect, we assume that passing from active to passive farming and vice versa is costless. This makes sense considering that land has been, in any case, kept in GAEC. Last, for the sake of simplicity, we assume that i) once invested, the project runs forever¹¹ and ii) the capital installed does not "rust" i.e., no maintenance is required.¹² Finally, it is assumed that the farmer is risk neutral and discounts future payoffs using the interest rate $r > \mu$.¹³

3 The model

Let $V(x_t; \alpha)$ represent the farm's operating value upon investment. Solving a standard dynamic programming problem we have¹⁴

$$V(x_t; \alpha) = \begin{cases} \tilde{A}x_t^{\beta_2} + \frac{\alpha^\gamma}{\gamma}\left(\frac{x_t}{r-\mu} - \frac{c}{r}\right) + \frac{s-m}{r} & \text{for } x_t > c \\ \tilde{B}x_t^{\beta_1} + \frac{s-m}{r} & \text{for } x_t \leq c \end{cases} \quad (4)$$

for any $\alpha \in [0, 1]$

where $\beta_2 < 0$ and $\beta_1 > 1$ are the roots of the characteristic equation $\Lambda(\beta) \equiv \frac{1}{2}\sigma^2\beta(\beta-1) + \mu\beta - r$.

As shown in Section A.1 of Appendix A, by imposing the value matching and smooth pasting conditions at $x_t = c$, we can determine the value of the constants \tilde{A} and \tilde{B} , that is,

$$\tilde{A} = \frac{\alpha^\gamma}{\gamma}A = \frac{\alpha^\gamma}{\gamma} \frac{r - \mu\beta_1}{(\beta_1 - \beta_2)r(r - \mu)} c^{1-\beta_2} \quad (5.1)$$

$$\tilde{B} = \frac{\alpha^\gamma}{\gamma}B = \frac{\alpha^\gamma}{\gamma} \frac{r - \mu\beta_2}{(\beta_1 - \beta_2)r(r - \mu)} c^{1-\beta_1} = \tilde{A} \frac{r - \mu\beta_2}{r - \mu\beta_1} c^{\beta_2-\beta_1} \quad (5.2)$$

Note that both constants are nonnegative and concave in the capital intensity α .¹⁵ This makes sense considering that the value associated with both options depends on the capacity $q(\alpha)$ corresponding to the chosen capital intensity α .

¹¹This is an assumption that does not affect the quality of our results.

¹²A complete analysis on the cost of suspending, maintaining and restarting a project is presented in Dixit and Pindyck (1994, chap. 7).

¹³This restriction is needed in order to ensure convergence. See Dixit and Pindyck (1994, pp. 138).

¹⁴See Section A.1 in Appendix A.

¹⁵On the value of the options to switch see Dixit and Pindyck (1994, pp. 188-189).

In Eq. (4) we observe that for $x_t > c$ (active farming scenario), the value of the farm is given by the value of the option to switch to passive farming, $\tilde{A}x_t^{\beta_2}$, plus the net benefit from farming, $\frac{\alpha^\gamma}{\gamma}(\frac{x_t}{r-\mu} - \frac{c}{r})$, and the discounted flow of the net subsidy, $\frac{s-m}{r}$. Note that the value of the option to switch to passive farming is, consistently, decreasing in the price level x_t and increasing in the unit production cost c . This makes sense considering that this option becomes less valuable if profits from active farming decrease. On the other branch of the value function, i.e., for $x_t \leq c$ (passive farming scenario), the operating value of the farm is given by the value of the option to switch from passive to active farming as soon as active farming becomes profitable, i.e., $\tilde{B}x_t^{\beta_1}$, plus the discounted flow $\frac{s-m}{r}$. Note that the value of the option to restart agricultural activities is increasing in the price level x_t and decreasing in the unit production cost c . This makes sense considering that this option becomes more valuable if profits from active farming are higher.

In the following, we will assume that $\frac{s-m}{r} \leq k_1$. This is to avoid the consideration of trivial investment projects where, as the discounted flow of net subsidy, $\frac{s-m}{r}$, is higher than k_1 , it would be worth investing immediately with minimum capital intensity.

3.1 The optimal intensity

In this section we determine the optimal intensity level α^* that the landowner should adopt. As discussed above, the landowner sets α^* taking also into account the options implicitly purchased by investing. The options to switch between passive and active farming (and vice versa), due to the flexibility associated, may result particularly valuable as they allow hedging against the volatility that, via the market price, may characterize profits from farming. The value associated with this flexibility depends on the capital intensity adopted, thus it does not come for free. The landowner must then set α^* trading off the associated benefits in terms of production capacity and flexibility with the corresponding investment cost.

In the following we will restrict our analysis to the scenario where farming is profitable, i.e., $x_t > c$.¹⁶

3.1.1 Optimal land development under active farming

When $x_t > c$, as active farming is profitable, the landowner would use land for production as soon as the investment has been undertaken. The optimal level of intensity should then be set so that the corresponding expected net present value is maximized. The optimal $\bar{\alpha}$ solves the following problem

$$\bar{\alpha} = \arg \max NPV^a(x_t, \alpha), \text{ s.t. } 0 < \bar{\alpha} \leq 1 \quad (6)$$

where

$$NPV^a(x_t, \alpha) = V(x_t, \alpha) - I(\alpha) = \tilde{A}x_t^{\beta_2} + \frac{\alpha^\gamma}{\gamma} \left(\frac{x_t}{r-\mu} - \frac{c}{r} \right) + \frac{s-m}{r} - (k_1 + k_2\alpha) \quad (6.1)$$

The solution of problem (6) leads to the following proposition

Proposition 1 *Provided that $\Psi = k_2 - Bc^{\beta_1} > 0$,¹⁷ the optimal intensity level when investing at*

¹⁶The less realistic scenario where the landowner considers converting idle land to farmland when farming is not profitable, is presented in Appendix B where we show that the relative investment timing problem has no interior solution.

¹⁷In Section A.2 of Appendix A, we also derive the optimal capital intensity for $\Psi = k_2 - Bc^{\beta_1} \leq 0$. In that case, $\bar{\alpha}(x_t)$ is equal to 1 for any $x_t > c$. Note that the relative analysis is similar to the one provided for $\bar{\alpha}(x_t) = 1$ under $\Psi > 0$.

$x_t > c$ is

$$\bar{\alpha}(x_t) = \begin{cases} \left(\frac{O(x_t)}{k_2}\right)^{\frac{1}{1-\gamma}} & \text{for } c < x_t < \bar{x} \\ 1 & \text{for } \bar{x} \leq x_t \end{cases} \quad (7)$$

where $O(x_t) \equiv Ax_t^{\beta_2} + \frac{x_t}{r-\mu} - \frac{c}{r}$, and \bar{x} is such that $O(\bar{x}) = k_2$.

Proof. See Section A.2 in Appendix A. ■

As one may easily check, the optimal intensity level $\bar{\alpha}(x_t)$ is increasing in x_t in the interval $c < x_t < \bar{x}$. This is the result of two opposing forces. First, as x_t increases, due to the higher expected net benefits associated to farming, i.e., $\frac{x_t}{r-\mu} - \frac{c}{r}$, the landowner would prefer to invest more intensively. Second, $\bar{\alpha}(x_t)$ is increasing in the value of the option to switch to passive farming, i.e., $Ax_t^{\beta_2}$. This makes sense considering that the option allows hedging against the volatility of profits from active farming. However, as x_t increases, switching to passive farming is less likely and then the value associated to this option is lower. As shown in Section A.2 of Appendix A, the first force is prevailing for any $x_t \in (c, \bar{x}]$. Last, substituting Eq. (7) into Eq. (6.1) yields

$$NPV^a(x_t, \bar{\alpha}(x_t)) = \begin{cases} \left(\frac{O(x_t)}{k_2}\right)^{\frac{1}{1-\gamma}} \left(\frac{1}{\gamma} - 1\right) k_2 + \frac{s-m}{r} - k_1 & \text{for } c < x_t < \bar{x} \\ \frac{O(x_t)}{\gamma} + \frac{s-m}{r} - (k_1 + k_2) & \text{for } \bar{x} \leq x_t \end{cases} \quad (8)$$

4 Value and timing of the investment

Let's now study the timing of the investment and derive the value of the option to invest in a land development project. We consider the option to invest in the continuation region $x_t \leq \hat{x}$ where \hat{x} is the price threshold triggering investment. The value of the option is given by

$$F(x_t) = \max_{\tau} E_t(e^{-r\tau} NPV^a(x_{\tau})) \quad (9)$$

where $\tau = \inf \{t \geq 0 \mid x_t = \hat{x}\}$ is the optimal investment stopping time.

Eq. (9) can be rearranged as follows¹⁸

$$F(x_t, \hat{x}) = \max_{\hat{x}} \left\{ \left(\frac{x_t}{\hat{x}}\right)^{\beta_1} NPV^a(\hat{x}) \right\} \quad (9.1)$$

From the first-order condition for the optimal \hat{x} we have¹⁹

$$\hat{x} = \beta_1 \frac{NPV^a(\hat{x})}{\frac{\partial NPV^a(\hat{x})}{\partial \hat{x}}} \quad (10)$$

Let's now consider the two investment scenarios illustrated in Proposition 1.

We start by considering the region where it is optimal to invest with the highest possible capital intensity, $\bar{\alpha}(x_t) = 1$, i.e., $\bar{x} \leq x_t$. In Appendix A we show that

Proposition 2 *Provided that $\frac{\bar{x}}{r-\mu} - \frac{c}{r} \geq \Delta$, the optimal investment threshold, x^* , for a project with capital intensity $\bar{\alpha}(x_t) = 1$ is the solution of the following equation*

$$x^* + \frac{\beta_1 - \beta_2}{\beta_1 - 1} Ax^{*\beta_2} (r - \mu) - \frac{\beta_1}{\beta_1 - 1} (r - \mu) \left\{ \frac{c}{r} - \gamma \left[\frac{s-m}{r} - (k_1 + k_2) \right] \right\} = 0 \quad (11)$$

where $\Delta = \frac{\frac{c}{r} + k_2\beta_2 - \beta_1[k_2(1-\gamma) + \gamma(\frac{s-m}{r} - k_1)]}{\beta_2 - 1}$.

¹⁸For the calculation of expected present values, see Dixit and Pindyck (1994, pp. 315-316).

¹⁹See Section A.3 in Appendix A for the derivation of Eq. (10). A more general presentation of how to approach similar maximization problems is given in Dixit et al. (1999).

Proof. See Section A.3.1 in Appendix A. ■

We observe that investment is conditional on having an expected profitability of active farming, $\frac{x_t}{r-\mu} - \frac{c}{r}$, higher than the level Δ at \bar{x} . Otherwise, the project is not worth investing.

Let's now turn to the region of prices where the landowner invests with capital intensity $\bar{\alpha}(x_t) < 1$, i.e., $c < x_t < \bar{x}$. We find that

Proposition 3 *Provided that $\frac{\bar{x}}{r-\mu} - \frac{c}{r} \leq \Delta$, the optimal investment threshold, x^{**} , for a project with capital intensity $\bar{\alpha}(x_t) < 1$ is the solution of the following equation*

$$x^{**} \frac{\partial \bar{\alpha}(x^{**})}{\partial x^{**}} - \beta_1 \left[\bar{\alpha}(x^{**}) + \frac{\gamma}{1-\gamma} \frac{\frac{s-m}{r} - k_1}{k_2} \right] = 0 \quad (12)$$

Proof. See Section A.3.2 in Appendix A. ■

In this case, the restriction posed requires that the expected profitability of unit active farming is below the level Δ at \bar{x} . Otherwise, it does not make sense investing with a capital intensity lower than the maximum possible. Let's now study the impact that the requirement for securing that land is in GAEC has on the timing of investment. In Section A.3 of Appendix A we show that

Proposition 4 *A landowner who contemplates investing in the development of idle land will, in expected terms and irrespective of the capital intensity chosen, hasten the investment decision as the net subsidy $s - m$ increases.*

This result is interesting since it implies that, if compared with a scenario where the policy is absent, i.e., $s = 0 \rightarrow (s - m)^+ = 0$, compensating farmers for keeping arable land in GAEC does not deter investment but, in contrast, fosters land development.

Interestingly, studying the case where the price level is such that it is optimal investing with capital intensity $\bar{\alpha}(x_t) < 1$, we can easily show that

Proposition 5 *When investing in the region $c < x_t < \bar{x}$, the chosen capital intensity is decreasing in the net subsidy $s - m$.*

As shown above, $\bar{\alpha}$ is increasing in x_t , hence, as by Proposition 4 $\partial x^{**}/\partial(s - m) < 0$, then $\partial \bar{\alpha}(x^{**})/\partial(s - m) < 0$. The result is interesting since it implies that, if compared with a scenario where the policy is absent, compensating landowners induces not only earlier investment but, at the same time, investment in development projects with lower capital intensity. Note that this would be in line with an underlying target behind the choice of having decoupled payments. In fact, as capital intensity is lower, the impact on market prices of additional capacity $q(\alpha)$ is more limited.

5 Epilogue

The decoupling of direct payments from commodity production was certainly a step further towards responsible production and sustainable management of natural resources but at the same time gave rise to several issues. In this paper, we have been focusing on the so-called passive farming, that is, maintaining land in GAEC without producing any commodity in order to be entitled to CAP support. Several parties have strongly criticized the support paid to passive farmers arguing that it may hinder rural development and an efficient use of land. We have focused on this specific issue and studied how decisions concerning investment in land development projects are affected by the current policy frame. We show that the policy, by implicitly providing hedging against volatile agricultural profits, may actually foster investment initiatives and land development. This result

contradicts one of the main arguments presented against the CAP support to passive farming. In addition, we show that landowners opt for investment projects characterized by lower capital intensity. This suggests that the current policy frame induces investment projects that secure the maintenance of land in GAEC (under both active and passive farming) with a lower impact in terms of capacity added, thus limiting the formation of excess capacity.

A Appendix A

A.1 The farm operating value

The standard arbitrage and hedging arguments (Dixit, 1989, pp. 624-628) require that the farm operating value, $V(x_t; \alpha)$, is the solution of the following dynamic programming equations:

$$\begin{aligned}\Gamma V(x_t; \alpha) &= - \left[\frac{\alpha^\gamma}{\gamma} (x_t - c) + s - m \right], & \text{for } x_t > c, \\ \Gamma V(x_t; \alpha) &= - (s - m), & \text{for } x_t \leq c,\end{aligned}\tag{A.1.1-A.1.2}$$

where Γ is the differential operator: $\Gamma = -r + \mu x \frac{\partial}{\partial x} + \frac{1}{2} \sigma^2 x^2 \frac{\partial^2}{\partial x^2}$. The solution of Eq. (A.1.1) and Eq. (A.1.2) requires the following boundary conditions

$$\begin{aligned}\lim_{x \rightarrow \infty} \left\{ V(x_t; \alpha) - \left[\frac{\alpha^\gamma}{\gamma} \left(\frac{x_t}{r-\mu} - \frac{c}{r} \right) + \frac{s-m}{r} \right] \right\} &= 0, & \text{for } x_t > c, \\ \lim_{x \rightarrow 0} \left\{ V(x_t; \alpha) - \frac{s-m}{r} \right\} &= 0, & \text{for } x_t \leq c.\end{aligned}$$

Hence, from the assumptions and the linearity of (A.1.1) and (A.1.2), using the above boundary conditions and imposing the value matching and the smooth pasting conditions at $x_t = c$ we obtain

$$\begin{aligned}\tilde{A}c^{\beta_2} + \frac{\alpha^\gamma}{\gamma} \left(\frac{c}{r-\mu} - \frac{c}{r} \right) + \frac{s-m}{r} &= \tilde{B}c^{\beta_1} + \frac{s-m}{r} \\ \tilde{A}\beta_2 c^{\beta_2-1} + \frac{\alpha^\gamma}{\gamma} \frac{1}{r-\mu} &= \tilde{B}\beta_1 c^{\beta_1-1}\end{aligned}\tag{A.1.3}$$

where $\beta_2 < 0$ and $\beta_1 > 1$ are the roots of the characteristic equation $\Lambda(\beta) \equiv \frac{1}{2} \sigma^2 \beta(\beta-1) + \mu\beta - r$. Solving, the system (A.1.3) yields:

$$\tilde{A} = \frac{\alpha^\gamma}{\gamma} A = \frac{\alpha^\gamma}{\gamma} \frac{r - \mu\beta_1}{(\beta_1 - \beta_2)r(r - \mu)} c^{1-\beta_2}\tag{A.1.4}$$

$$\tilde{B} = \frac{\alpha^\gamma}{\gamma} B = \frac{\alpha^\gamma}{\gamma} \frac{r - \mu\beta_2}{(\beta_1 - \beta_2)r(r - \mu)} c^{1-\beta_1} = \tilde{A} \frac{r - \mu\beta_2}{r - \mu\beta_1} c^{\beta_2-\beta_1}\tag{A.1.5}$$

which are non-negative.²⁰

A.2 Optimal intensity

Suppose that $x_t > c$, the optimal intensity level, $\bar{\alpha}$, should then be given by the solution of the following problem

$$\begin{aligned}\bar{\alpha} &= \arg \max \left\{ \tilde{A}x_t^{\beta_2} + \frac{\alpha^\gamma}{\gamma} \left(\frac{x_t}{r-\mu} - \frac{c}{r} \right) + \frac{s-m}{r} - I(\alpha) \right\} \\ &= \arg \max \left\{ \frac{\alpha^\gamma}{\gamma} \left(Ax_t^{\beta_2} + \frac{x_t}{r-\mu} - \frac{c}{r} \right) + \frac{s-m}{r} - (k_1 + k_2\alpha) \right\}.\end{aligned}\tag{A.2.1}$$

The first-order condition,

$$\bar{\alpha}^{\gamma-1} \left(Ax_t^{\beta_2} + \frac{x_t}{r-\mu} - \frac{c}{r} \right) - k_2 = 0\tag{A.2.1a}$$

yields

$$\bar{\alpha} = \left(\frac{Ax_t^{\beta_2} + \frac{x_t}{r-\mu} - \frac{c}{r}}{k_2} \right)^{\frac{1}{1-\gamma}}\tag{A.2.2}$$

²⁰On the value of options to switch see Dixit and Pindyck (1994, pp. 188-189).

It is easy to check that the second-order condition for Problem (A.2.1) always holds.

Note that, for having a sensible $\bar{\alpha}$, we need to check the conditions under which $\bar{\alpha} \in [0, 1]$ or, alternatively

$$0 \leq O(x_t) \leq k_2$$

where $O(x_t) \equiv Ax_t^{\beta_2} + \frac{x_t}{r-\mu} - \frac{c}{r}$.

Note that $O(x_t)$ is convex in x_t since

$$O''(x_t) = \beta_2(\beta_2 - 1)Ax_t^{\beta_2-2} > 0$$

Further,

$$O(c) = \frac{r - \mu\beta_2}{(\beta_1 - \beta_2)r(r - \mu)}c = Bc^{\beta_1} > 0$$

and

$$O'(c) = \frac{r - \mu\beta_2}{(\beta_1 - \beta_2)r(r - \mu)}\beta_1 > 0$$

Hence, it follows that $O(x_t) > 0$ and $O'(x_t) > 0$ for any $x_t > c$.

Let us now check under what conditions $O(x_t) \leq k_2$ (or $\bar{\alpha} \leq 1$). In general, the equation $O(x_t) = k_2$ has at most two (positive) roots. However, as $O'(c) > 0$, the only admissible root, \bar{x} , must lay above c and should be such that

$$O(\bar{x}) = A\bar{x}^{\beta_2} + \frac{\bar{x}}{r - \mu} - \frac{c}{r} = k_2 \text{ and } O'(\bar{x}) > 0$$

Note that

$$\bar{\alpha} = 1 \text{ for any } \bar{x} \leq x_t$$

Now, in order to completely characterize the function $\bar{\alpha}$, let's define

$$\Psi = O(\bar{x}) - O(c) = k_2 - Bc^{\beta_1}$$

Hence, it follows that

$$\begin{aligned} \text{Scenario A} \quad & \bar{\alpha} \leq 1, \quad \text{if } \Psi > 0 \rightarrow \bar{x} > c \\ \text{Scenario B} \quad & \bar{\alpha} = 1, \quad \text{if } \Psi \leq 0 \rightarrow \bar{x} \leq c \end{aligned}$$

It is worth discussing the role played by the sign of Ψ . Note that this term represents the net marginal cost of capital intensity $\alpha = 1$. In particular, it is given by the difference between the marginal investment cost, k_2 , and the marginal value of the option to switch to active farming, $Bx_t^{\beta_1}$, when evaluated at the boundary $x_t = c$. Then, even if at such a low price level, the marginal benefit, Bc^{β_1} , is higher than the marginal cost, k_2 , the farmer should just go for the highest capital intensity possible. Otherwise, a lower intensity is optimal. Note in fact that, in the latter case, only for price sufficiently high, i.e., $x_t \geq \bar{x}$, investing in the highest intensity possible is optimal.

A.3 Timing of land development

The net present value corresponding to the land development projects identified above can be easily computed by substituting the optimal intensity level, $\bar{\alpha}$, into the function

$$NPV(x_t; \alpha) = V(x_t; \alpha) - I(\alpha) \tag{A.3.1}$$

Substituting $\bar{\alpha}(x_t)$ into Eq. (A.3.1) we obtain:

(a) for $\Psi > 0$

$$NPV^a(x_t, \bar{\alpha}(x_t)) = \begin{cases} \left(\frac{O(x_t)}{k_2}\right)^{\frac{1}{1-\gamma}} \left(\frac{1}{\gamma} - 1\right) k_2 + \frac{s-m}{r} - k_1 & \text{for } c < x_t < \bar{x} \\ \frac{O(x_t)}{\gamma} + \frac{s-m}{r} - (k_1 + k_2) & \text{for } c < \bar{x} \leq x_t \end{cases} \quad (\text{A.3.2})$$

(b) for $\Psi \leq 0$

$$NPV^a(x_t, \bar{\alpha}(x_t)) = \frac{O(x_t)}{\gamma} + \frac{s-m}{r} - (k_1 + k_2) \quad \text{for } \bar{x} \leq c < x_t \quad (\text{A.3.3})$$

The value of the option to develop the land is given by the following function

$$F(x_t) = \max_{\tau} E_t(e^{-r\tau} NPV(x_{\tau})) \quad (\text{A.3.4})$$

where $\tau = \inf\{t \geq 0 \mid x_t = \hat{x}\}$ is the optimal stopping time where land development occurs.

Equation (A.3.4) is equivalent to

$$F(x_t, \hat{x}) = \max_{\hat{x}} \left\{ \left(\frac{x_t}{\hat{x}}\right)^{\beta_1} NPV^a(\hat{x}) \right\} \quad (\text{A.3.5})$$

Following Dixit et al. (1999) the threshold \hat{x} solves the following problem

$$\frac{\partial \left(\frac{x_t}{\hat{x}}\right)^{\beta_1} NPV^a(\hat{x})}{\partial \hat{x}} = 0 \quad (\text{A.3.6})$$

By rearranging it is easy to show that

$$\begin{aligned} \frac{\partial NPV(\hat{x})}{\partial \hat{x}} \left(\frac{x_t}{\hat{x}}\right)^{\beta_1} + NPV(\hat{x}) \frac{\partial \left(\frac{x_t}{\hat{x}}\right)^{\beta_1}}{\partial \hat{x}} &= 0 \\ \rightarrow \\ \hat{x} &= \beta_1 \frac{NPV(\hat{x})}{\frac{\partial NPV(\hat{x})}{\partial \hat{x}}} \end{aligned} \quad (\text{A.3.7})$$

Last, note that for the problem to be well-posed, the following condition must hold at $x_t = \hat{x}$

$$\begin{aligned} \left. \frac{\partial^2 NPV(\hat{x}) \left(\frac{x_t}{\hat{x}}\right)^{\beta_1}}{\partial x_t^2} \right|_{x_t=\hat{x}} &> \left. \frac{\partial^2 NPV(x_t)}{\partial x_t^2} \right|_{x_t=\hat{x}} \\ \rightarrow \\ \frac{\partial NPV(\hat{x})}{\partial \hat{x}} &> \frac{\hat{x}}{\beta_1 - 1} \frac{\partial^2 NPV(\hat{x})}{\partial \hat{x}^2} \end{aligned} \quad (\text{A.3.8})$$

A.3.1 Scenario A: $\bar{\alpha}(x_t) = 1$

Let's start our analysis by considering the interval where $\bar{\alpha}(x_t) = 1$, i.e., $c < \bar{x} \leq x_t$. Denote by x^* the optimal development threshold. Substituting Eq. (A.3.2) in Eq. (A.3.7) and rearranging, we obtain the equation

$$x^* + \frac{\beta_1 - \beta_2}{\beta_1 - 1} A x^{*\beta_2} (r - \mu) - \frac{\beta_1}{\beta_1 - 1} (r - \mu) \left\{ \frac{c}{r} - \gamma \left[\frac{s-m}{r} - (k_1 + k_2) \right] \right\} = 0 \quad (\text{A.3.9})$$

which must be solved for x^* .

Existence and uniqueness of x^* - Define the function

$$\Phi(x_t) = x_t + \frac{\beta_1 - \beta_2}{\beta_1 - 1} A x_t^{\beta_2} (r - \mu) - \frac{\beta_1}{\beta_1 - 1} (r - \mu) \left\{ \frac{c}{r} - \gamma \left[\frac{s - m}{r} - (k_1 + k_2) \right] \right\}$$

Note that $\Phi(x_t)$ is convex and that $\Phi(x^*) = 0$.

The existence of a solution requires that $\Phi(c) \leq 0$. It is easy to prove that, by the assumption $\frac{s-m}{r} \leq k_1$, this condition is always met since

$$\Phi(c) = \frac{\beta_1}{\beta_1 - 1} \gamma \left(\frac{s - m}{r} - (k_1 + k_2) \right) (r - \mu) < 0$$

This proves that the solution x^* is unique. Note also that at $x_t = x^*$

$$\left. \frac{\partial \Phi(x_t)}{\partial x_t} \right|_{x_t=x^*} = 1 + \beta_2 \frac{\beta_1 - \beta_2}{\beta_1 - 1} A x^{*\beta_2-1} (r - \mu) > 0$$

which, in turn, implies that the condition (A.3.8) holds as

$$\begin{aligned} \frac{\partial NPV(x^*)}{\partial x^*} &> \frac{x^*}{\beta_1 - 1} \frac{\partial^2 NPV(x^*)}{\partial x^{*2}} \\ &\rightarrow \\ (\beta_1 - 1) \frac{1}{\gamma} \frac{\partial O(x^*)}{\partial x^*} &> \frac{x^*}{\gamma} \frac{\partial^2 O(x^*)}{\partial x^{*2}} \\ &\rightarrow \\ 1 + \beta_2 \frac{\beta_1 - \beta_2}{\beta_1 - 1} A x^{*\beta_2-1} (r - \mu) &> 0 \end{aligned} \quad (\text{A.3.8a})$$

Last, the following necessary and sufficient condition must hold for having $\bar{x} \leq x^*$

$$\begin{aligned} \Phi(\bar{x}) &\leq 0 \\ &\rightarrow \\ \frac{\bar{x}}{r - \mu} - \frac{c}{r} &\geq \frac{\frac{c}{r} + k_2 \beta_2 - \beta_1 [k_2(1 - \gamma) + \gamma (\frac{s-m}{r} - k_1)]}{\beta_2 - 1} \end{aligned}$$

Policy impact on the investment timing - By differentiating Eq. (A.3.9) with respect to $s - m$ we obtain

$$\frac{\partial x^*}{\partial (s - m)} = - \frac{\frac{\gamma}{r} \frac{\beta_1}{\beta_1 - 1}}{1 + \frac{\beta_2}{\beta_1 - 1} \frac{r - \mu \beta_1}{r} \left(\frac{x^*}{c} \right)^{\beta_2 - 1}} (r - \mu) \quad (\text{A.3.10})$$

Note that, by condition (A.3.8a), the denominator must be strictly positive. Hence, we may conclude that $\frac{\partial x^*}{\partial (s - m)} < 0$.

A.3.2 Scenario A: $\bar{\alpha}(x_t) < 1$

Let's now consider the interval where $\bar{\alpha}(x_t) < 1$, i.e., $c < x_t < \bar{x}$. Denote by x^{**} the optimal development threshold. Substituting Eq. (A.3.2) in Eq. (A.3.7) we obtain the equation

$$x^{**} \frac{\partial \bar{\alpha}(x^{**})}{\partial x^{**}} - \beta_1 \bar{\alpha}(x^{**}) - \frac{\gamma}{1 - \gamma} \frac{\frac{s-m}{r} - k_1}{k_2} \beta_1 = 0 \quad (\text{A.3.11})$$

which must be solved for x^{**} .

Existence and uniqueness of x^{}** - Define the function

$$\Theta(x_t) = x_t \frac{\partial \bar{\alpha}(x_t)}{\partial x_t} - \beta_1 \bar{\alpha}(x_t) - \frac{\gamma}{1-\gamma} \frac{\frac{s-m}{r} - k_1}{k_2} \beta_1$$

First and second order derivatives with respect to x_t are as follows

$$\begin{aligned} \frac{\partial \Theta(x_t)}{\partial x_t} &= x_t \frac{\partial^2 \bar{\alpha}(x_t)}{\partial x_t^2} - \frac{\partial \bar{\alpha}(x_t)}{\partial x_t} (\beta_1 - 1) \\ \frac{\partial^2 \Theta(x_t)}{\partial x_t^2} &= x_t \frac{\partial^3 \bar{\alpha}(x_t)}{\partial x_t^3} - \frac{\partial^2 \bar{\alpha}(x_t)}{\partial x_t^2} (\beta_1 - 2) \end{aligned}$$

Note that in the interval considered

$$\begin{aligned} \frac{\partial \bar{\alpha}(x_t)}{\partial x_t} &= \frac{\partial \bar{\alpha}(O(x_t))}{\partial O(x_t)} O'(x_t) > 0 \\ \frac{\partial^2 \bar{\alpha}(x_t)}{\partial x_t^2} &= \frac{\partial \bar{\alpha}(O(x_t))}{\partial O(x_t)} O''(x_t) > 0 \\ \frac{\partial^3 \bar{\alpha}(x_t)}{\partial x_t^3} &= \frac{\partial \bar{\alpha}(O(x_t))}{\partial O(x_t)} O'''(x_t) < 0 \end{aligned}$$

Hence, as

$$\frac{\partial^2 \Theta(x_t)}{\partial x_t^2} = \frac{\partial \bar{\alpha}(O(x_t))}{\partial O(x_t)} \beta_2 (\beta_2 - 1) (\beta_2 - \beta_1) A x_t^{\beta_2 - 2} < 0$$

we can conclude that $\Theta(x_t)$ is concave.

The existence of a solution requires that $\Theta(c) \geq 0$. It is easy to prove that this condition is always met as

$$\Theta(c) = \beta_1 \frac{\gamma}{1-\gamma} \left(\bar{\alpha}(c) - \frac{\frac{s-m}{r} - k_1}{k_2} \right) > 0$$

This proves that the solution $x^{**} > c$ is unique. Note that at $x_t = x^{**}$

$$\left. \frac{\partial \Theta(x_t)}{\partial x_t} \right|_{x_t=x^{**}} = x^{**} \frac{\partial^2 \bar{\alpha}(x^{**})}{\partial x^{**2}} - (\beta_1 - 1) \frac{\partial \bar{\alpha}(x^{**})}{\partial x^{**}} < 0$$

which, in turn, implies that condition (A.3.8) holds as

$$\begin{aligned} \frac{\partial NPV(x^{**})}{\partial x^{**}} &> \frac{x^{**}}{\beta_1 - 1} \frac{\partial^2 NPV(x^{**})}{\partial x^{**2}} \\ &\rightarrow \\ x^{**} \frac{\partial^2 \bar{\alpha}(x^{**})}{\partial x^{**2}} - (\beta_1 - 1) \frac{\partial \bar{\alpha}(x^{**})}{\partial x^{**}} &< 0 \end{aligned} \tag{A.3.8b}$$

Last, the following necessary and sufficient requirement must hold for having $x^{**} \leq \bar{x}$

$$\begin{aligned} \Theta(\bar{x}) &\leq 0 \\ &\rightarrow \\ \frac{\bar{x}}{r - \mu} - \frac{c}{r} &\leq \frac{\frac{c}{r} + k_2 \beta_2 - \beta_1 [k_2(1 - \gamma) + \gamma (\frac{s-m}{r} - k_1)]}{\beta_2 - 1} \end{aligned}$$

Policy impact on the investment timing - Differentiating Eq. (A.3.11) with respect to $s - m$ yields

$$\frac{\partial x^{**}}{\partial (s - m)} = \frac{\frac{\beta_1}{r}}{\left(\frac{1}{\gamma} - 1\right) k_2 \left[x^{**} \frac{\partial^2 \bar{\alpha}(x^{**})}{\partial x^{**2}} - (\beta_1 - 1) \frac{\partial \bar{\alpha}(x^{**})}{\partial x^{**}} \right]}$$

It is easy to check that, by condition (A.3.8b), the investment threshold responds negatively to changes in $s - m$, i.e., $\frac{\partial x^{**}}{\partial (s - m)} < 0$.

A.3.3 Scenario B

For $\bar{x} \leq c$, the farmer would always invest in the highest possible capital intensity, i.e., $\bar{\alpha}(x_t) = 1$. The analysis is identical to the one provided for the corresponding case in Scenario A. Note that as $\Phi(c) < 0$, then $c < x^{**}$.

B Appendix B

For the convenience of the reader we provide also the analysis relative to the case where $x_t \leq c$, that is, the region where the commodity price is lower than the unit cost of production. We remind that in this region a farmer would manage her/his plot passively as soon as the investment has been undertaken.

B.1 Optimal intensity

The optimal intensity level should be given by the solution of the following problem

$$\begin{aligned} \underline{\alpha} &= \arg \max \left\{ \tilde{B}x_t^{\beta_1} + \frac{s - m}{r} - I(\alpha) \right\} \\ &= \arg \max \left\{ \frac{\alpha^\gamma}{\gamma} Bx_t^{\beta_1} + \frac{s - m}{r} - (k_1 + k_2\alpha) \right\}. \end{aligned} \quad (\text{B.1.1})$$

The relative first-order condition is

$$\underline{\alpha}^{\gamma-1} Bx_t^{\beta_1} - k_2 = 0 \quad (\text{B.1.1a})$$

which yields:

$$\underline{\alpha} = \left(\frac{Bx_t^{\beta_1}}{k_2} \right)^{\frac{1}{1-\gamma}} \quad (\text{B.1.2})$$

It is easy to check that the second-order condition for Problem (B.1.1) always holds.

Note that, for having a sensible $\underline{\alpha}$, we need to check the conditions under which $\underline{\alpha} \in [0, 1]$. By the non-negativity of x_t , $\underline{\alpha}$ is always positive. To secure that $\underline{\alpha} \leq 1$, we must impose that $Bx_t^{\beta_1} \leq k_2$. By the monotonicity of $Bx_t^{\beta_1}$, the equation $Bx_t^{\beta_1} = k_2$ admits a unique solution $\underline{x}(> 0)$.

Note that

$$\underline{\alpha} = 1 \text{ for any } \underline{x} \leq x_t$$

Summing up, the function $\underline{\alpha}$ can be characterized as follows

$$\begin{aligned} \text{Scenario C} \quad & \underline{\alpha} \leq 1, \quad \text{if } \Psi \leq 0 \rightarrow \underline{x} \leq c \\ \text{Scenario D} \quad & \underline{\alpha} < 1, \quad \text{if } \Psi > 0 \rightarrow \underline{x} > c \end{aligned}$$

where $\Psi = k_2 - Bc^{\beta_1}$.

B.2 Timing of land development

The net present value corresponding to the land development projects identified above can be easily computed by substituting the optimal intensity level $\underline{\alpha}$ into the function

$$NPV(x_t; \alpha) = V(x_t; \alpha) - I(\alpha) \quad (\text{B.2.1})$$

This yields

(a) for $\Psi \leq 0$

$$NPV^p(x_t, \underline{\alpha}(x_t)) = \begin{cases} \left(\frac{1}{\gamma} - 1\right) \left(\frac{Bx_t^{\beta_1}}{k_2}\right)^{\frac{1}{1-\gamma}} k_2 + \frac{s-m}{r} - k_1 & \text{for } x_t < \underline{x} \leq c \\ \frac{Bx_t^{\beta_1}}{\gamma} + \frac{s-m}{r} - (k_1 + k_2) & \text{for } \underline{x} \leq x_t \leq c \end{cases} \quad (\text{B.2.2})$$

(b) for $\Psi > 0$

$$NPV^p(x_t, \underline{\alpha}(x_t)) = \left(\frac{1}{\gamma} - 1\right) \left(\frac{Bx_t^{\beta_1}}{k_2}\right)^{\frac{1}{1-\gamma}} k_2 + \frac{s-m}{r} - k_1 \quad \text{for } x_t \leq c < \underline{x} \quad (\text{B.2.3})$$

B.2.1 Scenario C

Let's start our analysis by considering the interval where $\underline{\alpha}(x_t) = 1$, i.e., $\underline{x} \leq x_t \leq c$. Denote by \tilde{x}^* the optimal development threshold. The value of the option to develop is given by

$$F(x_t, \tilde{x}^*) = \max_{\tilde{x}^*} \left\{ \left(\frac{x_t}{\tilde{x}^*}\right)^{\beta_1} \left[\frac{B\tilde{x}^{*\beta_1}}{\gamma} + \frac{s-m}{r} - (k_1 + k_2) \right] \right\} \quad (\text{B.2.4})$$

Taking the first-order derivative of the objective with respect to \tilde{x}^* we have:

$$\frac{\partial \left(\frac{x_t}{\tilde{x}^*}\right)^{\beta_1} \left[\frac{B\tilde{x}^{*\beta_1}}{\gamma} + \frac{s-m}{r} - (k_1 + k_2) \right]}{\partial \tilde{x}^*} = -\frac{\beta_1}{\tilde{x}^*} \left(\frac{x_t}{\tilde{x}^*}\right)^{\beta_1} \left[\frac{s-m}{r} - (k_1 + k_2) \right] > 0$$

This implies that the landowner postpones the development of the land as much as possible and undertakes the investment at $\tilde{x}^* = c$. Note that the project is undertaken only if it is worthy enough, that is, if it would pay a non-negative net present value $NPV^p(c) \geq 0$.

Let's now consider the interval $x_t < \underline{x}$. Denote by \tilde{x}^{**} the optimal development threshold. The value of the option to develop is given by

$$F(x_t, \tilde{x}^{**}) = \max_{\tilde{x}^{**}} \left\{ \left(\frac{x_t}{\tilde{x}^{**}}\right)^{\beta_1} \left[\left(\frac{1}{\gamma} - 1\right) \left(\frac{B\tilde{x}^{**\beta_1}}{k_2}\right)^{\frac{1}{1-\gamma}} k_2 + \frac{s-m}{r} - k_1 \right] \right\} \quad (\text{B.2.5})$$

Similarly to the case above, we notice that

$$\frac{\partial \left(\frac{x_t}{\tilde{x}^{**}}\right)^{\beta_1} NPV^p(\tilde{x}^{**})}{\partial \tilde{x}^{**}} = -\frac{\beta_1}{\tilde{x}^{**}} \left(\frac{x_t}{\tilde{x}^{**}}\right)^{\beta_1} \left[\frac{s-m}{r} - (k_1 + k_2 \underline{\alpha}(\tilde{x}^{**})) \right] > 0$$

Hence, also under this scenario, the landowner postpones the development of the land as much as possible and undertakes the investment at $\tilde{x}^{**} = \underline{x}$. Also in this case the initiative is conditional on having $NPV^p(\underline{x}) \geq 0$.

B.2.2 Scenario D

For $c < \underline{x}$, the landowner would opt for a capital intensity, $\underline{\alpha}(x_t) < 1$. The analysis is identical to the one provided for Scenario C when $x_t < \underline{x}$. Land development occurs at $\tilde{x}^{**} = c$ and it is conditional on having $NPV^p(c) \geq 0$.

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