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Essays on Investment Efficiency and Timing

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Essays on Investment Efficiency and Timing

by

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Abstract

A standard framework for the analysis of investment opportunities in the literature of corporate finance is the real options approach. The real options approach examines the value and timing of investment projects building on the idea that the opportunity to invest in a project is analogous to a financial option on a real asset. This means that, when evaluating an investment opportunity characterized by uncertainty and irreversibility, the potential investor needs to factor in that, at the time of the investment, s/he forgoes the option to postpone the investment decision for some future time point when the uncertainty will be, naturally, partly resolved.

With the real options approach as a starting point, this thesis is comprised by three papers examining primarily investments undertaken in a supply-chain setting (paper 1 and paper 2) and, secondarily, projects aiming at land development (paper 3).

KEYWORDS: Investment Analysis, Real Options, Vertical Relations, Nash Bargaining, Information Asymmetries, Agency Conflicts, Land Development, Capital Intensity, Passive Farming.

Thesis Supervisor: Michele Moretto
Title: Professor of Economics

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As you set out for Ithaka
hope the voyage is a long one,
full of adventure, full of discovery.

C.P. Cavafy, Ithaka (part)

Abbreviations:

BPS: Basic Payment Scheme

CAP: Common Agricultural Policy

EU: European Union

GAEC: Good Agricultural and Environmental Conditions

SMR: Statutory Management Requirements

SPS: Single Payment Scheme

This doctoral thesis consists of a summary of the following publications:

1. Zormpas, D., 2017. How vertical relationships and external funding affect investment efficiency and timing? Working paper.

2. Zormpas, D., 2017. Investments under vertical relations and agency conflicts: The merits of supply chain transparency. Working paper.

3. Zormpas, D., Di Corato, L., 2017. Should I farm or should I not? Working paper.

All the references are available at the end of the manuscript.

Chapter 1

Introduction

Innovation is an important factor for a company's success and a crucial explanation for observed differentials in performance (McGrath and Nerkar, 2004). Consequently, a fundamental problem that a firm faces has to do with the decision to invest in a new product, technology or service market. As noted by Miller and Modigliani (1961), a significant part of many firms' market values consists of such future growth opportunities i.e. assets not yet in place. Myers (1977) argued that these assets are analogous to financial options, in the sense that one has the right but not the obligation to invest, and consequently stock option pricing methods should be used for their evaluation.

The real options approach acknowledges that investment opportunities are options on real assets and provides a way to apply option pricing methods to investment decision problems. It claims that the classic net present value rule is not always valid and argues that the option to postpone an investment decision characterized by uncertainty and irreversibility has to be taken into account. McDonald and Siegel (1986) gave an expression for the option value and showed that the optimal investment strategy is a trigger strategy in the sense that one should invest as soon as the project value is greater than a threshold, the value of which increases with uncertainty.[1]

Departing from the standard real options approach presentation, my goal in this thesis is to examine how the investment timing and the value of the opportunity to invest are affected

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[1]See e.g. Dixit and Pindyck (1994).

by factors that are beyond the potential investor's control, such as the special attributes of the industry (paper 1 and paper 2) and the relevant legislative framework (paper 3).

In the first chapter of my thesis I examine the case of a potential investor who contemplates entering an uncertain new market under two conditions. On one hand, the completion of the investment is conditional on the participation of an investment partner who is willing to bear some of the investment cost receiving compensation in return, whereas, on the other, a prerequisite for the project to take place is the purchase of a discrete input from an upstream firm with market power.

Beginning with the former, according to Chesbrough and Schwartz (2007), timely investments are often beyond the resources of a single firm and, as a result, an investment partner willing to share the cost of betting on the success of the business plan under consideration is frequently sought after (Kogut, 1991).[2] Of course, the investment partner anticipates financial (or other[3]) returns and this is what makes the interaction between the two associates particularly challenging.[4]

At the same time, as Billette de Villemeur et al. (2014) point out, the investment is not always performed in-house, as for instance would be the case for a research and development project.[5] Instead, in many cases, the completion of an investment project might depend on the provision of a discrete input produced by an upstream firm. For instance, Billette de Villemeur et al. (2014) refer to investments in the vaccine industry where facilities are specifically designed for the production of a novel vaccine. In this case, the needed customized equipment is sourced on an intermediate market from specialized input providers with market power. In the same vein, Pennings (2016) refers to large infrastructure projects as, e.g., a telecommunications network. In that case, an upstream firm (construction company) is responsible for the provision of an indispensable input (network), to a downstream firm (internet provider). In these cases, the investment cost is endogenous since it is specified by the vertical relationship between the external input supplier and the project manager who is making the investment decision on

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[2] According to Quinn (2000), using partnerships "companies have lowered innovation costs and risks by 60% to 90%, while similarly decreasing cycle time and leveraging their internal investments by tens to hundreds of times".

[3] For instance, a window on new technologies.

[4] See e.g. Vrande and Vanhaverbeke (2013), Dushnitsky and Lenox (2005a) and Reuer and Tong (2007).

[5] See also Hargadon and Sutton (2000) and Linder (2004).

behalf of the project originator.

Keeping all this in mind, the research question that is posed and addressed in the first paper of the thesis is: *How vertical relationships and external funding affect investment efficiency and timing?*

In the second paper of the thesis, and still working in a supply chain setting, I examine an investment project undertaken in a decentralized setting in the presence of information asymmetries.

By construction, the standard real options model does not account for agency conflicts and information asymmetries since the investment is always assumed to be managed by the project originator. However, in many modern corporations, investment decisions are delegated by the owner of the corporation (principal) to a manager (agent) who possesses a relevant skill set or piece of information.[6] Of course the principal benefits from the expertise of the agent but, at the same time, s/he might be exposed to information asymmetries. If the agent has an informational advantage over the principal, then the latter must carefully consider the underlying means and motives when deciding the terms of the delegation. More precisely, the principal needs to develop an appropriate mechanism in order to incentivize the agent to share private information resolving the information asymmetry. The use of such a mechanism is costly for the principal but, without it, s/he is due to face further distortions stemming from the coordination failure.[7]

As we will see in the next section, there is a growing body of papers that incorporate agency conflicts that stem from information asymmetries into the real options model. In spite of the differences in their analyses, what these papers share is the assumption that the investment cost is exogenous. The novelty of my work lies again on the fact that the investment cost is explicitly assumed to be endogenous. With Billette de Villemeur et al. (2014) as my starting point, I examine an investment project that: i) is characterized by uncertainty and irreversibility, ii) is undertaken in a decentralized setting and iii) depends on the provision of a necessary input by an external supplier with market power. Consequently, the research question that is posed and

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[6]Delegation is a standard practice especially in industries that have to do with textiles, construction, aeronautics, telecommunications, computers, automobiles and electronics. Melumad et al. (1997), Agrell et al. (2004), Lee et al. (2004), Schieg (2008), Tang et al. (2009), Deshpande et al. (2011), Doorey (2011), Kayis et al. (2013), Bolandifar et al. (2016) and Agrell and Bogetoft (2017) provide relevant examples.

[7]For an overview of the literature on asymmetric information see e.g. Laffont and Martimort (2002).

addressed in the second paper in the thesis is: *How vertical relationships and agency conflicts affect investment efficiency and timing?*

Last, in the third paper of the thesis and using again the real options approach, I examine a land allocation problem.

The Common Agricultural Policy (CAP) is one of the oldest and more dynamic policies of the European Union (EU). It was launched in 1962 in order to guarantee food security for the consumers and market stabilization for the farmers in the EU. 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 farming sector ensuring at the same time budget control and rural development.[8] As of today, the CAP has two main components: Pillar 1, that deals with payments to farmers and Pillar 2, used by the Member States in order to fund rural development programs.

Prior to the 2003 CAP reform, farmers received, through Pillar 1, payments which were coupled to crop production. This measure was deemed as successful during the early years of the CAP since it effectively secured the food autonomy of the EU. However, this scheme eventually led, by directly affecting cropping decisions at the farm level, to overproduction.[9] In an attempt to make the farming sector more efficient and more market oriented, the CAP budget devoted to coupled support has been limiting over the years. The introduction of the Single Payment Scheme (SPS) in 2003 was a relevant step in that direction.

As of today,[10] the actual production of agricultural commodities is not a prerequisite for the CAP income support.[11] On the contrary, landholders are entitled to income support as long as their land meets the so called cross-compliance requirements that include i) statutory management requirements (SMR) and, ii) Good Agricultural and Environmental Condition

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[8]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.

[9]See e.g. http://ec.europa.eu/agriculture/cap-history/index_en.htm.

[10]The 2013 reform of the Common Agricultural Policy replaced the SPS with the Basic Payment Scheme (BPS) which came into effect as from 2015. Similarly as the SPS, the BPS is based on payment entitlements, activated on eligible land and decoupled from production. See e.g. https://ec.europa.eu/agriculture/sites/agriculture/files/direct-support/direct-payments/docs/basic-payment-scheme_en.pdf.

[11]Despite the fact that 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.

(GAEC) standards relating to climate change, good agricultural condition of the land, plant health and animal welfare.[12] The main argument in favor of the decoupling of the CAP income support from the production of agricultural commodities is that the CAP should support the income of the farmer, rather than the production itself (see e.g. Keenleyside and Tucker, 2010). At the same time, according to the CAP,[13] a modern rural development policy needs farmers to act both as producers of food and as guardians of the countryside, undertaking sustainable farming practices that contribute to the preservation of the natural environment.

The merits of decoupling and its actual impact in the farming industry are however strongly debated. Decoupling is often seen as a measure that supports passive farming, i.e. the mere management of the farmland in order to meet the SMR and GAEC obligations but without producing commodities.[14] Passively farmed land is usually referred to as being underutilized or blocked since it could otherwise be used for producing commodities by expansion-willing farmers (LRF, 2009 and Ciaian et al., 2010).[15] Furthermore, as reported by Brady et al. (2009) and Ciaian et al. (2010), decoupled payments may, by discouraging farm exit and increasing part-time farming, slow down structural change in the industry. Last, according to Renwick et al. (2013), passive farming may hinder agricultural development and consequently even jeopardize food security.

Consequently, the research question that is posed and addressed in the third chapter of the thesis is: *How are the decoupled from production payments of the current CAP affecting the timing, the capital intensity and the value of investment projects undertaken by potential farmers in the EU?*

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[12] See Ciaian et al. (2010) for an illustration and discussion of cross-compliance requirements.

[13] 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.

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

[15] The 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).

Chapter 2

Literature review

2.1 Literature review for paper 1

The work in paper 1 relies on an established body of papers that integrate two research streams: the basic theory of irreversible investment under uncertainty as in Dixit and Pindyck (1994), and the classic presentation of vertical relationships as described e.g. by Tirole (1988).[1] Real option analysis has been used to study joint ventures (Kogut, 1991; Li et al., 2008; Cvitanić et al., 2011; Banerjee et al., 2014), R&D and technology development (McGrath and Nerkar, 2004; McGrath, 1997; Folta, 1998), outsourcing (Alvarez and Stenbacka, 2007; Kogut and Kulatilaka, 1994; Moretto and Rossini, 2012; Di Corato et al., 2017; Triantis and Hodder, 1990; Teixeira, 2014), as well as venture capital investments (Lukas et al., 2016; Vrande and Vanhaverbeke, 2013; Dushnitsky and Lenox, 2005b) and acquisitions (Folta and Miller, 2002; Benson and Ziedonis, 2009; Lambrecht, 2004; Tong and Li, 2011).

The most closely related work I have identified is in corporate finance and supply chain management, most notably Lambrecht (2004), Banerjee et al. (2014) and Chen (2012), Lukas and Welling (2014).

Lambrecht (2004) analyzes a merger between two firms motivated by economies of scale using two different sequences of moves. According to the first ("friendly merger"), one of the two parties is choosing the optimal timing and then the terms of the merger are commonly decided,

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[1]Recent overviews of the related literature include Chevalier-Roignant et al., 2011; Azevedo and Paxson, 2014; Guimarães Dias and Teixeira, 2010; Huisman et al., 2004.

whereas, according to the second ("hostile takeover"), the two parties commit to the terms of the merger first and the timing is decided second. A comparison between the two suggests that, the way synergies are divided may influence the timing of the merger. Similarly, Banerjee et al. (2014) use a two-stage decision-making framework in which the parties determine the sharing rule as an outcome of Nash bargaining and one of them makes the timing decision related to the exercise of the jointly held option. Considering both cash transfers and ownership stakes, they show that when the exercise decision is made first, timing is always optimal[2] whereas, when the sharing rule is determined first ("hostile takeover" case from Lambrecht, 2004) investment timing is socially inefficient unless a combination of stake in the project and a cash transfer is used. In this case, it generally matters which firm makes the timing decision and how the bargaining power is distributed.

In the supply chain management literature, Chen (2012) models a two-echelon supply chain consisting of one supplier and one retailer. The two-stage optimization problem evolves in the following way. In the first stage, the two agents negotiate over the optimal quantities whereas in the second stage, they coordinately determine the optimal timing of investing in the supply chain under uncertain demand. The results show that the volatility of demand shock has an ambiguous effect on the investment threshold with increasing impacts at lower level and decreasing impacts at higher level of uncertainty. Lastly, Lukas and Welling (2014) model the optimal timing of "climate-friendly" investments in a supply chain framework and enrich the contribution of Chen (2012) in the following ways. Firstly, they adopt a non-cooperative game theoretic setting according to which the optimal timing is decided, not jointly but by one of the participating firms and, secondly, they extend the two-echelon supply chain allowing for more than two participants showing that a supply chain becomes less efficient with every additional link as the timing distortion builds up.

In spite of the differences in their analyses, what all these papers have in common is the nature of the investment cost which is tacitly assumed to be exogenous. As Billette de Villemeur et al. (2014) point out, this assumption seems reasonable when the investment is performed largely in-house, but this is not always the case. For instance, there are many other cases in

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[2]This is a generalization of the friendly merger case discussed in Lambrecht (2004) and in Morellec and Zhdanov (2005).

which the completion of a firm's investment project depends on an upstream supplier who is responsible for the provision of a discrete input. In that case, the cost of the single firm's investment is endogenous since it is specified by the vertical relationship between the external supplier and the potential investor.

The novelty of my work lies on the fact that the investment cost is explicitly assumed to be endogenous, hence the research question: *How vertical relationships and external funding affect investment efficiency and timing?* In the paper, I initially study a non-cooperative game-theoretic setting according to which, the optimal timing is decided by the investment partner whereas the sharing rule is decided by the project originator, given the price of an indispensable input provided by an external supplier with market power. I subsequently readdress this three-agent[3] problem deriving the conditions under which it would be socially preferable to determine the sharing rule as an outcome of Nash bargaining and I find that the presence of the upstream firm makes a substantial difference when one considers the timing and the value of the option to invest in a given project, both in the cooperative (Nash bargaining solution) and in the non-cooperative case.

2.2 Literature review for paper 2

My work in paper 2 contributes to the research area that integrates the basic theory of irreversible investment under uncertainty as in Dixit and Pindyck (1994) and the literature on asymmetric information as in Laffont and Martimort (2002).

There is a growing body of papers that incorporate agency conflicts that stem from information asymmetries into the real options model. For instance, Grenadier and Wang (2005) analyze the timing and efficiency of an investment undertaken in a decentralized setting under the presence of information asymmetries and hidden action between the project originator and the project manager. Shibata (2009) extends the analysis of Grenadier and Wang (2005)

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[3]Note that this framework involves three agents of different type: the project originator, the investment partner and the input supplier. It is true that models with more than two agents have already been analyzed in the literature. For instance, Billette de Villemeur et al. (2014) present the case of a downstream duopoly with an upstream supplier and Banerjee et al. (2014) extend their two-party model to any number of investment partners. However, in both cases, as well as in the N-echelon supply chain presented by Lukas and Welling (2014), the types of agents are always two. The introduction of a third type is the key originality of this framework.

replacing the originally used bonus-incentive mechanism with an audit technology. Shibata (2008) focuses on the impact of uncertainty on the timing and the value of the project whereas Shibata and Nishihara (2010), Grenadier and Malenko (2011), Morellec and Schürhoff (2011), Hori and Osano (2014) and Cardoso and Pereira (2015) among others examine the effect of capital structure and financing of the investment. Cong (2013) and Bouvard (2014) examine the implications of endogenous learning and experimentation respectively, whereas Mæland (2010) and Koskinen and Mæland (2016) approach the agency conflict assuming that the project manager is actually the winner of an auction in which a number of experts (potential delegates) participate. Last, Broer and Zwart (2013) examine the optimal regulation of an investment undertaken by a monopolist who has private information on the investment cost whereas Arve and Zwart (2014) examine the case where the information asymmetry between the delegator-entrepreneur and the delegate-expert has to do with the starting point of the process that is used to capture the fluctuations of the stochastic parameter.

The most closely related papers I have identified are Grenadier and Wang (2005), Shibata (2009) and the first paper of the present thesis. Grenadier and Wang (2005) examine the interaction between a potential investor who contemplates an investment decision characterized by uncertainty and irreversibility and the expert who is delegated to make the investment decision on behalf of the potential investor. It is shown that under hidden action and hidden information between the two parties, the principal can induce the agent both to extend effort and to reveal private information by using a bonus-incentive contract. Despite the fact that the use of such an instrument is suboptimal in the sense that the chosen investment timing differs significantly from the timing in the full information setting, the principal's losses are reduced since further distortions are avoided.[4] Shibata (2009) extends the model presented by Grenadier and Wang by replacing the bonus-incentive contract with an audit technology. Focusing on the adverse-selection-only case he shows that, by using auditing instead of a bonus-incentive, the timing inefficiency is reduced, the principal's value is appreciated whereas the agent's value is

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[4]In Grenadier and Wang (2005) the management effort is assumed to be exogenous. Shibata and Nishihara (2011) approach the same problem using a two-stage optimization problem that allows investment timing and management effort endogenously decided. The numerical examples that they present suggest that the management effort is greater under asymmetric information than under full information. This in turn implies that there are trade-offs between investment efficiency and management effort under asymmetric information. In the same vein, Hori and Osano (2009) examine the replacement timing of a manager as an incentive mechanism.

depreciated. Nevertheless, the audit technology does not necessarily lead to an increase in the aggregate value of the opportunity to invest.

Despite the differences detected in the adopted framework, what the two papers have in common is the assumption that the investment cost is exogenous. However, as highlighted by Billette de Villemeur et al. (2014), the cost of an irreversible investment project characterized by uncertainty does not always reflect the project's economic fundamentals. Using a stochastic dynamic programming model the authors show that, if the completion of an investment project depends on the provision of an indispensable input from an outside firm, a vertical distortion arises. This eventually leads to the suboptimal delay of the investment which is also translated into a reduced value for the project originator.

The analysis presented in the first paper of the present thesis applies the endogenous pricing of the input à la Billette de Villemeur et al. (2014) in a setting that describes an investment project the completion of which depends on the successful interaction between the project originator and a foreign firm. The foreign firm is assumed to be an investment partner willing to undertake an exogenously given share of the sunk investment cost claiming a share of the project in return. The derived results suggest that the presence of an upstream supplier that is responsible for the provision of an indispensable input causes the suboptimal postponement of the investment which is then reflected in a lower project value. Of course, the fact that the involved foreign firm acts as an investment partner (and not as a project manager) is important since it implies that there is no information asymmetry to foster an agency conflict downstream. Consequently, the presence of the external input supplier affects the timing of the investment and the payoffs of the two partners but not their interaction itself.

Extending that piece of work, I now study the case where the foreign firm is not an investment partner but, instead, an expert delegated by the project originator to exercise the investment option on her/his behalf. The key originality of this framework is exactly the combination of the decentralized investment setting and the endogenous pricing of a necessary input. I approach the principal's investment problem assuming that, under information asymmetries, s/he uses a bonus-incentive mechanism to guarantee that the project manager will truthfully share private information related to the cost of the investment. Given this, the upstream supplier who has (full or partial) information about the structure of the downstream industry and

the evolution of the stochastic process that captures the fluctuations of the value of the project over time, chooses the price of the necessary input. The relevant research question is: *How vertical relationships and agency conflicts affect investment efficiency and timing?*

2.3 Literature review for paper 3

In terms of methodology, the most closely related literature stream that I have identified is the one that is comprised by papers that are focusing on the impact of subsidies on investment projects characterized by uncertainty and irreversibility (see e.g. Pennings, 2000). The papers in this strand of the literature analyze how the policy maker can use the subsidy as a policy instrument to induce a certain action. For instance, Thorsen (1999) presents the case where a subsidy is paid to incentivize the afforestation of degraded land and Song et al. (2011) and Musshoff (2012) analyze the use of subsidies as a measure to encourage the cultivation of energy crops. Similarly, Kuminoff and Wossink (2010) use it to model the transition from conventional to organic farming whereas Schatzki (2003) and Isik and Yang (2004) model habitat conservation. As expected, the policy maker can, by choosing the level of the subsidy, affect the timing of the transition from the old to the new state.

Despite the fact that the effects of the CAP on the investment behavior of the European farmers and landholders have been well discussed in political and academic circles since the implementation of the policy back in the early 1960s, the phenomenon of passive farming itself has attracted up to now limited attention. Trubins (2013) was the first to describe the phenomenon and its characteristics focusing on the effect of the policy on land use in Sweden. In the same vein, Brady et al. (2017), using a static and deterministic framework, show that passive farming occurs generally when active farmers do not meet landowners' minimal rental price who eventually prefer to manage their land passively, cashing the decoupled payments. Building on this work, 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 lease bargaining process under uncertain farming returns. Solving a dynamic problem, they show that decoupled payments accelerate the timing of land development if compared to the case where this support is not provided. Secondly, they verify that, because of the presence

of decoupled payments, the agreement between a lessee and a landowner is conditional on the farming project reaching a minimum of expected profitability and, last, they show that cooperative bargaining makes both parties better-off.

In this paper, I investigate the impact that the decoupled payments may have on i) the level of optimal capital intensity, ii) the timing of the investment and iii) the value of the opportunity to invest, hence the research question: *How are the decoupled from production payments of the current CAP affecting the timing, the capital intensity and the value of investment projects undertaken by potential farmers in the EU?*

As in Di Corato and Brady (2017), I use the real options approach. This is an appropriate method to use since land development projects involve sunk costs (e.g. the mere transformation of idle land into farmland), uncertainty of future payoffs (e.g. the prices of agricultural commodities are volatile) and flexibility (e.g. the option to postpone the investment or the option to switch between active and passive farming according to the market trends once the investment is undertaken).[5] My contribution lies on the fact that I relate the temporal flexibility available before the investment is undertaken, i.e. the option to invest, with the operational flexibility available once invested, i.e. the option to suspend and the option to restart farming.

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[5]See also Feil et al. (2013).

Chapter 3

Synthesis of paper 1

In this paper, I use the real options approach in order to examine the interaction among i) a firm who is contemplating entering an uncertain new market, ii) a firm who acts like an investment partner partly financing this project receiving a share of the final investment in return and iii) an upstream supplier with market power who is responsible for the provision of an input that is necessary for the investment to take place. Using a stochastic dynamic programming model, I examine how the involvement of the two alien agents affects the investment timing and how the observed timing discrepancies are reflected in the value of the opportunity to invest.

3.1 The model

3.1.1 The basic set-up

Firm A is a risk neutral potential investor willing to enter a market with growing but uncertain demand. The profit flow that A is cashing upon investment is $y_t \pi_M$ where $\pi_M > 0$ is the instantaneous monopolistic profit per unit of y_t and y_t is a stochastic scale parameter that fluctuates according to the following geometric Brownian motion:

$$\frac{dy_t}{y_t} = \alpha dt + \sigma dW_t, \ y_0 = y, \tag{1}$$

where $\alpha > 0$ is the drift, $\sigma > 0$ is the instantaneous volatility and dW_t is the standard increment of a Wiener process (standard Brownian motion) uncorrelated over time satisfying $E[dW_t] = 0$

and $E\left[dW_t^2\right] = dt$.

A discrete input is a prerequisite for A to operate in the final market and this input is supplied by a risk neutral upstream firm with market power called C. It is assumed that C prices this input taking into consideration the structural parameters of the geometric Brownian motion presented above, but without ever observing y_t.[1]

The completion of the project depends also on the cooperation of a risk neutral investment partner B who is willing to bear a share of the investment cost, asking for compensation in return. Contrary to the upstream firm, it is assumed that the investment partner is in a position to continuously and verifiably observe the fluctuations of the scale parameter over time. One can argue that this is a sensible assumption since B will consider joining forces with A only if s/he has enough information for the considered project. For instance, one can think of B as a financial institution and A as a customer asking for a business loan. The customer will need to present a thorough business plan in order to convince the financial institution about the promising character of the project. In this case, the potential investor is basically voluntarily sharing her/his information endowment with the investment partner. Alternatively, one can assume that B might actually be in a position to observe the scale parameter over time without A's help. For instance, Mulherin and Boone (2000) as well as Vrande and Vanhaverbeke (2013) report evidence for significant industry clustering for merger and acquisition activities. These findings support the argumentation from Puranam et al. (2009) and Dushnitsky and Lenox (2005b) who suggest that firms seem to seek ventures similar to their own because this appears to facilitate the possible integration of technological resources in the future.

Before analyzing the three-agent case where the interaction among A, B and C is discussed, I briefly review the problem under (i) vertical integration and (ii) outsourcing or partial external funding (but not both).

3.1.2 Vertical Integration

The vertically integrated case will be the benchmark. In this simplified setting it is assumed that the potential investor produces the input in-house funding privately the completion of the

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[1] As noted by Billette de Villemeur et al. (2014), if C is in a position to continuously and verifiably observe the state of y_t, then s/he can expropriate the project by choosing a suitable input price. Here I assume that the upstream firm has no access to this kind of information.

project.

Following the real options literature, one should keep in mind that there is some flexibility when one considers an investment opportunity under irreversibility and uncertainty. As firstly reported by McDonald and Siegel (1986), the ability to delay an irreversible investment expenditure is an important source of flexibility that profoundly affects the decision to invest. A will only invest when the project's expected payoff exceeds the cost of the investment by the option value of further postponing the investment into the future.[2]

Assuming that the initial market size is positive and sufficiently small so that a delay of the investment is preferable, the optimal investment time point τ^{VI} is derived through the solution of the following maximization problem:

$$F_A^{VI}(y) = \max_{\tau^{VI}} E_y\left((V_{\tau^{VI}} - I)e^{-r\tau^{VI}}\right) = \max_{y^{VI}}\left(\frac{y^{VI}\pi_M}{r-\alpha} - I\right)\left(\frac{y}{y^{VI}}\right)^\beta, \tag{2}$$

where $V_t = E_t\left[\int_t^\infty y_s\pi_M e^{-r(s-t)}ds\right] = \frac{y_t\pi_M}{r-\alpha}$ is the value of the project, $\beta \equiv \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1$ is the positive root of the characteristic equation $\frac{1}{2}\sigma^2\beta(\beta-1)+\alpha\beta-r = 0$, $r\,(>\alpha)$ is the common to all firms discount rate,[3] $I > 0$ is the sunk cost of producing the input in-house and $\tau^{VI} = \inf\left\{t \geq 0 \,\middle|\, y_t = y^{VI}\right\}$ is the random first time point that y_t hits the barrier y^{VI} which is the market size that triggers the investment. The expressions for $F_A^{VI}(y)$ and β are standard in the real options literature (see Dixit and Pindyck (1994), Chapters 5-6 and Dixit (1993), Section 2). From the first-order condition one obtains

$$y^{VI} = \frac{\beta}{\beta-1}\frac{r-\alpha}{\pi_M}I. \tag{3}$$

As expected, y^{VI} is increasing in the sunk investment cost I and the volatility σ but is decreasing in the present value of the profit flow $\frac{\pi_M}{r-\alpha}$.[4] In words, a firm stands to gain more by holding, rather than exercising, an investment option with a high strike price (I in this case), a high underlying asset volatility (σ in this case) but small return ($\frac{\pi_M}{r-\alpha}$ in this case).[5]

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[2]O'Brien et al. (2003) present strong empirical evidence in favor of this argument. More precisely, they find that entrepreneurs account for the value of the option to delay entering a new market when contemplating such a decision.

[3]The inequality $r > \alpha$ guarantees convergence.

[4]Note that the effect of volatility on the investment threshold passes through β.

[5]Note that the classic net present value rule would dictate the lower investment threshold $y^{NPV} = \frac{r-\alpha}{\pi_M}I$. As

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Combining Eq. (2) with Eq. (3) we obtain the value of the option to invest

$$F_A^{VI}(y) = \frac{I}{\beta - 1} \left(\frac{y}{y^{VI}} \right)^{\beta}. \tag{4}$$

These results lead to the first proposition:

Proposition 1 *A single firm that produces the input in-house and self-finances the investment project, will enter the market as soon as the scale parameter reaches a threshold $y^{VI} = \frac{\beta}{\beta-1} \frac{r-\alpha}{\pi_M} I$. The value of the option to invest in this project is $F_A^{VI}(y) = \frac{I}{\beta-1} \left(\frac{y}{y^{VI}} \right)^{\beta}$.*

3.1.3 The input is outsourced and the investment is privately funded

Suppose now that the input is produced by an upstream firm with market power C. Adopting the framework presented by Billette de Villemeur et al. (2014), A and C engage in a leader-follower game at time zero. Moving backwards, A (the follower) decides the optimal investment threshold taking into consideration the constant input price p. Then, C (the leader) decides the optimal p accounting for the production cost I, the structural parameters of the stochastic term y_t and A's timing decision.

The optimal investment threshold is derived through the solution of the following maximization problem:

$$F_A^{OS}(y) = \max_{y^{OS}(p)} \left(\frac{y^{OS}(p)\pi_M}{r - \alpha} - p \right) \left(\frac{y}{y^{OS}(p)} \right)^{\beta} \tag{5}$$

Solving we obtain

$$y^{OS}(p) = \frac{\beta}{\beta - 1} \frac{r - \alpha}{\pi_M} p. \tag{6}$$

The decision problem of C, involves only the choice of p that is derived as the solution of $F_C^{OS}(y) = \max_{p^{OS}} \left(p^{OS} - I \right) \left(\frac{y}{y^{OS}(p^{OS})} \right)^{\beta}$:

$$p^{OS} = \frac{\beta}{\beta - 1} I. \tag{7}$$

Combining the optimal investment trigger from Eq. (6) with the optimal input price from Eq.

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one can see, even a risk neutral potential investor is sensitive to uncertainty when considering an irreversible investment the realization of which can be postponed.

(7), we obtain $y^{OS}\left(p^{OS}\right) = \frac{\beta}{\beta-1}\frac{r-\alpha}{\pi_M}\frac{\beta}{\beta-1}I$ which can be written as

$$y^{OS}\left(p^{OS}\right) = \frac{\beta}{\beta-1}y^{VI}\left(> y^{VI}\right).$$ (8)

From Eq. (7) and Eq. (8) one can see that both p^{OS} and $y^{OS}\left(p^{OS}\right)$ are decreasing in β i.e. are increasing in volatility. This implies that A will probably consider abandoning a very risky project or, in any case, will delay the investment as much as possible.[6] C takes this into account setting a high p^{OS} discounting this way for the delay between the time that p^{OS} is chosen until the time it is cashed. Similarly, a project that involves very little risk will be undertaken relatively quickly by A and this will also be reflected in a lower input price. Note however, that there is a minimum for p^{OS}: $\lim_{\sigma\to 0} p^{OS} = \frac{r}{r-\alpha}I > I$. As one can see, despite the fact that the acceleration of the project is beneficial for C, s/he is not willing to lower p^{OS} below a minimum $\frac{r}{r-\alpha}I$. This has to do with the fact that, for prices below $\frac{r}{r-\alpha}I$, the completion of the project is indeed further hastened but what is sacrificed in terms of cash flow is not remunerated from the additional acceleration of the project.

Combining Eq. (5), (7) and (8) we have

$$F_A^{OS}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta-1}F_A^{VI}(y).$$ (9)

Also, for C:

$$F_C^{OS}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta}F_A^{VI}(y)$$ (10)

The following proposition summarizes these findings:

Proposition 2 *A single firm that outsources the input and self-finances the investment project, will enter the market as soon as the scale parameter reaches a threshold* $y^{OS}\left(p^{OS}\right) = \frac{\beta}{\beta-1}y^{VI}$. *The value of the option to invest in this project is* $F_A^{OS}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta-1}F_A^{VI}(y)$.

Comparing the findings from Propositions 1 and 2 we obtain the following:

Proposition 3 *When an upstream supplier is responsible for the provision of the input, the*

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[6] $\lim_{\beta\to 1} y^{OS}\left(p^{OS}\right) \to \infty$

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investment is postponed $\left(y^{OS} > y^{VI}\right)$ and the potential investor's option to invest is less valuable $\left(F_A^{OS}(y) < F_A^{VI}(y)\right)$.

As one can see, the effect of the presence of C is twofold. On one hand, it increases the investment threshold delaying the completion of the project and, on the other, it reduces the value of the option to invest for the potential investor A.

3.1.4 The input is produced in-house and the investment is partly externally funded

Going back to the case of vertical integration, it is assumed that the potential investor produces the input in-house. However, the realization of the project that A has in mind depends now on the cooperation of an investment partner B.

Following Lukas and Welling (2014), B is willing to undertake an exogenously given share $\xi \in (0, 1)$ of the sunk investment cost, and this allows A to fund only the rest of the project. In return, A and B negotiate over the compensation that the former needs to pay to the latter. More precisely, it is assumed that at time zero A credibly commits to offer a fraction $\psi \in (0, 1)$ of the project to B. Now B has the option to accept this offer immediately disbursing the capital needed for the realization of the project or, alternatively, can delay this contribution for some future time.[7] Similarly to the previous subsection, we have a leader-follower game with A (the leader) deciding the compensation offer and B (the follower) deciding the optimal timing taking the compensation offer ψ into account.[8]

Starting with the problem of the follower we have $F_B^{VC}(y) = \max\limits_{y^{VC}(\psi)} \left(\psi \frac{y^{VC}(\psi)\pi_M}{r-\alpha} - \xi I \right) \left(\frac{y}{y^{VC}(\psi)} \right)^\beta$. Solving we obtain

$$y^{VC}(\psi) = \frac{\xi}{\psi} y^{VI}. \tag{11}$$

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[7] As one can see, the adopted framework is general enough to describe joint ventures and independent venture capital investments. However, it seems particularly suitable to describe corporate venture capital (CVC) investments. According to Roberts and Berry (1985), CVC investments consist of minority equity stakes in relatively new, not publicly traded companies and their purpose is to identify and value early-stage technology in start-ups. This description corresponds exactly to the behavior of the investment partner B who agrees to receive a share ψ of A's project instead of a standard cash flow.

[8] One can also consider the case where B is the game-leader submitting the compensation offer and A is the game-follower deciding the investment timing. In subsection 3.4.1 of the Appendix, I show that such a change does not affect the nature of the main results.

As expected, $y^{VC}(\psi)$ is increasing in ξ and decreasing in ψ. This just means that the investment will be postponed as the cost share for the investment partner is increasing, a result that can be neutralized if the potential investor is willing to improve the submitted compensation offer. As one can see, A faces a dilemma since a low compensation offer implies access to a larger cash flow later in the future whereas a high compensation offer shortens the waiting period but gives access to a smaller cash flow in return.

The potential investor takes into consideration the reaction of the investment partner and decides the compensation offer that is derived as the solution of the following maximization problem:

$$F_A^{VC}(y) = \max_{\psi^{VC}} \left(\left(1 - \psi^{VC}\right) \frac{y^{VC}(\psi^{VC})\pi_M}{r - \alpha} - (1 - \xi)\, I \right) \left(\frac{y}{y^{VC}(\psi^{VC})} \right)^{\beta}, \qquad (12)$$

which yields

$$\psi^{VC} = \frac{\xi\,(\beta - 1)}{\beta - 1 + \xi}. \qquad (13)$$

Combining Eq. (11) and Eq. (13) we obtain

$$y^{VC}(\psi^{VC}) = \frac{\beta - 1 + \xi}{\beta - 1} y^{VI} \left(> y^{VI} \right). \qquad (14)$$

Studying the optimal compensation offer, one can see that ψ^{VC} is increasing both in β and in ξ. Focusing on the effect of ξ, it is interesting to see that the maximum optimal offer is always below 100%. This has to do with the fact that a more generous compensation offer will indeed hasten the completion of the project but will only make the potential investor worse-off since what is sacrificed in terms of compensation is not remunerated from the acceleration of the investment.

One can also observe that $y^{VC}(\psi^{VC})$ is increasing in ξ and decreasing in β. Actually, the "distance" between $y^{VC}(\psi^{VC})$ and y^{VI} increases in ξ despite the fact that, at the same time, ψ^{VC} is also increasing in ξ. This happens because $y^{VC}(\psi^{VC})$ is a linear, whereas ψ^{VC} is a concave function of ξ. In words, despite the fact that the compensation offer is becoming more generous as the share of the cost covered by B increases, in real terms the offer worsens and this is reflected in a higher investment threshold.

Last, combining Eq. (12), (13) and (14) we obtain

$$F_A^{VC}(y) = \left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^{\beta - 1} F_A^{VI}(y). \tag{15}$$

Also, for B we have

$$F_B^{VC}(y) = \xi \left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^{\beta} F_A^{VI}(y). \tag{16}$$

The following proposition summarizes these results.

Proposition 4 *In the case where the single firm produces the input in-house but the completion of the project depends on external funding, the investment occurs when the scale parameter reaches a threshold $y^{VC}(\psi^{VC}) = \frac{\beta - 1 + \xi}{\beta - 1} y^{VI}$. The value of the option to invest in this project is $F_A^{VC}(y) = \left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^{\beta - 1} F_A^{VI}(y)$.*

Comparing these findings with the values derived in the vertically integrated case we have:

Proposition 5 *In the case where the single firm produces the input in-house but the completion of the project depends on external funding, the investment is delayed $\left(y^{VC} > y^{VI}\right)$ and the potential investor's option to invest is less valuable $\left(F_A^{VC}(y) < F_A^{VI}(y)\right)$.*

As in the previous subsection, the effect of the presence of the additional agent is twofold since, on one hand, it increases the investment threshold delaying the completion of the project and, on the other, it reduces the value of the option to invest for the potential investor.

3.2 The three-agent case

In this section I combine the analyses presented above and I show how the synchronous presence of B and C affects the performance and the actions of A as well as the investment threshold. The three-agent game evolves in the following way:

1. C is the game-leader and decides the input price that maximizes her/his value of the opportunity to invest.

2. Given the input price and the cost share ξ, A submits the compensation offer ψ to B and, finally,

3. B evaluates this compensation offer and decides when to accept it, disbursing the amount that is required for the realization of A's project.

Keeping in mind that A and B continuously and verifiably observe the magnitude of y_t whereas C only knows the structural parameters of the related stochastic process, we move backwards and first study the behavior of the investment partner B. The optimal investment threshold is derived through the solution of: $F_{B3}(y) = \max\limits_{y_3(\psi,p)} \left(\psi \frac{y_3(\psi,p)\pi_M}{r-\alpha} - \xi p \right) \left(\frac{y}{y_3(\psi,p)} \right)^\beta$. Solving, we obtain

$$y_3 (\psi, p) = \frac{\beta}{\beta - 1} \frac{r - \alpha}{\pi_M} p \frac{\xi}{\psi}. \tag{17}$$

The potential investor A will take into consideration the decision of the investment partner and will choose the compensation offer taking the price of the input as given. The optimal ψ is derived as the solution of $F_{A3}(y) = \max\limits_{\psi_3} \left((1 - \psi_3) \frac{y_3(\psi_3,p)\pi_M}{r-\alpha} - (1 - \xi)p \right) \left(\frac{y}{y_3(\psi_3,p)} \right)^\beta$. From the first-order condition we have

$$\psi_3 = \frac{\xi (\beta - 1)}{\beta - 1 + \xi}. \tag{18}$$

As one can check, this is exactly the compensation offer that we derived in Eq. (13) where C was absent. Obviously, the presence/absence of C does not affect the magnitude of the optimal compensation offer that A submits to B since the exogenously given cost share ξ has to do with the generic investment cost no matter if this is I or p.

Let's conclude with the game-leader C. The input supplier observes the behavior both of A and of B and optimally decides the price of the input solving $F_{C3}(y) = \max\limits_{p_3} (p_3 - I) \left(\frac{y}{y_3(\psi_3,p_3)} \right)^\beta$ which yields:

$$p_3 = \frac{\beta}{\beta - 1} I \tag{19}$$

Comparing Eq. (19) with Eq. (7), one can see that $p_3 = p^{OS}$ which means that the presence/absence of B does not affect the optimal price of the input that is decided by C. This is not a surprise since, C is indifferent to the means that A uses to fund the project.

Combining Eq. (17), (18) and (19) we derive the investment threshold which, in this case, is

$$y_3 (\psi_3, p_3) = \frac{\beta}{\beta - 1} \frac{\beta - 1 + \xi}{\beta - 1} y^{VI} \left(> y^{VI} \right). \tag{20}$$

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Note that $y_3(\psi_3, p_3)$ is decreasing in β and increasing in ξ. Similarly to $y^{VC}(\psi^{VC})$, the "distance" between $y_3(\psi_3, p_3)$ and y^{VI} increases in ξ in spite of the simultaneous improvement of the corresponding compensation offer. The reasoning is the same: the investment trigger is a linear whereas the compensation offer is a concave function of the cost share ξ. As we have seen in the previous subsection, despite the fact that the compensation offer is becoming more generous as the cost share ξ increases, in real terms the offer worsens and actually, in the three-agent case, this effect is even more dramatic since the compensation offer worsens "faster" as the (positive) slope of y_3 with respect to ξ is larger than the (positive) slope of y^{VC} with respect to ξ exactly because of the presence of C.

I conclude this subsection returning to the option values for the three agents. Keeping in mind the values for $y_3(\psi_3, p_3)$, p_3 and ψ_3 we obtain

$$F_{A3}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta-1}\left(\frac{\beta-1}{\beta-1+\xi}\right)^{\beta-1} F_A^{VI}(y), \tag{21.1}$$

$$F_{B3}(y) = \xi\left(\frac{\beta-1}{\beta}\right)^{\beta-1}\left(\frac{\beta-1}{\beta-1+\xi}\right)^{\beta} F_A^{VI}(y), \tag{21.2}$$

$$F_{C3}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta}\left(\frac{\beta-1}{\beta-1+\xi}\right)^{\beta} F_A^{VI}(y). \tag{21.3}$$

The following proposition summarizes these results.

Proposition 6 *In the three-agent case where the single firm outsources the production of the input and the completion of the project depends on external funding, the investment occurs when the scale parameter reaches a threshold $y_3(\psi_3, p_3) = \frac{\beta}{\beta-1}\frac{\beta-1+\xi}{\beta-1}y^{VI}$. The value of the option to invest in this project for the potential investor is $F_{A3}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta-1}\left(\frac{\beta-1}{\beta-1+\xi}\right)^{\beta-1} F_A^{VI}(y)$.*

Comparing our findings with the values derived in the vertically integrated case we have:

Proposition 7 *In the three agent case the investment takes place inefficiently late $\left(y_3(\psi_3, p_3) > y^{VI}\right)$ and this is also reflected in the potential investor's option value $\left(F_{A3}(y) < F_A^{VI}(y)\right)$.*

3.2.1 Discussion

In the previous subsections I focused on the effect that the presence of additional agents has on the investment threshold and the potential investor's option value both for the two-agent and

the three-agent case. Keeping all this in mind one can examine this effect in the level of the industry as a whole.

The input is outsourced and the investment is privately funded: We have already computed the value of the option to invest for the potential investor A and the input supplier C. Now adding up Eq. (9) and Eq. (10) we obtain

$$F^{OS}(y) \equiv F_A^{OS}(y) + F_C^{OS}(y) = \frac{(\beta - 1)^{\beta - 1}}{\beta^\beta}(2\beta - 1)F_A^{VI}(y). \tag{22}$$

As one can see, the presence of the firm C affects negatively the value of the option to invest for the whole industry since $F^{OS}(y) < F_A^{VI}(y)$.

The input is produced in-house and the investment is partly externally funded: Summing Eq. (15) and Eq. (16) we obtain

$$F^{VC}(y) \equiv F_A^{VC}(y) + F_B^{VC}(y) = \frac{\beta - 1 + \xi\beta}{\beta - 1}\left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^\beta F_A^{VI}(y). \tag{23}$$

The presence of firm B affects negatively the value of the option to invest for the whole industry since $F^{VC}(y) < F_A^{VI}(y)$.

The three-agent case: Summing up the values of the option to invest for A, B and C from Eq. (21) we obtain

$$
\begin{aligned}
F_3(y) &\equiv F_{A3}(y) + F_{B3}(y) + F_{C3}(y) \tag{24} \\
&= \left(\frac{\beta - 1}{\beta}\right)^{\beta - 1}\left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^\beta\left(\frac{\beta - 1 + \xi}{\beta - 1} + \xi + \frac{\beta - 1}{\beta}\right)F_A^{VI}(y).
\end{aligned}
$$

A comparison of the results derived in this and the previous subsections is given in the following proposition:

Proposition 8 *A comparison among the investment triggers and the option values presented above gives the following rankings:*

1) $y_3(\psi_3, p_3) > y^{OS}(p^{OS}) > y^{VC}(\psi^{VC}) > y^{VI}$,

2) $F_3(y) < F^{OS}(y) < F^{VC}(y) < F_A^{VI}(y)$,

3) $F_{A3}(y) < F_A^{OS}(y) < F_A^{VC}(y) < F_A^{VI}(y)$,

4) $F_{B3}(y) < F_B^{VC}(y)$ and

5) $F_{C3}(y) < F_C^{OS}(y)$.

A number of interesting results can be derived by these comparisons. First of all, we see that as the number of agents involved in an investment project increases, the completion of this project is postponed to the detriment of the investment's value both in the firm and in the industry level. As expected, the vertically integrated case represents the most favorable whereas the three-agent case represents the least favorable scenario. Another interesting observation has to do with the comparison between the effect of the presence of the upstream firm C and the effect of the presence of the investment partner B. As one can see, external funding is preferred to outsourcing in terms of timing and, consequently, in terms of option value.[9]

3.2.2 Numerical Examples

I conclude this subsection using some numerical examples that illustrate the effect of outsourcing and external funding on the investment timing and the value of the option to enter the new market.

The parameters vary as follows: The drift, α, and the volatility, σ, take values $\{0.025, 0.035\}$ and $\{0.2, 0.25, 0.3, 0.35, 0.4\}$ respectively. A high magnitude of the drift captures a high expected increase in the size of the new market whereas different levels of volatility are used to demonstrate the impact of uncertainty on the investment thresholds and option values. The sunk investment cost I takes values $\{24, 48\}$ whereas both the initial level of the stochastic parameter y_0 and the instantaneous monopolistic profit per unit of y_t, π_M, are set equal to unity ($y_0 = \pi_M = 1$). I allow for three different levels of exogenous cost share: $\xi_1 = 0.1$, $\xi_2 = 0.5$ and $\xi_3 = 0.9$ in order to demonstrate how the participation of an investment partner affects the timing and the performance of the investment project. The interest rate r is initially

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[9]In subsection 3.4.2 of the Appendix it is shown that the ranking of the investment thresholds and, con-sequently, the ranking of the aggregate option values, is the same even when A and B swap places i.e. if A becomes the time-deciding agent (game-follower) and B becomes the one that chooses the compensation share (game-leader). However, I also show that this is not the case for the ranking of A's option values which is actually sensitive to such a change.

set equal to 5% but I also check the effect of an increase to 6% which corresponds to a higher opportunity cost of capital.

In TABLE 1, I use $\alpha = 0.025, \sigma = 0.2, r = 0.05, y_0 = 1, \xi = 0.5$ and $I = 24$ and I obtain the values that serve as the standard of comparison. As one can check, TABLE 1 demonstrates how the investment threshold and the value of the opportunity to invest in a given project are affected by the presence of an investment partner and/or the presence of an upstream firm. In accordance to Proposition 8, we see that the presence of any alien agent causes the postponement of the investment. The investment threshold is, roughly, doubled when an investment partner is involved, and tripled when a necessary input is outsourced. However, the combined effect is more dramatic since, under both outsourcing and external funding, the investment threshold is more than six times higher than the investment threshold under vertical integration.

As for the project value itself, we see that the changes in the investment threshold are also reflected in the value of the option to invest. The project depreciates whenever its completion depends on the contribution of one of the other two parties, with outsourcing being less preferable than an investment partnership but more preferable than the three-agent case. Interestingly, under external funding the investor's share of the project is equal to 71% of her/his share under vertical integration whereas, when outsourcing is explicitly taken into consideration the percentage drops to 42%. Unsurprisingly, a similar effect is observed when one studies the value of the option to invest in the level of the industry. Arguably, these results underline the difference that the nature of the investment cost (endogenous or exogenous) can make when an

investment project characterized by uncertainty and irreversibility is considered.

TABLE 1

Standard of Comparison

	Vertical Integration	External Funding	Outsourcing	Three-Agent Case
y^*	1.90	3.96	6.02	12.55
F_A	20.35	14.50	11.96	8.52
F_B	-	3.48	-	2.04
F_C	-	-	3.77	1.29
F	20.35	17.98	15.73	11.85

In TABLE 2, I examine the effect that a change in the cost I has on the investment thresholds and the option values presented above. For $I = 48$, i.e. for an investment cost two times higher than the standard of comparison, all the investment thresholds are doubled in magnitude and all the option values drop to, about, 73% of their corresponding values given in TABLE 1. Starting with the investment thresholds, it is evident that a potential investor will have less rush to invest in a, other things equal, more expensive project. As for the depreciation of the option values, one can argue that two opposing forces drive this result. On one hand, the value of the option to delay a costly and irreversible investment is valuable, and this value is expected to increase in I since, the more expensive the investment, the more valuable the option to postpone it. On the other hand however, the higher investment threshold implies a further delay of the investment which eventually distances the anticipated cash flow further in

the future. As one can see, the second force prevails.

TABLE 2

The Effect of a Change in the Investment Cost on Timing and Option Value

$I = 48$				
	Vert. Integ.	Ext. Funding	Outsourcing	Three-Agent Case
y^*/y_{T1}^*	2	2	2	2
F_A/F_A^{T1}	0.73	0.73	0.73	0.73
F_B/F_B^{T1}	-	0.73	-	0.73
F_C/F_C^{T1}	-	-	0.73	0.73
F/F^{T1}	0.73	0.73	0.73	0.73

In TABLE 3, I study the effect that changes in the drift, α, may have. A comparison of the option values of TABLE 3 with the ones derived in TABLE 1 shows that an increase in the expected growth rate from $\alpha = 0.025$ to $\alpha = 0.035$, is beneficial both in the firm and in the industry level. However, the effect of such a change in the investment triggers is not as obvious. Actually, we observe that a higher α is, *ceteris paribus,* encouraging the acceleration of a project under vertical integration but is causing the further postponement of projects the completion of which is conditional on the participation of a second or a third party. Especially, in the three-agent case, we see that a $\Delta\alpha = 0.01$ is enough to (more than) double the related investment threshold. The intuition behind this result has to do exactly with the absence or the presence of the alien firms. When the potential investor acts unilaterally, a positive change in α signals the shortening of the expected waiting period until the right time for the investment to take place has come. This, of course, is reflected in a lower investment threshold.[10] Nevertheless, under the presence of an upstream supplier and/or an investment partner, the situation is quite different. The upstream firm updates the price of the input asking a higher price whereas the compensation offer that the investment partner receives is now readjusted for the higher α.

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[10] As we can see from Eq. (3), this is actually the effect of two opposing forces. On one hand, a higher a implies a higher present value for the profit flow $\left(\frac{\pi_M}{r-\alpha}\right)$ which, in return, favors the acceleration of the investment. On the other hand however, an increased drift implies a lower $\frac{\beta}{\beta-1}$ which is the factor that corrects the investment threshold for uncertainty and irreversibility. Apparently, under vertical integration, the first force prevails.

Eventually, the time-deciding agent accounts for these changes choosing a higher, instead of lower, investment threshold.

TABLE 3

The Effect of a Change in the Drift on Timing and Option Value

$\alpha = 0.035$				
	Vert. Integ.	Ext. Funding	Outsourcing	Three-Agent Case
y^*	1.80	5.40	9	27
F_A	46.04	34.98	30.79	23.39
F_B	-	5.83	-	3.89
F_C	-	-	6.15	1.55
F	46.04	40.81	36.94	28.83

As for the volatility σ, in Figure 1 and Figure 2 we see how an increase in σ from $\sigma = 0.2$ to $\sigma = 0.4$ affects the timing and the value of the option to invest in the project under consideration. As expected, all the investment thresholds are increasing in σ. As is standard in the real options literature, the presence of uncertainty and irreversibility calls for a more careful investment policy. Hence, investment projects should occur at higher return levels, a decision which in turn requires waiting longer before investing. Note however that higher investment thresholds do not cause the depreciation of the value of the corresponding project. On the contrary, a higher volatility is, as anticipated, increasing the value of the option to delay the completion of an investment project characterized by uncertainty and irreversibility.

What is interesting to see here is that the investment threshold in the three-agent case is significantly more sensitive to an increase in volatility with respect to the other three investment scenarios, a result which is also reflected in a proportionately higher option value. As before, the intuition here is that the investment threshold under both outsourcing and external funding is affected both by the decisions of the project originator and by the actions of the investment partner and the upstream firm which are also affected by changes in σ. For instance, we know that the upstream firm anticipates that an increase in σ will further delay the completion of the investment project. This foresight calls for the decision of a higher input price that will

act as compensation against this (further) delayed cash flow. Similarly, the project originator also anticipates a (further) postponement in the completion of the project and, using analogous reasoning, decides to decrease the submitted compensation offer. Finally, the time-deciding investment partner observes the increase in σ as well as the updated input price and compensation offer and chooses an appropriately high investment threshold that accounts for all this.

FIGURE 1

The Effect of a Change in Volatility on the Investment Threshold
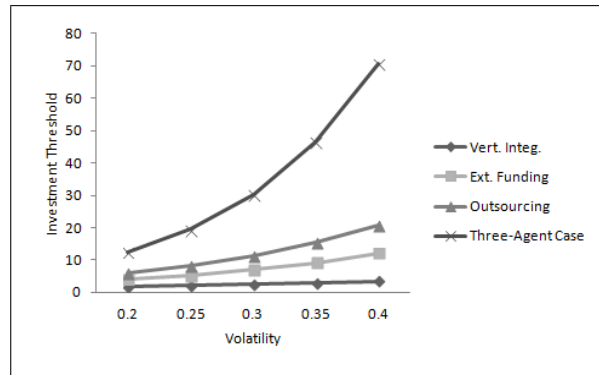
FIGURE 2

The Effect of a Change in Volatility on the Option Value
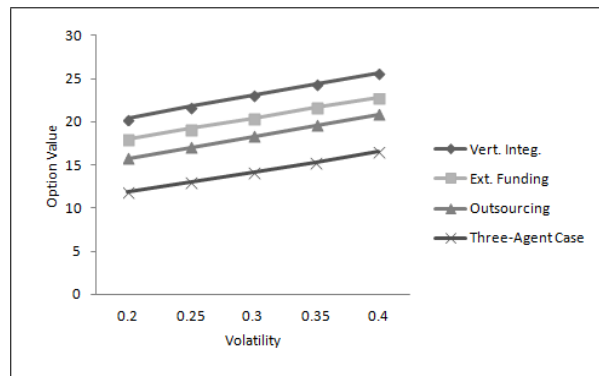
In TABLE 4, I focus on the impact that a change in the exogenous investment cost share ξ may have. The benchmark value that I choose is $\xi = 0.5$ which implies a perfectly balanced investment scheme with both partners undertaking equal portions of the sunk cost. I subse-

quently allow both for high ($\xi = 0.9$) and for low ($\xi = 0.1$) investment cost shares and I also present, for comparison's sake, the case where there is no partnership ($\xi = 0$). Starting with the investment thresholds, one notices that a higher involvement of an investment partner always implies the postponement of the project. Of course, keeping in mind the analysis of subsection 3.1.4 and subsection 3.2.1, this is hardly a surprise. As we have already seen there, a higher cost share ξ implies a higher nominal, but lower real, compensation offer from the project originator to the investment partner. Eventually, this is reflected in a higher investment threshold and the further postponement of the investment (in expected terms).

The effect of a change in ξ on the option values of the three parties is nothing but an extension of the effect that we observe in the investment triggers. A higher ξ causes the depreciation of the value of the opportunity to invest for every party apart from the investment partner who is favored by such a change. This adverse effect is also clearly reflected in the value

of the investment opportunity of the industry as a whole.

TABLE 4

The Effect of a Change in the Exogenous Cost Share on Timing and Option Value

	$\xi = 0$		$\xi = 0.1$	
	Ext. Funding	Three-Agent Case	Ext. Funding	Three-Agent Case
y^*	1.90	6.02	2.31	7.33
F_A	20.35	11.96	18.60	10.92
F_B	0	0	1.53	0.90
F_C	-	3.77	-	2.83
F	20.35	15.73	20.13	14.65

	$\xi = 0.5$		$\xi = 0.9$	
	Ext. Funding	Three-Agent Case	Ext. Funding	Three-Agent Case
y^*	3.97	12.56	5.61	17.79
F_A	14.50	8.52	12.35	7.26
F_B	3.48	2.04	3.77	2.21
F_C	-	1.29	-	0.78
F	17.98	11.85	16.12	10.25

Last, in TABLE 5, I examine the effect of a change in the interest rate r. Let's start with the vertically integrated case. As far as the investment threshold is concerned, two opposing forces are acting. On one hand, an increase in r makes the potential investor more impatient since, with a higher interest rate, the present becomes relatively more important than the future which implies the selection of a lower investment threshold. At the same time however, the increase in r implies a decrease in the present value of the profit flow that the project is meant to generate once it takes place. This limits the interest of the potential investor to invest right now in a project which does not cover the high opportunity cost of capital. As we see in TABLE 5, the second force prevails causing the postponement of the investment.

In the case where we deal with an investment partnership, an increase in the interest rate from 0.05 to 0.06 causes a similar effect but of smaller magnitude. The analysis of the previous

paragraph holds here as well. However, one needs to take into account the fact that the investment trigger is now also affected by the change in the compensation offer that is submitted to the time-deciding agent. The project originator, being impatient her/himself, is willing to make a more generous compensation offer in an attempt to shorten the waiting period till the completion of the project. As one can see, this makes a difference almost neutralizing the increase in r.

The most interesting cases involve the participation of the upstream firm. Despite the fact that the argumentation from above still applies, the presence of an impatient upstream firm causes, as one can see in TABLE 5, the acceleration of the investment. In order to understand the intuition behind this result, one should keep in mind that the effect of a change in r is different for the upstream firm than it is for the two investment partners. It is true that all the involved firms discount the value of the option to invest with a common discount factor.[11] However, the way that each agent evaluates the net present value of the project at the delivery date is different. For the two investment partners, the completion of the investment project signals the commencing of a profit flow that needs to be appropriately discounted. Of course, a change in r affects the chosen discount factor. On the contrary, when the delivery date is reached, the upstream firm receives a lump sum which corresponds to the price of the input that s/he supplied and which is not affected by changes in r. As a consequence, even a small increase in the discount rate is enough to make the upstream supplier sufficiently impatient and willing to ask a lower input price as soon as this will lead to the acceleration of the investment. Indeed, in TABLE 5 we see that, when an upstream firm is present, an increased discount rate encourages the acceleration of the completion of the project, a result which is most prevalent in the three-agent case where the impatience of the two alien agents concurs.

As for the value of the option to invest, we see that even a slightly increased interest rate can considerably reduce the project's option value. As we have already stressed above, an increased interest rate implies that the present becomes financially more important than the future. Hence, the option to delay an investment project for some future time point naturally

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[11]Recall that in subsection 3.1.3 we have $\left(\frac{y}{y^{OS}(p^{OS})}\right)^{\beta}$ both for A and for C, in subsection 3.1.4 we have $\left(\frac{y}{y^{VC}(\psi^{VC})}\right)^{\beta}$ both for A and for B and in subsection 3.2 we have $\left(\frac{y}{y_3(\psi_3,p_3)}\right)^{\beta}$ for all three agents.

becomes less valuable.

<div align="center">TABLE 5</div>

<div align="center">The Effect of a Change in the Interest Rate on Timing and Option Value</div>

$r = 0.06$				
	Vert. Integ.	Ext. Funding	Outsourcing	Three-Agent Case
y^*/y^*_{T1}	1.16	1.02	0.97	0.84
F_A/F_A^{T1}	0.54	0.52	0.50	0.49
F_B/F_B^{T1}	-	0.60	-	0.56
F_C/F_C^{T1}	-	-	0.60	0.68
F/F^{T1}	0.54	0.54	0.53	0.52

3.3   The compensation as the product of Nash bargaining

In subsection 3.1.4 and in subsection 3.2, I used a non-cooperative setting in order to describe the interaction between the potential investor A and the investment partner B. However, as noticed by the extant literature, co-development partnerships are an increasingly utilized way of improving profitability, competitiveness and innovation effectiveness.[12] In the following, I re-approach the potential investor's business plan using a cooperative framework. More precisely, I assume that the compensation offer will now be replaced by a Nash bargaining solution that will explicitly reflect the bargaining power of the involved agents. I begin with the two-agent case and I subsequently allow for outsourcing.

3.3.1   The input is produced in-house and the investment is partly externally funded

Similarly to the presentation of subsection 3.1.4, I assume that A can produce the input in-house and that the completion of the project is conditional on the participation of a firm B who acts like an investment partner. As before, B is willing to undertake a share ξ of the sunk investment cost given that s/he will receive compensation in return. What is new here

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[12]See Zhou and Yang (2008), Biehl et al. (2006) and Cvitanić et al. (2011) respectively.

with respect to the analysis of subsection 3.1.4 is that, by assumption, A agrees with B on the compensation share and then decides the optimal investment threshold. Note that, contrary to the initial analysis, it is now assumed that A, not B, is the time deciding agent. Apparently, A sacrifices her/his exclusivity on the decision of ψ in order to become the time-deciding agent and similarly B sacrifices her/his position as the time-deciding agent in order to have a say in the decision of ψ.[13] In the following, we see under what conditions this cooperative framework can replace the non-cooperative one.

Starting with the maximization problem of the time-deciding agent we have:

$$F_{AN}(y) = \max_{y_N(\psi)} \left((1-\psi) \frac{y_N(\psi)\pi_M}{r-\alpha} - (1-\xi)I \right) \left(\frac{y}{y_N(\psi)} \right)^{\beta}. \tag{25}$$

Solving we obtain

$$y_N(\psi) = \frac{1-\xi}{1-\psi} y^{VI}. \tag{26}$$

Moving one step back, the two parties bargain anticipating that A will invest as soon as y_t reaches the trigger $y_N(\psi)$. Given this, the new optimal compensation share is derived as the solution of

$$\max_{\psi_N} \left(\psi_N \frac{y_N(\psi_N)\pi_M}{r-\alpha} - \xi I \right)^{\eta_B} \left((1-\psi_N) \frac{y_N(\psi_N)\pi_M}{r-\alpha} - (1-\xi)I \right)^{1-\eta_B} \left(\frac{y}{y_N(\psi_N)} \right)^{\beta}, \tag{27}$$

where η_B represents B's bargaining power.[14] Solving we obtain

$$\psi_N = \frac{\xi(\beta-1) + \eta_B(1-\xi)}{\beta-\xi}. \tag{28}$$

Combining Eq. (26) and Eq. (28) we have

$$y_N(\psi_N) = \frac{\beta-\xi}{\beta-\eta_B} y^{VI}. \tag{29}$$

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[13] In subsections 3.4.1 and 3.4.2 of the Appendix, I show how the analysis presented in subsections 3.1.4 and 3.2 of the main body of the paper changes if A and B swap places. In subsections 3.4.3 and 3.4.4 of the Appendix, I do the same for the analysis presented in subsection 3.3 where the initial non-cooperative game-theoretic framework is replaced by a Nash bargaining solution and I show that such a change does not affect the nature of the main results.

[14] It is assumed that the distribution of bargaining power is exogenous and that $\eta_A + \eta_B = 1$ with $\eta_A \geq 0$ and $\eta_B \geq 0$, where η_i is the bargaining power of agent i with $i \in \{A, B\}$.

One can check that the compensation ψ_N increases linearly in η_B.[15] It is also true that, contrary to the compensation offers that we have encountered in the previous subsections, ψ_N is not always increasing in β, hence decreasing in volatility. More precisely, here we have $\frac{\partial \psi_N}{\partial \beta} \gtrless 0$ for $\xi \gtrless \eta_B$. In words, the compensation offer is decreasing in volatility only when the bargaining power of B is sufficiently low. Another interesting point is that when B bears almost the whole investment cost ($\xi \to 1$), we obtain $\psi_N \simeq 1$. Contrary to the compensation offer ψ^{VC} that cannot be larger than $\frac{\beta-1}{\beta}$, ψ_N can reach values as high as 100%, irrespective of the magnitude of β, if the cost share of the time-deciding agent A is small enough.

As far as the investment threshold is concerned, one can see that, as expected, $y_N(\psi_N)$ is increasing in η_B[16] and that in the special case where $\eta_B = \xi$ we have exactly $y_N(\psi_N) = y^{VI}$. In general, when the bargaining power of B is smaller (larger) than the exogenously given ξ, the investment takes place inefficiently early (late). Finally, one can check that $\frac{\partial \frac{y_N(\psi_N)}{y^{VI}}}{\partial \beta} \gtrless 0$ for $\xi \gtrless \eta_B$ which means that when the bargaining power of B is sufficiently low (high), an increase in volatility results in a lower (higher) investment threshold $y_N(\psi_N)$ relative to y^{VI}.

Given $y_N(\psi_N)$ and ψ_N, we can compute the value of the opportunity to invest both for the potential investor and for the investment partner. For A we obtain

$$F_{AN}(y) = (1 - \xi) \left(\frac{\beta - \eta_B}{\beta - \xi} \right)^\beta F_A^{VI}(y), \tag{30}$$

and for B we have

$$F_{BN}(y) = \eta_B \left(\frac{\beta - \eta_B}{\beta - \xi} \right)^{\beta-1} F_A^{VI}(y).^{17} \tag{31}$$

Of course the two agents will choose the Nash bargaining solution over the non-cooperative one only if $F_{AN}(y) \geq F_A^{VC}(y)$ and $F_{BN}(y) \geq F_B^{VC}(y)$ or, alternatively, if $(1-\xi)\left(\frac{\beta-\eta_B}{\beta-\xi}\right)^\beta \geq \left(\frac{\beta-1}{\beta-1+\xi}\right)^{\beta-1}$ and $\eta_B\left(\frac{\beta-\eta_B}{\beta-\xi}\right)^{\beta-1} \geq \xi\left(\frac{\beta-1}{\beta-1+\xi}\right)^\beta$ hold simultaneously.

It is interesting to see that the condition $F_{AN}(y) \geq F_A^{VC}(y)$ implies $\xi > \eta_B$ which basically means that the Nash bargaining solution guarantees that the investment will take place (inefficiently) early: $y_N(\psi_N) < y^{VI}$. Let's recall that when we solved the same problem un-

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[15] One can also check that ψ_N is increasing and convex in ξ.

[16] One can also check that $y_N(\psi_N)$ is linearly decreasing in ξ.

[17] Note that, as expected, $\frac{\partial F_{iN}(y_t)}{\partial \eta_i} > 0, i \in \{A, B\}$.

der the non-cooperative framework in subsection 3.1.4, we found that the investment would take place inefficiently late: $y^{VC}(\psi^{VC}) > y^{VI}$. Comparing these two results we derive a quite straightforward conclusion: the adopted game-theoretic framework determines the nature of the interaction between A and B as well as the way that this is reflected in the chosen investment threshold and the value of the option to invest. The importance of this statement will become clearer in the next subsection where the three-agent case is discussed. Summing up our results:

Proposition 9 *In the case where the input is produced in-house and the completion of the project depends on external funding, the Nash bargaining solution can replace the non-cooperative one when the participation conditions $F_{AN}(y) \geq F_A^{VC}(y) \Rightarrow (1 - \xi)\left(\frac{\beta - \eta_B}{\beta - \xi}\right)^{\beta} \geq \left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^{\beta - 1}$ and $F_{BN}(y) \geq F_B^{VC}(y) \Rightarrow \eta_B \left(\frac{\beta - \eta_B}{\beta - \xi}\right)^{\beta - 1} \geq \xi \left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^{\beta}$ are satisfied. If this is the case, then the investment occurs when the scale parameter reaches a threshold $y_N(\psi_N) = \frac{\beta - \xi}{\beta - \eta_B} y^{VI}$. Notably, $F_{AN}(y) \geq F_A^{VC}(y) \Rightarrow \xi > \eta_B \Rightarrow y_N(\psi_N) < y^{VI}$ which means that a Nash bargaining solution guarantees that the investment will take place inefficiently early.*

For instance, for $\alpha = 0.025, \sigma = 0.2, r = 0.05, y_0 = \pi_M = 1, \xi = 0.5$ and $I = 24$, the Nash bargaining solution can take place for any $\eta_B \in [0.147, 0.236]$. If e.g. $\eta_B = 20\%$, we have $y_N = 1.45, F_{AN} = 15.13$ and $F_{BN} = 4,61$. Comparing these with the corresponding values of TABLE 1 we see that, as expected, the option values of both parties are appreciated and that the investment threshold under Nash bargaining is smaller than the investment threshold under vertical integration.

3.3.2 The three-agent case

Let's now see what is different if a third agent is involved in the completion of the project. Similarly to the presentation of subsection 3.2 it is assumed that the input is produced by an external supplier with market power. The game evolves in the following way:

1. The upstream firm C decides the input price that maximizes her/his individual option value.

2. Given the price of the input, A and B engage in a Nash bargaining in order to decide the compensation that A will submit to B and finally,

3. A decides what is the optimal investment threshold given the price of the input and the decided compensation.

Moving backwards, I begin by studying the behavior of A. The optimal investment threshold in the three-agent case is derived as the solution of the following maximization problem:

$$F_{A3N}(y) = \max_{y_{3N}(\psi,p)} \left((1-\psi) \frac{y_{3N}(\psi,p)\,\pi_M}{r-\alpha} - (1-\xi)\,p \right) \left(\frac{y}{y_{3N}(\psi,p)} \right)^{\beta} \tag{32}$$

From the first-order condition we obtain

$$y_{3N}(\psi,p) = \frac{\beta}{\beta-1} \frac{r-\alpha}{\pi_M} p \frac{1-\xi}{1-\psi}. \tag{33}$$

Given $y_{3N}(\psi,p)$, A and B engage in a Nash bargaining in order to commonly decide the optimal compensation ψ_{3N} which is derived as the solution of

$$\max_{\psi_{3N}} \left(\psi_{3N} \frac{y_{3N}(\psi_{3N})\pi_M}{r-\alpha} - \xi I \right)^{\eta_B} \left((1-\psi_{3N}) \frac{y_{3N}(\psi_{3N})\pi_M}{r-\alpha} - (1-\xi)\,I \right)^{1-\eta_B} \left(\frac{y}{y_{3N}(\psi_{3N})} \right)^{\beta}. \tag{34}$$

Solving we obtain

$$\psi_{3N} = \frac{\xi(\beta-1) + \eta_B(1-\xi)}{\beta-\xi}. \tag{35}$$

Unsurprisingly, we find $\psi_{3N} = \psi_N$. The intuition behind this result is that, as in the non-cooperative case, the presence/absence of C does not affect the interaction between A and B since the exogenously given cost share ξ has to do with the generic investment cost no matter if that is I or p.

Finally, the input supplier C observes how A and B behave and chooses the familiar $p_{3N} = \frac{\beta}{\beta-1} I$ solving $F_{C3N}(y) = \max_{p_{3N}} (p_{3N} - I) \left(\frac{y}{y_{3N}(\psi_{3N},p_{3N})} \right)^{\beta}$. Apparently, the price that maximizes the value of the option to invest for the upstream firm is not affected by the distribution of bargaining power between A and B. Again, C is indifferent to the means that A uses to fund her/his project.

Now, substituting ψ_{3N} and p_{3N} in the formula for the investment threshold we obtain

$$y_{3N}(\psi_{3N}, p_{3N}) = \frac{\beta}{\beta-1} \frac{\beta-\xi}{\beta-\eta_B} y^{VI} > y_N(\psi_N). \tag{36}$$

Similarly to $y_N(\psi_N)$, the threshold $y_{3N}(\psi_{3N}, p_{3N})$ is increasing in η_B.[18] One can also check that, contrary to the two-agent case where we had $\frac{\partial \frac{y_N(\psi_N)}{y^{VI}}}{\partial \beta} \gtrless 0$ for $\xi \gtrless \eta_B$, here we have $\frac{\partial \frac{y_{3N}(\psi_{3N}, p_{3N})}{y^{VI}}}{\partial \beta} < 0$ which means that as the volatility of the scale parameter increases, the relative investment threshold gets larger, irrespective of how η_B compares to ξ. This has to do with the fact that the delivery price p_{3N}, contrary to I, is increasing in the volatility of the scale parameter and, as a result, there is no level of bargaining power low enough to guarantee a negative relationship between the relative investment threshold and the volatility. As a consequence, we have $y_{3N}(\psi_{3N}, p_{3N}) > y^{VI}$. Note that this is the result of two opposing forces. On one hand, the interaction between A and B drives the investment threshold below y^{VI} but,[19] on the other, the effect of the presence of C has the opposite direction.[20] Apparently the second one prevails. It is interesting to recall here that when we discussed the three-agent case under the non-cooperative setting in subsection 3.2, we similarly had $y_3(\psi_3, p_3) > y^{VI}$. However, there the two effects were not opposing but, on the contrary, they were complementing each other. As a result, the importance of explicitly taking C into account was, to some extent, less obvious.

We conclude with the value of the option to invest for the three agents and we have

$$F_{A3N}(y) = (1 - \xi) \left(\frac{\beta - 1}{\beta}\right)^{\beta - 1} \left(\frac{\beta - \eta_B}{\beta - \xi}\right)^{\beta} F_A^{VI}(y), \qquad (37.1)$$

$$F_{B3N}(y) = \eta_B \left(\frac{\beta - 1}{\beta}\right)^{\beta - 1} \left(\frac{\beta - \eta_B}{\beta - \xi}\right)^{\beta - 1} F_A^{VI}(y), \qquad (37.2)$$

$$F_{C3N}(y) = \left(\frac{\beta - 1}{\beta}\right)^{\beta} \left(\frac{\beta - \eta_B}{\beta - \xi}\right)^{\beta} F_A^{VI}(y). \qquad (37.3)$$

A and B will choose the Nash bargaining solution over the non-cooperative one only if $F_{A3N}(y) \geq F_{A3}(y)$ and $F_{B3N}(y) \geq F_{B3}(y)$. As in the previous subsection, we find that if the conditions $(1 - \xi)\left(\frac{\beta - \eta_B}{\beta - \xi}\right)^{\beta} \geq \left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^{\beta - 1}$ and $\eta_B \left(\frac{\beta - \eta_B}{\beta - \xi}\right)^{\beta - 1} \geq \xi \left(\frac{\beta - 1}{\beta - 1 + \xi}\right)^{\beta}$ hold simultaneously, then both A and B are better-off. Once again this has to do with the fact that the presence/absence of C does not affect the interaction between A and B. Finally, as far

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[18] Note that, similarly to $y_N(\psi_N)$, $y_{3N}(\psi_{3N}, p_{3N})$ is linearly decreasing in ξ.
[19] This first effect was discussed in subsection 3.3.1.
[20] This second effect was discussed in subsection 3.1.3.

as C is concerned, the Nash bargaining solution is preferred to the non-cooperative one when $F_{C3N}(y) \geq F_{C3}(y) \Rightarrow \left(\frac{\beta-\eta_B}{\beta-\xi}\right)^{\beta} > \left(\frac{\beta-1}{\beta-1+\xi}\right)^{\beta}$. One can easily check that this is always the case since $F_{A3N}(y) \geq F_{A3}(y)$ implies $F_{C3N}(y) \geq F_{C3}(y)$. Concluding we have:

Proposition 10 *In the case where the input is outsourced and the completion of the project depends on external funding, the Nash bargaining solution can replace the non-cooperative one when the participation conditions $F_{A3N}(y) \geq F_{A3}(y) \Leftrightarrow F_{AN}(y) \geq F_A^{VC}(y)$ and $F_{B3N}(y) \geq F_{B3}(y) \Leftrightarrow F_{BN}(y) \geq F_B^{VC}(y)$ hold simultaneously. If this is the case, the investment occurs when the scale parameter reaches a threshold $y_{3N}(\psi_{3N}, p_{3N}) = \frac{\beta}{\beta-1}\frac{\beta-\xi}{\beta-\eta_B}y^{VI} > y^{VI}$ i.e. the investment takes place inefficiently late. Despite the fact that the presence of B favors the acceleration of the project[21] the presence of C, which dictates the postponement of the investment, prevails.*

For instance, for $\alpha = 0.025, \sigma = 0.2, r = 0.05, y_0 = \pi_M = 1, \xi = 0.5$ and $I = 24$, the Nash bargaining solution can take place, as before, for any $\eta_B \in [0.147, 0.236]$. If e.g. $\eta_B = 20\%$, we have: $y_{3N} = 4.59, F_{A3N} = 8.89, F_{B3N} = 2,71$ and $F_{C3N} = 5,61$. Comparing these with the corresponding values of TABLE 1 we see that, as expected, the option values of all three parties are appreciated and that the investment threshold under Nash bargaining is larger than the investment threshold under vertical integration.

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[21] *See Proposition 9.*

3.4 Appendix

3.4.1 The input is produced in-house and the investment is partly externally funded: A review of subsection 3.1.4

In the main body of the paper I describe the interaction between a potential investor A and an investment partner B following the presentation by Lukas and Welling (2014) according to which A is the game-leader submitting the compensation offer and B is the game-follower choosing the investment timing. This framework seems suitable to describe the efforts of a potential investor who seeks out funding for the business plan that is under consideration. However, one can also consider the case where B is the game-leader submitting the compensation offer and A is the game-follower deciding the investment timing. This framework seems more appropriate to describe partnerships in which a venture capitalist makes the first step declaring her/his interest to invest in an emerging firm.[22]

Moving backwards, we find that the solution of A's decision problem gives an investment threshold $y^{RVC} = \frac{1-\xi}{1-\psi} y^{VI}$ whereas the solution of B's decision problem gives a compensation share $\psi^{RVC} = \frac{1-2\xi+\xi\beta}{\beta-\xi}$.[23] Combining the two we find that the optimal investment threshold is given by

$$y^{RVC} \left(\psi^{RVC} \right) = \frac{\beta - \xi}{\beta - 1} y^{VI} \left(> y^{VI} \right). \tag{A.1}$$

As far as the value of the option to invest is concerned, for the potential investor A we have

$$F_A^{RVC}(y) = (1 - \xi) \left(\frac{\beta - 1}{\beta - \xi} \right)^\beta F_A^{VI}(y), \tag{A.2}$$

whereas for the investment partner B we obtain

$$F_B^{RVC}(y) = \left(\frac{\beta - 1}{\beta - \xi} \right)^{\beta - 1} F_A^{VI}(y). \tag{A.3}$$

One can easily check that, similarly to what we find in subsection 3.1.4, the presence of firm B causes the postponement of the investment[24], making the potential investor worse-off with

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[22]Cvitanić et al. (2011) present a similar case.

[23]Check that ψ^{RVC}, similarly to ψ^{VC}, is increasing in ξ, but contrary to ψ^{VC} is decreasing in β.

[24]Note that y^{RVC}, similarly to y^{VC}, is decreasing in β, but contrary to y^{VC} is decreasing in ξ.

respect to the vertically integrated case.

3.4.2 The three-agent case: A review of subsection 3.2

In this subsection I review the three-agent case as presented in subsection 3.2 assuming however that A and B swap places. More precisely:

1. C is still the game-leader who decides the input price.

2. Given the price of the input, B decides what is the optimal compensation that s/he should ask from A and

3. A decides what is the optimal investment threshold given the price of the input and the compensation share.

Solving backwards, from the potential investor's maximization problem we obtain $y_{3R}(\psi, p) = \frac{\beta}{\beta-1}\frac{1-\xi}{1-\psi}\frac{r-\alpha}{\pi_M}p$. Taking this into consideration, the investment partner is choosing $\psi_{3R} = \frac{1-2\xi+\xi\beta}{\beta-\xi}$ $\left(=\psi^{RVC}\right)$.[25] Finally, the upstream firm, keeping in mind the reactions of A and B, decides the optimal price of the input $p_{3R} = \frac{\beta}{\beta-1}I$. Plugging the compensation offer and the input price in the formula for the investment threshold we obtain

$$y_{3R}(\psi_{3R}, p_{3R}) = \frac{\beta}{\beta-1}\frac{\beta-\xi}{\beta-1}y^{VI}\left(> y^{VI}\right). \tag{A.4}$$

Given this, we also have

$$F_{A3R}(y) = (1-\xi)\left(\frac{\beta-1}{\beta}\right)^{\beta-1}\left(\frac{\beta-1}{\beta-\xi}\right)^{\beta}F_A^{VI}(y), \tag{A.5.1}$$

$$F_{B3R}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta-1}\left(\frac{\beta-1}{\beta-\xi}\right)^{\beta-1}F_A^{VI}(y), \tag{A.5.2}$$

$$F_{C3R}(y) = \left(\frac{\beta-1}{\beta}\right)^{\beta}\left(\frac{\beta-1}{\beta-\xi}\right)^{\beta}F_A^{VI}(y). \tag{A.5.3}$$

Similarly to subsection 3.2, we find that the synchronous presence of B and C causes the postponement of the project and that this is also reflected in A's option value.

Finally, note that from Eq. (A.2), Eq. (A.3) and Eq. (A.5) we find that $F^{RVC}(y) = $

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[25] Check that the equality $\psi_{3R} = \psi^{RVC}$ is analogous to the equality $\psi_3 = \psi^{VC}$ that we find in subsection 3.2 of the main body of the paper.

$\frac{2\beta-\beta\xi-1}{\beta-1}\left(\frac{\beta-1}{\beta-\xi}\right)^{\beta}F_A^{VI}(y)$ and $F_{3R}(y) = \left(1-\xi+\frac{\beta-\xi}{\beta-1}+\frac{\beta-1}{\beta}\right)\left(\frac{\beta-1}{\beta}\right)^{\beta-1}\left(\frac{\beta-1}{\beta-\xi}\right)^{\beta}F_A^{VI}(y).^{26}$ Summing up

Proposition 11 *A comparison among the option values and the investment triggers derived in subsection 3.4.1 and subsection 3.4.2 of the Appendix gives the following rankings:*

1) $y_{3R}\left(\psi_{3R}, p_{3R}\right) > y^{OS}\left(p^{OS}\right) > y^{RVC}\left(\psi^{RVC}\right) > y^{VI}$,

2) $F_{3R}(y) < F^{OS}(y) < F^{RVC}(y) < F_A^{VI}(y)$,

3) $F_{A3R}(y) < F_A^{RVC}(y) < F_A^{OS}(y) < F_A^{VI}(y)$,

4) $F_{B3R}(y) < F_B^{RVC}(y)$ *and*

5) $F_{C3R}(y) < F_C^{OS}(y)$.

Comparing Proposition 11 (where B is the game-leader and A is the game-follower) with Proposition 8 (where A is the game-leader and B is the game-follower) we find that, in both cases, as the number of agents involved in an investment project increases, the completion of the project is postponed at the expense of the project's option value both in the firm and in the industry level. We also find that the rankings of the investment thresholds and the aggregate option values remain the same whereas the only difference that we observe has to do with the ranking of A's option values. As one can see, when A is the game-follower (game-leader), an interaction with C (B) is preferred to an interaction with B (C) which means that the way that A is affected by the presence of the alien firms depends on the role that s/he has in the game.

Another interesting point is that $F_A^{RVC}(y) < F_A^{VC}(y)$ and $F_B^{RVC}(y) > F_B^{VC}(y)$ which means that being the game-leader is always preferable, no matter the values of ξ and β. Finally, one can also check that $y^{RVC}\left(\psi^{RVC}\right) \gtrless y^{VC}\left(\psi^{VC}\right)$ and $y_{3R}\left(\psi_{3R}, p_{3R}\right) \gtrless y_3\left(\psi_3, p_3\right)$, and consequently that $F^{RVC}(y) \lessgtr F^{VC}(y)$ and $F_{3R}(y) \lessgtr F_3(y)$, when $0.5 \gtrless \xi$. In words, it is socially optimal for the agent who undertakes the lion's share of the sunk investment cost to be the game-leader either when the input is outsourced or not. This means that the analysis of the main body of the paper where A is the game-leader and B is the game-follower would be preferred from a social point of view for $0.5 < \xi$ whereas the analysis presented here would be socially preferable for $0.5 > \xi$.

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[26]We define $F^{RVC}(y) \equiv F_A^{RVC}(y) + F_B^{RVC}(y)$ and $F_{3R}(y) \equiv F_{A3R}(y) + F_{B3R}(y) + F_{C3R}(y)$.

3.4.3 The input is produced in-house and the investment is partly externally funded: A review of subsection 3.3.1

In subsection 3.4.1 I presented a leader-follower game where B decides the compensation and, given that, A chooses the optimal investment threshold. Let's now see what is different if the compensation is the product of bargaining between the two agents. The game evolves in the following way: initially A and B bargain over the compensation share ψ and then, given that, B decides the optimal investment threshold. Notice that contrary to subsection 3.4.1, the time-deciding agent is B, not A. Alternatively put, my goal in this section is to find the conditions under which A would be willing to let B decide the timing of the investment, given that the compensation share will be the product of bargaining between the two agents instead of a unilateral decision of B.

Starting with the maximization problem of the time-deciding agent B we obtain $y_{NR} = \frac{\xi}{\psi} y^{VI}$. Moving one step back, the two parties bargain anticipating that B will invest as soon as y_t reaches the threshold y_{NR}. Given this, the bargaining over the compensation share gives $\psi_{NR} = \xi \frac{\beta - 1 + \eta_B}{\beta - 1 + \xi}$ [27] and, consequently,

$$y_{NR}(\psi_{NR}) = \frac{\beta - 1 + \xi}{\beta - 1 + \eta_B} y^{VI} \quad \text{[28]} \tag{B.1}$$

Given the compensation offer and the optimal investment threshold, one can compute the value of the option to invest both for the potential investor and for the time-deciding investment partner. More precisely, for A we obtain

$$F_{ANR}(y) = (1 - \eta_B) \left(\frac{\beta - 1 + \eta_B}{\beta - 1 + \xi} \right)^{\beta - 1} F_A^{VI}(y), \tag{B.2}$$

and for B we have

$$F_{BNR}(y) = \xi \left(\frac{\beta - 1 + \eta_B}{\beta - 1 + \xi} \right)^{\beta} F_A^{VI}(y). \tag{B.3}$$

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[27] One can check that the compensation share ψ_{NR} increases linearly in η_B and that it is also increasing and concave in ξ. Finally, $\frac{\partial \psi_{NR}}{\partial \beta} \gtrless 0$ for $\xi \gtrless \eta_B$.

[28] $y_{NR}(\psi_{NR})$ is decreasing in η_B, linearly increasing in ξ and, with respect to β, we have $\frac{\partial \frac{y_{NR}(\psi_{NR})}{y^{VI}}}{\partial \beta} \gtrless 0$ if $\eta_B \gtrless \xi$. This basically means that in the special case where $\eta_B = \xi$ we have exactly $y_{NR}(\psi_{NR}) = y^{VI}$ but, in general, when the bargaining power of B is sufficiently low (high), an increase in volatility results in a higher (lower) investment threshold $y_{NR}(\psi_{NR})$ relative to y^{VI}.

As expected, A and B will choose the Nash bargaining solution over the non-cooperative one only if $F_{ANR}(y) \geq F_A^{RVC}(y)$ and $F_{BNR}(y) \geq F_B^{RVC}(y)$ or, alternatively, if $(1 - \eta_B) \left(\frac{\beta - 1 + \eta_B}{\beta - 1 + \xi} \right)^{\beta - 1} \geq$ $(1 - \xi) \left(\frac{\beta - 1}{\beta - \xi} \right)^{\beta}$ and $\xi \left(\frac{\beta - 1 + \eta_B}{\beta - 1 + \xi} \right)^{\beta} \geq \left(\frac{\beta - 1}{\beta - \xi} \right)^{\beta - 1}$ hold simultaneously. One can also easily check that the condition $F_{BNR}(y) \geq F_B^{RVC}(y)$ implies $\xi < \eta_B$ which means that any Nash bargaining solution guarantees that the investment will take place (inefficiently) early. Note that this is no different from what we found in subsection 3.3.1 of the main body of the paper.

3.4.4   The three-agent case: A review of subsection 3.3.2

Let's now see what is different if the input is outsourced. The starting point is again the investment threshold decision by B. From the first-order condition we have $y_{3NR}(\psi, p) = \frac{\beta}{\beta - 1} \frac{r - \alpha}{\pi_M} p \frac{\xi}{\psi}$. Moving one step back, A and B bargain anticipating that B will invest as soon as y_t reaches the chosen threshold and eventually choose $\psi_{3NR} = \xi \frac{\beta - 1 + \eta_B}{\beta - 1 + \xi} (= \psi_{NR})$.[29] Finally, the game-leader C observes the behavior of A and B and decides the input price $p_{3NR} = \frac{\beta}{\beta - 1} I$.

Substituting the optimal price and the compensation offer in the investment threshold from above we have

$$y_{3NR}(\psi_{3NR}, p_{3NR}) = \frac{\beta}{\beta - 1} \frac{\beta - 1 + \xi}{\beta - 1 + \eta_B} y^{VI}. \tag{B.4}$$

Note that $y_{3NR}(\psi_{3NR}, p_{3NR}) > y^{VI}$.[30] This is the result of two opposing forces. On one hand, the interaction between A and B drives the investment trigger below y^{VI} but,[31] on the other, the effect of the presence of C has the opposite direction.[32] Apparently, the second one prevails. It is interesting to recall that Eq. (A.4) that corresponds to the non-cooperative case gives also an investment threshold higher than y^{VI}: $y_{3R}(\psi_{3R}, p_{3R}) > y^{VI}$. However, there the two effects were not opposing but, on the contrary, they were complementing each other. Note that the analysis here is totally symmetric to the one presented in subsection 3.3.2 of the main body of the paper.

Keeping in mind the formulas for ψ_{3NR}, p_{3NR} and $y_{3NR}(\psi_{3NR}, p_{3NR})$, the option values for

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[29] Check that the equality $\psi_{3NR} = \psi_{NR}$ is analogous to the equality $\psi_{3N} = \psi_N$ that we find in subsection 3.3.2 of the main body of the paper.

[30] Note also that $\frac{\partial \frac{y_{3NR}(\psi_{3NR}, p_{3NR})}{y^{VI}}}{\partial \beta} < 0$.

[31] This effect was discussed in subsection 3.4.3.

[32] This effect was discussed in subsection 3.1.3.

the three agents are

$$F_{A3NR}(y) \;=\; (1-\eta_B)\left(\frac{\beta-1}{\beta}\frac{\beta-1+\eta_B}{\beta-1+\xi}\right)^{\beta-1} F_A^{VI}(y), \qquad (B.5.1)$$

$$F_{B3NR}(y) \;=\; \xi\left(\frac{\beta-1}{\beta}\right)^{\beta-1}\left(\frac{\beta-1+\eta_B}{\beta-1+\xi}\right)^{\beta} F_A^{VI}(y), \qquad (B.5.2)$$

$$F_{C3NR}(y) \;=\; \left(\frac{\beta-1}{\beta}\right)^{\beta}\left(\frac{\beta-1+\eta_B}{\beta-1+\xi}\right)^{\beta} F_A^{VI}(y). \qquad (B.5.3)$$

A and B will choose the Nash bargaining solution over the non-cooperative one only if $F_{A3NR}(y) \geq F_{A3R}(y)$ and $F_{B3NR}(y) \geq F_{B3R}(y)$ or, alternatively, if the familiar $(1-\eta_B)\left(\frac{\beta-1+\eta_B}{\beta-1+\xi}\right)^{\beta-1} \geq (1-\xi)\left(\frac{\beta-1}{\beta-\xi}\right)^{\beta}$ and $\xi\left(\frac{\beta-1+\eta_B}{\beta-1+\xi}\right)^{\beta} \geq \left(\frac{\beta-1}{\beta-\xi}\right)^{\beta-1}$ hold simultaneously. As far as C is concerned, the Nash bargaining solution is preferred to the non-cooperative one when $F_{C3NR}(y) \geq F_{C3R}(y) \Rightarrow \left(\frac{\beta-1+\eta_B}{\beta-1+\xi}\right)^{\beta} \geq \left(\frac{\beta-1}{\beta-\xi}\right)^{\beta}$. One can easily see that this is always the case since $F_{B3NR}(y) \geq F_{B3R}(y)$ implies $F_{C3NR}(y) \geq F_{C3R}(y)$. Concluding we have:

Proposition 12 *In the case where the input is outsourced and the completion of the project depends on external funding, the Nash bargaining solution can replace the non-cooperative one when the participation conditions $F_{A3NR}(y) \geq F_{A3R}(y) \Leftrightarrow F_{ANR}(y) \geq F_A^{RVC}(y)$ and $F_{B3NR}(y) \geq F_{B3R}(y) \Leftrightarrow F_{BNR}(y) \geq F_B^{RVC}(y)$ hold simultaneously. If this is the case, the investment occurs when the scale parameter reaches a threshold $y_{3NR}(\psi_{3NR}, p_{3NR}) = \frac{\beta}{\beta-1}\frac{\beta-1+\xi}{\beta-1+\eta_B}y^{VI} > y^{VI}$, i.e., the investment takes place inefficiently late. Despite the fact that the presence of B favors the acceleration of the project the presence of C, which dictates the postponement of the investment, prevails.*

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Chapter 4

Synthesis of paper 2

In this paper a stochastic dynamic programming model is used to examine an investment project that: i) is characterized by uncertainty and irreversibility, ii) is undertaken in a decentralized setting and iii) depends on the provision of a necessary input by an external supplier with market power. Bearing in mind the different ways that the game might unfold, I examine how:

1. the agency conflict between the project originator and the project manager,

2. the timing and

3. the value of the investment opportunity,

   are affected by the presence of the upstream firm.

4.1 The model

4.1.1 The basic set-up

Firm P holds the option to undertake an investment project and delegates the decision rights to agent B.[1] The value of the project, net of the wage of the agent, is represented by X_t which is assumed to be fluctuating over time according to the following geometric Brownian motion:

$$\frac{dX_t}{X_t} = \mu dt + \sigma dz_t, X_0 = x \tag{1}$$

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[1] Decentralization of decision-making is a standard practice when managing large enterprises (see e.g. Amaral et al., 2006 and Lee and Whang, 1999).

The term μ stands for the positive constant drift, σ is the positive constant volatility and dz_t is the increment of a Wiener process. It is assumed that P can continuously and verifiably observe the realizations of X_t over time and, in order to guarantee coordination in the supply chain, s/he shares this information with the delegate B.[2]

The completion of the aforementioned investment project is assumed to be conditional on the procurement of a discrete input that is exclusively produced by an upstream firm A. The supplier A is pricing the input taking into consideration information related both to the structure of the downstream industry and to the evolution of the stochastic parameter.[3]

Unless otherwise specified (see subsections 4.2.2 and 4.2.3), agent B is delegated not only with the investment decision, but with the procurement of the discrete input as well. Consequently, s/he knows the true magnitude of the input price whereas P knows only its distribution.[4] The asymmetry of information and the corresponding incentive misalignment between the delegate B and the delegator P, imply that P will have to use a bonus-incentive mechanism to make B reveal private information at the time of the exercise of the investment option in order to prevent further distortions.

All the parties are assumed to be risk neutral with the risk-free interest rate denoted by r. For convergence I assume $r > \mu$.[5]

Before analyzing the agency conflict under the presence of an external input supplier, I briefly review the case with information symmetry and in-house production of the input in subsection 4.1.2 and the case with information asymmetry and in-house production of the input in subsection 4.2.3.

4.1.2 Information symmetry and in-house production of the input

In this subsection it is assumed that B is in the position to produce the needed input in-house, and, consequently, s/he does not need to procure the input from an external supplier.[6] Before

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[2]Information sharing among members of a supply chain is an important mechanism for coordination. See for instance, Lee and Whang (1998), Lee et al. (2004) and Agrell and Bogetoft (2017).

[3]The exact information endowment will be presented in detail in the beginning of each relevant section.

[4]This is the "delegation to a middleman" case from Mookherjee and Tsumagari (2004) and Mookherjee (2006).

[5]See e.g. Dixit and Pindyck (1994, pp. 138).

[6]We tacitly assume that if B can manufacture the needed input in-house, s/he will do so. In other words, insourcing is assumed to be always less costly than outsourcing.

discussing the delegation of the investment decision from P to B, let's recall that, according to the real options literature, when a potential investor contemplates undertaking an investment project characterized by uncertainty and irreversibility, the ability to delay the investment for some future time point is a source of flexibility that profoundly affects the decision to invest (see e.g. McDonald and Siegel, 1986). The investment takes place only as soon as the project's expected payoff exceeds the cost of the investment by a margin equal to the option value of further postponing the completion of the project into the future.[7]

Let $F(x; I)$ denote the value of the opportunity to invest in a project the value of which fluctuates over time according to process (1), and I denote the corresponding sunk investment cost. Assuming that the initial state value x is sufficiently small so that investing at time zero is not preferable,[8] the optimal investment time point τ is derived through the solution of the following maximization problem:

$$F(x; I) = \max_{\tau} E_x \left[e^{-r\tau} (X^* - I) \right], \tag{2.1}$$

which can be rearranged as[9]

$$F(x; I) = \max_{X^*} (X^* - I) \left(\frac{x}{X^*} \right)^{\beta}, \tag{2.2}$$

where:

- $\tau = \inf \{ t > 0 \,|\, X_t = X^* \}$ is the random first time point that X_t hits the barrier X^* which is the project value that triggers the investment and,

- $\beta = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2} \right)^2 + \frac{2r}{\sigma^2}} > 1$ is the positive root of the characteristic equation $\frac{1}{2}\sigma^2 \beta(\beta - 1) + \mu\beta - r = 0$.[10]

Now, applying the real options approach to our context, the project originator P contemplates investing in a project like the one described in problem (2), and delegates the correspond-

[7]O'Brien et al. (2003) present strong empirical evidence in favor of this argument. More precisely, they find that entrepreneurs account for the value of the option to delay entering a new market when contemplating such a decision.

[8]If the initial state value x is sufficiently large so that investing at time zero is preferable, our problem reduces to a standard net present value maximization since the option to invest is exercised as soon as possible.

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

[10]The expressions for $F(x; I)$ and β are standard in the real options literature (see e.g. Dixit and Pindyck, 1994).

ing investment decision to the project manager B. The generic term I corresponds in this case to the in-house production cost of the input. I assume that I can take one of two possible values: I_1 with probability q or I_2 with probability $1-q$ where $I_2 > I_1 > 0$ and $\Delta I \equiv I_2 - I_1$.[11] Of course, I_1 represents a "lower" whereas I_2 a "higher" expenditure.

Under symmetry of information, that is when the true magnitude of I is known both to the principal and to the agent, B has no informational advantage over P and, consequently, it is as if we are dealing with a problem without delegation of the investment decision. In this case B is just an intermediary who is granted access to exactly enough resources to successfully complete the delegated task. Consequently, the ex-ante optimization problem for P is

$$\max_{X_1^{SI}, X_2^{SI}} q \left(X_1^{SI} - I_1\right) \left(\frac{x}{X_1^{SI}}\right)^{\beta} + (1-q) \left(X_2^{SI} - I_2\right) \left(\frac{x}{X_2^{SI}}\right)^{\beta}, \tag{3}$$

where X_i^{SI}, $i \in \{1, 2\}$ are the investment thresholds under symmetry of information.[12] From the first-order conditions we have

$$X_i^{SI} = \frac{\beta}{\beta - 1} I_i, i \in \{1, 2\}. \tag{4}$$

Note that, since $I_2 > I_1$, we obtain $X_2^{SI} > X_1^{SI}$. In words, the completion of a more expensive investment project is, in expected terms, realized later.

Last, P's ex-ante value of the opportunity to invest can be written as:

$$\begin{aligned} f\left(x; I_1, I_2\right) &= qF\left(x; I_1\right) + (1-q) F\left(x; I_2\right) \tag{5.1} \\ &= q\frac{I_1}{\beta - 1} \left(\frac{x}{X_1^{SI}}\right)^{\beta} + (1-q) \frac{I_2}{\beta - 1} \left(\frac{x}{X_2^{SI}}\right)^{\beta} \tag{5.2} \end{aligned}$$

As one can easily see, the quantity $f\left(x; I_1, I_2\right)$ is the ex-ante value of the opportunity to invest, not only for the project originator, but for the whole industry as well.[13]

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[11] In the Appendix (subsection 4.4.2) I extend the analysis considering a continuous I.

[12] The superscript SI refers to symmetry of information.

[13] Since B has no informational advantage over P under information symmetry, her/his option value is equal to zero.

4.1.3 Information asymmetry and in-house production of the input

As in the previous subsection, B is qualified to produce the discrete input in-house. What is different from before is that now the true I is not common knowledge but is instead assumed to be privately observed by the agent B. This is a reasonable assumption since the individual with the best information on the production cost is usually the producer her/himself (Celik, 2009). Of course, this implies an information asymmetry between P and B. As in Grenadier and Wang (2005), Amaral et al. (2006) and Shibata (2009), this information asymmetry results in an agency conflict since the agent has an incentive to report the higher I_2 when I_1 is the true production cost, attempting to appropriate the positive difference ΔI. The principal might not be able to observe the true I verifying the agent's (dis)honesty, but s/he can induce B to reveal the true magnitude of the expenditure by giving a bonus-incentive. In order to do so, s/he designs a menu of contracts contingent on the observable X_t.

It is assumed that P submits the menu of contracts to her/his delegate at time zero and that the chosen contract commits the actions of the two parties at the time of the investment.[14] Once the menu of contracts is submitted, B observes the true I and chooses the corresponding contract. Given that I can take one of two possible values, "high" or "low", this menu is comprised by two contracts consisting of one money transfer (t) and one investment threshold $\left(X^{AI}\right)$ each.[15] The principal's objective is to maximize the ex-ante value of the investment opportunity through the choice of the contract terms $\left\{X_i^{AI}, t_i\right\}, i \in \{1, 2\}$. The problem that P needs to solve is formulated as:

$$\max_{\left\{\left(X_1^{AI}, t_1\right); \left(X_2^{AI}, t_2\right)\right\}} q\left(X_1^{AI} - t_1\right)\left(\frac{x}{X_1^{AI}}\right)^\beta + (1-q)\left(X_2^{AI} - t_2\right)\left(\frac{x}{X_2^{AI}}\right)^\beta \qquad (6.1)$$

---

[14]Renegotiation of the contract terms is not allowed. This assumption is justified if the contract is enforceable and if the market of the agent is competitive. For a similar treatment see Grenadier and Wang (2005) and Shibata (2009).

[15]Note that one can also allow for a menu of contracts comprised by one pair of t and X^{AI}, i.e. a pooling equilibrium. However, the pooling equilibrium is always dominated by a separating one and this allows us to focus on the latter. See e.g. Shibata (2009).

Subject to:

$$(t_1 - I_1) \left(\frac{x}{X_1^{AI}} \right)^\beta \geq (t_2 - I_1) \left(\frac{x}{X_2^{AI}} \right)^\beta \tag{7.1}$$

$$(t_2 - I_2) \left(\frac{x}{X_2^{AI}} \right)^\beta \geq (t_1 - I_2) \left(\frac{x}{X_1^{AI}} \right)^\beta \tag{8.1}$$

$$t_1 - I_1 \geq 0 \tag{9.1}$$

$$t_2 - I_2 \geq 0 \tag{10.1}$$

$$q (t_1 - I_1) \left(\frac{x}{X_1^{AI}} \right)^\beta + (1 - q) (t_2 - I_2) \left(\frac{x}{X_2^{AI}} \right)^\beta \geq 0 \tag{11.1}$$

As one can see, the objective function in problem (6.1) is symmetric to the objective function in problem (3).[16] The only difference between the two is that the money transfer t_i replaces the cost expenditure I_i.

The inequalities (7.1) and (8.1) are the incentive compatibility constraints. They guarantee that if agent B observes that the true I is equal to I_i, s/he will (weakly) prefer contract $\left\{ X_i^{AI}, t_i \right\}$ to contract $\left\{ X_j^{AI}, t_j \right\}$ where $i, j \in \{1, 2\}$ and $i \neq j$. In other words, constraints (7.1) and (8.1) guarantee that, at the time of the investment, the reported I is the true one. As one can see, an incentive compatible scheme eliminates potential incentive misalignments since both the principal and the agent are better-off when following the decision rules that are optimal for the system as a whole.[17]

The inequalities (9.1) and (10.1) are the limited liability conditions and they are necessary to provide an incentive for the agent to get involved in the project.[18] Finally, inequality (11.1) is the agent's ex-ante participation constraint which ensures that B's total value of accepting to abide by P's menu of contracts is non-negative.

The problem (6.1)-(11.1) can be alternatively formulated in the following way:

$$\max_{\left\{ \left(X_1^{AI}, w_1 \right); \left(X_2^{AI}, w_2 \right) \right\}} q \left(X_1^{AI} - w_1 - I_1 \right) \left(\frac{x}{X_1^{AI}} \right)^\beta + (1 - q) \left(X_2^{AI} - w_2 - I_2 \right) \left(\frac{x}{X_2^{AI}} \right)^\beta \tag{6.2}$$

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[16] The superscript AI denotes asymmetry of information.

[17] See e.g. Lee and Whang (1999).

[18] If the limited liability conditions do not hold, B's involvement in the project might generate losses.

Subject to:

$$w_1 \left(\frac{x}{X_1^{AI}} \right)^\beta \geq (w_2 + \Delta I) \left(\frac{x}{X_2^{AI}} \right)^\beta \tag{7.2}$$

$$w_2 \left(\frac{x}{X_2^{AI}} \right)^\beta \geq (w_1 - \Delta I) \left(\frac{x}{X_1^{AI}} \right)^\beta \tag{8.2}$$

$$w_1 \geq 0 \tag{9.2}$$

$$w_2 \geq 0 \tag{10.2}$$

$$q w_1 \left(\frac{x}{X_1^{AI}} \right)^\beta + (1 - q) w_2 \left(\frac{x}{X_2^{AI}} \right)^\beta \geq 0 \tag{11.2}$$

The term $w_i = t_i - I_i, i \in \{1, 2\}$ stands for the information rent. Formally, the information rent is defined as the difference between the money transfer t_k and the true expenditure I_i: $w_{k,i} \equiv t_k - I_i, \ i, k \in \{1, 2\}$ where k is the reported, but not necessarily true (i), expenditure.[19] Of course under incentive compatibility the reported and the true expenditures coincide $(k = i)$ which gives $w_{i,i} = t_i - I_i$. By slightly abusing notation, $w_{i,i}$ reduces to w_i which is the term appearing above.

Solving the problem (6)-(11) we obtain the following menu of contracts:[20]

$$\left\{ X_1^{AI} (I_1), w_1 (I_1, I_2) \right\} = \left\{ \frac{\beta}{\beta - 1} I_1, \left(\frac{X_1^{AI} (I_1)}{X_2^{AI} (I_1, I_2)} \right)^\beta \Delta I \right\} \tag{12.1}$$

$$\left\{ X_2^{AI} (I_1, I_2), w_2 (I_1, I_2) \right\} = \left\{ \frac{\beta}{\beta - 1} I_2 + \frac{\beta}{\beta - 1} \frac{q}{1 - q} \Delta I, 0 \right\} \tag{12.2}$$

Thanks to the incentive compatibility conditions, contract (12.1) will be chosen by B when the cost turns out to be equal to I_1, whereas, contract (12.2) will be chosen when the cost turns out to be equal to I_2.

Note that, on one hand, $X_1^{AI} (I_1) = X_1^{SI} (I_1)$, $X_2^{AI} (I_1, I_2) > X_2^{SI} (I_2)$ and that, on the other, $w_1 (I_1, I_2) > 0$, $w_2 (I_1, I_2) = 0$. In words, the agency conflict does not affect the timing of the investment when I_1 is observed, but it does when I_2 is observed causing the (suboptimal) postponement of the investment. However, this does not mean that when I_1 is the true investment cost there is no distortion since a positive information rent is to be paid to B.

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[19] See e.g. Laffont and Martimort, 2002.
[20] The solution of the problem is analytically presented in the Appendix (subsection 4.4.1).

Substituting the components of menu (12) in the value functions of the two parties we obtain

$$
\begin{aligned}
V_P\left(x; I_1, I_2\right) &= q\left(X_1^{AI}\left(I_1\right) - I_1 - w_1\left(I_1, I_2\right)\right)\left(\frac{x}{X_1^{AI}\left(I_1\right)}\right)^{\beta} \tag{13} \\
&\quad + (1-q)\left(X_2^{AI}\left(I_1, I_2\right) - I_2\right)\left(\frac{x}{X_2^{AI}\left(I_1, I_2\right)}\right)^{\beta}, \\
V_B\left(x; I_1, I_2\right) &= q w_1\left(I_1, I_2\right)\left(\frac{x}{X_1^{AI}\left(I_1\right)}\right)^{\beta}, \tag{14}
\end{aligned}
$$

where $V_P\left(x; I_1, I_2\right)$ and $V_B\left(x; I_1, I_2\right)$ stand for the investment opportunity values of the principal and the agent respectively. The total value of the project $V\left(x; I_1, I_2\right) \equiv V_P\left(x; I_1, I_2\right) + V_B\left(x; I_1, I_2\right)$, is then equal to:

$$
V\left(x; I_1, I_2\right) = q\left(X_1^{AI}\left(I_1\right) - I_1\right)\left(\frac{x}{X_1^{AI}\left(I_1\right)}\right)^{\beta} + (1-q)\left(X_2^{AI}\left(I_1, I_2\right) - I_2\right)\left(\frac{x}{X_2^{AI}\left(I_1, I_2\right)}\right)^{\beta} \tag{15}
$$

Note that this is symmetric to Eq. (5). The only difference between the two is that, in Eq. (15), the larger $X_2^{AI}\left(I_1, I_2\right)$ replaces the smaller $X_2^{SI}\left(I_2\right)$ resulting in

$$
V\left(x; I_1, I_2\right) < f\left(x; I_1, I_2\right). \tag{16}
$$

In words, the agency conflict between the principal and the agent that stems from the corresponding information asymmetry is reflected in a suboptimally lower aggregate option value.

4.2 A as the exclusive producer of the input

Up to now, we have discussed the interaction between the principal P and the agent B assuming that the latter can produce the needed input in-house. Nevertheless, the project manager might lack the equipment and/or the expertise to manufacture the needed input (Deshpande et al., 2011). Investment projects are often rather complex and relationship-specific inputs tailored to a specific client are common in supply chains (Agrell and Bogetoft, 2017). Keeping this in mind, I now assume that the upstream firm A is the exclusive producer of the required input.

As outlined in subsection 4.1.1, A is pricing the input considering information related both to the structure of the downstream industry and to the evolution of X_t. More precisely,

- In subsection 4.2.1 I examine the case of a non-transparent supply chain in the sense that every individual in the supply chain is dealing exclusively with her/his immediate neighbor(s).[21] In this case, P delegates to B not only the exercise of the investment decision but the procurement of the necessary input as well. At the same time, A prices the input that s/he sells to B knowing the fundamental parameters of process (1) but without ever observing the true magnitude of X_t.

- In subsection 4.2.2 I allow for a more transparent framework where all the companies in the supply chain are able to track the product's flow throughout the production process. In this case, P still delegates the investment decision to B but can now procure the input directly from A if this proves to be the best alternative. The upstream firm A is now informed about the delegation of the project from P to B but still prices the input knowing nothing but the fundamental parameters of process (1).

- Last, in subsection 4.2.3 I discuss a fully transparent supply chain where P, B and A all share the same information about X_t.

4.2.1 Non-transparent supply chain

In this subsection I discuss a non-transparent supply chain in the sense that the upstream firm A deals only with the project manager B and prices the produced input knowing the structural parameters of process (1) but without ever observing the true magnitude of X_t. Non-transparent supply chains are often found in consumer industries such as the garment industry (Boström et al., 2012; Doorey, 2011).

Algebraically, A's problem is given by

$$\max_{p_1,p_2} q\left(p_1 - I_1\right)\left(\frac{x}{X_1^M\left(p_1\right)}\right)^\beta + (1-q)\left(p_2 - I_2\right)\left(\frac{x}{X_2^M\left(p_2\right)}\right)^\beta, \tag{17}$$

where p_i is the price of the input when the in-house production cost is I_i and $X_i^M\left(p_i\right), i \in \{1,2\}$ is the relevant investment threshold.

A is choosing p_i anticipating that B will complete the (supposedly private) investment once the investment threshold $X_i^M\left(p_i\right) = \frac{\beta}{\beta-1}p_i$, $i \in \{1,2\}$ is reached. Of course the formula for

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[21] The plural is for B who is purchasing the input from A in order to deliver P's project.

$X_i^M(p_i)$ is identical to the one for X_i^{SI} from Eq. (4) if, instead of I_i, we use p_i.[22] Given this, we solve the maximization problem (17) and we obtain:

$$p_i = \frac{\beta}{\beta - 1} I_i, i \in \{1, 2\} \tag{18}$$

Note that, unsurprisingly, $p_i > I_i$ which means that the presence of an upstream firm with market power naturally makes the investment more costly.[23]

Now, we can go back to the agency conflict as it was discussed in subsection 4.1.3 and see how the replacement of I_i by p_i affects our results. Replacing also ΔI with $\Delta p \equiv p_2 - p_1$ we obtain:

$$\left\{ X_1^R(p_1), \omega_1(p_1, p_2) \right\} = \left\{ \frac{\beta}{\beta - 1} p_1, \left(\frac{X_1^R(p_1)}{X_2^R(p_1, p_2)} \right)^\beta \Delta p \right\} \tag{19.1}$$

$$\left\{ X_2^R(p_1, p_2), \omega_2(p_1, p_2) \right\} = \left\{ \frac{\beta}{\beta - 1} p_2 + \frac{\beta}{\beta - 1} \frac{q}{1 - q} \Delta p, 0 \right\} \tag{19.2}$$

The term ω_i stands for the information rent that the delegate B receives through the menu of contracts in (19), whereas the term X_i^R stands for the (real) investment threshold.[24] Note that $X_1^R(p_1) = X_1^M(p_1)$ but $X_2^R(p_1, p_2) > X_2^M(p_2)$. This implies that A's inability to acknowledge that s/he is selling the input to the agent, and not to the principal, is costly when the true I is equal to I_2. In that case, the upstream firm expects to cash the lump sum p_2 when $X_2^M(p_2)$ is reached but will have to wait until X_t reaches the higher $X_2^R(p_1, p_2)$ before this actually happens.

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[22] Analytically, the term $X_i^M(p_i) = \frac{\beta}{\beta - 1} p_i$, $i \in \{1, 2\}$ is derived solving $\max\limits_{X_1^M, X_2^M} q \left(X_1^M - p_1 \right) \left(\frac{x}{X_1^M} \right)^\beta +$

$(1 - q) \left(X_2^M - p_2 \right) \left(\frac{x}{X_2^M} \right)^\beta$ which of course is reminiscent of the maximization problem (3).

[23] Note also that, thanks to $I_2 > I_1$, we obtain $p_2 > p_1$.

[24] The derivation of menu (19) is totally symmetric to the one of menu (12).

The option values for the three parties P, B and A are:

$$\Pi_P (x; p_1, p_2) = q \left(X_1^R (p_1) - p_1 - \omega_1 (p_1, p_2) \right) \left(\frac{x}{X_1^R (p_1)} \right)^\beta \tag{20}$$

$$+ (1 - q) \left(X_2^R (p_1, p_2) - p_2 \right) \left(\frac{x}{X_2^R (p_1, p_2)} \right)^\beta$$

$$\Pi_B (x; p_1, p_2) = q \omega_1 (p_1, p_2) \left(\frac{x}{X_1^R (p_1)} \right)^\beta \tag{21}$$

$$\Pi_{AR} (x; p_1, p_2) = q (p_1 - I_1) \left(\frac{x}{X_1^R (p_1)} \right)^\beta + (1 - q) (p_2 - I_2) \left(\frac{x}{X_2^R (p_1, p_2)} \right)^\beta \tag{22.1}$$

Note that A anticipates to receive

$$\Pi_{AM} (x; p_1, p_2) = q (p_1 - I_1) \left(\frac{x}{X_1^M (p_1)} \right)^\beta + (1 - q) (p_2 - I_2) \left(\frac{x}{X_2^M (p_2)} \right)^\beta, \tag{22.2}$$

where $\Pi_{AR} (x; p_1, p_2) < \Pi_{AM} (x; p_1, p_2)$. As I have already underlined above, the difference between the true Π_{AR} and the expected Π_{AM} has to do with the difference between $X_2^R (p_1, p_2)$ and $X_2^M (p_2)$.

Last, the aggregate value of the investment opportunity is:

$$\Pi (x; p_1, p_2) \equiv \Pi_P (x; p_1, p_2) + \Pi_B (x; p_1, p_2) + \Pi_{AR} (x; p_1, p_2) = \tag{23.1}$$

$$q \left(X_1^R (p_1) - I_1 \right) \left(\frac{x}{X_1^R (p_1)} \right)^\beta + (1 - q) \left(X_2^R (p_1, p_2) - I_2 \right) \left(\frac{x}{X_2^R (p_1, p_2)} \right)^\beta \tag{23.2}$$

Let's now check how the presence of the upstream firm A affects the timing and the value of the investment. As we have already seen above, the presence of a supplier with market power makes the investment more costly since $p_i / I_i = \beta / \beta - 1$, $i \in \{1, 2\}$. The fact that the investment is more expensive is then reflected in higher investment thresholds and a larger information rent. More precisely, we have:

$$\frac{X_1^R (p_1)}{X_1^{AI} (I_1)} = \frac{X_2^R (p_1, p_2)}{X_2^{AI} (I_1, I_2)} = \frac{\omega_1 (p_1, p_2)}{w_1 (I_1, I_2)} = \frac{\beta}{\beta - 1} > 1 \tag{24}$$

One can also show that

$$\Pi_P\left(x;p_1,p_2\right) \quad < \quad V_P\left(x;I_1,I_2\right), \tag{25.1}$$

$$\Pi_B\left(x;p_1,p_2\right) \quad < \quad V_B\left(x;I_1,I_2\right), \tag{25.2}$$

$$\Pi\left(x;p_1,p_2\right) \quad < \quad V\left(x;I_1,I_2\right). \tag{25.3}$$

In words, the presence of an external supplier with market power makes both the project originator and the project manager worse-off a result which is eventually mirrored in a lower aggregate option value.[25]

The following proposition summarizes our findings:

Proposition 13 *Consider an investment project the completion of which depends on the provision of a necessary input that is exclusively produced by an upstream firm with market power. Assume also that the project originator delegates both the procurement of the necessary input and the investment decision to a project manager with an informational advantage. Then, comparing this case with the one where the needed input is produced in-house by the project manager,*

i) the sunk investment cost and the corresponding investment triggers are larger whereas,

ii) the value of the opportunity to invest for the principal, the agent and the whole supply chain is smaller.

4.2.2 The case of traceability

In a supply chain setting, the term *transparency* is often used as a synonym of traceability, i.e. the disclosure of the names of the suppliers involved in a supply chain to the other firms in the supply chain as well as to end-users.[26] For instance, Nike, Adidas and H&M have disclosed the names of their first-tier suppliers whereas the All American Clothing Co allows consumers to trace the flow of the final product from the cotton field and onward.[27]

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[25]Using standard option valuation arguments, we know that a firm stands to gain more by exercising rather than holding an investment option with a low strike price. In our setting where $p_i > I_i$, one expects to find $X_i^R > X_i^{AI}$, $i \in \{1,2\}$ and $V_j > \Pi_j$, $j \in \{P,B\}$ which is exactly what we have in Eq. (24) and Eq. (25).

[26]See e.g. Doorey (2011) and Laudal (2010).

[27]See e.g. Egels-Zanden and Hansson (2016) and the references therein.

Supply chain transparency is usually seen as a mechanism to promote sustainability, improve compliance with labor standards and deter unethical activities at the production site.[28] Despite the fact that many companies were initially taking a firm position against supplier factory disclosure, transparency is perceived today as a new corporate social responsibility strategy signaling that the corporation has "nothing to hide".[29]

In the present setting, traceability implies that:

i) A knows the structure of the downstream industry, that is, s/he knows that P is the project originator whereas B is the project manager and,

ii) P knows that A is the supplier of the necessary input.

It is important to stress here that A is still assumed to be pricing the input taking into consideration the structural parameters of process (1), but without observing the realizations of the stochastic parameter over time. The importance of this point will become clearer in the next subsection where this assumption will be relaxed.

Reapproaching the problem under traceability, we have the following. The input supplier A, observing the delegation of the investment decision downstream, anticipates that the agency conflict will result in, not $\Pi_{AM}(x; p_1, p_2)$ but the smaller, $\Pi_{AR}(x; p_1, p_2)$. Of course A can prevent that from happening by sharing the true price of the input both with B and P. This way, the input supplier makes sure that there will be information symmetry downstream and that, consequently, the principal will not have to use a bonus-incentive mechanism in order to guarantee the successful delivery of the project. Actually, by pricing the input according to Eq. (18), A can secure $\Pi_{AM}(x; p_1, p_2)$ for her/himself.

As far as the principal and the agent are concerned, the symmetry of information implies a zero option value for B and a positive option value for P that is equal to:

$$
\begin{aligned}
\pi_P(x; p_1, p_2) &= q\left(X_1^M(p_1) - p_1\right)\left(\frac{x}{X_1^M(p_1)}\right)^{\beta} + (1-q)\left(X_2^M(p_2) - p_2\right)\left(\frac{x}{X_2^M(p_2)}\right)^{\beta} \quad (26.1) \\
&= \left(\frac{\beta-1}{\beta}\right)^{\beta-1} f(x; I_1, I_2) \quad (26.2)
\end{aligned}
$$

---

[28] See Egels-Zanden (2007), Bartley (2007) and Zyglidopoulos and Fleming (2011) respectively.

[29] Bhaduri and Ha-Brookshire (2011), Bradu et al. (2014) and Egels-Zanden and Hansson (2016) show that supply chain transparency influences positively the purchasing intentions of the consumer.

The inequality $\pi_P(x; p_1, p_2) < f(x; I_1, I_2)$ implies that, even under information symmetry downstream, the option value of the principal is suboptimal. Of course this is to be expected since, despite the fact that P does not need to pay an information rent to B anymore, s/he still needs to pay a "market rent" to A who exploits her/his market power as the exclusive producer of the needed input.

The aggregate option value in this case is:

$$
\begin{aligned}
\pi(x; p_1, p_2) &\equiv \pi_P(x; p_1, p_2) + \Pi_{AM}(x; p_1, p_2) && (27.1) \\
&= q\left(X_1^M(p_1) - I_1\right)\left(\frac{x}{X_1^M(p_1)}\right)^\beta + (1-q)\left(X_2^M(p_2) - I_2\right)\left(\frac{x}{X_2^M(p_2)}\right)^\beta && (27.2)
\end{aligned}
$$

As one can see, Eq. (27) is symmetric to Eq. (5). Also, one can easily check that $\pi(x; p_1, p_2) < f(x; I_1, I_2)$ which means that the market power of the input supplier is reflected in a suboptimal aggregate option value, even under information symmetry downstream.

Let's now identify how the transparency in the supply chain affects the investment project. First of all, agent B is clearly worse-off since there is no information asymmetry for her/him to exploit. On the contrary, we see that the input supplier as well as the principal are both better-off since $\Pi_{AR}(x; p_1, p_2) < \Pi_{AM}(x; p_1, p_2)$ and $\Pi_P(x; p_1, p_2) < \pi_P(x; p_1, p_2)$. This of course has to do with the fact that the principal does not need a bonus-incentive mechanism to guarantee that the agent reports the true investment cost. At the same time, also the aggregate value of the investment opportunity is higher since $\Pi(x; p_1, p_2) < \pi(x; p_1, p_2)$.

Summing up, traceability in a supply chain might not be beneficial for the project manager but is beneficial for all other parties as well as the supply chain as a whole.

The following proposition summarizes our findings:

Proposition 14 *Consider the investment project from Proposition 13. In a supply chain where the traceability of the final product is guaranteed, there is no information asymmetry for the agent to exploit. This makes the delegate worse-off but is beneficial for the principal, the input supplier and the supply-chain as a whole.*

Finally, one can notice that $V(x; I_1, I_2)$ from Eq. (15) and $\pi(x; p_1, p_2)$ from Eq. (27) correspond to the two ends of the same spectrum: $V(x; I_1, I_2)$ is the aggregate value of an investment

project that involves downstream asymmetry of information but a perfectly competitive input market, whereas $\pi(x; p_1, p_2)$ is the aggregate option value of a project that involves downstream symmetry of information but a monopolist input supplier.

4.2.3 Transparent supply chain

As stated in the previous subsection, *transparency* is often used as a synonym of traceability. Nevertheless, supply chain transparency is a much broader concept since it has to do with sharing data regarding order and production statuses and forecasts among the supply chain partners especially when dealing with customized products like in this paper (see e.g. Gavirneni et al.,1999 and Lee and Whang, 1999).

In this subsection, I allow for a fully transparent supply chain in the sense that, apart from traceability, it is also assumed that P, B and A all share the same information related to the stochastic parameter. A is now in the position to observe the realizations of X_t continuously and verifiably. In this case, s/he can specify both the investment threshold and the input price at the same time. This way, and by dictating the investment threshold X_i^{SI}, i.e. the investment threshold that maximizes the aggregate value of the investment opportunity, A can appropriate all the benefits above the investor's reservation value. The investor's reservation value is, as expected, set equal to $\Omega_i \equiv \left(X_i^M(p_i) - p_i\right) \left(\frac{x}{X_i^M(p_i)}\right)^\beta, i \in \{1, 2\}$.[30]

Keeping all this in mind, A is choosing the input price solving

$$\max_{\varphi_i} (\varphi_i - I_i) \left(\frac{x}{X_i^{SI}}\right)^\beta \tag{28}$$

such that

$$\left(X_i^{SI} - \varphi_i\right) \left(\frac{x}{X_i^{SI}}\right)^\beta \geq \Omega_i, i \in \{1, 2\}.[31] \tag{29}$$

The term φ_i stands for the (new) price of the input. Since the objective function in problem (28) is increasing in φ_i, the solution is derived from the constraint (29). A binding constraint (29) implies that, φ_i is such that P is indifferent between an investment that costs φ_i and takes

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[30]Note that, unless the reservation value is higher, or at least equal to Ω_i, there is not reason for P to engage in information sharing with A.

[31]See Billette de Villemeur et al. (2014) for a similar treatment.

place when X_i^{SI} is reached, and an investment that costs p_i and takes place when the higher $X_i^M(p_i)$ is reached. Solving we obtain

$$\varphi_i = \frac{\beta}{\beta-1} I_i \left(1 - \frac{(\beta-1)^{\beta-1}}{\beta^\beta}\right).^{32} \tag{30}$$

The input supplier A, chooses $\varphi_i (> I_i)$ at X_i^{SI} submitting a take-it-or-leave-it offer to the project originator P and to her/his delegate B.

In this case, the principal's ex-ante option value is:

$$\Phi_P(x; \varphi_1, \varphi_2) = q \left(X_1^{SI} - \varphi_1\right) \left(\frac{x}{X_1^{SI}}\right)^\beta + (1-q) \left(X_2^{SI} - \varphi_2\right) \left(\frac{x}{X_2^{SI}}\right)^\beta \tag{31}$$

The ex-ante option value for A is given by:

$$\Phi_A(x; \varphi_1, \varphi_2) = q \left(\varphi_1 - I_1\right) \left(\frac{x}{X_1^{SI}}\right)^\beta + (1-q) \left(\varphi_2 - I_2\right) \left(\frac{x}{X_2^{SI}}\right)^\beta \tag{32}$$

Finally, combining the two, the aggregate option value is

$$\Phi(x; \varphi_1, \varphi_2) \equiv \Phi_P(x; \varphi_1, \varphi_2) + \Phi_A(x; \varphi_1, \varphi_2) \tag{33.1}$$
$$= q \left(X_1^{SI} - I_1\right) \left(\frac{x}{X_1^{SI}}\right)^\beta + (1-q) \left(X_2^{SI} - I_2\right) \left(\frac{x}{X_2^{SI}}\right)^\beta \tag{33.2}$$
$$= f(x; I_1, I_2) \tag{33.3}$$

The equality $\Phi(x; \varphi_1, \varphi_2) = f(x; I_1, I_2)$ is to be expected since, as we have seen in the beginning of this subsection, A will attempt to dictate the investment thresholds that maximize the industry value and then appropriate all the benefits above the potential investor's reservation value. In other words, by construction, we have $\Phi_A(x; \varphi_1, \varphi_2) = f(x; I_1, I_2) - \Phi_P(x; \varphi_1, \varphi_2)$ and consequently $\Phi_P(x; \varphi_1, \varphi_2) + \Phi_A(x; \varphi_1, \varphi_2) = f(x; I_1, I_2)$.

Comparing the transparent supply chain with the one under traceability as this was presented in the previous subsection, we have $\pi_P(x; p_1, p_2) = \Phi_P(x; \varphi_1, \varphi_2)$ and $\Phi_A(x; \varphi_1, \varphi_2) > \Pi_{AM}(x; p_1, p_2).^{33}$ In words, while the project originator and the project manager are indiffer-

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[32] Note also that, thanks to $I_2 > I_1$, we obtain $\varphi_2 > \varphi_1$.

[33] Note that $\pi_P(x; p_1, p_2) = \Phi_P(x; \varphi_1, \varphi_2)$ holds as soon as constraint (29) is binding.

ent between a supply chain characterized by traceability and a transparent one, both the input supplier and the supply chain as a whole are better-off.

Proposition 15 summarizes our findings:

Proposition 15 *Consider the investment project from Proposition 13. In a transparent supply chain where the principal, the agent and the input supplier can all continuously and verifiably observe the realizations of the stochastic parameter over time, the investment is realized when the optimal investment threshold is reached. Also, despite the fact that the principal and the agent are indifferent between a transparent supply chain and one characterized by traceability, the input supplier and, consequently, the supply chain as a whole, are better-off.*

The findings are in accordance with real world examples from Seifert (2003) and Yan and Pei (2011) which suggest that information sharing contributes to better decision making, fewer coordination failures and a stronger supply chain performance.

4.3   Comparison

In this last section, I discuss the presented results and some of the assumptions of the model in more detail.

As far as the results of the analysis are concerned, TABLE 6 presents exactly how the sunk investment costs, the investment thresholds and the values of the investment opportunity

change given the different levels of transparency in the supply chain.

TABLE 6

	Non-transparency		Traceability		Transparency	First-Best
Cost	p_i	$=$	p_i	$>$	φ_i	I_i
Threshold	X_i^R	$\geqslant$	X_i^M	$>$	X_i^{SI}	X_i^{SI}
Inv. Value:						
Aggregate	Π	$<$	π	$<$	f	f
B	Π_B	$>$	0	$=$	0	0
A	Π_{AR}	$<$	Π_{AM}	$<$	Φ_A	0
P	Π_P	$<$	π_P	$=$	Φ_P	f

First of all, one can see that irrespective of the level of information sharing in the supply chain, the presence of an upstream input supplier with market power is always making the investment more expensive ($\varphi_i > I_i, i \in \{1, 2\}$). Secondly, as for the investment triggers, the comparisons suggest that the higher investment costs are not always reflected in higher investment thresholds. Actually, as we saw in subsection 4.2.3, in a transparent supply chain, the investment takes place as soon as the optimal investment trigger is reached, i.e., there is no inefficient postponement of the investment at all. Similarly, the way that the presence of the input supplier affects the aggregate value of the investment opportunity is also ambiguous. According to Eq. (25.3), the presence of an upstream firm with market power in a non-transparent supply chain will reduce the value of the investment opportunity if compared to the case where the input is insourced ($\Pi(x; p_1, p_2) < V(x; I_1, I_2)$). Nevertheless, the level of transparency makes a difference since, as one can see, the aggregate value of the investment opportunity reaches its first-best when the supply chain is transparent.

Fourthly, as far as the components of the aggregate value of the investment opportunity are concerned, we find that the presence of the upstream firm is affecting differently the principal and the agent. Starting with the latter, the presence of the input supplier is always making the agent worse-off. Even under a non-transparent supply chain which is the most favorable scenario for the delegate, the higher sunk investment costs imply an investment

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opportunity with lower value.[34] Of course, both under traceability and under transparency, the agency conflict is automatically resolved and consequently there is no information asymmetry for the agent to exploit. This might be unfavorable for the agent but is clearly favorable for the principal who, nevertheless needs to deal with the monopolist input supplier $(\pi_P(x; p_1, p_2) = \Phi_P(x; \varphi_1, \varphi_2) < f(x; I_1, I_2))$.

Now, given the results presented above, it is worth stressing the difference between investments undertaken in a transparent supply chain and investments undertaken in a centralized setting. In both settings the aggregate value of the investment opportunity as well as the timing of the investment are the same. However, the two frameworks differ significantly since under a transparent supply chain the project originator shares the project with the input supplier. Apparently, even under frictionless information sharing, the presence of an agent with market power changes the balance in the supply chain even if this is not translated in distortions in the timing and/or the aggregate value of the investment.

The inequality $\Pi_{AR}(x; p_1, p_2) < \Pi_{AM}(x; p_1, p_2)$ presents also an interesting result. As we have already discussed in subsection 4.2.1, in a non-transparent supply chain the principal uses a menu of contracts to guarantee that, at the time of the investment, the project manager will truthfully report the magnitude of the sunk investment cost. Furthermore, in line with the relevant literature, we find that the mechanism is costly for the principal $(\Pi_P(x; p_1, p_2) < \pi_P(x; p_1, p_2))$ who has the contractual obligation to, i) pay a positive information rent to the agent if p_1 turns out to be the true input price, or, ii) wait until the inefficiently high investment threshold $X_2^R(p_1, p_2)$ is reached if p_2 turns out to be the true input price. Apparently however, the distorting effects of the use of the bonus-incentive mechanism are not limited to the principal. The inequality $\Pi_{AR}(x; p_1, p_2) < \Pi_{AM}(x; p_1, p_2)$ suggests that, even parties that are not involved in the downstream agency conflict are affected by it. In our case for instance, the upstream firm A, who does not anticipate the investment threshold $X_2^R(p_1, p_2) (> X_2^M(p_2))$ suffers an ex-ante loss equal to $\Pi_{AM}(x; p_1, p_2) - \Pi_{AR}(x; p_1, p_2)$, which is directly reflected in a reduced aggregate value of the opportunity to invest. It is important to stress here that this is actually a deadweight loss in the sense that the difference $\Pi_{AM}(x; p_1, p_2) - \Pi_{AR}(x; p_1, p_2)$ is not funding a bonus-incentive mechanism as for instance

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[34]Recall that from Eq. (25.2) we have $\Pi_B(x; p_1, p_2) < V_B(x; I_1, I_2)$.

is the case with the difference $\pi_P(x; p_1, p_2) - \Pi_P(x; p_1, p_2)$. Consequently, when considering the merits of supply chain transparency, one should keep in mind that by making the bonus-incentive mechanism obsolete, supply chain transparency is not only benefiting the principal, but is effectively dealing with the relevant negative externalities as well.

Given the comparison of the results presented in TABLE 6, let's now discuss the relevant implications. Let's start with agent B. As already stated above, by definition, B possesses a relevant expertise. For instance, s/he might be a professional manager with specialized information related to the upstream firm's production costs (Mookherjee and Tsumagari, 2004), or s/he might be responsible for the solution of a matching problem if direct communication between the project originator and the input supplier is impossible, or prohibitively expensive (Faure-Grimaud and Martimort, 2001). In these two cases, the level of information sharing among the principal P and the input supplier A depends exclusively on the willingness of the intermediary B to ease communication between the two extreme links of the supply chain. Since according to TABLE 6 the manager has nothing to gain from transparency in the supply chain, one expects to find an agent with these characteristics when studying non-transparent supply chains.

Alternatively, B might just be the "person on the spot" (Hayek, 1945). In many cases, the agent's expertise has to do with nothing else but the intimate knowledge of the particular circumstances of time and place. For instance, McAfee and McMillan (1995) assume that the management of the project takes time and the principal's time is limited, whereas Van Zandt (1999) argues that delegation might stem from the fixed information processing capacity of the principal. In both cases, the information sharing between the input supplier and the principal does not depend on the agent's willingness to behave as a communication channel. Consequently, one expects to find agents behaving as "the person on the spot" when studying supply chains characterized by traceability and transparency.

Last, note that an agent B who cannot prevent communication between the other two links of the supply chain is a necessary but not sufficient condition for better coordination. In this model I tacitly assume that all the supply chain partners possess the skills to process the shared information costlessly but this is not necessarily true. In reality, companies might actually

need to invest in developing capabilities to utilize the shared information in an effective way.[35]

Similarly, information sharing can be constrained by antitrust regulations or by non-disclosure

agreements among some of the supply chain partners.

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[35]Let's for instance go back to subsection 4.2.2. In that case I assume that the input supplier A shares information with P who is benefited by the updated information endowment gaining the positive difference $\pi_P(x; p_1, p_2) - \Pi_P(x; p_1, p_2)$. Now, if P faces a positive information processing cost larger than this difference, s/he will never make use of the new information endowment and the supply chain will remain non-transparent in spite of A's actions.

Similarly, in subsection 4.2.3 I assume that P shares information related to process (1) with A who is benefited by the updated information endowment gaining the positive difference $\Phi_A(x; \varphi_1, \varphi_2) - \Pi_{AM}(x; p_1, p_2)$. If A faces a positive information processing cost larger than this difference, s/he will never make use of the new information endowment and the supply chain will remain non-transparent in spite of P's actions.

4.4 Appendix

4.4.1 Information asymmetry and in-house production of the input

Under information asymmetry and in-house production of the discrete input, P needs to solve the following problem:

$$\max_{\{(X_1^{AI}, w_1); (X_2^{AI}, w_2)\}} \left(\frac{x}{X_1^{AI}}\right)^{\beta} (X_1^{AI} - w_1 - I_1) + \frac{1-q}{q} \left(\frac{x}{X_2^{AI}}\right)^{\beta} (X_2^{AI} - w_2 - I_2) \quad (A.1)$$

Subject to:

$$\left(\frac{x}{X_1^{AI}}\right)^{\beta} w_1 \geq \left(\frac{x}{X_2^{AI}}\right)^{\beta} (w_2 + \Delta I) \quad (A.2)$$

$$\left(\frac{x}{X_2^{AI}}\right)^{\beta} w_2 \geq \left(\frac{x}{X_1^{AI}}\right)^{\beta} (w_1 - \Delta I) \quad (A.3)$$

$$w_1 \geq 0 \quad (A.4)$$

$$w_2 \geq 0 \quad (A.5)$$

$$q \left(\frac{x}{X_1^{AI}}\right)^{\beta} w_1 + (1-q) \left(\frac{x}{X_2^{AI}}\right)^{\beta} w_2 \geq 0 \quad (A.6)$$

Working with constraints (A.2) and (A.5) we have:

$$\left(\frac{x}{X_1^{AI}}\right)^{\beta} w_1 \geq \left(\frac{x}{X_2^{AI}}\right)^{\beta} (w_2 + \Delta I) \geq \left(\frac{x}{X_2^{AI}}\right)^{\beta} \Delta I > 0$$

$$\rightarrow$$

$$w_1 > 0$$

Consequently, constraint (A.4) and constraint (A.6) are slack. This allows us to solve problem (A.1) only subject to constraints (A.2), (A.3) and (A.5). Setting constraint (A.3) aside for now, the Lagrangian is

$$
\begin{aligned}
L = & \left(\frac{x}{X_1^{AI}}\right)^{\beta} (X_1^{AI} - w_1 - I_1) + \frac{1-q}{q} \left(\frac{x}{X_2^{AI}}\right)^{\beta} (X_2^{AI} - w_2 - I_2) \\
& + \lambda_1 \left[\left(\frac{x}{X_1^{AI}}\right)^{\beta} w_1 - \left(\frac{x}{X_2^{AI}}\right)^{\beta} (w_2 + \Delta I)\right] \\
& + \lambda_2 w_2,
\end{aligned}
\quad (A.7)
$$

where λ_1 is the Lagrangian multiplier that corresponds to constraint (A.2) and λ_2 is the Lagrangian multiplier that corresponds to constraint (A.5).

Now, keeping in mind the complementary slackness conditions for the two constraints, we can maximize the Lagrangian with respect to X_1^{AI}, X_2^{AI}, w_1 and w_2. The first-order conditions with respect to w_1 and w_2 give $\lambda_1 = 1$ and $\lambda_2 = \left(\frac{1-q}{q} + \lambda_1\right)\left(\frac{x}{X_2^{AI}}\right)^\beta > 0$ respectively. This means that both the incentive compatibility condition (A.2) and the limited liability condition (A.5) are binding, i.e.,

$$w_2 = 0 \tag{A.8}$$

and

$$w_1 = \left(\frac{X_1^{AI}}{X_2^{AI}}\right)^\beta \Delta I. \tag{A.9}$$

Given these, the first-order conditions with respect to the investment thresholds X_1^{AI} and X_2^{AI} result in:

$$X_1^{AI}(I_1) = \frac{\beta}{\beta - 1}I_1 \tag{A.10}$$

$$X_2^{AI}(I_1, I_2) = \frac{\beta}{\beta - 1}\left(I_2 + \frac{q}{1-q}\Delta I\right) \tag{A.11}$$

One can easily show that the derived solutions in Eq. (A.8)-(A.11) satisfy the constraint (A.3) comprising the menu of contracts that P submits to A.

4.4.2 The investment cost as a continuous variable

In the main body of the paper I use a two-point distribution for the in-house production cost I. Here I generalize allowing for a continuum of different levels of I in the interval $[I_1, I_2]$. Let $c(I)$ and $C(I)$ be the density and the cumulative distribution of I respectively. The interval $[I_1, I_2]$ is the support and, consequently, $C(I_1) = 0$ and $C(I_2) = 1$. As in subsection 4.1 and subsection 4.2 of the main body of the paper, I first analyze the case with in-house production of the input and then I consider the case with an external input supplier.

Information symmetry and in-house production of the input under a continuous distribution of I

Following the analysis of subsection 4.1.2 we know that when the agent has no informational advantage over the principal, it is as if there is no delegation of the project. In this case, the optimization problem that P needs to solve is given by

$$\max_{X^{CSI}(I)} \left\{ \int_{I_1}^{I_2} \left(X^{CSI}(I) - I \right) \left(\frac{x}{X^{CSI}(I)} \right)^{\beta} dC(I) \right\}. \tag{A.12}$$

Solving pointwise we obtain:

$$X^{CSI}(I) = \frac{\beta}{\beta - 1} I, \text{ for any } I \in [I_1, I_2] \tag{A.13}$$

As expected, Eq. (A.13) is reminiscent of Eq. (4).[36]

Information asymmetry and in-house production of the input under a continuous distribution of I

Following the analysis of subsection 4.1.3, I now examine the case where the true magnitude of the investment cost is not common knowledge but is instead privately observed by the agent B. As in subsection 4.1.3, the principal needs to design a menu of contracts contingent on the observable component X_t. The only difference with respect to the case that I examine in subsection 4.1.3 is that here the menu is comprised, not by two, but by a continuum of contracts, one for every $I \in [I_1, I_2]$. The problem that P needs to solve is formulated as:

$$\max_{\{X^{CAI}(I), w^{CAI}(I)\}} \left\{ \int_{I_1}^{I_2} \left(X^{CAI}(I) - I - w^{CAI}(I) \right) \left(\frac{x}{X^{CAI}(I)} \right)^{\beta} dC(I) \right\} \tag{A.14}$$

---

[36]The letter C in the superscript stands for "continuum" whereas the letters SI stand for "symmetric information".

Subject to:

$$w^{CAI}(I)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} \geq \left(w^{CAI}(\widetilde{I}) + \widetilde{I} - I\right)\left(\frac{x}{X^{CAI}(\widetilde{I})}\right)^{\beta} \tag{A.15}$$

$$w^{CAI}(I) \geq 0 \tag{A.16}$$

$$\int_{I_1}^{I_2} w^{CAI}(I)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} dC(I) \geq 0, \text{ for any } \widetilde{I}, I \in [I_1, I_2] \tag{A.17}$$

The objective function in problem (A.14) is the ex-ante option value of the principal.[37] The inequalities in (A.15) are the incentive compatibility constraints, the inequalities in (A.16) are the limited liability conditions and inequality (A.17) is the agent's ex-ante participation condition. The term I stands for the true, whereas the term $\widetilde{I}$ stands for the reported, level of investment cost.

Following the analysis from subsection 4.4.1 of the Appendix and using similar arguments we know that the constraint (A.17) is slack, whereas the constraint (A.16) gives $w^{CAI}(I_2) = 0$ and $w^{CAI}(I) > 0$ for every $I \in [I_1, I_2)$. The problem that we need to solve is then reduced to:

$$\max_{\{X^{CAI}(I), w^{CAI}(I)\}} \left\{ \int_{I_1}^{I_2} \left(X^{CAI}(I) - I - w^{CAI}(I)\right)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} dC(I) \right\} \tag{A.14}$$

Subject to:

$$w^{CAI}(I)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} \geq \left(w^{CAI}(\widetilde{I}) + \widetilde{I} - I\right)\left(\frac{x}{X^{CAI}(\widetilde{I})}\right)^{\beta} \tag{A.15}$$

$$w^{CAI}(I_2) = 0, \text{ for any } \widetilde{I}, I \in [I_1, I_2] \tag{A.18}$$

Let's now focus on the constraints in Ineq. (A.15). It is useful to recall that the information rent is defined as $w^{CAI}(\widetilde{I}, I) = t(\widetilde{I}) - I, \forall \widetilde{I}, I \in [I_1, I_2]$ where I is the true investment cost and $t(\widetilde{I})$ is the money transfer from the principal to an agent who reports $\widetilde{I}$. Now, according to Ineq. (A.15), the quantity $(t(I) - I)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta}$ needs to be larger than any quantity $\left(t(\widetilde{I}) - I\right)\left(\frac{x}{X^{CAI}(\widetilde{I})}\right)^{\beta}, \widetilde{I} \neq I$. Let's now write this using the first and the second order condi-

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[37] The letter C in the superscript stands for "continuum" whereas the letters AI stand for "asymmetric information".

tions:

FOC and SOC Note first that

$$\frac{\partial \left(t(\widetilde{I}) - I \right) \left(\frac{x}{X^{CAI}(\widetilde{I})} \right)^{\beta}}{\partial \widetilde{I}} = \left(\frac{x}{X^{CAI}(\widetilde{I})} \right)^{\beta} \left(\dot{t}(\widetilde{I}) - \beta \left(t(\widetilde{I}) - I \right) \frac{\dot{X}^{CAI}(\widetilde{I})}{X^{CAI}(\widetilde{I})} \right), \qquad (A.19)$$

where $\frac{\partial t(\widetilde{I})}{\partial \widetilde{I}} \equiv \dot{t}(\widetilde{I})$ and $\frac{\partial X^{CAI}(\widetilde{I})}{\partial \widetilde{I}} \equiv \dot{X}^{CAI}(\widetilde{I})$. Now, given the first-order derivative from Eq. (A.19), the first-order condition gives:

$$\dot{t}(I) - \beta \left(t(I) - I \right) \frac{\dot{X}^{CAI}(I)}{X^{CAI}(I)} = 0 \qquad (A.20)$$

where $\left. \frac{\partial t(\widetilde{I})}{\partial \widetilde{I}} \right|_{\widetilde{I}=I} = \dot{t}(I)$ and $\left. \frac{\partial X^{CAI}(\widetilde{I})}{\partial \widetilde{I}} \right|_{\widetilde{I}=I} = \dot{X}^{CAI}(I)$. The second-order derivative is:

$$\frac{\partial^2 \left(t(\widetilde{I}) - I \right) \left(\frac{x}{X^{CAI}(\widetilde{I})} \right)^{\beta}}{\partial \widetilde{I}^2} = \qquad (A.21)$$

$$\left(\frac{x}{X^{CAI}(\widetilde{I})} \right)^{\beta} \left[\begin{array}{c} -\beta \frac{\dot{X}^{CAI}(\widetilde{I})}{X^{CAI}(\widetilde{I})} \left(\dot{t}(\widetilde{I}) - \beta \left(t(\widetilde{I}) - I \right) \frac{\dot{X}^{CAI}(\widetilde{I})}{X^{CAI}(\widetilde{I})} \right) + \\ \left(\ddot{t}(\widetilde{I}) - \beta \left(\dot{t}(\widetilde{I}) \frac{\dot{X}^{CAI}(\widetilde{I})}{X^{CAI}(\widetilde{I})} + \left(t(\widetilde{I}) - I \right) \frac{\ddot{X}^{CAI}(\widetilde{I}) X^{CAI}(\widetilde{I}) - \dot{X}^{CAI}(\widetilde{I})^2}{X^{CAI}(\widetilde{I})^2} \right) \right) \end{array} \right]$$

From the second-order condition and keeping in mind Eq. (A.20) we have:

$$\ddot{t}(I) - \beta \left(\dot{t}(I) \frac{\dot{X}^{CAI}(I)}{X^{CAI}(I)} + \left(t(I) - I \right) \frac{\ddot{X}^{CAI}(I) X^{CAI}(I) - \dot{X}^{CAI}(I)^2}{X^{CAI}(I)^2} \right) \leq 0 \qquad (A.22)$$

Last, from the first-order condition we have:

$$\frac{\partial \left(\dot{t}(I) - \beta \left(t(I) - I \right) \frac{\dot{X}^{CAI}(I)}{X^{CAI}(I)} \right)}{\partial I} = 0 \qquad (A.23)$$

$$\rightarrow$$

$$\ddot{t}(I) - \beta \dot{t}(I) \frac{\dot{X}^{CAI}(I)}{X^{CAI}(I)} - \beta \left(t(I) - I \right) \frac{\ddot{X}^{CAI}(I) X^{CAI}(I) - \dot{X}^{CAI}(I)^2}{X^{CAI}(I)^2} = -\beta \frac{\dot{X}^{CAI}(I)}{X^{CAI}(I)}$$

From Ineq. (A.22) and Eq. (A.23) we obtain:

$$\dot{X}^{CAI}(I) \geq 0 \tag{A.24}$$

This is a standard monotonicity constraint.[38] Last, applying the envelope theorem we obtain:

$$\frac{\partial \left(t(I) - I\right)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta}}{\partial I} = -\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} \tag{A.25}$$

Rewriting the problem Using Ineq. (A.24) and Eq. (A.25) we can rewrite the problem in the following way:

$$\max_{\{X^{CAI}(I), w^{CAI}(I)\}} \left\{ \int_{I_1}^{I_2} \left(X^{CAI}(I) - I - w^{CAI}(I)\right)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} dC(I) \right\} \tag{A.14}$$

Subject to:

$$\dot{X}^{CAI}(I) \geq 0 \tag{A.24}$$

$$\frac{\partial \left(t(I) - I\right)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta}}{\partial I} = -\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} \tag{A.25}$$

$$w^{CAI}(I_2) = 0 \tag{A.18}$$

Now, from Eq. (A.25) and Eq. (A.18) we have:

$$\left(t(I) - I\right)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} = \int_{I}^{I_2} \left(\frac{x}{X^{CAI}(\nu)}\right)^{\beta} d\nu \tag{A.26a}$$

$$\rightarrow$$

$$w^{CAI}(I)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} = \int_{I}^{I_2} \left(\frac{x}{X^{CAI}(\nu)}\right)^{\beta} d\nu \tag{A.26b}$$

Using Eq. (A.26), the objective function from problem (A.14) becomes:

$$\int_{I_1}^{I_2} \left[\left(X^{CAI}(I) - I - \frac{C(I)}{c(I)}\right)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta}\right] dC(I) \tag{A.27}$$

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[38] See Chapter 2 from Laffont and Martimort (2002) for more details. One can easily check that the monotonicity holds also when I is a discrete random variable.

Using this expression we can rewrite the problem as:

$$\max_{X^{CAI}(I)} \left\{ \int_{I_1}^{I_2} \left[\left(X^{CAI}(I) - I - \frac{C(I)}{c(I)} \right) \left(\frac{x}{X^{CAI}(I)} \right)^{\beta} \right] dC(I) \right\} \tag{A.28}$$

subject to,

$$\dot{X}^{CAI}(I) \geq 0. \tag{A.24}$$

Momentarily ignoring the monotonicity constraint (A.24), we solve the maximization problem (A.28) pointwise and we obtain

$$X^{CAI}(I) = \frac{\beta}{\beta - 1} \left(I + \frac{C(I)}{c(I)} \right), \text{ for any } I \in [I_1, I_2]. \tag{A.29}$$

From Eq. (A.29) we see that there is no timing distortion when the investment cost I takes its minimum value (since $C(I_1) = 0$), whereas there is an upward distortion for any $I \in (I_1, I_2]$. Of course, the $X^{CAI}(I_1) = X^{CSI}(I_1)$ and $X^{CAI}(I) > X^{CSI}(I), \forall I \in (I_1, I_2]$ are symmetric to the $X^{AI}(I_1) = X^{SI}(I_1)$ and $X_2^{AI}(I_1, I_2) > X_2^{SI}(I_2)$ that we derived in subsection 4.1.3 of the main body of the paper.

The last thing that we need to check is under what conditions our solution respects the monotonicity constraint (A.24). From Eq. (A.29) we have

$$\dot{X}^{CAI}(I) = \frac{\beta}{\beta - 1} \left(1 + \frac{\partial}{\partial I} \left(\frac{C(I)}{c(I)} \right) \right).$$

The monotone hazard rate property $\frac{\partial}{\partial I} \left(\frac{C(I)}{c(I)} \right) \geq 0$ is a sufficient condition for $\dot{X}^{CAI}(I) \geq 0$ to hold. This condition is satisfied by most parametric single-peak densities (see Bagnoli and Bergstrom, 2005).

Last, note that from Eq. (A.26) we can also derive the relevant information rent:

$$w^{CAI}(I) = \int_{I}^{I_2} \left(\frac{X^{CAI}(I)}{X^{CAI}(\nu)} \right)^{\beta} d\nu, \text{ for any } I \in [I_1, I_2] \tag{A.30}$$

In words, the menu of contracts designed by P is built in such a way that for any $I \in [I_1, I_2)$ a positive information rent is to be paid. The information rent is equal to zero only when I takes its maximum value $(w^{CAI}(I_2) = 0)$. As one can notice, this is symmetric to $w_1 > 0$ and $w_2 = 0$

from subsection 4.1.3 of the main body of the paper.

The presence of an upstream supplier

When an upstream supplier is responsible for the provision of the needed input, we can distinguish between two separate cases:

- If there is no information asymmetry downstream (subsection 4.2.2 and 4.2.3 of the main body of the paper), no information rent is paid to the project manager.

Under traceability (subsection 4.2.2), the price of the input is derived as the solution of

$$\max_{p_I} \int_{I_1}^{I_2} (p_I - I) \left(\frac{x}{X^{CM}(p_I)} \right)^{\beta} dC(I), \tag{A.31}$$

where $X^{CM}(p_I) = \frac{\beta}{\beta-1} p_I$, for any $I \in [I_1, I_2]$. Note that $X^{CM}(p_I)$ is identical to $X^{CSI}(I)$ from Eq. (A.13) if instead of I we use p_I.[39] Solving, we obtain

$$p_I = \frac{\beta}{\beta - 1} I, \text{ for any } I \in [I_1, I_2]. \tag{A.32}$$

In this case, the value of the opportunity to invest for the principal P is equal to

$$\pi_P(x; p.) = \int_{I_1}^{I_2} \left(X^{CM}(p_I) - p_I \right) \left(\frac{x}{X^{CM}(p_I)} \right)^{\beta} dC(I), \tag{A.33}$$

whereas the value of the opportunity to invest for the upstream firm A is equal to

$$\Pi_{AM}(x; p.) = \int_{I_1}^{I_2} (p_I - I) \left(\frac{x}{X^{CM}(p_I)} \right)^{\beta} dC(I).[40] \tag{A.34}$$

Under a transparent supply chain (subsection 4.2.3), that is when A observes continuously and verifiably the evolution of the stochastic term, the price of the input is derived as the solution of

$$\max_{\varphi_I} \int_{I_1}^{I_2} (\varphi_I - I) \left(\frac{x}{X^{CSI}(I)} \right)^{\beta} dC(I), \tag{A.35}$$

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[39] The symmetry between $X^{CM}(p_I)$ and $X^{CSI}(I)$ is reminiscent of the symmetry between $X_i^M(p_i)$ and X_i^{SI} (see subsection 4.2.1 of the main body of the paper).

[40] The term $p.$ stands for the continuum of input prices that corresponds to the continuum of investment costs.

subject to,

$$\left(X^{CSI}(I) - \varphi_I\right)\left(\frac{x}{X^{CSI}(I)}\right)^{\beta} \geq \Psi_I, \text{ for any } I \in [I_1, I_2]. \tag{A.36}$$

Similarly to what we have in subsection 4.2.3 of the main body of the paper, the term φ_I stands for the price of the input and the term Ψ_I is the chosen reservation value. Using similar argumentation, we choose $\Psi_I = \left(X^{CM}(p_I) - p_I\right)\left(\frac{x}{X^{CM}(p_I)}\right)^{\beta}$ and solving we obtain:

$$\varphi_I = \frac{\beta}{\beta - 1}I\left(1 - \frac{(\beta - 1)^{\beta - 1}}{\beta^{\beta}}\right), \text{ for any } I \in [I_1, I_2]. \tag{A.37}$$

Finally, the value of the investment opportunity for the two parties is

$$\Phi_P\left(x; \varphi.\right) = \int_{I_1}^{I_2}\left(X^{CAI}(I) - \varphi_I\right)\left(\frac{x}{X^{CAI}(I)}\right)^{\beta} dC(I), \tag{A.38}$$

and

$$\Phi_A\left(x; \varphi.\right) = \int_{I_1}^{I_2}\left(\varphi_I - I\right)\left(\frac{x}{X^{CSI}(I)}\right)^{\beta} dC(I), \tag{A.39}$$

for the principal and for the agent respectively.[41] Last,

- If the supply chain is non-transparent (subsection 4.2.1 of the main body of the paper), we can use Eq. (A.32) as the starting point and reapproach the problem (A.14)-(A.17) deriving an updated menu of a continuum of contracts. Of course, this new menu of contracts will be totally symmetric to the one that we derived in Eqs. (A.29)-(A.30) as the menu of contracts in (19) is totally symmetric to the menu of contracts in (12).

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[41] The term φ. stands for the continuum of input prices that corresponds to the continuum of investment costs.

Chapter 5

Synthesis of paper 3

Keeping in mind the current Common Agricultural Policy, I examine the case of a landholder who is contemplating the opportunity to invest in order to convert a piece of idle land into farmland. It is assumed that, once the land is converted, the farmer can switch between two states: i) s/he can cultivate the land and sell the crop yield in the market whenever active farming is profitable, or ii) can suspend farming operations when active farming is not profitable, keeping however the option to restart active farming as soon as active farming turns profitable again. In the meantime and irrespective of the exact state, the farmer cashes a periodic net income equivalent to the difference between the direct payment that is conditional on cross-compliance and the very cost of cross-compliance. The problem that the landholder faces is twofold. Firstly, s/he must determine the level of capital intensity and, secondly, s/he needs to set the timing of the investment taking into account that profits from agriculture are random and that, consequently, holding the options to suspend and to restart farming gives some operational flexibility.[1]

5.1 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 capital-land ratio (see Capozza and Li, 1994). Assume that, without loss of generality, the targeted

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[1]See for instance Capozza and Li (1994) for a similar treatment.

land surface is normalized to 1 and denote by $\alpha \in (0,1]$ the degree of capital intensity that the landholder may select.[2] The initial sunk investment cost, $I(\alpha)$, associated with the project takes the following functional form:

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

where k_1 and k_2 are dimensional parameters.[3] The term k_1 includes any fixed cost associated with the mere land conversion while the term $k_2\alpha$ considers costs associated with a higher capital-land ratio.

Note that the generic term landholder is used on purpose. S/he can be either a landowner or a lessee. The only difference is that, in the latter case, the term k_1 contains both the cost related to land conversion, as well as the rental price agreed with the landowner.

A periodic direct payment $s \geq 0$ is made to the landholder conditional on having land satisfying the cross-compliance requirements defined by the Common Agricultural Policy (CAP). The periodic compliance cost is assumed to be equal to $m \in [0,s]$.[4] Hence, once accounted for this cost, the net periodic payment accruing to the landholder is $p = s - m \geq 0$.[5]

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**: the land is cultivated and the yield is assumed to be 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, by assumption, constant and equal to $c > 0$ while the unit market price for the commodity produced, x_t, is stochastic and fluctuates according to the following

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[2] Note that, at no loss of generality, the frame is normalized by setting the maximum intensity level equal to 1.

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

[4] I abstract from the consideration of land maintenance that the farmer may, irrespective of the decoupled payment, consider optimal to undertake. In other words, I assume that no free meals are provided to the farmers.

[5] I implicitly assume that if $s < m$ applying for the payment would make no sense as the corresponding net payment would be negative, i.e. $p < 0$.

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.[6]

Summing up, since a rational landholder is expected to maintain her/his land according to the cross-compliance requirements ($p \geq 0$), the periodic total profits for an active farmer are equal to

$$\pi_t^a(x_t, \alpha) + p,$$

where $\pi_t^a(x_t, \alpha) = q(\alpha)(x_t - c)$.

- **passive farming**: the land is not cultivated but may still qualify for direct support. Assuming again that the farmer fulfills all the cross-compliance requirements, the periodic total profits for a passive farmer would then be equal to p.

As one may immediately see when comparing the payoffs associated with the two scenarios, active farming is profitable when $x_t > c$. Otherwise, that is when $x_t \leq c$, the farmer should opt for passive farming. Hence, at each time point the profit flow associated with the investment project 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 active farmer may be viewed as holding the option to suspend farm operations whenever farming is not profitable, i.e. $x_t \leq c$. This option is clearly valuable as a positive payoff is associated with passive farming. Similarly, a passive farmer may be viewed as holding the option to restart farm operations as soon as farming becomes profitable, i.e. $x_t > c$. Also in this case, as the corresponding payoff, once the option is exercised, is positive, a positive value is associated with this option. In the following, I will assume for simplicity that switching from active to passive farming and vice versa is costless.[7] Last, again for the sake of simplicity,

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

[7]With switching costs, conclusions do not change qualitatively. We simply have a larger hysteresis area in the sense that the farmer waits a bit more before switching from active to passive farming and vice versa. A complete analysis of the case where costs are associated with suspending and restarting a project is presented in

I assume that i) once invested, the project runs forever[8] and ii) the capital installed does not "rust" i.e., no maintenance is required.[9] Finally, I assume that the farmer is risk neutral and discounts future payoffs using the interest rate $r > \mu$.[10]

5.2 The farm's operating value

Let $V(x_t; \alpha)$ represent the farm's operating value upon investment. Solving the underlying dynamic programming problem yields:[11]

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

where $\beta_2 < 0$ and $\beta_1 > 1$ are the roots of the characteristic equation $\Lambda(\beta) \equiv (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 value associated with the options to suspend and restart farm operations, respectively. Note that the constants, $\widetilde{A}$ and $\widetilde{B}$, are both non-negative, increasing and concave in the capital intensity α.[12] This makes sense considering that the value associated with both options depends on the productive capacity $q(\alpha)$ associated with the adopted capital intensity.

In Eq. (5) we observe that for $x_t > c$, i.e. under active farming, the operating value of

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Dixit and Pindyck (1994, chap. 7).

[8] Note that this assumption does not affect at all the quality of our results.

[9] The case where costs are associated with the maintainance of a project is presented in Dixit and Pindyck (1994, chap. 7).

[10] This restriction is needed in order to ensure convergence. See Dixit and Pindyck (1994, pp. 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.

[11] See subsection 5.6.1 in Appendix A.

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

the farm is given by the sum of the value of the option to switch to passive farming (that is, to suspend farm operations), $\widetilde{A}x_t^{\beta_2}$, 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 direct 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 if profits from active farming decrease. On the other branch of the value function, that is for $x_t \leq c$, i.e. under passive farming, the value of the farm is given by the sum of the value of the option to switch from passive to active farming (that is to restart farm operations), $\widetilde{B}x_t^{\beta_1}$, plus the present value of the flow of net direct 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 are higher.

5.3   The optimal capital intensity

In this subsection I determine the optimal capital intensity level that the landholder should adopt when setting up the farm. This level 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 and vice versa. As one can see, these two aspects are clearly interrelated as the acquired flexibility allows hedging against the volatility that, via the market price, may affect farming profits.

Production 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 increasing in the capital intensity level as well. In the following, I determine the optimal capital intensity only for the scenario where investment in land development occurs when active farming is profitable, i.e., for $x_t > c$.[13]

When $x_t > c$, the farmland is immediately used for production of agricultural commodities. The optimal level of capital intensity, $\overline{\alpha}$, should be such that the expected net present value

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[13]A scenario where the landholder contemplates investment in land development when active farming is not profitable, i.e. $x_t \leq c$, seems less realistic. However, the relative analysis is provided in Appendix B (subsection 5.7).

associated with the current and future farm operations is maximized, i.e.:

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

where,

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

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

Proposition 16 *Provided that* $\Psi = k_2 - Bc^{\beta_1} > 0$, *the optimal intensity level when investing at* $x_t > c$ *is*

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

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

Proof. See subsection 5.6.2 in Appendix A. ■

One can show that the optimal capital intensity $\overline{\alpha}(x_t)$ is increasing in x_t in the interval $c < x_t < \overline{x}$. 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, i.e., $\frac{x_t}{r-\mu} - \frac{c}{r}$, the landholder would prefer to invest in a higher $\overline{\alpha}(x_t)$ so that s/he can produce more.[14] Second, $\overline{\alpha}(x_t)$ is increasing in the value, per unit of production, of the option to switch to passive farming, i.e., $Ax_t^{\beta_2}$. 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, $Ax_t^{\beta_2}$, is decreasing in x_t as, the higher the x_t, the less likely is the future switching to passive farming.

It is worth discussing the nature of the condition set on Ψ in Proposition 16.[15] The term Ψ represents the net marginal cost of capital intensity $\overline{\alpha} = 1$. In particular, it is given by the difference between the marginal investment cost, k_2, and the marginal value of the option to

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[14]Note that the volume of produced commodity, $q(\alpha)$, is increasing in capital intensity as well.

[15]In Appendix A (subsection 5.6.2) I also consider the scenario where $\Psi = k_2 - Bc^{\beta_1} \leq 0$ and I show that, when this is the 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 $x_t \geq \overline{x}$.

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, k_2, associated with investing in the highest feasible capital intensity, adopting a lower capital intensity, i.e. $\overline{\alpha} < 1$, is optimal. The capital intensity will then increase with x_t and be equal to 1 only when a commodity price sufficiently high is considered i.e., $x_t \geq \overline{x}$.

Last, plugging Eq. (7) in Eq. (6.1) yields:

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

5.4 Value and timing of the investment

Let's now determine the value of the opportunity to invest in the land development project, as well as the optimal investment timing.

Denote by $\widehat{x}$ the price threshold triggering investment. Assuming that the initial market price x is sufficiently small so that investing at time zero is not preferable (i.e. $x < \widehat{x}$), the value of the opportunity 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.[16]

Eq. (9) can be rearranged as follows:[17]

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

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[16] Of course if $x \geq \widehat{x}$ our problem reduces to a standard net present value maximization since the potential investor decides to exercise the option to invest as soon as possible.

[17] 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 get:[18]

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

Let's now consider the two investment scenarios proposed in subsection 5.3, 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 the commodity price is higher than $\overline{x}$. In the Appendix, I show that:

Proposition 17 *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:*

$$x^* + \frac{\beta_1 - \beta_2}{\beta_1 - 1} A x^{*\beta_2}(r - \mu) - x^n = 0, \tag{11}$$

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

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

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 subsection 5.6.3 in Appendix A. ∎

Proposition 17 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 or higher 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. Note that the term x^n in Eq. (11) is equivalent to the investment threshold for the case where the options to switch between active

and passive farming are not present, i.e. $A = 0$. As one can see $x^* < x^n$. This implies that the presence of these options, by providing a hedge against profit volatility, induces, in expected terms, an earlier investment. In contrast, without this hedge, profit volatility would induce a delayed investment. Investment should in fact occur at a price level at which the likelihood of a fall in the profit associated with active farming is sufficiently low. Finally, 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 lost 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 net direct payments and that the farmer is eager to cash the amount $\frac{p}{r} - (k_1 + k_2) \geq 0$.

Case $\overline{\alpha} < 1$ - Let's 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 is shown that:

Proposition 18 *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 opportunity to invest in the project is:

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

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 subsection 5.6.3 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 above, also in this case, as the investment cost is fully covered, the farmer rushes as s/he is eager to cash the net gain $\frac{p}{r} - (k_1 + k_2\overline{\alpha}(c)) \geq 0$.

5.5   The effect of the policy instrument

In this subsection, I study the impact that different levels of the net direct payment $p = s - m$ may have on the timing of the investment, the adopted capital intensity and the value of the investment opportunity.

Let's start by considering the limit case where $p = 0$. This holds either when $s = m = 0$ or when $s = m > 0$. There is an important distinction to be made between these two cases. Under $s = m = 0$, we are basically dealing with a CAP that is not setting any cross-compliance requirements ($m = 0$) and, consequently, is not paying any decoupled payments ($s = 0$). In this case, the landholder/potential investor that is contemplating entering the farming business, knows that s/he can count on positive farming profits only when the prices of the agricultural commodities are high enough. On the contrary, s/he anticipates that during the periods when the prices of the agricultural commodities are too low, s/he will have no cash flows whatsoever. During these periods s/he will just be, voluntarily, undertaking the minimum level of maintenance that will allow her/him to re-enter the farming business once this becomes a profitable alternative. This however, is just part of a farmer's routine and should not be attributed to the CAP.

The case under which $s = m > 0$ seems more interesting. According to the current CAP, today's generation of farmers is supposed to combine the roles of farmer and steward of the countryside and, consequently, a positive cross-compliance cost is to be expected.[19]   Under

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

$m > 0$, the level of net decoupled payments is equal to zero ($p = 0$) only if the direct payment (s) is chosen to be exactly equal to the maintenance cost (m). This, of course, is technically demanding because of the relevant information asymmetries between the policy maker (CAP) and the policy taker (EU farmers). However, it clearly shows that the decoupled payments are financially neutral when optimally calibrated. In other words, passive farming support could ideally guarantee a minimum of maintenance of the EU farmland without any unnecessary money transfers. This argument proves that, if there are any flaws in passive farming support, they lie in the implementation rather than the nature of the policy.

Let's now focus on the case where positive policy rents ($p > 0$) may be cashed. Assuming that the policy is not purposefully providing unconditional money transfers, a positive net decoupled payment implies a payment s that is not correctly calibrated to be in line with the actual cost of cross-compliance m. This may very well be the case in reality considering, as underlined above, the presence of asymmetric information related to the actual cost of compliance.

Note first that a change in $p(> 0)$, even if not affecting the threshold $\overline{x}$ delimiting the choice of capital intensity $\overline{\alpha} = 1$ rather than capital intensity $\overline{\alpha} < 1$, affects the magnitude of the term Δ. In particular, a higher p, by increasing Δ, makes higher the level of profitability required in order to consider only land development projects with capital intensity $\overline{\alpha} = 1$. Additionally, a change in p is also affecting the necessary conditions $\frac{p}{r} < k_1 + k_2$ and $\frac{p}{r} < k_1 + k_2\overline{\alpha}(c)$ from Proposition 17 and Proposition 18 respectively. Nevertheless, and unless the policy is terribly miscalibrated, a change in p is expected to violate neither the first nor the second.

As far as the two investment thresholds are concerned, in subsection 5.6.3 of Appendix A it is shown that:

Proposition 19 *A landholder 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 direct payment p increases since, $\frac{\partial x^*}{\partial p} < 0$ and $\frac{\partial x^{**}}{\partial p} < 0$.*

As one can see from Proposition 19, compensating passive farmers fosters, rather than deters,

land development, at least in terms of timing. The intuition behind this result is as follows. Instead of seeing p as a cash flow that accrues over time, one can interpret the present value of the flow of the net direct payments, $\frac{p}{r}$, as an investment subsidy that is basically decreasing the sunk cost of the investment. Now, using some standard option valuation arguments, we know that a firm stands to gain more by exercising, rather than holding, an investment option with a low strike price. In this framework, the firm is the landholder, the investment option is the land development project and the strike price is exactly the sunk investment cost. Of course, a positive periodic payment p decreases this sunk investment cost by $\frac{p}{r}$ favoring the exercise of the investment option which, in this case, is the entrance of the landholder in the farming business.

Further, focusing on the scenario where the price level is such that it is optimal investing in a project with capital intensity $\overline{\alpha} < 1$, one can show that:

Proposition 20 *When investing in the region $(c, \overline{x})$, the chosen partial capital intensity is decreasing in the net direct payment p.*

As discussed in subsection 5.3, $\overline{\alpha}$ is increasing in x_t within the interval $(c, \overline{x})$. In other words, when investing in a project characterized by partial capital intensity, the potential acceleration of the investment would imply a project of smaller magnitude. Hence, as by Proposition 19 we have $\partial x^{**}/\partial p < 0$, then $\partial \overline{\alpha}(x^{**})/\partial p < 0$. This result implies that positive net direct payments induce not only earlier investment but, at the same time, investment in land development projects with lower capital intensity. Note however that since the productive capacity $(q(\alpha))$ is increasing in capital intensity (α), individual farms produce less output and, by doing so, the potential excess output (and the need to manage it) is more limited. This is of course in line with the CAP's intentions, as described in the Introduction, that eventually lead to the decoupling of payments from production.

Last, the comparative statics concerning the impact on the value of the opportunity to invest in a land development project reveal that:

Proposition 21 *The value of the opportunity to invest in the development of idle land is, irrespective of the capital intensity chosen, favored by an increase in the net direct payment p.*

Keeping in mind that x^* and x^{**} satisfy Eq. (10), we can use the envelope theorem and derive

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

where $x^i \in \{x^*, x^{**}\}$.

In words, an increase in the net decoupled payment p as a source of income that is not exposed to the market price volatility, increases the value of the opportunity to invest in a land development project. The underlying mechanism is as follows. An increase in p is, as outlined above, reflected in a lower sunk investment cost and, through that, in a higher NPV.[20] However, the effect of p on F is corrected by the discount factor $\left(\frac{x}{x^i}\right)^{\beta_1} < 1$. In words, the landholder will reap the benefits of a higher p only as soon as s/he decides to enter the farming business and not before that. Note that unless we explicitly take into consideration the option of the potential investor to postpone her/his investment decision for some future time point, the discount factor $\left(\frac{x}{x^i}\right)^{\beta_1}$ will not appear in the calculations. This will be the case if instead of the real options approach we use the standard NPV rule considering the landholder's investment decision a "now or never" problem.

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[20] This is obvious from Eq. (8).

5.6 Appendix A

5.6.1 The farm's operating value

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

$$\Gamma V^H(x_t; \alpha) = -[q(\alpha)(x_t - c) + p] \quad \text{for } x_t > c$$
$$\Gamma V^L(x_t; \alpha) = -p \qquad\qquad\qquad \text{for } x_t \leq c$$

(A.1.1-A.1.2)

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

Taking into account the boundary conditions

$$\lim_{x_t \to \infty} \{V^H(x_t; \alpha) - [q(\alpha)(\frac{x_t}{r-\mu} - \frac{c}{r}) + \frac{p}{r}]\} = 0 \quad \text{for } x_t > c$$
$$\lim_{x_t \to 0} \{V^L(x_t; \alpha) - \frac{p}{r}\} = 0 \qquad\qquad\qquad \text{for } x_t \leq c$$
,

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

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

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

$$\widetilde{A} c^{\beta_2} + \frac{\alpha^\gamma}{\gamma}(\frac{c}{r-\mu} - \frac{c}{r}) + \frac{p}{r} = \widetilde{B} c^{\beta_1} + \frac{p}{r},$$
$$\widetilde{A}\beta_2 c^{\beta_2-1} + \frac{\alpha^\gamma}{\gamma}\frac{1}{r-\mu} = \widetilde{B}\beta_1 c^{\beta_1-1},$$

(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:

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

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

5.6.2 Optimal capital intensity

Suppose that $x_t > c$. The optimal capital intensity, should then be given by the solution of

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

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

The first-order condition for Problem (A.2.1) yields,[21]

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

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:

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

Note that:

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

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

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

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

---

[21] Note that the second-order condition for Problem (A.2.1) is always satisfied.

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

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

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

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

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

5.6.3   Investing in land development

Once the optimal intensity level is set, one 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 $\Psi > 0 \rightarrow \overline{x} > c$,

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

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

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

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

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

where $\tau = \inf\{t \geq 0 \mid x_t = \widehat{x}\}$ is the (random) first time that the process x_t hits the barrier $\widehat{x}$ 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[22]

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

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 $\widehat{x}$:

$$\left.\frac{\partial^2[(x/\widehat{x})^{\beta_1} NPV^a(\widehat{x})]}{\partial x^2}\right|_{x=\widehat{x}} > \left.\frac{\partial^2 NPV^a(x)}{\partial x^2}\right|_{x=\widehat{x}}$$

$$\rightarrow$$

$$\frac{\partial NPV^a(\widehat{x})}{\partial\widehat{x}} > \frac{\widehat{x}}{\beta_1 - 1}\cdot\left.\frac{\partial^2 NPV^a(x)}{\partial x^2}\right|_{x=\widehat{x}} \tag{A.3.8}$$

Investment under scenario A

Case $\overline{\alpha} = 1$ - Let's 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

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

---

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

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

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

$$\rightarrow$$

$$O'(x^*) > \frac{x^*}{\beta_1 - 1} O''(x^*)$$

$$\rightarrow$$

$$\Phi'(x^*) = 1 + \beta_2 \frac{\beta_1 - \beta_2}{\beta_1 - 1} Ax^{*\beta_2 - 1}(r - \mu) > 0. \qquad (A.3.8a)$$

This implies that if a solution x^* exists, then it is unique since $\Phi'(x^*) > 0$.[23] Hence, by the convexity of $\Phi(x)$, a necessary condition for the existence of a solution x^* to the investment timing problem is:[24]

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

Note that otherwise, i.e. for $\Phi(c) \geq 0$, the potential investor should invest immediately. This should, not surprisingly, 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

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

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

CASE $\overline{\alpha} < 1$ - Let's consider the interval $(c, \overline{x})$ where, as shown in Eq. (A.3.2), the land

---

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

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

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

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

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

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

$$\rightarrow$$

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

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

Let's now identify the conditions under which $\overline{\alpha} < 1$, that is, $c < x^{**} < \overline{x}$. First, 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:

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

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, not surprisingly, 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 condition (A.3.13) holds, one must check that $x^{**} < \overline{x}$. This leads to the following necessary condition:

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

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

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

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

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

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

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.

5.7 Appendix B

Here I provide 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. In this region a landholder, once invested in order to develop her/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, $\widetilde{B}x_t^{\beta_1}$.

5.7.1 Optimal capital intensity

Suppose that $x_t \leq c$. The optimal capital intensity level, $\underline{\alpha}$, should then be given by the solution of the following problem:

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

The first-order condition for Problem (B.1.1) yields,[25]

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

Thanks to the positivity of x_t,[26] $\underline{\alpha} > 0$ for any $x_t \leq c$. One must however secure that $\underline{\alpha} \leq 1$, which 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

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

---

[25] Note that the second-order condition for Problem (B.1.1) is always satisfied.
[26] Recall that x_t is log-normally distributed. See e.g. Chapter 3 in Dixit and Pindyck (1994).

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

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

5.7.2 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 $\Psi \leq 0$,

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

Scenario D when $\Psi > 0$,

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

Investing under scenario C

CASE $\underline{\alpha} = 1$ - Let's 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 opportunity to invest in the land development project is given by the following function:

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

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's 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 opportunity to invest in the land development project is given by the following function:

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

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 $\frac{p}{r}$.

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.

Chapter 6

Discussion

In the first paper of the thesis, I consider the investment problem of a firm who contemplates entering an uncertain new market under two conditions. On one hand, an upstream firm with market power is responsible for the provision of a discrete input that is a prerequisite for the completion of the project and, on the other, an investment partner undertakes a share of the sunk investment cost claiming a share of the project in return.

Following the real options approach, I build a stochastic dynamic programming model in order to study the interaction among the three agents and I find the following. Firstly, I verify that the optimal investment timing and, consequently, the maximum value of the opportunity to invest are reached when the potential investor acts autonomously (vertically integrated case). On the contrary, in a non-cooperative game-theoretic setting, the presence of any additional agent involved in the completion of the project causes the delay of the investment which, as is shown, also implies a smaller value of the investment opportunity. However, despite the fact that the presence of any additional agent affects the timing and the value of the opportunity to invest the same way, the magnitude of the effect itself is not the same. Actually, a comparison between external funding and input outsourcing denotes that the former is always less distorting than the latter.

Secondly, I focus on the three-agent case and I find that the synchronous involvement of an upstream supplier and an investment partner in the project, constitutes the worst-case scenario since we basically deal with a combination of the corresponding distorting effects. In this case, the value of the opportunity to invest reaches its minimum whereas the investment threshold

reaches its maximum.

In the last part of the paper, I present the conditions under which the original non-cooperative setting is replaced by a Nash bargaining solution and I show that, even in that case, the optimal investment threshold is unattainable. Actually, the analysis shows that if the upstream firm is absent (i.e. the input is produced in-house) the project realizes inefficiently early whereas, if the upstream firm is present (i.e. the input is outsourced) it realizes inefficiently late. This is, again, evidence of the importance of the nature of the sunk investment cost when modelling investment projects characterized by uncertainty and irreversibility, especially if instead of a single potential investor, an investment partner is also involved in their completion.

The results of the first paper of the thesis underline the importance of the nature (endogenous vs. exogenous) of the sunk investment cost when examining investment projects undertaken not unilaterally but in a supply chain framework. Building on this finding, in the second paper of the thesis I examine how the presence of an upstream firm with market power is affecting an investment undertaken in a decentralized setting.

This paper contributes to a growing research area that integrates the theory of irreversible investment under uncertainty and the literature on asymmetric information and agency conflicts. According to this body of papers, when an investment project that is characterized by uncertainty and irreversibility is undertaken in a decentralized setting, the information asymmetry between the project originator and the project manager will lead to an agency conflict. This results in the postponement of the investment and in the reduction of the value of the investment opportunity.

My primary interest in this paper is to examine how the analysis changes if the investment is conditional on the provision of an indispensable input that is exclusively produced by an input supplier. Using a stochastic dynamic programming model, I identify the cost, the timing and the value of the opportunity to undertake an investment that i) is characterized by uncertainty and irreversibility, ii) its completion depends on the provision of a discrete input that is exclusively produced by an upstream firm with market power and iii) is undertaken in a decentralized setting. The results suggest that the presence of the external supplier always makes the investment more expensive which, *ceteris paribus*, implies the suboptimal postpone-

ment of its completion as well as a reduced value of the opportunity to invest for the principal, the agent and the industry as a whole. However, the effect of the upstream firm's presence depends heavily on her/his information endowment. Under traceability in the supply chain, i.e., when the structure of the supply chain is common knowledge, the presence of the input supplier restores information symmetry between the delegator and the delegate. The investment might be more expensive, but the presence of the foreign firm impedes the development of the agency conflict. Similarly, if the supply chain is transparent, that is, if the structure of the supply chain is common knowledge and the upstream firm is in the position to verifiably observe the realizations of the project's value over time then, information symmetry, optimal investment timing and a first-best aggregate value of the opportunity to invest are guaranteed. Nevertheless, a transparent supply chain does not coincide with the first best case since the aggregate value of the investment opportunity is shared between the project originator and the input supplier.

This work has some limitations that can be addressed in future research. Firstly, in this paper it is assumed that traceability and transparency do not require any kind of infrastructure along the supply chain. However, in reality, information sharing is on its own a demanding and expensive practice. The implementation of a cross-organizational information system is costly, time-consuming and risky. Partners may not agree on the exact specifications of the system or on how to split the relevant investment costs.[1] Secondly, distributional channel phenomena like the bullwhip effect[2] suggest that information sharing is always subject to a certain level of "noise". This in turn implies that a transparent supply chain is, by construction, unattainable. It could be interesting to reapproach the present analysis taking explicitly into consideration noise in the information channels along the supply chain.

Last, in the third paper of the thesis, I examine the effect of passive farming support on the timing and value of land development projects. 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 agri-

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[1] For example, personal computer manufacturers often complain about not being able to get accurate sell-through data from their resellers since, for instance, some resellers share data on a monthly whereas some others on a weekly basis (Lee and Whang, 1998).

[2] The bullwhip effect refers to the case where a small shift in the consumer demand causes a distortion between sales and orders which is increasing as we move along the supply chain. See e.g. Lee et al. (2004).

cultural 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.[3] In accordance with these objectives, and thanks to the introduction of direct payments back 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 direct payments are regarded as non-trade-distorting.[4]

A farmer, when passively managing her/his farmland, is basically maintaining the land in good agricultural and environmental condition according to the SMR and GAEC standards in order to be entitled to CAP support, without however producing any agricultural commodities. Several parties have strongly criticized the support paid to passive farmers. According to one of the main arguments used by the adversaries of the policy, passive farming may hinder rural development. I have focused on this specific issue and studied how decisions concerning investment in land development projects are affected by the current policy frame. More precisely, I analyze the case of a landholder/potential investor who is contemplating investing in a piece of idle land in order to transform it into farmland. The potential investor needs to decide both the capital intensity and the timing of the investment given that, once s/he enters the farming business, s/he will have the opportunity to actively farm the land when the profit margin is positive, and passively farm the land otherwise.

Three original findings are presented. First, it is shown that, irrespective of the level of chosen capital intensity, the support to passive farming is encouraging the acceleration (in expected terms) of the completion of the investment project. In other words, by implicitly providing hedging against volatile farming profits, the introduction of decoupled payments will actually foster investment initiatives and land development. Secondly, I show that the policy will also incentivize landholders to 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 according to the cross-compliance requirements (under both active and

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

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

passive farming) with a lower impact in terms of capacity added, thus limiting the potential oversupply of agricultural products. In other words, direct payments support land development in a responsible way, without risking the reappearance of permanent surplus output as in the 1980s.[5] Thirdly, I find that the positive net direct payments increase, through the NPV, the value of the opportunity to invest. This of course is to be expected since a higher decoupled payment naturally implies a higher profit flow that is unaffected by market volatilities which is then mirrored in the higher aggregate project value.

One limitation of this work is that it is concentrated on the effect that support to passive farmers has on investment projects. However, the notion of land development is broader since it incorporates also the corresponding environmental impact as well as changes in social and animal welfare attributed to the implementation of the policy. The analysis of passive farming support as a measure that affects land development would benefit from further research in that direction.

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[5] http://ec.europa.eu/agriculture/cap-history/index_en.htm

Chapter 7

Conclusion

The essays comprising this thesis are contributing to the area of investment under uncertainty and irreversibility. The modern investment theory, suggests that the opportunity to make an investment decision that is risky and, at least partly, irreversible is analogous to an option on a real asset in the sense that the potential investor needs to factor in that, at the time of the investment, the value of the project should fully cover not only the investment cost but the opportunity cost of reconsidering the investment option in the future as well. While the frequently used net present value rule does not consider this opportunity cost, the real options approach shows that it is both substantial and highly sensitive to uncertainty and that, consequently, it needs to be explicitly taken into consideration.

With the real options approach as my starting point, I focus primarily on investments undertaken in a supply-chain setting (first and second paper of the thesis) and, secondarily, on projects aiming at land development (third chapter of the thesis). More precisely, I have formulated and examined the following research questions:

1. How vertical relationships and external funding affect investment efficiency and timing?

2. How vertical relationships and agency conflicts affect investment efficiency and timing?

3. How are the decoupled from production payments of the current CAP affecting the timing, the capital intensity and the value of investment projects undertaken by potential farmers in the EU?

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The common point among the three papers is a potential investor who contemplates undertaking an investment project characterized by uncertainty and irreversibility when the investment decision depends on factors beyond the potential investor's control. For instance in the first paper, the investment opportunity depends on the contribution of an investment partner whereas, at the same time, a prerequisite for the completion of the project is the procurement of an indispensable input from an upstream firm with market power. The second paper of the thesis approaches a similar case where, instead of an investment partnership, I consider a decentralized setting where the project originator is delegating the investment decision and the procurement of the needed input to a project manager who enjoys an informational advantage. Last, in the third paper of thesis, I examine how the policy and legislation governing a certain industry can affect the behavior of a potential investor.

What differentiates the three papers is the presented industry setting. The results of the first two papers are readily applicable to any supply chain framework that satisfies the relevant criteria. On the contrary, the third paper is examining the debate that is currently taking place in EU circles and has to do with the phenomenon of passive farming and its effect on land development. This variety of applications is evidence of the appropriateness of the real options approach to describe a number of phenomena providing at the same time insight both to policy makers and to potential investors.

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