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In this paper, we study how decoupled payments influence the decision to invest in farming. We show that decoupling is implicitly providing a costless hedge against volatile farming profits. Consequently, a higher decoupled payment leads the potential farmer to hasten its investment but also results in a farm with lower productive capacity.

Keywords
Decoupling, Real Options, Land Development, Capital Intensity, Passive Farming

JEL Codes
C61, Q15, R14

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Investment in farming under uncertainty and decoupled support: a real options approach*

Luca Di Corato[†] Dimitrios Zormpas [‡]

February 25, 2019

Abstract

Under the current version of the Common Agricultural Policy (CAP), payments to EU farmers are decoupled from the production of agricultural commodities. In fact, farmers qualify for CAP support as soon as their land is maintained in good agricultural and environmental condition.

In this paper, we study how decoupled payments influence the decision to invest in farming. We show that decoupling is implicitly providing a costless hedge against volatile farming profits. Consequently, a higher decoupled payment leads the potential farmer to hasten its investment but also results in a farm with lower productive capacity.

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1 Introduction

The Common Agricultural Policy (CAP) was firstly launched in 1962 having as its main objectives the food security, market stabilization and farmers' income support in the European Union (EU). The 1992 CAP reform, the Agenda 2000 and the 2003 CAP reform have later reshaped the initial policy frame. These reforms were introduced in order to increase the competitiveness of the farming sector in the EU, ensuring at the same time a stricter budget control and rural development.[1] As of today, the CAP has two main components: Pillar 1, dealing with payments to farmers and Pillar 2, used by EU Member States in order to fund rural development programs.

Before the 2003 CAP reform, payments to farmers were coupled to the production of agricultural commodities. Initially, this measure increased food security but eventually led, by perversely influencing capacity choices at farm level, to overproduction and permanent surpluses. These surpluses were disposed of at a cost as subsidies were introduced in order to have them absorbed within the EU or exported abroad. Low farm efficiency, market distortions and high operating costs soon made

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[1] For a detailed description of the mission and the historical development of the CAP the reader may refer to http://ec.europa.eu/agriculture/cap-history/index_en.htm.

coupled payments unpopular among consumers and taxpayers and paved the way for the consideration of a reform.[2] A new policy frame, the Single Payment Scheme (SPS),[3] was introduced in 2003. The solution proposed in order to fix the issues mentioned above was straightforward and consisted in having payments decoupled from the production of agricultural commodities.[4] Payments became in fact conditional to the maintenance of land according to the, so-called, "cross-compliance" requirements. Cross-compliance relates to issues such as climate change, good agricultural condition of the land, plant health and animal welfare and covers two elements: i) Statutory Management Requirements (SMRs) and, ii) Good Agricultural and Environmental Condition standards (GAECs) (see Table 1).[5]

According to the main argument for decoupling, the CAP should support farmers' income rather than production itself (see e.g. Keenleyside and Tucker, 2010). In addition, a modern rural development policy must count on farmers ability to produce agricultural commodities efficiently, guaranteeing at the same time the preservation of the natural environment and traditional landscapes through sustainable farming practices.[6] Nevertheless, the actual impact of decoupling in the farming sector has been questioned. For instance, Brady et al. (2009) and Ciaian et al. (2010) report that decoupled payments may, by discouraging farm exit and by increasing part-time farming, slow down structural change. Further, decoupled payments are often viewed as transfers supporting passive farming, i.e., minimum land maintenance undertaken without any productive goal but only in order to satisfy the cross-compliance requirements.[7] In turn, active and expansion-willing farmers perceive passively farmed land as underutilized or blocked,[8] as it could have been otherwise used for producing agricultural commodities[9] (see e.g. LRF, 2009; Ciaian et al., 2010), and also as a potential threat for food security (Renwick et al., 2013).

OECD (2001) distinguishes broadly between static and dynamic effects of decoupling. The former materialize whenever policies affect farmers' income by influencing input and output prices. The latter, instead, affect investment decisions taken at farm level. As Moro and Sckokai (2013) point out, decoupled payments may affect labor/leisure choices, on-farm and off-farm labor allocation, financial constraints, land values, land-use transitions, entry-exit decisions and the technical efficiency of the farm.

[2]See e.g. http://ec.europa.eu/agriculture/50-years-of-cap/files/history/history_book_lr_en.pdf

[3]Note that in 2013 the SPS was replaced by the Basic Payment Scheme (BPS) which came into effect in 2015. The BPS is similar to the SPS and is based on i) entitlements to be activated on eligible land and ii) payments decoupled from production. See e.g. https://ec.europa.eu/agriculture/sites/agriculture/files/direct-support/direct-payments/docs/basic-payment-scheme_en.pdf.

[4]Note that, even though the CAP budget devoted to coupled support is limited, EU member states may still adopt coupled payments in order to support potentially vulnerable farming sectors. See for instance https://ec.europa.eu/agriculture/sites/agriculture/files/policy-perspectives/policy-briefs/05_en.pdf, page 7.

[5]Each EU Member State sets the minimum requirements at national or regional level on the basis of the Rules on Cross-Compliance presented in Annex II of the Council Regulation (EC) No. 1306/2013. This allows taking into account specific characteristics of the targeted areas such as soil and climatic conditions, existing farming systems, land use, crop rotation, farming practices and farm structures. See Ciaian et al. (2010) for an illustration and discussion of cross-compliance requirements.

[6]See e.g. https://ec.europa.eu/agriculture/sites/agriculture/files/direct-support/direct-payments/docs/direct-payments-schemes_en.pdf and http://ec.europa.eu/agriculture/50-years-of-cap/files/history/history_book_lr_en.pdf.

[7]According to Trubins (2013), in some, mostly marginal, regions of the EU, 20-30% of the land is managed passively.

[8]Brady et al. (2017) show that passive farming occurs generally when active farmers do not meet the minimal rental price set by the landowners who eventually prefer managing their land passively and cash the payments.

[9]This debate is particularly strong in Sweden where the Federation of Swedish Farmers has taken a clear position against passive farming. Concerns about the impact of passive farming on the land rental market have also been expressed by the Swedish Agricultural Leaseholders Association, the Dairy Association and the Swedish Bioenergy Association (see e.g. Björnsson, 2011; Trubins, 2013; Brady et al., 2017).

In this paper, we shed light on a facet of decoupled payments that the literature has not considered, that is, the impact of this payment scheme on the farm's operational flexibility. We consider a landholder contemplating the opportunity to invest in order to convert a piece of idle land into farmland. We assume that, once the land is converted and the farm is set up, the farmer can switch between two states: i) he can cultivate the land and sell the crop yield when market prices are sufficiently high to make farming profitable, or ii) he can suspend farming operations when no profits can be made, keeping however the option to restart farming as soon as this turns profitable again. Irrespective of the actual state, the farmer cashes a periodic positive net income equivalent to the difference between the payment and the cost of cross-compliance. Given all this, the problem that the landholder faces is twofold: he must select i) the level of productive capacity characterizing the land development project, and ii) the timing of the investment, taking into account, when setting both, that profits from agriculture are volatile and that, consequently, there is a valuable operational flexibility to be associated with the options to suspend and to restart farming.

We study the impact of decoupled payments on productive capacity, timing and value of the land development project by developing a real-options model.[10] This allows, as well known,[11] to properly take into account the presence of i) sunk investment costs (e.g. the cost of converting idle land into farmland), ii) uncertain future payoffs (e.g. volatile prices of agricultural commodities) and iii) temporal and operational flexibility (e.g. the option to postpone the investment and the option to rearrange the farm operations).

Within this framework, we find the following. First, we show that decoupled payments accelerate, in expected terms, investment in land development and increase the value of the option to invest. These results are due to the implicit hedge that decoupled payments provide against farm profit volatility. In fact, the farmer can, even when not actively farming, always count on a positive income flow, i.e., the CAP payment net of the cross-compliance costs. As a result, the farmer recovers more rapidly the investment capital outflow and, consequently, he might invest earlier as the profit threshold triggering investment is lower than in a scenario where no payments are made. At the same time, as satisfying the cross-compliance requirements is contributing to the farmers' cash flow, it is also increasing the value of the option to invest. Second, we find that decoupled payments are not affecting directly the productive capacity of the farm. In other words, in contrast with what was occurring with coupled payments in the past, the farm productive capacity does not depend directly on the payment level. Of course this is not surprising given that, by construction, the payments are decoupled from production. Nevertheless, we identify an indirect effect passing through the investment timing. In fact, as decoupled payments lower the profit threshold triggering investment, they also lower the chosen productive capacity. This is because a higher capacity would require, by increasing the investment cost, postponing investment and then waiting more before cashing profits from farm operations. Summing up, decoupled payments are beneficial when it comes to supporting farmers' income but are definitely not neutral, as often stated, for the definition of farm capacity.

Our contribution can be included in the literature studying how a policy maker may, by using a subsidy, foster the transition from a certain land use to a targeted one in the presence of uncertain payoffs and irreversibility. Thorsen (1999), for instance, presents the case where the afforestation of degraded land is subsidized while Song et al. (2011), Musshoff (2012) and Di Corato et al. (2013) analyze the use of subsidies as a measure to encourage the cultivation of energy crops. In the same vein, Kuminoff and Wossink (2010) study how to support the decision to switch from

[10] See Dixit and Pindyck (1994) for an insightful illustration of the real-options approach.

[11] On irreversible land development under uncertainty see e.g. Capozza and Schwann (1990), Williams (1991), Capozza and Sick (1991) and Capozza and Li (1994).

conventional to organic farming whereas Schatzki (2003) and Isik and Yang (2004) the decision to set aside agricultural land for conservation purposes. More closely related to this paper, Di Corato and Brady (2017) study the effect of decoupled payments on i) the timing and the value of the opportunity to invest in land development and ii) the bargaining between a potential farmer and a landowner for the definition of the rental payment. A main finding is that if compared to a no-policy scenario, decoupled payments foster investment while they slow it down if compared to the case where payments are coupled with production, i.e., only active farmers are eligible for CAP support. Secondly, the authors show that decoupled payments do not deter the potential farmer and the landowner from reaching a deal for the lease of land but only increase the rental payment due to their capitalization.

Our paper departs from previous literature by explicitly considering the effect of decoupled payments on the operational flexibility of the farm. This is relevant since, as explained above, operational flexibility provides hedging against farm profit volatility. In addition, operational flexibility influences the timing of the investment by inducing an earlier investment with respect to the case where one considers only temporal flexibility (see e.g. Capozza and Li, 1994).

The remainder of the paper is as follows. In Section 2 we present the basic set-up, in Section 3 we derive the farm's operating value and in Section 4 we determine the optimal productive capacity of the farm. In Section 5 we study the value and the timing of the investment and in Section 6 we discuss the effects of the policy. Section 7 concludes.

Table 1: Rules on Cross-Compliance#

Area	Main Issue	Requirements and Standards
Environment, climate change and good agricultural condition of land	Water	SMR 1: protection of waters against pollution caused by nitrates GAEC 1: establishment of buffer strips along water courses GAEC 2: compliance with authorization procedures GAEC 3: protection of ground water against pollution
	Soil and Carbon stock	GAEC 4: minimum soil cover GAEC 5: minimum land management reflecting site specific conditions to limit erosion GAEC 6: maintenance of soil organic matter level through appropriate practices
	Biodiversity	SMR 2: conservation of wild birds SMR 3: conservation of natural habitats and of wild flora and fauna
	Landscape, minimum level of maintenance	GAEC 7: retention of landscape features
Public health, animal health and plant health	Food Safety	SMR 4: food law SMR 5: prohibition on the use in stockfarming of certain substances
	Identification and registration of animals	SMR 6: identification and registration of pigs SMR 7: identification and registration of bovine animals SMR 8: identification and registration of ovine and caprine animals
	Animal diseases	SMR 9: rules for the prevention, control and eradication of transmissible spongiform encephalopathies
	Plant protection products	SMR 10: regulation concerning the placing of plant protection products on the market
Animal welfare	Animal welfare	SMR 11: minimum standards for the protection of calves SMR 12: minimum standards for the protection of pigs SMR 13: directive concerning the protection of animals kept for farming purposes

#This table is an extract of the Annex II of Council Regulation (EC) No 1306/2013.

2 The basic set-up

Consider a landholder contemplating the development of idle land. The underlying investment problem involves the choice of timing of development and of capital intensity, i.e., the choice of the capital-land ratio (see Capozza and Li, 1994). Without loss of generality the targeted land surface is normalized to 1 and we denote by $\alpha \in (0, 1]$ the capital intensity that the landholder may select.[12] The sunk investment cost, $I(\alpha)$, associated with the project takes the following form

$$I(\alpha) = k_1 + k_2\alpha, \tag{1}$$

where $k_1 \geq 0$ and $k_2 > 0$ are two dimensional parameters.[13] The term k_1 includes any fixed cost associated with the mere conversion of land while the term $k_2\alpha$ includes costs associated with a higher capital-land ratio.[14]

A periodic constant payment s is made to the landholder conditional on having land satisfying the cross-compliance requirements set by the policy maker.[15] The periodic cost of compliance is equal to $m > 0$. We assume that s is set such that the participation constraint is satisfied, i.e., $s \geq m$.[16] Hence, the net periodic payment accruing to the landholder is $p = s - m \geq 0$.

Once invested in a land development project characterized by a generic capital intensity level α, the following two post-investment scenarios may occur:

- **active farming**: land is cultivated and the crop yield is increasing and concave in α. The amount of commodity produced is given by the following function:

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

The unit production cost is constant and equal to $c > 0$ while the market price for the commodity produced, x_t, is stochastic and fluctuates according to the following geometric Brownian motion:

$$dx_t/x_t = \mu dt + \sigma dL_t \text{ with } x_0 = x \tag{3}$$

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.[17]

Note that as participation in the CAP payment program is rational ($p \geq 0$), the landholder maintains his land according to the cross-compliance requirements. Hence, the periodic total income of the farmer is equal to $\pi_t^a(x_t, \alpha) + p$ where $\pi_t^a(x_t, \alpha) = q(\alpha)(x_t - c)$.[18]

- passive farming: land is not cultivated but, as participation in the CAP payment program is rational, land is maintained according to the cross-compliance requirements and the periodic total income of the farmer is equal to p.

[12] At no loss of generality, we normalize our frame by setting the maximum intensity level equal to 1.

[13] We may easily allow for a more general function such as $I(\alpha) = k_1 + k_2\frac{\alpha^\omega}{\omega}$, with $\omega \geq 1$. This would not have, however, any impact on the quality of our results.

[14] The landholder can be either a landowner or a lessee. The only difference is that, in the latter case, the term k_1 would include also the rental price paid to the landowner.

[15] Note that policy uncertainty, concerning, for instance, the duration of the policy itself and/or changes in the magnitude of the payments granted, may be easily incorporated in our model. This can be done by characterizing any sudden shift in the policy through a Poisson process. The flow of payments should then be discounted using a rate adjusted in order to account for i) the likelihood of a jump in the process, i.e. the intensity of the Poisson process, and ii) the impact of the shift on the payment level. For the inclusion of policy uncertainty in a standard investment problem see Dixit and Pindyck (1994, ch. 5, pp. 167-173 and ch. 9, pp. 303-309).

[16] Note in fact that if $s < m$, applying for the payment would not make any sense given that the corresponding net payment would be negative.

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

[18] The superscript a in π_t^a stands for "active farming".

As one can see when comparing the payoffs associated with the two scenarios, active farming is profitable when $x_t > c$. Otherwise, i.e., when $x_t \leq c$, the farmer should opt for passive farming. Hence, depending on the price level at each time point, the profit flow associated with the farm, once invested, is as follows:

$$\pi_t = \begin{cases} \pi_t^a(x_t, \alpha) + p, & \text{for } x_t > c \\ p, & \text{for } x_t \leq c \end{cases} \tag{4}$$

Note that the farmer can then be viewed, when active, as holding the option to suspend farm operations whenever active farming becomes not profitable, i.e., as soon as $x_t \leq c$. Similarly, the farmer can be viewed, when passive, as holding the option to restart farm operations as soon as active farming becomes profitable, i.e., as soon as $x_t > c$.

In the following, we will assume for simplicity that when switching from active to passive farming and vice versa there are no additional costs.[19] This makes sense considering that the farmer maintains land in good agricultural condition under any post-investment scenario.

Finally, we assume that i) the farmer is risk neutral and discounts future payoffs using the interest rate $r > \mu$,[20] ii) once invested, the project runs forever[21] and iii) the capital installed does not "rust", i.e., no maintenance is required.[22]

3 The operating value of the farm

Let $V(x_t; \alpha)$ represent the operating value of the farm upon investment. Solving the underlying dynamic programming problem, we obtain:[23]

$$V(x_t; \alpha) = \begin{cases} \widetilde{A}x_t^{\beta_2} + q(\alpha)(\frac{x_t}{r-\mu} - \frac{c}{r}) + \frac{p}{r} & \text{for } x_t > c \\ \widetilde{B}x_t^{\beta_1} + \frac{p}{r} & \text{for } x_t \leq c \end{cases} \tag{5}$$
$$\text{for any } \alpha \in (0, 1],$$

where $\beta_2 < 0$ and $\beta_1 > 1$ are the roots of the characteristic equation $\Lambda(\beta) = (1/2)\sigma^2\beta(\beta-1)+\mu\beta-r$

and

$$\widetilde{A} = q(\alpha)A = \frac{\alpha^\gamma}{\gamma}\frac{r - \mu\beta_1}{(\beta_1 - \beta_2)r(r - \mu)}c^{1-\beta_2}, \tag{5.1}$$

$$\widetilde{B} = q(\alpha)B = \frac{\alpha^\gamma}{\gamma}\frac{r - \mu\beta_2}{(\beta_1 - \beta_2)r(r - \mu)}c^{1-\beta_1}. \tag{5.2}$$

The terms $\widetilde{A}x_t^{\beta_2}$ and $\widetilde{B}x_t^{\beta_1}$ in Eq. (5) represent the values associated with the option to suspend and restart farming operations, respectively. Note that the constants, $\widetilde{A}$ and $\widetilde{B}$, are both positive and linearly increasing in the productive capacity $q(\alpha)$ associated with the capital intensity α.[24].

[19] With switching costs, the quality of our conclusions would not change. We would only have a larger hysteresis, that is, the farmer would wait longer before switching from active to passive farming and vice versa. A complete analysis of the impact of switching costs when suspending and restarting a project is presented in Dixit and Pindyck (1994, chap. 7).

[20] This restriction is needed in order to ensure convergence. See Dixit and Pindyck (1994, p. 138). Note that in order to use an interest rate incorporating a proper risk adjustment, expectations should be taken with respect to a distribution of x_t adjusted for risk neutrality. See Cox and Ross (1976) for further details.

[21] Note that this assumption does not affect the quality of our results.

[22] A complete analysis of the case where capital maintenance costs are considered can be found in Dixit and Pindyck (1994, chap. 7).

[23] See Section A.1 in Appendix A.

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

In Eq. (5) we observe that for $x_t > c$, i.e., under active farming, the operating value of the farm is given by the sum of the value of the option to switch to passive farming, $\widetilde{A}x_t^{\beta_2}$, plus the net present value associated with active farming, $q(\alpha)(\frac{x_t}{r-\mu} - \frac{c}{r})$, and the present value of the flow of net payments, $\frac{p}{r}$. Note that the value of the option to switch to passive farming is decreasing in the price level x_t and increasing in the production cost c. This makes sense considering that this option becomes more valuable when profits from active farming decrease. On the other branch of the value function, that is for $x_t \leq c$, the value of the farm is given by the sum of the value of the option to switch from passive to active farming, $\widetilde{B}x_t^{\beta_1}$, plus the present value of the flow of net payments, $\frac{p}{r}$. Note that the value of this option is increasing in the price level x_t and decreasing in the production cost c. This makes sense considering that the option to restart farming operations becomes more valuable when profits associated with active farming increase.

4 The optimal productive capacity

In this section, we determine the productive capacity, $q(\alpha)$, that the landholder should adopt when setting up the farm. Note that, from Eq. (2), this is equivalent to setting the capital intensity, α, characterizing the farm's operations. The capital intensity must be chosen taking into account, i) the future potential evolution of farming profits and, ii) the operational flexibility associated with the options to switch between passive and active farming. As one can see, these two aspects are clearly interrelated as the acquired flexibility allows hedging against the volatility that, via the market price, affects farming profits.

Productive capacity and operational flexibility are increasing in capital intensity but do not come for free. The corresponding benefits must in fact be traded off with an investment cost that is also increasing in the level of capital intensity. In the following, we will determine, in the light of the trade-off between benefits and costs, the optimal capital intensity for the scenario where investment in land development occurs when active farming is profitable, i.e., for $x_t > c$.[25] In this case, the farmland can be immediately used for the production of the agricultural commodity. The optimal level of capital intensity, $\overline{\alpha}$, should be such that the expected net present value associated with the current and future farm operations is maximized, that is:

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

where,[26]

$$NPV^a(x_t, \alpha) = V(x_t, \alpha) - I(\alpha) = \widetilde{A}x_t^{\beta_2} + q(\alpha)(\frac{x_t}{r-\mu} - \frac{c}{r}) + \frac{p}{r} - (k_1 + k_2\alpha)\,. \tag{6.1}$$

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

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

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

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

[25] A scenario where the landholder opts for investment in land development when active farming is not profitable, i.e. $x_t \leq c$, seems to us less realistic. We provide, however, the relative analysis in Appendix B.

[26] The superscript a in NPV^a stands for "active farming" which is the farming operation when $x_t > c$.

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

Note that the optimal capital intensity $\overline{\alpha}(x_t)$ is increasing in x_t in the interval $(c, \overline{x})$. This property results from the sum of two opposing forces within the term $O(x_t)$. First, as x_t increases, due to the higher expected profits per unit of production, $\frac{x_t}{r-\mu} - \frac{c}{r}$, the landholder would prefer investing in a higher $\overline{\alpha}(x_t)$ so that he can produce more. Second, $\overline{\alpha}(x_t)$ is increasing in the marginal value of the option to switch to passive farming, $Ax_t^{\beta_2}$. This makes sense considering that a higher $Ax_t^{\beta_2}$ secures a higher hedge against the volatility of farming profits. In this respect, the value associated with the option to switch to passive farming is decreasing in x_t as, the higher the x_t, the less likely is switching to passive farming in the future. One can easily show that the first force prevails.[27]

Let us now discuss the condition set on Ψ in Proposition 1.[28] The term Ψ represents the net marginal cost of capital intensity $\overline{\alpha} = 1$. In particular, it is the difference between the marginal investment cost, k_2, and the marginal value of the option to switch to active farming, $Bx_t^{\beta_1}$, evaluated at the boundary price $x_t = c$. Note that if at this price level the marginal benefit, Bc^{β_1}, is higher than the marginal cost associated with investing in the highest feasible capital intensity, k_2, adopting a lower capital intensity ($\overline{\alpha} < 1$) is optimal. The capital intensity is equal to 1 only when prices are sufficiently high, i.e., when $x_t \geq \overline{x}$.

It is worth highlighting that the optimal capital intensity $\overline{\alpha}$ and consequently the farm productive capacity $q(\overline{\alpha})$ do not depend on the net payment p. This is of course not too surprising given that, by definition, payments are decoupled from production.

Last, plugging Eq. (7) in Eq. (6.1) we obtain:

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

This is the expected net present value associated with the operations of a farm where the optimal capital intensity $\overline{\alpha}(x_t)$ has been adopted.

5 Value and timing of the investment

Let us now determine the value of the option to invest in the land development project and the optimal investment timing. We denote by $\widehat{x}$ the price threshold triggering investment. Then, the value of the option to invest is

$$F(x, \widehat{x}) = \max_{\tau} E_0 \left(e^{-r\tau} NPV^a(\widehat{x})\right), \tag{9}$$

where the time of investment, τ, is a random variable defined as $\tau = \inf\{t \geq 0 \mid x_t = \widehat{x}\}$ and E_0 is the corresponding conditional expectation.

Assuming that the initial market price x is sufficiently small so that investing at time zero is not preferable (i.e., $x < \widehat{x}$),[29] Eq. (9) can be rearranged as follows:[30]

$$F(x, \widehat{x}) = \max_{\widehat{x}} \{(x/\widehat{x})^{\beta_1} NPV^a(\widehat{x})\} \tag{9.1}$$

[27] See Section A.2 in Appendix A.

[28] In the Appendix (Sections A.2 and A.3.2) we also consider the scenario where $\Psi = k_2 - Bc^{\beta_1} \leq 0$ and we show that in this case $\overline{\alpha}(x_t)$ is equal to 1 for any $x_t > c$. Note that the analysis of the investment decision under this scenario is similar to the one provided for $\Psi > 0$ and $\overline{\alpha}(x_t) = 1$ under $x_t \geq \overline{x}$.

[29] Note that if $x \geq \widehat{x}$ the potential investor should immediately exercise the option to invest. Note also that if this is the case our problem reduces to the mere maximization of the net present value in Eq. (8).

[30] See Dixit and Pindyck (1994, pp. 315-316) for the calculation of this expected present value.

From the first-order condition of Problem (9.1) we obtain:[31]

$$\widehat{x} = \beta_1 \frac{NPV^a(\widehat{x})}{\frac{\partial NPV^a(\widehat{x})}{\partial \widehat{x}}} \tag{10}$$

Let us now consider the two investment scenarios proposed in Section 4, namely, the scenario where $\overline{\alpha} = 1$ and the scenario where $\overline{\alpha} < 1$.

Case $\overline{\alpha} = 1$ - The landholder is contemplating investing in a project characterized by the highest possible capital intensity, $\overline{\alpha} = 1$. As shown above, this is the case whenever prices are higher than $\overline{x}$. In the Appendix, we show that:

Proposition 2 *Provided that* $\frac{p}{r} < k_1 + k_2$ *and* $\frac{\overline{x}}{r-\mu} - \frac{c}{r} \geq \Delta$*, the optimal investment threshold* x^* *for a project with capital intensity* $\overline{\alpha} = 1$ *is the solution of the following equation:*

$$x^* + \frac{\beta_1 - \beta_2}{\beta_1 - 1} A x^{*\beta_2}(r-\mu) - \frac{\beta_1}{\beta_1 - 1}(r-\mu)\{\frac{c}{r} - \gamma[\frac{p}{r} - (k_1 + k_2)]\} = 0, \tag{11}$$

where $\Delta = \frac{\frac{c}{r} + k_2\beta_2 - \beta_1\left[k_2(1-\gamma) + \gamma\left(\frac{p}{r} - k_1\right)\right]}{\beta_2 - 1}$*, while the value of the opportunity to invest in the project is:*

$$F(x, x^*) = [\frac{O(x^*)}{\gamma} + \frac{p}{r} - (k_1 + k_2)](\frac{x}{x^*})^{\beta_1} \tag{12}$$

Otherwise, i.e., if $\frac{p}{r} \geq k_1 + k_2$ *and* $\frac{\overline{x}}{r-\mu} - \frac{c}{r} \geq \Delta$*, the landholder should invest immediately.*

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

Proposition 2 presents two potential investment scenarios, namely, a scenario where the present value of the flow of net payments, $\frac{p}{r}$, is lower than the investment cost, $I(1) = k_1 + k_2$, and the scenario where this cost is equal to, or lower than, $\frac{p}{r}$. We observe that when $\frac{p}{r} < k_1 + k_2$ the investment in a land development project with capital intensity $\overline{\alpha}(x^*) = 1$ is conditional on having at $x^* = \overline{x}$ an expected profitability, $\frac{\overline{x}}{r-\mu} - \frac{c}{r}$, associated with active farming higher than the level Δ. Otherwise, the project is not worth investing in. On the contrary, when the present value of the flow of net payments, $\frac{p}{r}$, is equal or higher than the investment cost, $k_1 + k_2$, the concern about investing at a price level high enough to take into account the investment cost and the option value is absent and the landholder should invest immediately. This is, of course, not surprising considering that the investment cost is covered by the flow of net payments and that the farmer is eager to cash the project value $\frac{p}{r} - (k_1 + k_2) \geq 0$.

Case $\overline{\alpha} < 1$ - Let us now turn to a scenario characterized by a commodity price lying in the region $(c, \overline{x})$. Within this region, the landholder contemplates investing in a land development project characterized by capital intensity $\overline{\alpha} < 1$. In the Appendix, we show that:

Proposition 3 *Provided that* $\frac{p}{r} < k_1 + k_2\overline{\alpha}(c)$ *and* $\frac{\overline{x}}{r-\mu} - \frac{c}{r} < \Delta$*, the optimal investment threshold,* x^{**}*, for a project with capital intensity* $\overline{\alpha} < 1$ *is the solution of*

$$x^{**}\frac{\partial \overline{\alpha}(x^{**})}{\partial x^{**}} - \beta_1(\overline{\alpha}(x^{**}) + \frac{\gamma}{1-\gamma}\frac{\frac{p}{r} - k_1}{k_2}) = 0, \tag{13}$$

while the value of the option to invest in the project is:

$$F(x, x^{**}) = [(\frac{O(x^{**})}{k_2})^{\frac{1}{1-\gamma}}(\frac{1}{\gamma} - 1)k_2 + \frac{p}{r} - k_1](\frac{x}{x^{**}})^{\beta_1} \tag{14}$$

[31] See Section A.3 in Appendix A for the derivation of Eq. (10). An exhaustive discussion of the underlying solution concept is provided by Dixit et al. (1999).

Otherwise, i.e., if $\frac{p}{r} \geq k_1 + k_2\overline{\alpha}(c)$ and $\frac{\overline{x}}{r-\mu} - \frac{c}{r} < \Delta$, the landholder should invest immediately in a land development project characterized by the minimum capital intensity, i.e., $\overline{\alpha}(c)$.

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

Similarly to the case where $\overline{\alpha}(x^*) = 1$, also here we have two potential investment scenarios. The main difference is that now the two scenarios are defined on the basis of the investment cost associated with a land development project characterized by the minimum capital intensity $\overline{\alpha}(c)$, i.e., $I(\overline{\alpha}(c)) = k_1 + k_2\overline{\alpha}(c)$. When this cost is not covered by the present value of the flow of net payments, $\frac{p}{r}$, the realization of the project is conditional on having at $x^{**} = \overline{x}$ an expected profitability, $\frac{\overline{x}}{r-\mu} - \frac{c}{r}$, associated with active farming lower than the level Δ. Otherwise, investing in a land development project with capital intensity $\overline{\alpha}(x^{**}) < 1$ would not make sense as the landholder should rather consider investing in a project with full capital intensity. Investment must occur when the price level x^{**} is reached and the farmer must adopt a capital intensity $\overline{\alpha}(x^{**}) < 1$. In contrast, when $\frac{p}{r} \geq k_1 + k_2\overline{\alpha}(c)$, the farmer should rush and invest immediately in a project with the lowest possible capital intensity, i.e., $\overline{\alpha}(c)$. Similarly to the case presented above, as the investment cost is fully covered, the potential farmer rushes as he is eager to cash the project value $\frac{p}{r} - (k_1 + k_2\overline{\alpha}(c)) \geq 0$.

6 The effect of the policy instrument

In this section, we discuss the impact of decoupled payments on the timing of the investment, the adopted capital intensity and the value of the investment option. Starting with the effect on timing, we show in the Appendix that:

Proposition 4 *The investment timing for the conversion of idle land into farmland is, irrespective of the productive capacity chosen, decreasing in the net payment p, i.e., $\partial x^*/\partial p < 0$ and $\partial x^{**}/\partial p < 0$.*

Proof. See Section A.3 of Appendix A. ■

In the real-options literature, the option to invest is viewed as a call option with the investment cost $I(\alpha)$ as its strike price. In our problem, as a net payment p accrues over time irrespective of the farm activities, the landholder may count on a sequence of net payments having a present value equal to p/r. The actual strike price is then lower than $I(\alpha)$ and equal to $I(\alpha) - p/r$. As well known in option theory, to a lower strike price should correspond an earlier exercise which, in our frame, implies an earlier investment. Hence, the higher the net payment p, the lower the strike price $I(\alpha) - p/r$ and the earlier the investment occurs.

In addition, from Propositions 2 and 3 we notice that the net payment p influences also the conditions delimiting the opportunity of investment postponement, i.e., $\frac{p}{r} < k_1 + k_2$ for x^*, and $\frac{p}{r} < k_1 + k_2\overline{\alpha}(c)$ for x^{**}. Note in fact that if p is sufficiently high, the inequalities $\frac{p}{r} < k_1 + k\overline{\alpha}(c)$ and $\frac{p}{r} < k_1 + k_2$ may not hold. In that case, the landholder should invest immediately since the policy secures a flow of net payments covering the entire sunk investment cost. Obviously, setting up the farm is costless and consequently there is no reason for waiting.

Let us now turn to the impact that p may have on the determination of the optimal productive capacity $q(\overline{\alpha})$. When $\overline{x} \leq x_t$, the maximum productive capacity ($q(1)$) is adopted, and the level of p does not have any influence. In contrast, when $x_t < \overline{x}$, the productive capacity adopted is $q(\overline{\alpha})$ ($< q(1)$) which is affected by the level of p. In particular, we notice that

Proposition 5 *When investing in the region $(c, \overline{x})$, the optimal productive capacity $q(\overline{\alpha}(x^{**}))$ is decreasing in p.*

Proof. See Section A.3 of Appendix A. ■

This result does not contradict our conclusions from Section 4 according to which $\overline{\alpha}$, and consequently $q(\overline{\alpha})$, do not directly depend on p. However, it suggests that the net payment p affects the level of productive capacity ($q(\overline{\alpha}(x^{**}))$) through the investment timing x^{**}. More precisely, as the productive capacity ($q(\overline{\alpha}(x^{**}))$) is increasing in the chosen capital intensity ($\overline{\alpha}(x^{**})$) and, also, the chosen capital intensity is increasing in the investment threshold (x^{**}),[32] the net payment p, by lowering the threshold triggering investment ($\partial x^{**}/\partial p < 0$), lowers also the chosen productive capacity ($q(\overline{\alpha}(x^{**}))$). Interestingly, Proposition 5 shows that decoupled payments are not neutral, as commonly believed, but do affect the capacity choices taken at farm level.

Last, studying the impact of p on the value of the option to invest, we find that:

Proposition 6 *The value of the option to invest in the development of idle land is, irrespective of the productive capacity chosen, increasing in the net payment p.*

Proof. Provided that both x^* and x^{**} solve Eq. (10), a straightforward application of the envelope theorem yields

$$\frac{\partial F(x, x^i(p))}{\partial p} = \frac{1}{r}\left(\frac{x}{x^i(p)}\right)^{\beta_1} > 0, \tag{15}$$

where $x^i(p) \in \{x^*(p), x^{**}(p)\}$. ■

Obviously, a higher net payment p increases the value of the option to invest. This is due to the fact that the value associated with the hedge against farm profit volatility (p/r) increases in p. Note, however, that this effect is corrected by the stochastic discount factor $\left(x/x^i(p)\right)^{\beta_1} < 1$ which is capturing the impact of the time that the farmer should wait before investing.

Last, note that throughout the paper we discuss the potential farmer's investment problem focusing on the current version of the CAP where p is non-negative since $s \geq m > 0$. Nevertheless, our analysis holds irrespective of the sign of p and this allows us to use the same framework to discuss a hypothetical no-policy scenario where farmers do not receive any payment. Suppose that in such a setting the farmer finds convenient to be operationally flexible. This is, as above, conditional on keeping the land in good agricultural condition. In fact, if land maintenance entails a periodic cost $n > 0$, the profit flow associated with the operation of the farm is:

$$\pi_t = \begin{cases} \pi_t^a(x_t, \alpha) - n, & \text{for } x_t > c \\ -n, & \text{for } x_t \leq c \end{cases} \tag{16}$$

When $x_t > c$, the farmer is profitably cultivating the land cashing $q(\alpha)(x_t - c) - n$, where n is capturing the periodic farming costs that are independent of the yield (e.g., costs related to cleaning the land from farming residues and preparing it for the next use). When on the contrary $x_t \leq c$, the farmer opts for the interruption of farming activities because otherwise he is due to make losses. Nevertheless, the farmer can, by undertaking voluntary periodic land maintenance of cost n, switch to active farming as soon as the price of the agricultural commodity bounces back up.

As it can be easily seen once p is set equal to $-n$, Eq. (16) is equivalent to Eq. (4). This allows us to generalize our analysis by including the hypothetical no-policy scenario.[33] Hence, using our results concerning the impact of an increasing p on timing, magnitude and value of the option to invest when comparing the scenarios CAP vs. no-policy, decoupled payments i) turn hedging

[32] See Section 4.

[33] Note that the special case where $s = m > 0 \to p = 0$ differs from the no-policy setting since $m > 0$ suggests that cross-compliance requirements are in place. This special case would correspond instead to a budget-constrained CAP or to a policy maker for whom the farmers' income support is not a priority.

against volatile farming profits, by maintaining land in good conditions, from a costly ($p = -n$ in the no-policy scenario) into a costless practice ($p = s - m \geq 0$ in the current-CAP scenario), and, by so doing, ii) increase the value associated with farm investment.

7 Epilogue

According to Article 33 of the treaty establishing the European Community, the objectives of the CAP are: i) the increase of agricultural productivity by promoting technical progress and by ensuring the rational development of agricultural production and the optimum utilization of the factors of production, ii) the guarantee of a fair standard of living for the agricultural community, iii) the stabilization of the markets and iv) the guaranteed availability of supplies that reach consumers at reasonable prices.[34]

In accordance with these objectives, and thanks to the introduction of decoupled payments in 2003, the beneficiaries of the CAP enjoy in our days some financial security while being also encouraged to respond to market signals. The current version of the policy takes great account of the reality of an open world and, according to the World Trade Organization, 90% of the payments are regarded as non-trade-distorting.[35]

Nevertheless, the introduction of decoupled payments and the gradual phasing out of the traditional forms of farming subsidies that were conditional on the production of agricultural commodities was, and still is, heavily disputed in European circles. According to one of the main arguments used by the adversaries of this policy, decoupling is encouraging passive farming, which is in turn hindering rural development. In this paper, we focus on this specific issue and study how decisions concerning investment in land development projects are affected by decoupling. More precisely, we analyze the case of a potential farmer who is contemplating investing in a piece of idle land in order to convert it into farmland. The potential investor needs to choose both the productive capacity and the timing of the investment given that, once he enters the farming business, he will have the opportunity to farm actively the land when the profit margin is positive, and farm it passively otherwise.

We present three original findings. First, we find that decoupled payments encourage the acceleration of the investment in question and we show that this is due to the hedge against volatile farming profits implicitly provided by decoupling payments. Secondly, we show that decoupled payments are not directly affecting the level of productive capacity chosen by the investor. There is, however, an indirect effect passing through the earlier investment induced by the policy which reduces the adopted productive capacity. Last, we find that decoupled payments increase the value of the opportunity to invest. This is of course due to the positive effect of the valuable hedge against farm profit volatility.

There is a plethora of ways to advance the present work. First, it would be interesting to see how decoupling affects the decision of a farmer to leave the farming industry. The analysis related to the option-to-exit would complement our present analysis giving a clearer picture on how decoupling affects structural change in the farming sector. Secondly, it would be informative to approach the same topic allowing for both coupled and decoupled payments. In this way, one could isolate the effects of the two policies while discussing any composite effects. Last, a welfare analysis that will analytically consider the total costs and benefits of decoupling, including its impact on environment and rural landscape conservation, would allow the policy maker to identify the socially optimal payment to be set in the light of a given set of cross-compliance rules.

[34] See http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:11997E033&from=HR

[35] See http://europa.eu/rapid/press-release_MEMO-13-631_en.htm

A Appendix

A.1 The farm's operating value

The farm's operating value, $V(x_t;\alpha)$, is the solution of the following differential equations:

$$\begin{array}{ll} \Gamma V^H(x_t;\alpha) = -\left[q(\alpha)(x_t - c) + p\right] & \text{for } x_t > c \\ \Gamma V^L(x_t;\alpha) = -p & \text{for } x_t \leq c \end{array} \tag{A.1.1-A.1.2}$$

Γ is the differential operator $-r + \mu x_t \frac{\partial}{\partial x_t} + \frac{1}{2}\sigma^2 x_t^2 \frac{\partial^2}{\partial x_t^2}$, $V^H(x_t;\alpha)$ is the farm operating value under $x_t > c$ and $V^L(x_t;\alpha)$ is the farm operating value under $x_t \leq c$.

Taking into account the boundary conditions

$$\begin{array}{ll} \lim\limits_{x_t\to\infty} \{V^H(x_t;\alpha) - [q(\alpha)(\frac{x_t}{r-\mu} - \frac{c}{r}) + \frac{p}{r}]\} = 0 & \text{for } x_t > c \\ \lim\limits_{x_t\to 0} \left\{V^L(x_t;\alpha) - \frac{p}{r}\right\} = 0 & \text{for } x_t \leq c \end{array},$$

the general solution to the differential Eqs. (A.1.1) and (A.1.2) takes the form:

$$\begin{array}{ll} V^H(x_t;\alpha) = \widetilde{A} x_t^{\beta_2} + q(\alpha)(\frac{x_t}{r-\mu} - \frac{c}{r}) + \frac{p}{r} & \text{for } x_t > c \\ V^L(x_t;\alpha) = \widetilde{B} x_t^{\beta_1} + \frac{p}{r} & \text{for } x_t \leq c \end{array}$$

At $x_t = c$, standard optimality conditions, i.e., the value matching and smooth pasting conditions, require that

$$\begin{array}{l} \widetilde{A} c^{\beta_2} + \frac{\alpha^\gamma}{\gamma}(\frac{c}{r-\mu} - \frac{c}{r}) + \frac{p}{r} = \widetilde{B} c^{\beta_1} + \frac{p}{r}, \\ \widetilde{A}\beta_2 c^{\beta_2 - 1} + \frac{\alpha^\gamma}{\gamma}\frac{1}{r-\mu} = \widetilde{B}\beta_1 c^{\beta_1 - 1}, \end{array} \tag{A.1.3}$$

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

$$\widetilde{A} = q(\alpha)A = \frac{\alpha^\gamma}{\gamma}\frac{r - \mu\beta_1}{(\beta_1 - \beta_2)\, r(r-\mu)} c^{1-\beta_2} > 0, \tag{A.1.4}$$

$$\widetilde{B} = q(\alpha)B = \frac{\alpha^\gamma}{\gamma}\frac{r - \mu\beta_2}{(\beta_1 - \beta_2)\, r(r-\mu)} c^{1-\beta_1} > 0. \tag{A.1.5}$$

A.2 Optimal capital intensity

Suppose that $x_t > c$. The optimal capital intensity is

$$\begin{aligned} \overline{\alpha} &= \arg\max\{\widetilde{A} x_t^{\beta_2} + q(\alpha)(\frac{x_t}{r-\mu} - \frac{c}{r}) + \frac{p}{r} - I(\alpha)\} \\ &= \arg\max\{\frac{\alpha^\gamma}{\gamma} O(x_t) + \frac{p}{r} - (k_1 + k_2\alpha)\} \end{aligned} \tag{A.2.1}$$

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

The first-order condition for Problem (A.2.1) yields,[36]

$$\overline{\alpha} = (O(x_t)/k_2)^{\frac{1}{1-\gamma}}. \tag{A.2.2}$$

[36] Note that the second-order condition is always satisfied.

Note that, to be feasible, $\overline{\alpha}$ must be higher than 0 but not higher than 1, i.e., $\overline{\alpha} \in (0,1]$. This implies that the following condition must hold:

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

We note that:

$$\begin{aligned} O(c) &= \frac{r-\mu\beta_2}{(\beta_1-\beta_2)r(r-\mu)}c = Bc^{\beta_1} > 0, \; O'(c) = \frac{r-\mu\beta_2}{(\beta_1-\beta_2)r(r-\mu)}\beta_1 > 0, \\ \lim_{x_t \to 0} O(x_t) &= \infty \end{aligned}$$

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

Let us now check the conditions under which $O(x_t) \leq k_2$, i.e., $\overline{\alpha} \leq 1$. Define the function:

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

In the light of the properties of $O(x_t)$, we may distinguish two scenarios:

Scenario A if $\Psi > 0 \rightarrow \overline{x} > c$,

$$\overline{\alpha}(x_t) = \begin{cases} (O(x_t)/k_2)^{\frac{1}{1-\gamma}} & \text{for} \quad c < x_t < \overline{x} \\ 1 & \text{for} \quad \overline{x} \leq x_t \end{cases},$$

where $\overline{x}\,(> c)$ is such that $O(\overline{x}) = k_2$. Note also that $O'(\overline{x}) > 0$.

Scenario B if $\Psi \leq 0 \rightarrow \overline{x} \leq c$,

$$\overline{\alpha}(x_t) = 1, \text{ for } x_t > c.$$

A.3 Investing in land development

Once the optimal intensity level is set, we can determine the net present value corresponding to the land development project by substituting $\overline{\alpha}(x_t)$ into the function:

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

Taking into account the potential scenarios identified above, we get:

Scenario A when $\Psi > 0 \rightarrow \overline{x} > c$,

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

Scenario B when $\Psi \leq 0 \rightarrow \overline{x} \leq c$,

$$NPV^a(x_t,\overline{\alpha}(x_t)) = \frac{O(x_t)}{\gamma} + \frac{p}{r} - (k_1+k_2) \quad \text{for} \quad c < x_t \tag{A.3.3}$$

Denote by $\widehat{x}$ the optimal investment threshold. Hence, using standard arguments, in the continuation region $x < \widehat{x}$ the value of the option to invest in the land development project is:

$$F(x,\widehat{x}) = \max_{\tau} E_0\left(e^{-r\tau}NPV(\widehat{x})\right), \tag{A.3.4}$$

where $\tau = \inf\{t \geq 0 \mid x_t = \widehat{x}\}$ is the first time that the process x_t hits the barrier $\widehat{x}$ from below and E_0 is the expectation taken at the initial time point $t = 0$.

As one can easily show, Eq. (A.3.4) is equivalent to[37]

$$F(x, \widehat{x}) = \max_{\widehat{x}}\{(x/\widehat{x})^{\beta_1} NPV^a(\widehat{x})\}. \tag{A.3.5}$$

Following Dixit et al. (1999), optimality requires that the following first-order condition holds:

$$\frac{\partial[(x/\widehat{x})^{\beta_1} NPV^a(\widehat{x})]}{\partial\widehat{x}} = (x/\widehat{x})^{\beta_1}\frac{\partial NPV^a(\widehat{x})}{\partial\widehat{x}} + NPV^a(\widehat{x})\frac{\partial(x/\widehat{x})^{\beta_1}}{\partial\widehat{x}} = 0. \tag{A.3.6}$$

Rearranging Eq. (A.3.6):

$$\widehat{x} = \beta_1 \frac{NPV^a(\widehat{x})}{\frac{\partial NPV^a(\widehat{x})}{\partial\widehat{x}}} \tag{A.3.7}$$

Last, for Problem (A.3.5) to be well-posed, the following condition must hold at $\widehat{x}$:

$$\begin{aligned}
\left.\frac{\partial^2[(x/\widehat{x})^{\beta_1} NPV^a(\widehat{x})]}{\partial x^2}\right|_{x=\widehat{x}} &> \left.\frac{\partial^2 NPV^a(x)}{\partial x^2}\right|_{x=\widehat{x}} \\
&\rightarrow \\
\frac{\partial NPV^a(\widehat{x})}{\partial\widehat{x}} &> \frac{\widehat{x}}{\beta_1 - 1}\cdot\left.\frac{\partial^2 NPV^a(x)}{\partial x^2}\right|_{x=\widehat{x}}
\end{aligned} \tag{A.3.8}$$

A.3.1 Investment under scenario A

Case $\overline{\alpha} = 1$ - Let us consider the interval where the land development project is characterized by the highest possible capital intensity, i.e., $\overline{\alpha} = 1$. Denote by x^* the optimal investment threshold. Substituting the second branch of Eq. (A.3.2) into Eq. (A.3.7) and rearranging, we find that x^*can be determined by solving the following equation:

$$x^* + \frac{\beta_1 - \beta_2}{\beta_1 - 1}Ax^{*\beta_2}(r - \mu) - \frac{\beta_1}{\beta_1 - 1}(r - \mu)\{\frac{c}{r} - \gamma[\frac{p}{r} - (k_1 + k_2)]\} = 0 \tag{A.3.9}$$

Existence and uniqueness of x^* - Define the function

$$\Phi(x) = x + \frac{\beta_1 - \beta_2}{\beta_1 - 1}Ax^{\beta_2}(r - \mu) - \frac{\beta_1}{\beta_1 - 1}(r - \mu)\{\frac{c}{r} - \gamma[\frac{p}{r} - (k_1 + k_2)]\}.$$

Note that $\Phi(x)$ is convex in x. Hence, the equation $\Phi(x^*) = 0$ may admit up to two roots. However, we note that by condition (A.3.8):

$$\begin{aligned}
\frac{\partial NPV^a(x^*)}{\partial x^*} &> \frac{x^*}{\beta_1 - 1}\cdot\left.\frac{\partial^2 NPV^a(x)}{\partial x^2}\right|_{x=x^*} \\
&\rightarrow \\
O'(x^*) &> \frac{x^*}{\beta_1 - 1}O''(x^*) \\
&\rightarrow \\
\Phi'(x^*) &= 1 + \beta_2\frac{\beta_1 - \beta_2}{\beta_1 - 1}Ax^{*\beta_2 - 1}(r - \mu) > 0.
\end{aligned} \tag{A.3.8a}$$

[37] See Dixit and Pindyck (1994, pp. 315-316) for the calculation of the expected present value in Eq. (A.3.4).

This implies that if a solution x^* exists, then it is unique since $\Phi'(x^*) > 0$.[38] Hence, by the convexity of $\Phi(x)$, a necessary condition for the existence of a solution x^* to the investment timing problem is:[39]

$$\Phi(c) = \frac{\beta_1}{\beta_1 - 1}\gamma[\frac{p}{r} - (k_1 + k_2)](r - \mu) < 0 \tag{A.3.10}$$

Note that otherwise, i.e., for $\Phi(c) \geq 0$, the potential investor should invest immediately. This should occur when the present value of the flow of net payments, $\frac{p}{r}$, is equal or higher than the investment cost, $k_1 + k_2$.

Last, provided that condition (A.3.10) holds, we need to check for $\overline{\alpha} = 1$, that is, $x^* \geq \overline{x}$. This leads to the following necessary condition:

$$\Phi(\overline{x}) \leq 0 \rightarrow \frac{\overline{x}}{r-\mu} - \frac{c}{r} \geq \Delta = \frac{\frac{c}{r} + k_2\beta_2 - \beta_1\left[k_2(1-\gamma) + \gamma\left(\frac{p}{r} - k_1\right)\right]}{\beta_2 - 1}$$

Policy impact on the investment timing - Differentiating Eq. (A.3.9) with respect to p yields

$$\frac{\partial x^*}{\partial p} = -\frac{\frac{\gamma}{r}\beta_1}{\frac{\beta_1 - 1}{r-\mu} + \beta_2(\beta_1 - \beta_2)Ax^{*\beta_2 - 1}} \tag{A.3.11}$$

Note that, as by condition (A.3.8a) the denominator is strictly positive, we can conclude that $\partial x^*/\partial p < 0$.

CASE $\overline{\alpha} < 1$ - Let us consider the interval $(c, \overline{x})$ where, as shown in Eq. (A.3.2), the land development project is characterized by a capital intensity lower than 1. Denote by x^{**} the optimal investment threshold. Substituting the first branch of Eq. (A.3.2) into Eq. (A.3.7) and rearranging, we find that x^{**} can be determined by solving the following equation:

$$x^{**}\frac{\partial\overline{\alpha}(x^{**})}{\partial x^{**}} - \beta_1\overline{\alpha}(x^{**}) - \frac{\gamma}{1-\gamma}\frac{\frac{p}{r} - k_1}{k_2}\beta_1 = 0 \tag{A.3.12}$$

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

$$\Theta(x) = x\frac{\partial\overline{\alpha}(x)}{\partial x} - \beta_1\overline{\alpha}(x) - \frac{\gamma}{1-\gamma}\frac{\frac{p}{r} - k_1}{k_2}\beta_1.$$

First and second-order derivatives with respect to x are as follows

$$\begin{aligned}
\Theta'(x) &= x\frac{\partial^2\overline{\alpha}(x)}{\partial x^2} - (\beta_1 - 1)\frac{\partial\overline{\alpha}(x)}{\partial x}, \\
\Theta''(x) &= x\frac{\partial^3\overline{\alpha}(x)}{\partial x^3} - (\beta_1 - 2)\frac{\partial^2\overline{\alpha}(x)}{\partial x^2}.
\end{aligned}$$

Note that in the considered interval, we have

$$\begin{aligned}
\frac{\partial\overline{\alpha}(x)}{\partial x} &= \frac{\partial\overline{\alpha}(O(x))}{\partial O(x)}\frac{\partial O(x)}{\partial x} > 0, \\
\frac{\partial^2\overline{\alpha}(x)}{\partial x^2} &= \frac{\partial\overline{\alpha}(O(x))}{\partial O(x)}\frac{\partial^2 O(x)}{\partial x^2} > 0, \\
\frac{\partial^3\overline{\alpha}(x)}{\partial x^3} &= \frac{\partial\overline{\alpha}(O(x))}{\partial O(x)}\frac{\partial^3 O(x)}{\partial x^3} < 0.
\end{aligned}$$

[38] Note also that $\Phi'(c) = 0$.

[39] Recall that, as we saw in Eq. (A.3.2), the interval of interest is $c < \overline{x} \leq x^*$.

Hence, as

$$\Theta''(x) = \frac{\partial\overline{\alpha}(O(x))}{\partial O(x)}\beta_2(\beta_2-1)(\beta_2-\beta_1)A\theta^{\beta_2-2} < 0$$

we conclude that $\Theta(x)$ is concave in x. This implies that the equation $\Theta(x^{**}) = 0$ may admit up to two roots. We note however that by condition (A.3.8):

$$\frac{\partial NPV(x^{**})}{\partial x^{**}} > \frac{x^{**}}{\beta_1 - 1}\left.\frac{\partial^2 NPV^a(x)}{\partial x^2}\right|_{x=x^{**}}$$

$$\rightarrow$$

$$\Theta'(x^{**}) = x^{**}\left.\frac{\partial^2\overline{\alpha}(x)}{\partial x^2}\right|_{x=x^{**}} - (\beta_1 - 1)\left.\frac{\partial\overline{\alpha}(x)}{\partial x}\right|_{x=x^{**}} < 0 \qquad \text{(A.3.8b)}$$

which in turn implies that the only root to be considered is the one where $\Theta'(x^{**}) < 0$.

Let us now identify the conditions under which $\overline{\alpha} < 1$, that is, $c < x^{**} < \overline{x}$. First, we note that $\Theta'(c) = 0$. By the concavity of $\Theta(x)$ and knowing that $\Theta'(x^{**}) < 0$, a necessary condition for the existence of a solution x^{**} to the investment timing problem requires:

$$\Theta(c) = -\beta_1\frac{\gamma}{1-\gamma}\frac{1}{k_2}[\frac{p}{r} - (k_1 + k_2\overline{\alpha}(c))] > 0 \qquad \text{(A.3.13)}$$

Note that otherwise, i.e., if $\Theta(c) \leq 0$, the landholder should invest immediately in a land development project with capital intensity $\overline{\alpha}(c)$. This should occur when the present value of the flow of net payments, $\frac{p}{r}$, is equal or higher than the investment cost associated with capital intensity $\overline{\alpha}(c)$, i.e., $I(\overline{\alpha}(c)) = k_1 + k_2\overline{\alpha}(c)$.

Last, provided that (A.3.13) holds, we must find under what conditions $x^{**} < \overline{x}$. This leads to:

$$\Theta(\overline{x}) < 0 \rightarrow \frac{\overline{x}}{r-\mu} - \frac{c}{r} < \Delta = \frac{\frac{c}{r} + k_2\beta_2 - \beta_1\left[k_2(1-\gamma) + \gamma\left(\frac{p}{r} - k_1\right)\right]}{\beta_2 - 1}$$

Policy impact on investment timing - Differentiating Eq. (A.3.12) with respect to p yields:

$$\frac{\partial x^{**}}{\partial p} = \frac{\frac{\gamma}{r}\beta_1}{(1-\gamma)\,k_2[x^{**}\left.\frac{\partial^2\overline{\alpha}(x)}{\partial x^2}\right|_{x=x^{**}} - (\beta_1 - 1)\left.\frac{\partial\overline{\alpha}(x)}{\partial x}\right|_{x=x^{**}}]} \qquad \text{(A.3.14)}$$

Note that, as by condition (A.3.8b) the denominator is strictly negative, we conclude that $\partial x^{**}/\partial p < 0$.

Policy impact on capital intensity - Differentiating $\overline{\alpha}(x^{**})$ with respect to p yields:

$$\frac{\partial\overline{\alpha}(x^{**})}{\partial p} = \frac{\overline{\alpha}(x^{**})}{1-\gamma}\frac{O'(x^{**})}{O(x^{**})}\frac{\partial x^{**}}{\partial p} < 0 \qquad \text{(A.3.15)}$$

Last, recall that $q(\alpha)$ is increasing in α which implies $\frac{\partial q(\overline{\alpha}(x^{**}))}{\partial p} < 0$. This result is reported in Proposition 5.

A.3.2 Investment under scenario B

When $\Psi \leq 0$, the landholder would always invest in a land development project characterized by the highest possible capital intensity, i.e., $\overline{\alpha} = 1$. The analysis of the investment timing is identical to the one provided above for the corresponding case in Scenario A.

B Appendix

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 landholder, once invested in order to develop his land, would manage it passively cashing periodically the net payment p while holding the option to switch to active farming which is worth, as discussed above, $\widetilde{B}x_t^{\beta_1}$.

B.1 Optimal capital intensity

Suppose that $x_t \leq c$. The optimal capital intensity $\underline{\alpha}$ is given by:

$$\begin{aligned} \underline{\alpha} &= \arg\max\{\widetilde{B}x_t^{\beta_1} + \frac{p}{r} - (k_1 + k_2\alpha)\} \\ &= \arg\max\{\frac{\alpha^\gamma}{\gamma}Bx_t^{\beta_1} + \frac{p}{r} - (k_1 + k_2\alpha)\} \end{aligned} \quad \text{(B.1.1)}$$

The first-order condition for Problem (B.1.1) yields,[40]

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

Thanks to the positivity of x_t,[41] $\underline{\alpha} > 0$ for any $x_t \leq c$. We must however check under what conditions $\underline{\alpha} \leq 1$. This implies:

$$Bx_t^{\beta_1} \leq k_2$$

By the monotonicity of $Bx_t^{\beta_1}$ in x_t, the solution of the equation $Bx_t^{\beta_1} = k_2$ is unique and equal to $\underline{x} = (k_2/B)^{1/\beta_1} > 0$. We may now distinguish two potential scenarios:

Scenario C if $\Psi = k_2 - Bc^{\beta_1} \leq 0 \rightarrow \underline{x} \leq c$ and

$$\underline{\alpha}(x_t) = \begin{cases} (Bx_t^{\beta_1}/k_2)^{\frac{1}{1-\gamma}} & \text{for} \quad 0 < x_t < \underline{x} \\ 1 & \text{for} \quad \underline{x} \leq x_t \leq c \end{cases}$$

Scenario D if $\Psi > 0 \rightarrow \underline{x} > c$ and

$$\underline{\alpha}(x_t) = (Bx_t^{\beta_1}/k_2)^{\frac{1}{1-\gamma}} \text{ for } 0 < x_t \leq c$$

B.2 Investing in land development

Once the optimal intensity level is set, we can determine the net present value corresponding to the land development project by substituting $\underline{\alpha}(x_t)$ into Eq. (A.3.1). This yields:

Scenario C when $\Psi \leq 0$,

$$NPV^p(x_t, \underline{\alpha}(x_t)) = \begin{cases} (\frac{1}{\gamma} - 1)(\frac{Bx_t^{\beta_1}}{k_2})^{\frac{1}{1-\gamma}}k_2 + \frac{p}{r} - k_1 & \text{for} \quad 0 < x_t < \underline{x} \\ \frac{Bx_t^{\beta_1}}{\gamma} + \frac{p}{r} - (k_1 + k_2) & \text{for} \quad \underline{x} \leq x_t \leq c \end{cases} \quad \text{(B.2.1)}$$ [42]

Scenario D when $\Psi > 0$,

$$NPV^p(x_t, \underline{\alpha}(x_t)) = \frac{Bx_t^{\beta_1}}{\gamma} + \frac{p}{r} - (k_1 + k_2) \quad \text{for} \quad 0 < x_t \leq c \quad \text{(B.2.2)}$$

[40] Note that the second-order condition is always satisfied.
[41] Recall that x_t is log-normally distributed. See e.g. Chapter 3 in Dixit and Pindyck (1994).
[42] The superscript p stands for "passive farming" which is the farming operation when $x_t \leq c$.

B.2.1 Investing under scenario C

CASE $\underline{\alpha} = 1$ - Let us consider the interval where $\underline{\alpha} = 1$, i.e., $[\underline{x}, c]$. Denote by $\widetilde{x}^*$ the optimal investment threshold. Hence, using standard arguments, in the continuation region, $x < \widetilde{x}^*$, the value of the option to invest in the land development project is given by the following function:

$$F(x, \widetilde{x}^*) = \max_{\widetilde{x}^*}\{(\frac{x}{\widetilde{x}^*})^{\beta_1}[\frac{B\widetilde{x}^{*\beta_1}}{\gamma} + \frac{p}{r} - (k_1 + k_2)]\} \tag{B.2.3}$$

Taking the first derivative of the objective with respect to $\widetilde{x}^*$ we get:

$$\frac{\partial (x/\widetilde{x}^*)^{\beta_1} NPV^p(\widetilde{x}^*)}{\partial \widetilde{x}^*} = -\frac{\beta_1}{\widetilde{x}^*}(\frac{x}{\widetilde{x}^*})^{\beta_1}[\frac{p}{r} - (k_1 + k_2)] \tag{B.2.4}$$

As one can see, the sign of the first derivative depends on the term $\frac{p}{r} - (k_1 + k_2)$. Two potential scenarios arise:

(i) if $\frac{p}{r} < (k_1 + k_2) \rightarrow \frac{\partial (x/\widetilde{x}^*)^{\beta_1} NPV^p(\widetilde{x}^*)}{\partial \widetilde{x}^*} > 0$: the landholder should postpone investing in land development up to $x = c$ and undertake the investment only if $NPV^p(c) \geq 0$.

(ii) if $\frac{p}{r} \geq (k_1 + k_2) \rightarrow \frac{\partial (x/\widetilde{x}^*)^{\beta_1} NPV^p(\widetilde{x}^*)}{\partial \widetilde{x}^*} \leq 0$: the landholder should invest immediately as the investment cost, $k_1 + k_2$, is lower than, or at most equal to, the present value of the flow of net payments $\frac{p}{r}$.

CASE $\underline{\alpha} < 1$ - Let us now consider the interval $(0, \underline{x})$ where $\underline{\alpha} < 1$. Denote by $\widetilde{x}^{**}$ the optimal development threshold. In the continuation region, $x < \widetilde{x}^{**}$, the value of the option to invest in the land development project is given by the following function:

$$F(x, \widetilde{x}^{**}) = \max_{\widetilde{x}^{**}}\{(\frac{x}{\widetilde{x}^{**}})^{\beta_1}[(\frac{1}{\gamma} - 1)(\frac{B\widetilde{x}^{**\beta_1}}{k_2})^{\frac{1}{1-\gamma}} k_2 + \frac{p}{r} - k_1)]\} \tag{B.2.5}$$

Taking the first derivative of the objective with respect to $\widetilde{x}^{**}$ we obtain:

$$\frac{\partial (x/\widetilde{x}^{**})^{\beta_1} NPV^p(\widetilde{x}^{**})}{\partial \widetilde{x}^{**}} = -\frac{\beta_1}{\widetilde{x}^{**}}(\frac{x}{\widetilde{x}^{**}})^{\beta_1}[\frac{p}{r} - (k_1 + k_2\underline{\alpha}(\widetilde{x}^{**}))]$$

As one can see, the sign of the first derivative depends on the term $\frac{p}{r} - (k_1 + k_2\underline{\alpha}(\widetilde{x}^{**}))$. Under $k_1 < \frac{p}{r} < k_1 + k_2$, the interior solution is equal to

$$\widetilde{x}^{**} = [(\frac{k_2}{B})(\frac{\frac{p}{r} - k_1}{k_2})^{1-\gamma}]^{1/\beta_1} = \underline{x}(\frac{\frac{p}{r} - k_1}{k_2})^{\frac{1-\gamma}{\beta_1}}.$$

Now, if $k_1 \geq \frac{p}{r}$, then $\frac{\partial (x/\widetilde{x}^{**})^{\beta_1} NPV^p(\widetilde{x}^{**})}{\partial \widetilde{x}^{**}} > 0$ which means that the potential investor should postpone investing until $\widetilde{x}^{**}$ approaches $\underline{x}$ and invest only if $\lim_{\widetilde{x}^{**} \to \underline{x}} NPV^p(\widetilde{x}^{**}) \geq 0$.

On the other hand, under $\frac{p}{r} \geq k_1 + k_2$, $\frac{\partial (x/\widetilde{x}^{**})^{\beta_1} NPV^p(\widetilde{x}^{**})}{\partial \widetilde{x}^{**}} < 0$ which means that the potential investor should invest immediately as the sunk investment cost $(k_1 + k_2\underline{\alpha}(\widetilde{x}^{**}))$ is lower than the present value of the flow of net payments $\frac{p}{r}$.

B.2.2 Investing under scenario D

When $\Psi > 0$, the landholder contemplates investing in a land development project characterized by capital intensity $\overline{\alpha} < 1$. The analysis of the investment timing is identical to the one provided above for the corresponding case in Scenario C.

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