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Abstract

From the beginning of the world, the agricultural sector has always played an essential role into our society, and contracts have massively been used by policy-makers for the implementation of (agri)environmental policies, especially when such policies concern the use and development of privately owned land, and information asymmetries between policy-makers and individuals exist. Even though the majority of (agri)environmental contracts are designed assuming individual's constant time-preferences, recent evidence from many behavioural studies on individual's intertemporal choices advocate declining time-preferences due to behavioural biases, which can be explained by hyperbolic discounting.

Therefore, in this dissertation we present a theoretical analysis of the impact of an intertemporal time-inconsistent individual into a contract for the provision of an (agri)environmental target, under both perfect and imperfect information. Our key finding suggests that the more inconsistent time-preferences an individual has, the higher the impact of them into contract design is, unless a commitment mechanism (perfect information) or higher detection probability of cheaters (imperfect information) is feasible. We also found that the duration of the contract has a significant impact into it, only in cases where individuals know precisely (i.e. they have sophisticated beliefs) how inconsistent their time-preferences are.

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β	The degree of deviation from an exponential discounting
η	The elasticity of a policy function f
ϕ	Iindividual-farmer's opportunity cost
ψ	Cost function associated with the conservation of e hectares of the land
θ	The penalty that an individual needs to pay for getting caught cheating on the contract
ε_j	The land that a hyperbolic discounting individual-farmer believes that she conserves in the future
d	The penalty that an individual needs to pay for any deviation from her inintial plan
$DPV\Pi_t$	The discounted present value of an individual-farmer profits generated by the contract at period t
e	The land that an individual-farmer chooses to conserve
e^*	The targeted amount of the land that needs to be conserved
f	A policy function that motivates an individual-farmer to comply with the contract
I	Iindividual-farmer's income contract generates
$MRS_{0,1}$	Marginal rate of subsitution between immediate costs and future benefits
p	Per-hectare subsidy

q	Detection probability/policy function
$self$-t	An individual-farmer at period t
T	The total duration of the contract
DI	The impact of dynamic inconsistencies for the policy-maker
IR	Incentive-rationality constraint
j	The type of an intertemporal time-inconsistent individual-farmer
y	Land Use Contract

Chapter 1

Introduction

From the beginning of the world, the agricultural sector has always played an essential role into our society. This has been the case, even when right after the industrialization many countries have favoured the development of the industrial and of the financial sector in order to boost their economies.

The main reason is that agriculture was –and still is- the primary source of covering population's both direct (e.g. plants, crops, etc) and indirect (e.g. meat) needs for food. In addition, agricultural products (e.g woods, mineral, crops, etc) are the basic inputs for many other sectors (e.g. industrial, pharmaceutical, etc) of the economy. Thus, the production (or extraction) of natural capital through agriculture has been seen as an alternative source of income for many households. Nowadays, increasing population and technological achievements have changed consumption patterns. In addition, many earth scientists (e.g. Owen et al., 2010; Shafiee and Topal, 2009) have alerted that fossil fuel reserves are going to reach its limits during the next few decades. Thus, agriculture attracted attention by both academia and policy-makers as an alternative source of covering this excess demand for energy (e.g. biomass).

One interesting aspect of agri-environmental sector is its circular interaction with the environment, and more precisely with climate. Agriculture affects environment through emissions of "greenhouse" gases (GHGs), namely carbon dioxide, methane and nitrous oxide. Additionally, in many circumstances agricultural activities require an extensive use of the land, which may in turn lead to deforestation, desertification, and soil and water degradation. Finally yet importantly, the exploitation of land minerals through extensive agriculture may decrease the ability of the Earth to absorb/reflect solar radiation. These effects due to anthropocentric activities lead to reform of geological landscape, which it lacks the ability to maintain the temperature of the atmosphere in sustainable levels, decreasing in that way the stability and resilience of the climate itself.

On the other hand, there is a positive externality of climate into agriculture. According to Challinor et al. (2009), changes of temperature, variations in the concentration of carbon dioxide in the atmosphere, precipitation and its interactions can affect agricultural production and reproduction properties of many crops. Additionally, unbalanced weather conditions can also affect the quality and quantity of agri-environmental goods and services. The following figures illustrate the impact of (agri)environmental sector into the environment and vice versa. The former (Figure 1.1) shows the contribution of agriculture into GHGs emissions is U.S. from 1990 to 2013, as it reported by EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks, where crop cultivation and livestock take the grands for the highest contribution in GHGs emissions, but land use and forestry has the highest percentage change (104.5%) at that period. In the latter (Figure 1.2), the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) presents the impact of air temperature into the production and reproduction of corn and soybean, respectively, based on the work of Karl and Melillo (2009). During the last few decades, both academia and policy-makers started to reconsider that by stabilizing this circular relationship between agriculture and environment, economies could maintain into a sustainable growth path without any further environmental degradation. As a consequence, targets such as adoption of organic farming techniques, conservation of a land in order to improve its quality, adoption of windmills and solar panels for electricity generation and many more, became essential parts into political agendas.

One "particularity" of such targets is that they concern the use and development of a land which is privately owned, and therefore the policy-maker has not direct control over the provision of the target. As a consequence, the policy-maker needs to design agreements -which in legal terms are expressed by contracts- by which he delegates the provision of the target to landowners (i.e. individuals) under a compensation scheme. Official Community Plan (OCP), Forest Land Use Agreement (FLAg), International Tropical Timber Agreement (ITTA) are examples of agreements that concern the use and the development of a land which is privately owned. Another important characteristic of (agri)environmental targets is that their benefits for the landowners come much latter than the costs associated with their provision. Recent behavioural studies have shown that this type of uncertainty may drive individuals to evaluate the future at a

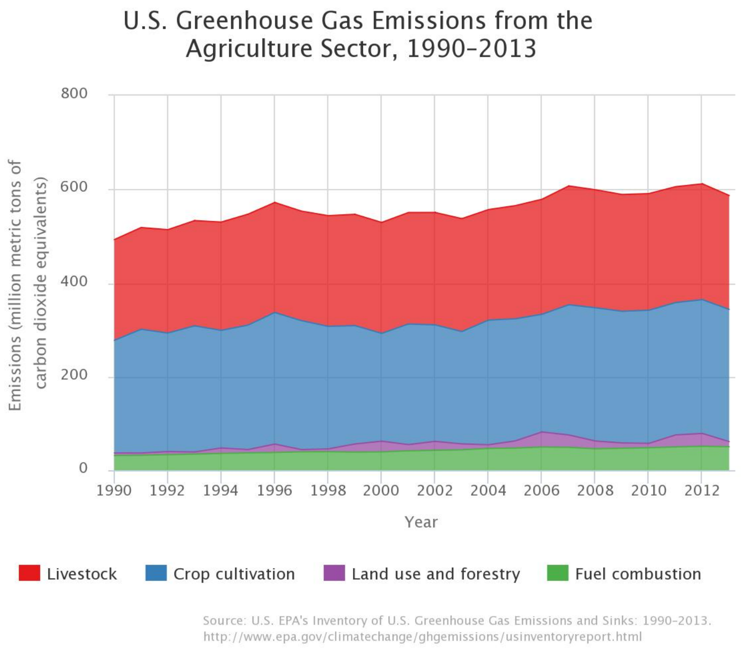

Figure 1.1: U.S. GHGs emissions from agricultural activities from 1990 to 2013

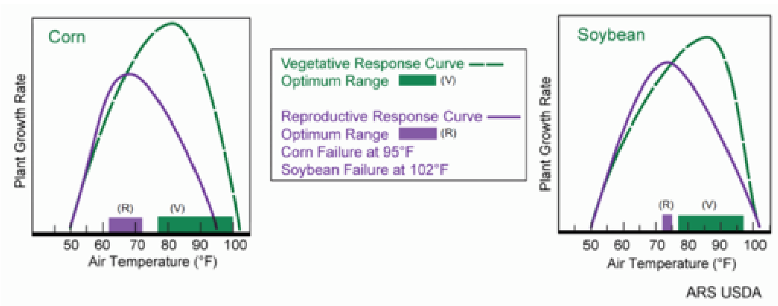

Figure 1.2: The impact of air temperature into the production and reproduction of corn and soybean, respectively

declining rate instead of a constant rate, which in turn it makes their time-preferences regarding the fulfilment of the contract inconsistent. In addition, policy-makers usually have limited information on whether participants actually complies with the contract, providing the necessary incentives to individuals to behave opportunistically. In other words, dynamic inconsistencies (due to behavioural failures) and *moral hazard* (due to information asymmetries on contract compliance) arise incentives to individuals to breach on the contract.

1.1 The purpose

As we have stated above, there is no solely (agri)environmental target that concerns the use and development of a private owned land. In this dissertation, we consider a hypothetical situation in which the Agricultural Agency wants to improve the quality of the land by decreasing the dependency on chemical fertilizers. In order to do so, the policy-maker offers a Land Use Contract (LUC) to individual-farmers in which he/she specifies how much of the agricultural activities of an individual-farmer must produced by organic farming practices (e.g. by the use of organic fertilizers), the duration of the contract and the compensation scheme. When the policy-maker designs such agreement, he/she is calling to solve two types of problems: From one side, he/she needs to provide these incentives in order to overcome dynamic inconsistencies of an individual decisions, and from the other side he/she needs to offer an appropriate incentive scheme that enforce compliance towards the contract.

Even though extensive theoretical research has been done in the elimination of the impact of *moral hazard* into (agri)environmental contracts, the impact of behavioural failures into such contracts has been limited analysed. In addition, even in cases where dynamic inconsistencies take into consideration, the effort that an individual-farmer provides is treated a binary variable (i.e. taking only two values, usually zero and one), ignoring with that way the possibility that participants provide "something" in between compliance and to "do nothing".

Therefore, the purpose of this dissertation is to present a theoretical analysis of a contract for the provision of an (agri)environmental target in the presence of intertemporal time-inconsistent individual-farmers, under both perfect and imperfect information, when effort provided by them takes continuous values in a predetermine interval. More precisely, in cases where the target is the adaptation to organic farming practices, our purpose is to provide a reliable answer to "how agricultural contracts for the adaptation to organic farming practices should be designed when dynamic inconsistencies on participant decisions and moral hazard exists?"

1.2 Method

Our theoretical framework belongs to the class of "Principal-Agent Model", where the policy-maker is "the principal" and an individual-farmer is "the agent". In order to achieve his target, the *principal* offers a performance-based contract to the *agent,* which its costs and benefits -for the *agent*- occur in different periods. Therefore, we use the term "time-preferences" to refer to *agent's* intretemporal preferences between immediate costs and future benefits, and also we use the terms "exponential discounting" and "hyperbolic discounting" to refer to the consistency and inconsistency of *agent's* time-preference, respectively. In other words, an exponential discounting *agent* is an individual-farmer whose decisions are time-consistent. Thus, the impact of dynamic inconsistencies will be introduced into this frame by distinguishing between the standard case of exponential discounting individual-farmers and the case of hyperbolic discounting individual-farmers.

Various functional forms have been used to capture the impact of dynamic inconsistencies (Ainslie, 1975; Herrnstein, 1981; Loewenstein and Prelec, 1991; Mazur, 1987) into models. Here, we assume that time takes discrete values and therefore we implement a (β, δ) model, in which the discount function of an intertemporal time-inconsistent individual-farmer takes the quasi-hyperbolic form as it firstly proposed by Phelps and Pollak (1968). Furthermore, we assume that the principal uses a commitment mechanism to overcome behavioural failures (and hence dynamic inconsistencies), and monitoring to overcome problems of *moral hazard.*

Once the *principal* set the target, the problem for him is to offer these incentives under which an *agent* at each point of time will not has an incentive to breach on the contract. We can determine these incentives by treating an *agent* as a sequence of independent selves who at every period of time act based on her best self-interest. Thus, we simply refer to an *agent* at period t as $self$-t, and the *incentive-compatible* contract is derived by solving the intertemporal game between the *principal* and *self-t* backwards.

1.3 Structure

The structure of this dissertation is as follows: In chapter 2, we present a brief overview of the literature addressing the moral hazard in the context of contract design. In addition, we will provide a discussion on the current debate around the role of discounting in economic decision-making. In chapter 3, we will present our theoretical framework under perfect information, when contracts are of one and two periods, respectively, and we will specify the incentives that makes a contract *incentive-compatible* for an exponential discounting individual-farmer and a hyperbolic discounting individual-farmer, respectively. In chapter 4, we analyse how incentives between these two types of individuals differ when moral hazard exists. In chapter 5, we discuss our key findings, and we also highlights potential problems and areas for further research.

Chapter 2

An Overview on Contract Theory, Intertemporal Choices and Discounting

2.1 Contract Theory: A Brief Review

In legal systems, a contract represents an agreement in which a predetermine target (object) enters voluntarily between two or more parties, each of them intends to create one or more legal obligations towards that target. The elements of a contract may vary among legal systems and purposes. The U.S. Legal System, for instance, states that "the requisite elements that must be established to demonstrate the formation of a legally binding contract are (1) offer; (2) acceptance; (3) consideration; (4) mutuality of obligation; (5) competency and capacity; and, in certain circumstances, (6) a written instrument" (US Legal Inc., n.d., Retrieved from http://contracts.uslegal.com/elements-of-a-contract/)

In economics, contract theory studies the "forces" that drive economic agents to behave within contractual arrangements, generally in the presence of uncertainty, asymmetric information and risk. A common form of such contract is voluntary agreements, in which one party (the principal) delegates an obligation to another party (the agent) under a compensation scheme. In that case, the problem for the former lies in providing appropriate incentives through optimization algorithms that motivate agents to provide his will as it specified by within the contract.

Adam Smith (1801) was the first who recognized the relationship between an owner of a land (landlord) and a worker, where the former delegates the right of cultivation to the latter. Later on, Barnard (1938) tried to establish an incentive theory in management, by stressing out monetary and non-monetary incentives. In addition, he recognized that personal long-run needs is the force that drives someone to perform a task ordered by his (or her) manager, and so incentives must satisfy these needs. The work of Barnard inspired Arrow (1963), who dedicated part of his work into the problems that information asymmetry and uncertainty create into portfolio choices (more precisely, on healthcare private system). In his article, Arrow analysed how imperfect information between patients and physicians on the diagnosis and the consequences of treatment can lead to failure of healthcare industry, setting in that way the fundamental frame of the problem of *moral hazard* and its consequences.

However, it was Jensen and Meckling (1979) who started to develop formally the principal-agent theory as a combined product of economics and institutional theory, and some years thereafter Milgrom and Roberts (1994) identified the four principles of contract design, namely Informativeness Principle (Hölmstrom, 1979), Incentive-Intensity Principle, Monitoring Intensity Principle and Equal Compensation Principle[1].

2.2 Information Asymmetry: The Problem of Moral Hazard

The above four principles highlight one of the most common problems that the principal calls to overcome in many real-time situations, namely his inability to perfectly observe and verify agent's action, due to political, ethical and/or technological boundaries (limitations). This type of information asymmetry between the principal and the agent is called *moral hazard,* and it motivates the latter to actions that drive markets to failures. Dependently the time it occurs relative to the outcome, *moral hazard* referred either as *ex-post* or *ex-ante moral hazard.*

The implications of problem of moral hazard do not concern only healthcare sector as Arrow (1963) (and later on Shavell, 1979; Rubinstein and Yaari, 1983; Zweifel and Manning, 2000) pointed out. Many other economists analysed the impact of this type of information asymmetry into financial sector (e.g. Besanko and Kanatas, 1993; Milgrom and Roberts, 1994; Eichengreen, 1999), in labour markets (e.g. Lambert, 1983; Foster

[1]The first principle states that any measure of performance that (on the margin) reveals information about the effort level chosen by the agent should be included in the compensation contract. The second principle states that the optimal intensity of incentives depends on four factors: (i) the incremental profits created by additional effort; (ii) the precision with which the desired activities are assessed; (iii) the agent's tolerance towards risk; (iv) the agent's responsiveness to incentives. The third principle states that in cases where the optimal intensity of incentives is high, the corresponding optimal level of monitoring is also high. The last principle states that action equally valued by the principal should be equally valuable to the agent.

and Rosenzweig, 1994), in federal fiscal constitutions (e.g. Persson and Tabellini, 1996) and in taxation (e.g. Varian, 1980; Arnott and Stiglitz, 1986).

Recently evidence on the negative effects of climate change into societies, changes in energy and consumption patterns, and also the "fear" of extinction of natural capital reserves (e.g. fossil fuels, minerals, etc.), made (agri)environmental policy an attractive field for further research, especially during the last twenty years.

For instance, Xepapadeas (1991); Fraser (2002); Hart and Latacz-Lohmann (2005); Fraser (2013) analysed the impact of moral hazard into optimal (agri)environmental contracts. Furthermore, researchers like MacKenzie et al. (2011); Salas and Roe (2012) tried to determine inefficiencies that moral hazard creates in carbon sequestration contracts, whereas other economists analysed how such informational problems affect crop insurance contracts Horowitz and Lichtenberg (1993); Smith and Goodwin (1996), nonpoint pollution control contracts (Segerson, 1988; Cabe and Herriges, 1992) and in resource extraction contracts (Engel and Fischer, 2008).

Environmental economists tried to eliminate the implications from moral hazard either due to principal's incomplete information (Latacz-Lohmann and Hamsvoort, 1998; Ozanne et al., 2001; Fraser, 2002) or imperfect information (Choe and Fraser, 1999), mainly by combining the frequency of individual auditing and the level of the penalty/reward. In cases, however, where such combination is unfeasible, Fraser (2012) also states that the principal can simply increase the risk for the agent of getting caught cheat on the contract, whereas other economists (e.g. Xepapadeas, 1991) tried to determine policy instruments (i.e. subsidies and fines) that enforce compliance towards environmental policy in the absence of individual monitoring.

In dynamic contracts, alternative to auditing-penalty/subsidies schemes have been proposed. Fraser (2004) for instance uses "targeting" as a mechanism of the elimination of moral hazard. Another approach is that of Lambert (1983), who uses long-term contracts in order to control moral hazard problems, whereas Fudenberg and Tirole (1990) uses renegotiations as a policy tool for eliminating the impact of moral hazard by "protecting" agents towards risk.

2.3 Intertemporal Time Preferences and Discounting

In decision theory, time-preferences refer to person's preferences for the immediate utility over deferring utility (Frederick et al., 2002a). Rae and Mixter (1905) were the first who made an attempt to identify the joint determinant of individual intertemporal choices[2], arguing that positive time-preferences eliminate the effective desire for accumulation. In addition, Jevons (1884, 1905) and Senior (1836) interpreted preferences as "immediate feelings", and therefore individuals time-discount[3] the future because either of the immediate pleasure of anticipation (Jevons, 1884, 1905) or the immediate "discomfort" of delaying gratification produced by self-denial (Senior, 1836).

Furthermore, von Böhm-Bawerk (1890) treated intertemporal choices as a problem of allocation of an individual resources over different points in time, and his main argument was that individuals favour present over future because they underestimate future events.

However, it was Samuelson (1937) the first who introduced the discounted utility model (DUM) as a theoretical framework to value immediate and future utility. In his model, an individual applies relative weights in period t, to her well-being in period $t + k$, and these weights (i.e. discount factor) depend on her *pure* rate of time-preferences (ρ), which in turn reflects the psychological factors that determines intertemporal choices.

A direct implication of Samuelson's model is it assumes positive discount rates, and hence positive time-preferences (i.e. $\rho > 0$). However, the logic of this argument has been questioned by many economists (Hirshleifer and Hall, 1970; Koopmans, 1960; Koopmans et al., 1964; Olson and Bailey, 1981), who stated that future events diminish to almost zero if a positive real rate of return in savings combined even with negative time-preferences[4] .

The question on whether time-preferences of an individual is a psychological construct, and hence they must be reflected in discount rates, has received a lot of debate among academia. There is a body of evidence that oppose the use of time-preferences into discount rates, because there is either low correlation between discount rates involving aspects of time-preferences behaviour (Chapman and Elstein, 1995; Chapman et al., 1999), or they are totally uncorrelated (Fuchs, 1980)[5]. Therefore, some economists

[2]Decisions involving trade-offs between costs and benefits occuring at different times.

[3]"*We use the term time discounting broadly to encompass any reason for caring less about a future consequence, including factors that diminish the expected utility generated by a future consequence, such as uncertainty or changing tastes*" (Frederick's et. al. (2002), p.352).

[4]When it comes to intertgenerational choices, Koopmans (1967) refers to this result as "the paradox of indefinitely postponed splurged".

[5]A psychological construct or trait must satisfy the criteria of constancy, generality and correlation between different measures (Wilkinson and Klaes, 2012).

(Loewenstein et al., 2001; Frederick et al., 2002b) propose an alternative approach in which time-preferences model in a pre-DUM way by "breaking" into their fundamental parts -namely, impulsivity, compulsivity and inhibition[6]-, and so the prediction of various aspect of behaviour becomes more reliable.

2.3.1 Exponential Discounting

In general, any discounting function can be represented by $D(t) = \prod_{k=0}^{t-1} \Big(1/(1+\rho_k)\Big)$, where ρ_k is the discount rate applied between periods k and $k+1$. Many DU-models assume that discount function takes the exponential form of $D(t) = 1/(1+\rho)^t$, in which discount rates are constant (i.e. $\rho_k = \rho$).

The attractive feature of such exponential discount function is that the constancy of discount rates implies that an individual at every period k applies the same weights in all future events, and therefore discounting is *stationary* (i.e. $D_k = D$).

In the context of intertemporal choices, *stationarity* of the discount function implies that at any point of time, a person values future utilities in exactly the same way, and therefore her preferences between immediate utility and delayed utility do not change at any point of time. In other words, exponential discount functions imply that person's intertemporal choices are time-consistent, and therefore time itself has zero impact her decisions.

However, there is a body of academia that opposes the preferences time-consistency assumption and its implications. Ramsey (1928) -for instance- claims that exponential discounting is a *"tyranny of the present over the future"*, meaning that an individual cannot observe future preferences and needs, and therefore with constant discount rates an individual falsely assumes that these future preferences are valued equally with her present one.

Furthermore, many laboratory experiments (Ainslie, 1992; Frederick et al., 2002a; DellaVigna, 2007) conclude that individuals discount the future at a declining rate instead of a constant rate, due to decision-making heuristic, cognitive biases, systematic errors, and self-control problems (Hepburn et al., 2010). The problem arises from declining discount rates is that intertemporal choices of an individual are time-inconsistent.

[6] Wilkinson and Klaes (2012) state that impulsivity refers to a situation in which people act in a spontaneous and unplanned way, compulsivity refers to a situation where people make plans and stick to them, and inhibition involves the ability to inhibit impulsive behavior that may follow visceral stimuli.

In the light of new era on human behaviour, enabled the interest of intertemporal choice researchers to rethink the realism of normative discounting theory, giving with that way the necessary space for more descriptive theoretical frameworks to come to the surface. Among these “new” descriptive models, hyperbolic discount functions attracted the most attention.

2.3.2 Hyperbolic Discounting

Strotz (1955) was the first economist who became aware of the limitations of exponential discounting (and hence constant discount rates), altering the need for alternative approaches to DU-models, but the first formal implementation of declining discount rates became by Chung and Herrnstein (1967) and Phelps and Pollak (1968), who used hyperbolic discount functions to capture the effects of individual time-preferences.

One reason that hyperbolic discount functions became so popular is that results from many behavioural traits that constructed under a reward scheme smaller-sooner/larger-later, state that individuals often have the tendency to “*procrastinate*” or to “*tempt*” their intertemporal choices[7] (Thaler and Shefrin, 1981), and so intertemporal preferences are inconsistent. Furthermore, other behavioural experiements conclude that people usually suffer from “*present bias*”[8] (Green et al., 1994; Kirby and Herrnstein, 1995; Millar and Navarick, 1984; Solnick et al., 1980)). It has been argued that hyperbolic discount function can eliminate such self-control problems (Akerlof, 1991) by the use of a commitment device, which it also improves person’s task performance (Giné et al., 2010).

Another reason that advocates the use of such functions is that they fit the data from various experiments on decision-making better than exponential functions, and hence hyperbolic discounting models provide more realistic recommendation (Kirby, 1997; Kirby and Maraković, 1995; Green and Myerson, 2004; Rachlin et al., 1991), and also biological experiments (e.g McClure et al. (2007) show that brain areas involved in inter-temporal decision-making support quasi-hyperbolic framework.

[7]This type of self-control problems arises when a person prefers the larger-later outcome over smaller-sooner outcome, but somewhere in the future this preference reverses. The term “temptation” is used to describe such self-control problems when the outcome is positive, whereas “procrastination” is used for negative outcomes (Wilkinson and Klaes, 2012).

[8]Present bias refers to a situation where individuals may prefer 100€ today over 110€ in a month, but they prefer 110€ in one year and a day over 100€ in one year.

Even though hyperbolic discount functions provides a more descriptive analysis into intertemporal choices, there is a body of economists who oppose the use of such functional forms. Among them, Chabris et al. (2006) highly criticized the use of hyperbolic discount function, where their main argument lies on that time preferences cannot be observed when exists intertemporal arbitrage opportunities, and so neither exponential discount functions nor hyperbolic discount functions can capture accurately the impact of behavioural failures.

Furthermore, Sopher and Sheth (2006) claimed that empirical research does not provide robust evidence in favour of hyperbolic discounting over other alternative methods. In addition, Rubinstein (2003) rejects that evidence from *"preference reversals"* [9]can be interpreted as evidence for hyperbolic discounting. Instead, he proposes that heuristic methods that based on *"similarity relations"*[10] can provide consistent results as well. Finally, according to some other scientists (Read, 2001), the evidence in favour of hyperbolic frame may reflect of *"sub-additive"* discounting, which implies that discount rate is not a function of time but is rather a function of delay.

2.3.2.1 Hyperbolic discounting and (agri)environmental policies

A major characteristic for many (agri)environmental projects and policies is that their benefits for an individual occur much latter than the costs she needs to pay for their provision. In addition, the outcome for many agricultural activities does not depends only on individual efforts, but also on factors in which she has limited or zero control (e.g. weather conditions, natural phenomena, etc.) and these factors have high-magnitude effects. Moreover, many (agri)environmental initiatives have spatial implications among different countries.

For these reason, economists like Kahneman et al. (1994); Shogren and Taylor (2008) pointed out the positive impact of behavioural economics into environmental planning, and motivated further research towards natural resource management (Hepburn, 2003; Settle and Shogren, 2004; Hepburn et al., 2010), climate change (Heal, 1997; Dasgupta, 2008; Anthoff et al., 2009) and land use (Laibson, 1997; Fearnside et al., 2000; Salois and Moss, 2011).

[9]Preference reversal refers to phenomenon in which individuals prefer a situation (or a lottery, a gamble, etc). A over B, but they attach a higher price in B than in A.

[10]Similarity relations refers to situation in which individuals ignore small differences when they compare decisions, and focus on large differences.

Chapter 3

Theoretical Framework under Perfect Information

Let's consider an Agricultural Agency (from now on "the principal") which wants to achieve a specific (agri)environmental target that concerns the use and development of a privately owned land. Since the Agency has no control over the land, the *principal* needs to design an agreement -legally expressed by the form of a contract- by which he delegates the provision of the target to landowner-farmers (from now on "the agent") under a compensation scheme. Emission reduction from greenhouse gases, reduction of chemical fertilizers, improvements of the quality of the land, forest conservation and wetlands afforestation are only some examples of such target, and Official Community Plan (OCP), Forest Land Use Agreement (FLAg), International Tropical Timber Agreement (ITTA) are examples of agreements that contained in the class of Land Use Contracts (LUC). However, there is no universal construction of a LUC. Its elements depend primarily on the nature of the target, on the *principal's* objectives and on the characteristics of the participants.

In this dissertation, we consider a hypothetical situation in which the Agriculture Agency wants to improve the quality of the land by decreasing the dependency on chemical fertilizers. In order to do so, the *principal* determines the degree of agricultural activities produced by organic farming techniques (i.e. the target), like by adopting organic fertilizers, and therefore he offers a LUC, $y^T(e^*) = \langle p \rangle$, to individual-farmers where:

1. Participation is voluntary,
2. The total duration of the contract is of T periods,
3. $e^* \in [0, 1]$ is the pre-period targeted organic agriculture. That is, $e^* = 0$ implies that agricultural activities are produced exclusively by conventional agriculture,

whereas $e^* = 1$ implies that agricultural activities are produced exclusively by organic agriculture,

4. The compensation that participants receive at every period is given by the following scheme: $R = pe$, where $p > 0$ is the pre-period price subsidy, and $e \in \left[0, e^*\right]$ is the agricultural activities that an individual individual-farmer chooses to produce by organic farming,

5. An individual-farmer can freely choose the organic farming technique.

Furthermore, the *principal* is assumed to be risk-neutral, and he has a utility function, $U(e)$, which is increasing and linear in the level of effort e ($U' > 0$). The Agricultural Agency cares only for its own well-being, and thus, by setting the target e^* wants to achieve utility $U(e^*)$.

For the sake of simplicity we assume that $T = 1$, and so the structure of such "static" contract is as follows: At period $t = 0$, an individual-farmer considers the choice of whether contract is profitable for him, and also she sets the level of effort maximizing her profits. At $t = 1$, the *principal* observes *agent's* effort, and at $t = 2$ the contract ends and participants receive their compensation regarding their effort at $t = 1$. The following figure illustrates the stages of the contract with respect to time

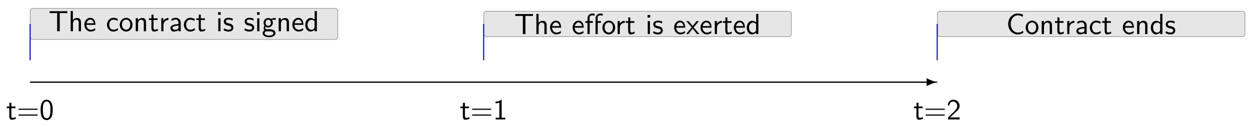

Figure 3.1: The stages of an one-period contract w.r.t. time (t)

So far we have mainly focused on *principal's* behaviour. Let's now characterize the *agent* in our model: An individual-farmer is assumed to be risk-neutral and she has an income, A, from conventional agricultural activities. If an *agent* sign the contract, then she needs to adopt organic farming techniques. However, it usually the case where such techniques lack of efficiency relative to conventional agriculture, and so by participation in the agreement an individual-farmer obtains a different level of income from agriculture, $I(e)$, which it is assumed that its value is substantial lower than A (that is, $I(e) < A$). In addition, there is nothing to indicate that higher adaptation to organic farming leads necessarily to lower and lower income. Since the scope of this dissertation is to emphasize on the *principal's* incentives for the provision of the target, it is reasonable to assume that the impact of the effort on I is almost zero (i.e. $I' \to 0$), and therefore we treat that new income as a constant (i.e. $I(e) \equiv I$).

Furthermore, the contract is costly for an individual-farmer only at the level of effort she exerts (i.e. the degree of organic farming adaptation), and this cost, ψ, is an increasing and convex function of e ($\psi' \geq 0$ and $\psi'' \geq 0$), and also $0 \leq \psi(e) \leq 1$. In the following, consistently with our assumptions, we assume that the cost function takes the quadratic form $\psi(e) = e^2/2$. The convexity of ψ implies that profits, $\Pi(e)$, from participation is an increasing and concave function in the level of effort, e ($\Pi' \geq 0$ and $\Pi'' \leq 0$).

Furthermore, consistency of an individual-farmer time-preferences reflects in her discount functions, $D(t)$, which we assume that they take discrete values with respect to time. Here we compare the behaviour of an intertemporal time-inconsistent farmer with the standard case of an intertemporal time-consistent farmer, where the former uses a quasi-hyperbolic discount function, $D_H(t)$, and the latter uses a discrete-value exponential discount function, D_E. Independently which discount function an *agent* uses, we treat her as a sequence of independent selves who at each point of time act based on her best-self interest. Hence, we refer to an individual-farmer at period $t \leq T$ simply as $self$-t, and thus we derive the *incentive compatible* contract by solving the intertemporal game between the *principle* and $self$*-t* backwards.

However, at $t \leq T - 1$ an hyperbolic discounting *agent* has different beliefs regarding the consistency of her decisions. Here, we consider only the two extreme cases, where an intertemporal time-inconsistent farmer is either completely unaware (i.e. *naive*) or completely aware (i.e. *sophisticated*) of the inconsistency of her time-preferences, and we use $j = N, S$ to denote their type. More precisely, *naive* is an intertemporal time-inconsistent farmer who falsely believes that her future actions are consistent with her current plans, and so she believes that future selves use D_E. On the other hand, *sophisticated* is an intertemporal time-inconsistent farmer who perfectly knows “how inconsistent” her future actions are relative to her current plans, and so she perfectly knows that future selves use exactly the same discount function D_H. Finally, we assume that an unaware hyperbolic discounting farmer lacks of self-learning processes from previous decisions. As a consequence, a *naive agent* remains *naive* for every period $T - 1$, but she becomes aware of the intertemporal time-inconsistency of her decisions only at the last period of the contract (i.e. only at T).

The structure of this section is as follows: We start by assuming that the *principal* has perfect information on *agent's* actions and we also use decisions of an exponential discounting decision-maker as a benchmark in order to draw our conclusions. Next, we extend our analysis into a two-period contracts, where the role of time itself in decision-making is further investigated. In the last part of this section we arise the assumption of perfect information and we analyse the behaviour of an intertemporal time-inconsistent decision-maker in one-period and two-period contracts, respectively keeping again normative economic theory as a benchmark.

3.1 Individuals with Intertemporal Consistent Time-Preferences

As we have already mentioned in the previous chapters, the behaviour of an intertemporal time-consistent individual-farmer can be modelled by the use of exponential discount functions. In a discrete-time framework, exponential discount functions have the form:

$$D_E(t) = \begin{cases} 1 & \text{when t=0} \\ \delta^t & \text{when t>0} \end{cases}$$

where $\delta = 1/(1+\rho)$ is the pre-period discount factor and ρ is the *pure* rate of time-preferences.

The problem for the Agricultural Agency is to determine these incentives that motivate provision of the targeted outcome, provided that an individual-farmer has singed the contract at $t = 0$. In that case, the *principal* knows that $self$-1 discounted present value of her net benefits is:

$$DPV\Pi_1(e) = -\psi(e) + (I + pe)\delta \tag{3.1}$$

The problem for self-1 (i.e. self-1's objective) is to choose the degree of organic farming into (i.e. effort) that maximizes (3.1), provided that $self$-0 has already signed the contract. The solution to this unconstrained profit-maximization problems gives the optimal condition[11] $\psi'(e) = p\delta$, which it says that an exponential discounting $self$-1 chooses to produce her agricultural activities by organic farming techniques up to that point, in which the marginal cost of the adaptation to organic farming equals her discounted marginal revenues (i.e. pre-period subsidy). More precisely, given the quadratic form of our cost function $self$-1 optimal effort degree of adaptation is:

$$\overline{e} = p\delta$$

where $\overline{e} \leq e^* \to p \leq e^*\delta^{-1}$.

[11]See section A in the appendix for a complete derivation

This restriction states that there is a threshold on the pre-period subsidy, at which any further increase of it will not produce more effort by an exponential discounting *agent*. In other words, *principal's* decision to offer more than $e^*\delta^{-1}$ would be unreasonable, since such higher price would not motivate participants to increase agricultural activities produced by organic farming. Thus, a time-consistent individual-farmer has an incentive to provide the targeted outcome ($\overline{e} = e^*$) under a price of $\overline{p} = e^*\delta^{-1}$.

Now, let's going back one period ($t = 0$). At that point of time, an exponential discounting $self$-0 considers the profitability of *principal's* offer relative to her conventional agricultural activities. If she decide to accept the offer, then she needs to forsake her income A from her agricultural activities produced by conventional farming, and her discounted present value of her net benefits will be:

$$DPV\Pi_0(e) = -\psi(e)\delta + (I + pe)\delta^2$$

Hence, at any price offered by the *principal,* $self$-0 plans to adopt organic farming by e_0=arg max$_e$DPVΠ_0 $\Leftrightarrow$ e_0=pδ, which is exactly the same with what $self$-1 actual does. Thus, from $self$-0 perspective participation in the agreement is profitable for her if and only if:

$$DPV\Pi_0(e_0) \geq DPVA$$

$$-\psi(e_0)\delta + (I + pe_0)\delta^2 \geq A\delta^2 \tag{3.2a}$$

Inequality (3.2a) describes $self$-0 incentive-rationality constraint (IR_E), and it states that an exponential discounting individual-farmer is willing to abandon her conventional farming techniques if and only if her discounted net benefits from undertaking effort e_0 are at least equal to her discounted income from conventional agriculture.

If we substitute $e_0 = p\delta$ into (3.2a) and solve with respect to the pre-period subsidy, then IR_E becomes:

$$p \geq \phi_E \tag{3.2b}$$

where $\phi_E = [2(A - I)/\delta]^{1/2}$ denotes $self$-0's opportunity cost from forgoing her income from conventional farming[12]. Thus, an alternative interpretation of IR_E could be that the price offered by the *principal* for the adaptation to e_0 degree of organic farming must covers $self$-$0's$ opportunity cost, otherwise contract becomes unprofitable relative to her income by conventional farming techniques.

[12]The reader can find detailed derivation of the incentive-rationality constraint for a time-consistent decision-maker at section B in the Appendix

The *principal* wants from the participant to provide effort e^*. As we have already presented, an intertemporal time-consistent individual-farmer provides the targeted outcome (e^*) under a price of $\overline{p}$. Hence, (3.2b) becomes $\overline{p} \geq [2(A-I)/\delta]^{1/2}$. For the rest of this dissertation, we refer to that as the incentive-compatible condition for an exponential discounting decision-makers (ICC_E).

Alternatively, we can express ICC_E in terms of the cost associated with the provision of the targeted outcome, by solving (3.2a) with respect to ψ and by also setting $p = \overline{p}$. In that case, we have that $-\psi(e^*) \leq -(A-I)\delta$, and it says that an exponential discounting *agent* signs the contract as long as the cost of adapting e^* organic farming techniques is lower than or equal to the cost that an individual-farmer experiences by maintain her conventional farming techniques, and hence by obtaining income A instead of I.

PROPOSITION 1: Let e^* be the targeted outcome. Then, a contract $y^1(e^*) = \langle \overline{p} \rangle$ is incentive compatible for an individual with intertemporal consistent time-preferences if and only if $\overline{p} \geq \phi_E$.

Summing up, the *principal* at $t = 0$ knows the followings: (i) $e_0 = \overline{e}$. That is, the actual performance of an exponential discounting individual-farmer at $t = 1$ is consistent with her plans at t=0; (ii) the price for the provision of the targeted adaptation to organic farming must also cover $self$-0's opportunity cost; (iii) $D_E(0)/D_E(1) = 1/\delta$, where the left-hand side is the marginal rate of substitution ($MRS^E_{0,1}$) between immediate costs and future benefits, and $MRS^E_{0,1}$ is the same for every $self$-t. That is, ρ shows the marginal rate of substitution between intermediate costs and future benefits for every exponential discounting $self$-t[13].

3.2 Individuals with Intertemporal Inconsistent Time-Preferences

As we have already mentioned in the previous chapter, the behaviour of an intertemporal time-inconsistent individual-farmer can be modelled by the use of hyperbolic discount functions. In a discrete-time framework, an approximation of a hyperbolic discount function can take the quasi-hyperbolic functional form (Phelps and Pollak, 1968):

[13]Note that $\delta = 1/(1+\rho) \Rightarrow 1/\delta = 1+\rho \Rightarrow \rho = (1-\delta)/\delta$

$$D_H(t) = \begin{cases} 1 & \text{when t=0} \\ \beta\delta^t & \text{when t>0} \end{cases}$$

where the parameter $\beta \in (0,1)$ shows the deviation from exponential discounting. Alternatively, Salois (2008) noted that the presence of β gives a measure of how payoffs from immediate decision valued more relative to the payoffs from postponing decisions, and therefore it is reasonable to argue that β shows the *degree of present bias*.

Following the same way of thinking as in the case of exponential discounting *agnets*, we start our analysis in a backward chronological order. Provided that an intertemporal time-inconsistent individual-farmer has signed the contract at $t = 0$, a hyperbolic discounting $self$-1 has discounted present value of her net benefits:

$$DPV\Pi_{h1}(e) = -\psi(e) + (I + pe)\beta\delta \tag{3.3}$$

and so, $self$-1 chooses to adopt organic farming by $\underline{e} = \arg\max_e DPV\Pi_{h1}$. Following the standard optimization procedure[14] we obtain the optimal condition $\psi'(e) = p\beta\delta$, which given the quadratic form of our cost function we obtain the optimal degree to organic farming adaptation for an intertemporal time-inconsistent individual-farmer:

$$\underline{e} = p\beta\delta$$

where $\underline{e} \leq e^* \rightarrow p \leq e^*(\beta\delta)^{-1}$.

This constraint is similar to the the price restriction for a time-consistent participant and it also states that a very high price is unreasonable, since $self$-1 does not consider to increase her agricultural activities produced by organic farming (i.e. to provide more effort) more than the targeted levels. Finally, the targeted adaptation to organic farming (i.e. e^*) maximizes equation (3.3) under a price of $\underline{p}$=$e^*(\beta\delta)^{-1}$. At that point of our analysis, the reader can recall that a time-consistent $self$-1 chooses to adapt organic farming techniques by $\overline{e} = p\delta$, and so $\underline{e} = \beta\overline{e}$. Given that $\beta \in (0,1)$, a hyperbolic discounting $self$-1 provides lower effort (i.e. adapt organic farming at a lower degree) than an exponential discounting $self$-1 ($\underline{e} < \overline{e}$), as a consequence the former requires a higher price than the latter in order to provide the targeted outcome, e^* ($\underline{p} > \overline{p}$).

[14]The procedure of solving self-1 profit-maximization problem is similar with the procedure for an intertemporal time-consistent individual-farmer, and therefore the reader can have a look in section A at the Appendix

Now, let's going back one period ($t = 0$). At that point of time, $self$-0 considers the profitability of *principal's* offer relative to her income from agricultural activities produced by conventional farming. If she decide to accept the offer, then she needs to abandon her income from agricultural activities produced by conventional farming, and the discounted present value of her net benefits will be:

$$DPV\Pi_{h0}(e) = -\psi(e)\beta\delta + (I + pe)\beta\delta^2$$

and so $self$-0 plans to adapt to organic farming by $e_{h0} = \arg\max_e DPV\Pi_{h0} \Leftrightarrow e_{h0} = p\delta = e_0$ units. That is, ahyperbolic discounting individual-farmer makes the same plans for the future with an exponential discounting individual-farmer. As a consequence, we could argue that planned effort is always the same independently the consistency of an individual time-preferences.

As we mentioned in the beginning of this chapter, at that point of time self-0 is either *naive* or *sophisticated.* As a consequence, self-0 has different beliefs on the discount function that $self$-1 uses, and hence whether her plans actually carry out by her. For this reason, an intertemporal time-inconsistent $self$-0 does not consider participation on her planned effort directly, but rather on another one which it also takes into account her beliefs. If we use ε_j to denote $self_j$-0 beliefs on the effort that $self$-1 provides, then

$$\varepsilon_j = \arg\max_e \Big\{ -\psi(e) + (I + pe)b_j\delta \Big\} \Leftrightarrow \varepsilon_j = b_j e_{h0}$$

where $b_j = \{\beta, 1\}$ is a parameter that shows the $self_j$-0 beliefs regarding the consistency of her plans (and hence, the functional form of the discount function that $self$-1 uses). Thus, for a *naive agent* $b_N = 1$, whereas for a *sophisticated agent* $b_S = \beta$. Therefore, $self_j$-0 is willing to sign the contract if and only if:

$$DPV\Pi_{h0}(\varepsilon_j) \geq DPVA$$

$$-\psi(\varepsilon_j)\beta\delta + (I + p\varepsilon_j)\beta\delta^2 \geq A\beta\delta^2 \tag{3.4a}$$

where inequality (3.4a) describes $self_j$-0 incentive-rationality constraint (IR_j).

We can express IR_j either with respect to the pre-period subsidy, or with respect to the cost associated with the planned effort e_{h0}. In the former case, IR_j becomes

$$p \geq \phi_j(T = 1) \tag{3.4b}$$

where $\phi_j(1) = [2(A-I)/b_j\delta(2-b_j)]^{1/2}$ is $self_j$-0 opportunity cost for abandoning her income from agricultural activities produced by conventional farming[15], whereas in the latter case, IR_j becomes -$\psi(e_{h0})$≤-δ(A-I)/b_j(2-b_j), where now the right-hand side shows the discounted cost for $self_j$-0 to maintain her conventional agriculture activities.

Let's consider the first interpretation of IR_j. In that case, we can show[16] that $\phi_S(1)$>$\phi_N(1)$=ϕ_E $\forall\beta$(0,1). In addition, a closer look at ε_j reveals that $self_N$-0 believes that for $self$-1 the $MRS^N_{0,1} = MRS^E_{0,1} = 1/\delta$. On the other hand, $self_S$-0 knows that for $self$-1 $MRS^S_{0,1} = MRS^H_{0,1} = 1/\beta\delta$. That is, a *naive agent* underestimates the costs associated with the provision of her plans, e_{h0} ($MRS^S_{0,1} > MRS^N_{0,1}$), and so she is more willing to abandon her conventional agricultural practices ($\phi_S(1) > \phi_N(1)$) than a *sophisticated agent* for any subsidy p. Hence, it is reasonable to argue that if the pre-period subsidy motivates participation for *naive* individual-farmers, then it does not necessarily mean that such price motivates also *sophisticated* individual-farmer toward participation, whereas the opposite always holds. Finally, the reader can recall that once the contract begins (i.e. at $t = 1$) both *naive* and *sophisticated agents* adapt to organic farming by e^* units under a price equals $\underline{p}$, and so we are ready to present our next proposition:

PROPOSITION 2: Let e^* *be the targeted outcome and* $\overline{p} \geq \phi_E$ *is the pre-period subsidy. Then, a contract* $y^1(e^*) = \langle\underline{p}\rangle$ *is always incentive compatible for naive hyperbolic discounting individual-farmers, but it becomes incentive compatible for both sophisticated and naive agents if and only if* $\underline{p} \geq \phi_S(1)$.

Summing up, the *principal* at $t = 0$ knows the followings: (i) $e_{h0} = e_0$. That is, both *naive* and *sophisticated agents* and exponential discounting decision-makers make the same plans for future levels of effort; (ii) at $t = 1$ both *naive* and *sophisticated agents* provide an effort substantial lower than exponential discounting *agents* ($\underline{e} < \overline{e}$); (iii) $D_H(0)/D_H(1) = 1/\beta\delta$, and so $MRS^H_{0,1} > MRS^E_{0,1}$. That is, the marginal rate of substitution between immediate costs and future benefits is higher for a dynamic discounting decision-maker than for an exponential discounting decision-maker, and so

[15] Detailed derivation of at section B, in the Appendix.

[16] The reader can find a complete proof in the Appendix, at Section B

provision of the same targeted outcome requires higher prices in the case of the former ($\underline{p} > \overline{p}$); (iii) *naive* and *sophisticated* individual-farmers have different opportunity costs ($\phi_S(1) > \phi_N(1) = \phi_E(1)$), and therefore a price that motivates participation for the former, does not necessarily implies that the same prices motivates participation for the latter.

The Introduction of a Commitment Mechanism

From the very beginning of this dissertation, we stated that our purpose is to provide a reliable answer on which is the impact of dynamic inconsistencies of individuals' decisions into contract design, when the target broadly concerns the use and development of a privately own land, and more precisely when the target is the adaptation to organic farming practices. At a first glance, the presence of an intertemporal time-inconsistent individual-farmer enforces the *principal* to offer a subsidy $p = \underline{p} > \overline{p}$ in order to motivate provision of e^*. This higher price creates a cost for the policy-maker, which it comes *purely* from individual behavioural failures to commit to their plans. Thus, the impact of dynamic inconsistencies (DI) is:

$$DI = \underline{p} - \overline{p} = \overline{p}\left(\frac{1-\beta}{\beta}\right)$$

where the extent of the impact of dynamic inconsistencies into contract design is determined by the *present bias ratio,* $r_\beta = (1-\beta)/\beta$.

Let's have a closer look at r_β. One can easily observe that the the lower is β, the higher is the *present bias ratio,* and hence the higher is the impact of dynamic inconsistencies into contract design , since the *principal* needs to offer a higher price in order to motivate the provision of e^*. Another interesting result is that the $\lim_{\beta\to 0} r_\beta = \infty$. That is, in cases where β approaches zero, then the the extent of the impact of dynamic inconsistencies of an individual's decisions approaches to infinity. The interpretation of this result is that when the *present bias* takes "extreme high values", then the policy-maker needs to offer an infinite subsidy in order to motivate the targeted adaptation to organic farming practices. However, such high price is practically impossible, and so we could argue that when β approaches zero, *incentive-compatible* contacts for intertemporal time-inconsistent individual-farmers do not exist. In that case, the only thing that *principal* can do is to offer $\overline{p}$, allowing to a hyperbolic discounting *agent* to underprovide, provided that $self_j$-0 has signed the contract[17].

The above discussion indicates that the presence of a hyperbolic discounting *agent* creates almost zero problems -in terms of the level of the subsidy the *principal* offers- only when her behaviour approaches that of an exponential discounting *agent* (i.e. when $\beta \to 1$). However, this argument is not completely correct. The reason is that both $self_N$-0 and $self_S$-0 individual-farmers have an incentive to adapt to organic farming practices by e^* units under a subsidy equals $\overline{p}$. Thus, the policy-maker can overcome the impact of dynamic inconsistencies by simply imposing a commitment mechanism which will enforce a hyperbolic discounting self-1 to stay in $self_j$-0's initial optimal plan.

Let's assume that such mechanism takes the form of a penalty according to the following scheme:

$$P(e) = \begin{cases} 0 & \text{if } e = e_0 \\ d(e_{h0} - e) & \text{if } e < e_0 \end{cases}$$

where $d > 0$ is the unit penalty that a hyperbolic discounting *agent* needs to pay for any deviation from $self_j - 0$ optimal plan. Once the *principal* impose such mechanism, self-1 discounted present value of her net benefits becomes:

$$DPV\Pi^*_{h1}(e) = -\psi(e) + (I + \overline{p}e - d(e^* - e))\beta\delta$$

and self-1 chooses to adapt to organic farming practices by $\underline{e}^* = \arg\max_e DPV\Pi^*_{h1}(e) \Leftrightarrow \underline{e}^* = \beta\delta(\overline{p} + d)$ units, where again $\underline{e}^* \in [0, e^*] \to d \leq \overline{p}(1-\beta)/\beta$.

This restriction on the value of the marginal penalty is similar to the restriction on the value of prices, and it states that an "extreme high" penalty is useless, because it does not motivate self-1 to do more than e^*. Hence, the targeted outcome maximizes self-1 profits if[18]:

$$d^* = \overline{p}\left(\frac{1-\beta}{\beta}\right)$$

This optimal value of a commitment mechanism provides us with very useful information. First of all, $d^* = DI$. In other words, optimal penalty is simply a lump-sum transfer paid by participants to the Agency, and so when such penalty is feasible, the *principal* offers $\overline{p}$ and the impact of dynamic inconsistencies impact into contract design is zero.

[17]The who is going to participate in the agreement specified by the value of $\overline{p}$. If $\overline{p} \geq \phi_S(1)$, then both *naive* and *sophisticated* sign the contract, whereas if $\phi_N(1) \leq \overline{p} < \phi_S(1)$, then only *naive agents* sign the contract.

[18]The reader can find a complete explanation at section A in the Appendix.

Secondly, $d^*/\overline{p} = (1-\beta)/\beta$. That is, the *present bias ratio* determines whether the value of optimal penalty exceeds the price for the provision of the targeted outcome. More precisely, if $\beta < 1/2$, then the optimal penalty exceeds the optimal subsidy ($d^* > \overline{p}$), whereas if $\beta > 1/2$, then the opposite holds ($d^* < \overline{p}$). The most interesting result, however, is that the $\lim_{\beta \to 0} d^* = \infty$. The interpretation is that if the *present bias* is "too high", the *principal* must impose an "extreme high" penalty in order to motivate provision of e^*. However, it is usually the case where such high penalty is practically infeasible due to technical, political and/or ethical boundaries. In that case, one could argue that the Agricultural Agency could offer $\underline{p}$, but as we have already explained such high price is also infeasible. As a consequence, we can argue that if d^* is infeasible, then *incentive-compatible* contracts for a hyperbolic discounting individual-farmer do not exists.

One interesting question would be concerned the impact of such commitment mechanism into $self_j$-0's incentive-rationality constraint. At $t = 0$, a hyperbolic discounting *agent* plans to adapt to organic farming practices by $e^*_{h0} = \arg\max_e DPV\Pi^*_{h0} \Leftrightarrow e^*_{h0} = (\overline{p}+d)\delta$ units, which $e^*_{h0} = e^* \; \forall d \geq 0$ since $e^*_{h0} \in [0, e^*]$. Therefore, a *naive agent* believes that she always provides e^*, independently how high the penalty is ($\varepsilon^*_N = e^*_{h0} = e^* \; \forall d \geq 0$). In addition, a *sophisticated agent* also knows that $self$-1 provides the target, provided that (a minimum) d^* is feasible ($\varepsilon^*_S = \beta e^*_{h0} = e^* \; \forall d \geq d^*$). As a consequence, $self_j$-0 incentive-rationality constraint becomes:

$$-\psi(\varepsilon^*_S)\beta\delta + (I + \overline{p}\varepsilon^*_S - d^*(e^* - \varepsilon^*_S)\beta\delta^2 \geq A\beta\delta^2$$

$$-\psi(e^*) + (I + \overline{p}e^*)\delta \geq A\delta$$

$$\overline{p} \geq \phi_E$$

That is, once the commitment mechanism takes place, a contract $y^1(e^*) = \langle \overline{p}; d^* \rangle$ is *incentive-compatible* for both *naive* and *sophisticated* individual-farmer provided ICC_E is satisfied. In that case, the contracts $y^1(e^*) = \langle \overline{p} \rangle$ and $y^1(e^*) = \langle \overline{p}; d^* \rangle$produce the same outcome for the *principal*, and so the Agricultural Agency can offer $y^1(e^*) = \langle \overline{p}; d^* \rangle$, without caring whether dynamic inconsistencies on individual-farmer time-preferences exists. Now we are ready to present our third proposition:

PROPOSITION 3: Let's consider the case where the following holds: e^* is the targeted outcome, $\overline{p} \geq \phi_E$, $\underline{p} \geq \phi_S(1)$ and $d > 0$ is the penalty set by the principal. Then, the value of present bias ratio determines the extent of dynamic inconsistencies into contract *design. More precisely,*

a) if $d \geq d^*(r_\beta)$ *, then* $y^1(e^*) = \langle \overline{p}; d^* \rangle$ *is the incentive-compatible contract for a hyperbolic discounting individual-farmer, and* $DI = 0$*,*

b) if $d < d^*(r_\beta)$*, then* $y^1(e^*) = \langle \underline{p} \rangle$ *is the incentive-compatible contract for a hyperbolic discounting individual-farmer, and* $DI = d^*$*,*

c) If $d^*(r_\beta)$ *approaches infinity, then the incentive-compatible contract for a hyperbolic discounting decision-maker does not exist.*

What we have seen so far is the impact of dynamic inconsistencies into contract design, when the Agricultural Agency has perfect information on individual-farmers' performance and the duration of the contract is only for one period. What comes next, is a modification of the above framework in which we increase the duration of the contract time by one period. The purpose of this modification is to analyse the impact of time itself when dynamic inconsistencies on individual-farmer time-preferences also exist[19].

3.3 A Two-Periods Theoretical Framework under Perfect Information

This part of our theoretical analysis under perfect information is dedicated to present the impact of time itself into contract design for the provision of an (agri)environmental good/service, under both perfect information and the presence of a hyperbolic discounting decision-maker. Here, we consider the hypothetical situation in which an individual-farmer needs to adapt to organic farming practices by e^* units at both the first and the second period. The structure of an two-periods contract describes as follows: At period $t = 0$, an individual-farmer decide whether to sign the contract. At $t = 1$, the contract begins and the *agent* chooses the current and future degree of adaptation to organic farming. At $t = 2$, the *principal* observes the level of effort that *agents* provided at $t = 1$ and he compensates them. At that point of time, the *agent* adapt again to organic farming, the degree of which becomes observable at the end of the contract (i.e. at $t = 3$). The following graph illustrates the stages of the contract with respect to time:

[19] However, the reader must keep in mind that given the limited nature of this dissertation with respect to time, the discussion that follows on the results of the following dynamic extension remains on the very basic

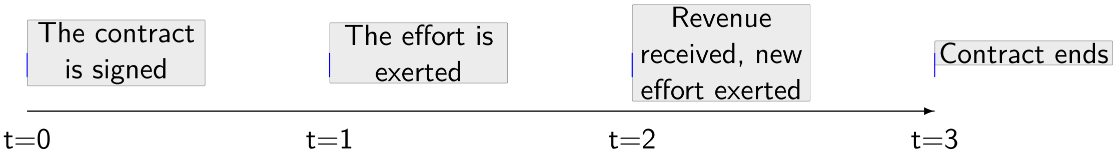

Figure 3.2: The stages of a two-period contract w.r.t. time (t)

As we have already demonstrated, an intertemporal time-consistent individual-farmer will always fulfil her plans. Thus, an exponential discounting *agent* adapt to organic farming practices by e^* units, if a pre-period subsidy $\overline{p}$ is feasible. In addition, the consistency of her time-preferences implies that the her opportunity cost is independent of the duration of the contact ($\phi_E(1) = \phi_E(2) = \cdots = \phi_E(T) \equiv \phi_E$). As a consequence, the contract $y^T(e^*) = \langle \overline{p} \rangle$ is *incentive-compatible* for an intertermporal time-consistent individual-farmer for any T, as long as $\overline{p} \geq \phi_E$. For this reason, we consider here only the case of individual-farmers with intertemporal inconsistent time-preferences.

Solving again the intertemporal game between the *principal* and $self$-t, we have that at $t = 2$ a hyperbolic discounting *agent* has discounted present value of her net benefits:

$$DPV\Pi_{h2}(e) = -\psi(e) + (I + pe))\beta\delta \tag{3.5}$$

One can observe that expression (3.5) is identical with expression (3.3) in one-period contract, and therefore $self$-2 adapts to organic farming exactly by the same degree with an intertemporal time-inconsistent $self$-1 in one-period contract. In other words, $self$-2 optimal effort is $\underline{e}_2 = p\beta\delta$, and therefore she has an incentive to adapt to the organic farming practices by the targeted degree under a price of $\underline{p}_2 = e^*(\beta\delta)^{-1}$.

Going back one period ($t = 1$), an intertemporal time-inconsistent $self_j$-1 has discounted present value of her net benefits:

$$DPV\Pi_{h1}(e_1, e_2) = \underbrace{-\psi(e_1) + (I + pe_1))\beta\delta}_{\text{Net Benefits from immediate actions}} + \underbrace{\Big(-\psi(e_2)\beta\delta + (I + pe_2))\beta\delta^2 \Big)}_{\text{Net Benefits from future actions}} \tag{3.6}$$

where e_2 denotes $self_j$-1 plans for the future. The key characteristic of expression (3.6) is that $self_j$-1's profits do not depend only on her current actions, but also on what future self (i.e s$self$-2) is going to do. Hence, by solving $self_j$-1 profit-maximization problem we obtain the optimal conditions[20] $\psi'(e_1) = p\beta\delta$ and $\psi'(e_2) = p\delta$, and given the quadratic form of our cost function we finally have that:

$$e_1 = e_2\beta \tag{3.7}$$

where condition (3.7) shows the optimal relationship between immediate and future efforts towards the degree of adaptation to organic farming practices. In other words, we can see that $e_2 > e_1 \; \forall \beta \in (0, 1)$, and so $self_j$-1 finds optimal to provide a lower effort now, but a higher effort at the next period. However, at that point of time an individual-farmer is either *sophisticated* or *naive*, and therefore $self_j$-1 has different beliefs regarding the consistency of her plans. That is, $self_j$-1 believes that $self$-2 adapts to organic farming by a degree of $\varepsilon_{j,1} = b_j e_2$, and therefore her current optimal degree of adaption is:

$$\underline{e}_{j,1} = \varepsilon_{j,1}\beta$$

and so,

$$\underline{e}_{j,1} = \begin{cases} p\delta\beta & \text{if self}_N\text{-1} \\ p\delta\beta^2 & \text{if self}_S\text{-1} \end{cases}$$

The reader can recall that in one-period contracts, beliefs determined only participation decision. However, when contracts extend to two periods, beliefs determine also the effort of a hyperbolic discounting $self$-1. More precisely, we can easily observe that $\underline{e}_{S,1} < \underline{e}_{N,1}$. In addition, we saw that at $t = 2$, a hyperbolic discounting individual-farmer adapts to organic farming practices by $\underline{e}_2$ units. Thus, the optimal degree to adaptation to organic farming for a *sophisticated* and for a *naive agent* in a two-periods contract is $\underline{e}_S = (\underline{e}_{S,1}, \underline{e}_2)$ and $\underline{e}_N = (\underline{e}_{N,1}, \underline{e}_2)$, respectively, where also $\underline{e}_{N,1} = \underline{e}_2$.

The interesting point by looking at $\underline{e}_S = (\underline{e}_{S,1}, \underline{e}_2)$ and $\underline{e}_N = (\underline{e}_{N,1}, \underline{e}_2)$ is that the *principal* needs to offer the same incentives to both *naive* and *sophisticated* individual-farmers at the second period, but during the first period each type of a hyperbolic discounting *agent* requires a different subsidy in order to provide e^*. More precisely, a *sophisticated agent* has an incentive to adapt organic farming practices by e^* under a price- decreasing scheme $\underline{p}_S$=($\underline{p}_{S,1}$,$\underline{p}_2$), where $\underline{p}_{S,1} = e^*\delta^{-1}\beta^{-2} > \underline{p}_2$, whereas a *naive agent* requires a price-constant scheme $\underline{p}_N = (\underline{p}_{N,1}, \underline{p}_2)$.

This difference on price requirements highlights that time itself does not necessarily

[20] The reader can find a complete derivation in the Appendix, section A

increase the extent of the impact of dynamic inconsistencies on an *agent's* decisions regarding the provision of e^*. At each period, a j type individual-farmer creates a cost for the *principal* equals $DI_{j,t} = \underline{p}_{j,t} - \overline{p}$. As a consequence, the presence of a *naive agent* creates a cost for the policy-maker at period t equals $DI_{N,t} = \underline{p}_{N,t} - \overline{p}$, which remains constant given that $\underline{p}_{N,1} = p_2$ $(DI_{N,1} = DI_{N,2})$. That is, the increase of the duration of the contract by one period did not create more problems for the policy maker than that she created in contracts with duration of one period. On the other hand, time itself makes the presence of a *sophisticated agent* more problematic for the policy-maker. That is,

$$\frac{DI_{S,1}}{DI_{S,2}} = \overline{p}\left(\frac{1-\beta^2}{\beta^2}\right) \Big/ \overline{p}\left(\frac{1-\beta}{\beta}\right) = \frac{1+\beta}{\beta}$$

and it states that the increase of the duration of the contract by one period, increased the cost for the *principal* of having *sophisticated agents* by $(1+\beta)/\beta$.

Going back one more period ($t = 0$), an intretemporal time-inconsistent $self_j$-0 has discounted present value of her net benefits from participating in the agreement:

$$DPV\Pi_{h0}(e_{01}, e_{02}) = \sum_{t=1}^{2} \beta\delta^t \Big[-\psi(e_{0t}) + (I + pe_{0t})\delta \Big] \tag{3.8}$$

where e_{01} and e_{02} represents her plans for $self_j$-1's and $self$-2's actions, respectively. At that point of time, a hyperbolic discounting individual-farmer want to maximize (3.8), and therefore the first-order conditions w.r.t. e_{01} and e_{02}, respectively are ψ'(e_{01})=ψ'(e_{02})=pδ. In other words, a hyperbolic discounting individual-farmer plans to adapt to organic farming by the same degree at both two periods, and also by the same degree with an exponential discounting individual-farmer. However, at that point of time an individual-farmer is either *naive* or *sophisticated,* and therefore she believes that $self_j$-1 and $self$-2 provide effort $\varepsilon_{j,01} = b_j e_{01}$ and $\varepsilon_{j,02} = b_j e_{02}$, respectively. In addition, we saw that $self_j$-1 is also either *sophisticated* or *naive,* and so that her optimal effort depends on her beliefs on self-2's actual actions. As a consequence, $e_{01} = \varepsilon_{j,1} = b_j e_2$, and so $self_j$-0 "considering" vector of efforts is $\varepsilon_{j,0} = \Big(\varepsilon_{j,01} = b_j^2 e_2, \varepsilon_{j,02} = b_j e_{02}\Big)$.

Thus, an intertemporal time-inconsistent $self_j$-0 is willing to sign the contract if and only if:

$$DPV\Pi_{h0}(\varepsilon_{j,0}) \geq DPVA$$

$$\sum_{t=1}^{2} \beta\delta^t \Big[-\psi(\varepsilon_{j,0t}) + (I + p\varepsilon_{j,0t})\delta \Big] \geq A\beta\delta^2(1+\delta)$$

$$p \geq \phi_j(2)$$

where $\phi_j(2) = \phi_E\Big[(1+\delta)/(2b_j(b_j+\delta) - b_j^2({b_j}^2+\delta))\Big]^{1/2}$ is $self_j$-0's opportunity cost when the contract is of two-periods ($T = 2$).

The reader can easily verify that the increment of the duration of the contract by one period did not affect the opportunity cost -and hence the incentive-rationality constraint- for a *naive* individual-farmer (that is, for $b = 1$, $\phi_N(2) = \phi_N(1) = \phi_E$). In addition, we presented that once the contract begins a *naive agent* provides the same effort period after period ($\underline{e}_{N,1} = \underline{e}_2$), and that effort is the same with what she actually provides in an one-period contracts. As a consequence, in case of a *naive* individual-farmer the *principal* can simply impose a penalty $d^*_N = (d^*, d^*)$, and hence $y^2(e^*) = \langle \overline{p}; d^*_N \rangle$ is the *incentive compatible* contract. That is, at both $y^1(e^*) = \langle \overline{p}; d^* \rangle$ and $y^2(e^*) = \langle \overline{p}; d^*_N \rangle$ the policy-maker offers exactly the same incentives for the provision of e^*, and therefore we could argue that when individual-farmers are unaware of their intertemporal time-inconsistency of their decisions, time itself has zero impact for the policy-maker.

On the other hand, time itself affects both participation decision and actual effort towards the adaptation to organic farming practices, making the design of a land use contract more complex especially during the first periods of it. The reason is that when $T = 2$, a *sophisticated* self-0 is willing to sign the contract if and only if $p \geq \phi_S(2)$, whereas for $T = 1$ she is willing to abandon her conventional farming practices (and hence her income A) for a price $p \geq \phi_S(1)$. However, we can show[21] that $\phi(2) > \phi(1)$, and so the increase of the duration of the contact by one period, increased the opportunity cost for a *sophisticated* $self$-0. Furthermore, we also presented that *sophisticated* optimal vector is $\underline{e}_S = (\underline{e}_{S,1}, \underline{e}_2)$. Thus, the *principal* can motivate provision of e^* either by offering the *incentive-compatible* contract $y^2(e^*) = \langle \underline{p}_S \geq \phi_S(2) \rangle$, or he can impose a commitment mechanism, in which the penalty vector is $d^*_S = (d^*_1, d^*_2)$, where $d^*_1 = \overline{p}(1-\beta^2)/\beta^2$ and $d^*_2 = \overline{p}(1-\beta)/\beta = d^*$, and so a *sophisticated agent* provides e^* under a pre-period subsidy $\overline{p}$. Both $\underline{p}_{S,1}$ and d^*_1 are higher than $\underline{p}_2$ and d^*_2, and therefore we could say that time itself becomes an important factor into contract design.

To sum up, even though this two-periods theoretical analysis is too simple on its basis, it yet provides us very interesting results on the impact of an intertemporal time-inconsistent individual-farmer into contracts with duration more than one periods: (i) in the absence of a commitment mechanism, the degree of self-awareness (i.e. the type of a time-inconsistent decision-maker) determines not only who is going to sign the

[21] The reader can find a complete proof of this argument in the Appendix, at section C

contract, but also the effort that a hyperbolic discounting *agent* exerts at $t = 1$; (ii) as the duration of the contract increases, the opportunity cost and for a *sophisticated* individual-farmer increases as well, whereas the opportunity cost for a *naive* remains the same; (iii) once the contract begins, a *naive* individual-farmer provides the same effort period after period. On the other hand, a *sophisticated* participant always increases her actual performance period by period, and so she provides the targeted outcome if a higher price/penalty is feasible during the first period of the contract; becomes more costly than the provision of it at the more distant periods; (iv) given that the *principal* perfectly knows the type of a time-inconsistent participant, he always offers either $y^T(e^*) = \langle \overline{p}; d_j^* \rangle$ or $y^T(e^*) = \langle \underline{p}_j \rangle$, depends on whether a policy vector d_j^* is feasible. If the answer is yes, then the former contract is offered and the $DI = 0$, whereas if the answer is no, then the latter contract is offered and $DI = d_j^*$.

PROPOSITION 4: Let e^* *be the targeted outcome and* $\overline{p} \geq \phi_E$*. Then:*

a) if $d \geq d_j^*$ *is feasible, then* $y^2(e^*) = \langle \overline{p}; d_j^* \rangle$*is the incentive-compatible contract for a j type individual-farmer,*

b) if $d_N^* \leq d < d_S^*$ *and , then* $y^2(e^*) = \langle \overline{p}; d_N^* \rangle$*is the incentive-compatible contract for a naive agent, and* $y^2(e^*) = \langle \underline{p}_S \rangle$*is the incentive-compatible contract for a sophisticated agent, as long as* $\underline{p}_S \geq \phi_S(2)$*,*

c) if d_N^* *approaches the infinity, then the incentive-compatible contract does not exist for neither naive nor sophisticated individual-farmer*

In the next chapter, we relax the assumption of perfect information and we analyse how the behaviour of an intertemporal time-inconsistent individual-farmer deviates from that of a time-consistent, when the *principal* can only observe her actions according to some probability, but he still perfectly observes and verify her type, both one-period and two-periods contracts. In other words, the purpose of the next chapter is to present the consequences of both the informational and behavioural failures into contract design, when the duration of such contract is both of one and two periods, respectively.

Chapter 4

Theoretical Framework under Moral Hazard

What we have seen so far is that under perfect information, the presence of an intertemporal time-inconsistent individual-farmer does not necessarily imply that the policy-maker needs to offer higher prices in order to motivate participation -in the first place- and provision of the targeted outcome -in the second place. The extend of the impact of dynamic inconsistencies are as the duration of the contract increases, depends on which commitment mechanism is feasible. We saw that if $d_N^* \leq d \leq d_S^*$, then time itself has zero impact into dynamic consistencies if and only if participants are *naive*, whereas if $d \geq d_S^*$, then the *principal* offers $y^2(e^*) = \langle \overline{p}; d_S \rangle$ without caring for the consistency of individual-farmer's time-preferences.

However, reality is more complex and it is usually the case where the Agricultural Agency can observe and verify the actual effort of an individual-farmer only by some probability. This information asymmetry -*moral hazard*-, provides an incentive to *agents* to behave opportunistically. The most common way to overcome these opportunistic actions is through monitoring techniques, which provide to the Agency the necessary information on who complies and who cheats on the contract. For the sake of simplicity, we are going to keep the same assumptions on the characteristics of the *principal* and of the *agents*, respectively. In order to eliminate *moral hazard*, we assume that the principal performs monitoring under which actual effort is observed and verified, and that monitoring is *complete* in a sense that there is no possibility an *agent* who complies with the contract to be detected of cheating and vice versa. In cases where *agents* detect of cheating, they are penalized according to a specific penalty scheme. Let's define as q the probability for an individual-farmer to be detected of cheating on the contract, and $\Theta(e) = \theta(e^* - e)$, is the penalty functon by which the *principal* penalizes the cheaters and $0 < \theta \leq \theta^{max}$ is the marginal penalty which we assume that it cannot exceed a specific level due to technical, political and/or ethical boundaries associated with a very high penalty.

One interesting aspect of this framework under *moral hazard* is that $e \in [0, e^*]$ does not denote the effort itself, but rather reflects the *degree of compliance* with the targeted outcome. Thus, we can define the strategy set for an individual-farmers as Ω={e=e^*,e<e^*,e=0}, where the first term refers to full compliance (we refer to this simply as compliance), the second term refers to partial compliance, and the third term refers to full cheating (we refer to this simply as cheating). Therefore, compliance dominates any other strategy if and only if it provides profits to an individual-farmer that are greater than or equal to profits provided by any other strategy. In the literature this condition is called *incentive-compatibility constraint.* When effort takes continuous values in a predetermine interval, satisfaction of this constraint is equivalent with the determination of the policy tools, under which compliance (i.e. the target) maximizes *agent's* expected profits.

As a consequence, the purpose of this chapter is to present the incentives that *principal* must provide, in order -from one side- to motivate participation and -from the other side- to make compliance towards the targeted outcome the dominant decision. Laffont and Martimort (2009) define a contract that satisfies both these conditions as *incentive feasible.* Therefore, we could say that the purpose of this chapter is to present the impact of dynamic inconsistencies into *incentive feasible* contracts. Following again backward analysis, we determine firstly the condition that make an one-period contract *incentive feasible* for an exponential discounting individual-farmer, and after that we present how these conditions differentiate when individual-farmers have intertemporal inconsistent time-preferences. The last section of this chapter is dedicated to contracts with duration of two periods, in which we present the circumstances under which time itself has a significant impact into decisions of an intertemporal time-inconsistent individual-farmer.

4.1 Individuals with Intertemporal Consistent Time-Preferences

Similar with the case of perfect information, the problem for the Agricultural Agency is to determine these incentives that motivate an individual-farmer to comply with the targeted degree of the adaptation to organic farming practices, provided that an individual-farmer has already singed the contract at $t = 0$. At $t = 1$, the *principal* knows that $self$-1's discounted present value of her expected net benefits is:

$$DPVE\Big[\Pi_1(e)\Big] = \underbrace{(1-q)(-\psi(e) + (I + pe^*)\delta)}_{\text{expected net benefits from not detect of cheating}} + \underbrace{q(-\psi(e) + (I + pe^* - \theta(e^* - e))\delta)}_{\text{expected net benefits from detect of cheating}}$$

The first term on the right-hand side shows $self$-1's expected net benefits from not get caught cheating, whereas the second term on the right-hand side shows her expected net benefits from get caught cheating. The above expression simplifies into:

$$DPVE\Big[\Pi_1(e)\Big] = -\psi(e) + (I + pe^* - q\theta(e^* - e))\delta \tag{4.1}$$

A time-consistent $self$-1 chooses to adapt to organic farming practices by such degree that maximizes (4.1). From the F.O.C. we obtain that $\psi'(e) = q\theta\delta$, where given the quadratic form of our cost function, $\psi(e) = e^2/2$, $self$-1's optimal degree to adaptation to organic farming is:

$$\overline{e} = q\theta\delta$$

where $\overline{e} \leq e^* \rightarrow q\theta \leq e^*\delta^{-1}$. That is, $\overline{e}$ states that an exponential discounting $self$-1 chooses her degree of compliance towards the contract based on her expected marginal cost of cheating. More precisely, given that the *principal* can detect cheaters (i.e. $q > 0$) and penalises them (i.e. $\theta > 0$), $self$-1's optimal response to a policy (q, θ) varies between full and partial compliance, whereas cheating becomes her optimal decision only in cases where at least on of the policy tools (i.e. q and/or θ) equals zero. As a consequence, the problem for the *principal* is to specify the condition under which compliance becomes $self$-1's dominant strategy. That is, an exponential discounting individual-farmer chooses to comply with the contract (i.e. $\overline{e} = e^*$), if her expected marginal cost of cheating equals:

$$q\theta = \overline{p}$$

where as we have already seen $\overline{p} = e^*\delta^{-1}$. That is, as long as the *principal* can impose a policy (q, θ) such that the product of its components equals $\overline{p}$, an exponential discounting individual-farmer has no reason to not fully comply with the contract. Therefore, the policy-maker chooses detection probability:

$$q = \overline{p}\left(\frac{1}{\theta}\right) \equiv f(\theta)$$

where f denotes *principal's* policy function towards compliance with the contract. As a consequence, $self$-1's optimal response (ω_E^*) to any policy function f is:

$$\omega_E^* = \begin{cases} \{e^*\} & \text{if } q \geq f(\theta) \\ \{\overline{e}(\theta, q)\} & \text{if } q < f(\theta) \\ \{0\} & \text{if } f(\theta) = 0 \end{cases}$$

However, the implementation of such policy (i.e. to detect by a probability $f(\theta)$) does not come at zero cost for the policy-maker. That is, the *principal* needs to spend a part of his economic resources into monitoring in order to detect *agents* by a probability q. Thus, the *principal* wants to impose the lowest possible detection probability and at the same time to motivate compliance towards the contract. A closer look at f reveals that if an infinite penalty is feasible, then detection probability approaches to zero, and so the cost of monitoring approaches zero as well[22]. However, a really high penalty is practically, politically and/or ethically infeasible, and so the *principal* chooses the detection probability subject to $\theta \leq \theta^{max}$, where we assume that θ^{max} reflects individual-farmer's tolerance towards penalization. That is, $\theta^{max} \equiv \theta^*$, and so the policy-maker chooses to impose a penalty $\theta = \theta^*$ and to detect by a probability $\overline{q} = f(\theta^*)$, experiencing with that way a cost of monitoring equals $\xi(\overline{q})$. In addition, we can show the followings:

(a) $\theta f'(\theta)/f(\theta) = -1$, where the left-hand side is the elasticity of the policy function (η_e) to percentage changes of the penalty (θ)[23]. That is, $\eta_e = -1$ and it states that for 1% increase (respectively decrease) of the penalty, the detection probability must be decreased (respectively increased) by the same percentage, in order for compliance to still be $self$-1 the dominant strategy. In other words, we could claim that the elasticity of the policy function shows the trade-off between the policy tools q and θ,

(b) Given that $\overline{q} \in (0, 1)$, we can show that [24]$\theta^* \gtreqless d^*$. That is, the penalty that the *principal* imposes for eliminating the impact of *moral hazard* may exceeds the penalty he needs to impose in order to overcome *agent's* behavioural failures under perfect information. Whether $\theta^* > d^*$ depends on the value of the *present bias ratio* (r_β).

Going back one period ($t = 0$) the *principal* knows that contract itself generates profits for an *agent* equal $DPVE\Big[\Pi_0(e)\Big] = -\psi(e)\delta + (I + pe^* - c(e^* - e))\delta^2$, and so *agent's*

[22]The reader can clarify the validity of this argument by considering that the $\lim_{\theta \to \infty} f(\theta) = 0$.

[23]The reader can find more details at section C, in the Appendix

[24]The reader can find a complete proof at section C in the Appendix.

optimal strategy (i.e. the decision the degree of compliance towards the contract) is $e_0 = \arg\max_e DPVE\Big[\Pi_0(e)\Big] \Leftrightarrow e_0 = q\theta\delta = \overline{e}$.

As a consequence, at any pair of policy tools set by the *principal,* an exponential discounting self-0 is willing to sign the contract if and only if:

$$E[DPV\Pi_0(e_0)] \geq DPV\overline{\Pi}$$

$$-\psi(e_0)\delta + (I + pe^* - q\theta(e^* - e_0))\delta^2 \geq A\delta^2$$

$$p \geq \phi_E^M \tag{4.2a}$$

where $\phi_E^M = (A - I)/e^* + q\theta[2e^* - q\theta\delta]/2e^*$ is self-0 net opportunity cost for abandoning her income from agricultural activities produced by conventional farming practices, and hence inequality (4.2a) is self-0 incentive-rationality constraint (IR_E)[25].

As we have already discussed, *principal's* optimal policy for the elimination of *moral hazard* towards an exponential discounting individual-farmer is $\{\theta^*, f(\theta^*)\}$, and therefore IR_E becomes:

$$p \geq \phi_E^M(\theta^*, \overline{q}) \tag{4.2b}$$

where $\phi_E^M(\theta^*, \overline{q}) = 2(A - I)/e^* + e^*/2\delta$. If further we assume that the *principal* offer $\overline{p}$, then inequality (4.2b) converges to the ICC_E (i.e. $\overline{p} \geq \phi_E$). That is, an intertemporal time-consistent individual-farmer is always willing to abandon her conventional farming practices in the favour of a contract for the adaptation to e^*units of organic farming under a subsidy of $\overline{p}$, independently the information that *principal* has on her true actions. In other words, the *principal* always offers $\overline{p} \geq \phi_E$ to intertemporal time-consistent individual-farmers in order to motivate them to sign the contract, independently whether *moral hazard* exists.

Now, we are ready to present our next proposition:

PROPOSITION 5: Let e^* *be the targeted outcome,* $q \in (0, 1)$ *is the detection probability and* $0 < \theta \leq \theta^*$ *denotes the marginal penalty. Then, a contract* $y^1(e^*) = \langle \overline{p}; \{\theta^*, f(\theta^*)\}\rangle$ *is incentive-feasible for a time-consistent individual-farmer if and only if* $\overline{p} \geq \phi_E$.

[25]The reader must note that $IR_E = IR_N$, and so he (or she) can find a complete derivation of it by having a look for the derivation of *naive agent's* incentive-rationality constraint at section B on the Appendix

4.2 Individuals with Intertemporal Inconsistent Time-Preferences

Similarly with the case of exponential discounting individual-farmers, the problem for the Agricultural Agency is to determine these incentives that motivate a hyperbolic discounting *agent* to comply with the contract, provided that she has already singed the contract at $t = 0$. Thus, at $t = 1$, an intertemporal time-inconsistent individual-farmer has discounted present value of her net benefits:

$$DPVE\Big[\Pi_{h1}(e)\Big] = \underbrace{(1-q)(-\psi(e) + (I + pe^*)\beta\delta)}_{\text{expected profits without monitoring}} + \underbrace{q(-\psi(e) + (I + pe^* - \theta(e^* - e))\beta\delta)}_{\text{expected profits with monitoring}}$$

which simplifies into

$$E\Big[DPV\Pi_{h1}(e)\Big] = -\psi(e) + (I + pe^* - q\theta(e^* - e))\beta\delta \tag{4.3}$$

An intertemporal time-inconsistent self-1 chooses degree of compliance $\underline{e}$=arg max$_e$DPVE$\Big[\Pi_{h1}(\mathrm{e})\Big]$, and so from the F.O.C. we have that $\psi'(e) = q\theta\beta\delta$, where given the quadratic form of our cost function, $\psi(e) = e^2/2$, we finally have:

$$\underline{e} = q\theta\beta\delta$$

where $0 < \underline{e} \leq e^* \rightarrow q\theta \leq e^*(\beta\delta)^{-1}$.

That is, given that $q, \theta > 0$, a hyperbolic discounting $self$-1 never chooses to cheat on the contract. Whether she fully or partially comply with it depends on her expected marginal cost of cheating. Therefore, compliance ($\underline{e} = e^*$) becomes the dominant strategy for a hyperbolic discounting $self$-1 if:

$$q\theta = \overline{p}/\beta$$

were $\overline{p} = e^*\delta^{-1}$. That is, as long as the *principal* can impose a policy (q, θ) such that the product of its components equals $\overline{p}/\beta$, a hyperbolic discounting individual-farmer has no reason to does not fully comply with the contract. Therefore, the policy-maker chooses detection probability:

$$q = \overline{p}\left(\frac{1}{\theta\beta}\right) \equiv f_h(\theta)$$

where f_h denotes *principal's* policy function towards compliance with the contract. As a consequence, $self$-1's optimal response (ω_H^*) to any policy function f_h is:

$$\omega_H^* = \begin{cases} \{e^*\} & \text{if } q \geq f_h(\theta) \\ \{\underline{e}(\theta, q)\} & \text{if } q < f_h(\theta) \\ \{0\} & \text{if } f_h(\theta) = 0 \end{cases}$$

In addition, f_h has the following properties:

(a) $\eta_h = \eta_e = -1$. That is, f_h has the same elasticity with f[26]. In other words, the presence of a time-inconsistent decision-maker does not affect the trade-off between policy tools $\{q, \theta\}$, and so percentage changes of the penalty leads to percentage changes of detection probability which is independent from the consistency of *agent's* decisions,

(b) $f_h = f/\beta$, where given that $\beta \in (0, 1)$, we have that $f_h(\theta) > f(\theta)$. That is, an intertemporal time-inconsistent individual-farmer requires a higher penalty than a time-consistent individual-farmer in order to comply with the contract under the same penalty θ,

(c) $f(\theta) < f_h(\theta) < 1$, and therefore the penalty that the *principal* imposes to hyperbolic discounting *agents* (θ_h) in order to overcome *moral hazard* is more likely to exceed the penalty he imposes to overcome their behavioural failures than the penalty he imposes to exponential discounting *agents* (θ_e) in order to overcome *moral hazard.* That is, the sign of the inequality $\theta_h \gtrless d^*$ also depends on the value of r_β. In cases, however, where the *principal* can impose $\theta_h > \theta_e$, this penalty is more likely to exceed d^*.

Going back one period ($t = 0$), an intertemporal time-inconsistent $self_j$-0 considers the choice of participation. At that point of time, the discounted present value of her expected profits from the contract is $\text{DPVE}\Big[\Pi_{h0}(\text{e})\Big]$=-$\psi$(e)$\beta\delta$+(I+pe*-q$\theta$($e^*$-e))$\beta\delta^2$, and so $self_j$-0 plans to comply with the contract by the degree of $e_{h0} = \arg\max_e DPVE\Big[\Pi_{h0}(e)\Big]$. However, at that point of time an hyperbolic discounting individual-farmer is either *naive* or *sophisticated,* and therefore her decision regarding participation depends on her beliefs on whether $self$-1 is going to comply with the contract by e_{h0}. Thus, $self_j$-0 considers participation on the degree of compliance $\varepsilon_j = b_j e_{h0}$, and so she chooses to participate if and only if

$$E[DPV\Pi_{h0}(\varepsilon_j)] \geq DPVA$$

[26] The reader can find a complete explanation at section C in the Appendix

$$-\psi(\varepsilon_j)\beta\delta + (I + pe^* - q\theta(e^* - \varepsilon_j))\beta\delta^2 \geq A\beta\delta^2$$

$$p \geq \phi_j^M \tag{4.4a}$$

where $\phi_j^M = (A - I)/e^* + b_j q\theta[2e^* - q\theta\delta(2 - b_j)]/2e^*$ is $self_j$-0's net opportunity cost, and hence inequality (4.4a) is $self_j$-0's incentive-rationality constraint (IR_j).

Furthermore, the *principal* knows that once the contract begins, a hyperbolic discounting individual-farmer complies with the contract under a policy $\{\theta, f_h(\theta)\}$, and so inequality (4.4a) becomes:

$$p \geq \phi_j^M(\theta, f_h(\theta)) \tag{4.4b}$$

where $\phi_j^M(\theta, f_h(\theta)) = 2(A - I)/e^* + e^*/2\delta$, and also $\phi_j^M(\theta, f_h(\theta)) = \phi_E^M(\theta, f(\theta))$, and so That is, both an exponential discounting *agent* and a hyperbolic discounting *agent* (both *naive* and *sophisticated*) have the same net opportunity cost, and hence they require the same price in order to abandon their conventional farming practices and to adapt to organic farming by the degree of e^*. Thus, if the *principal* offer $\overline{p} \geq \phi_E$, the both exponential and hyperbolic discounting *agents* are willing to sign the contract. Therefore, we are ready to present our sixth proposition:

PROPOSITION 6: *Let* e^* *be the targeted outcome,* $q \in (0, 1)$ *is the detection probability and* $\theta > 0$ *denotes the marginal penalty imposed to hyperbolic discounting agents. Then,* $y^1(e^*) = \langle \overline{p}; \{\theta, f_h(\theta)\}\rangle$ *is the incentive-feasible for any type j time-inconsistent decision-maker if and only if* $\overline{p} \geq \phi_E$.

A brief conclusion from our so far analysis under imperfect information is that at the end of the day, both *naive* and *sophisticated* individual-farmers behaves exactly the same, in a sense that at any policy $\{\theta, f_h(\theta)\}$ they make the same plans over future degree of compliance, they require the same price in order to sign the contract, and once the contract begins they actually comply on the contract by the same degree.

However, there is a difference between *naive and sophisticated agents* regarding the actual values of the penalty and of the detection probability. The reader can recall that the maximum feasible penalty for an exponential discounting individual-farmer is θ^*. However, there is nothing to indicate that a *sophisticated* individual-farmer has necessarily the tolerance towards penalization (and hence the same θ^{max}). It might be the case where she has higher tolerance towards penalization than an exponential discounting, due to her self-awareness of the inconsistency of her decisions. If we use θ_h^* to denote the maximum feasible penalty for a *sophisticated agent,* then for the sake of simplicity we assume that $\theta_h^* = \theta^*/\beta$. Finally, let's say that $\overline{p} \geq \phi_E$, and so both $self_N$-*0* and $self_S$-0 are willing to sign the contract.

At $t = 0$, the *principal* knows that a *naive agent* believes exactly the same with exponential discounting *agents,* and so they cannot accept a penalty higher than θ^*. In that case, a *naive agent* complies with the contract under a policy $\{\theta^*, f_h(\theta^*)\}$. On the other hand, a *sophisticated agent* is aware of the intertemoral time-inconsistency of her time-preferences and therefore she has higher tolerance towards penalization. In that case, the *principal* can motivate compliance towards under a policy $\{\theta_h^*, f_h(\theta_h^*)\}$.

A comparison between these two policies reveals that $f_h(\theta^*) > f_h(\theta_h^*)\ \forall\beta \in (0, 1)$. That is, a *naive agent* requires a higher detection probability than a *sophisticated agent,* and hence the presence of the former increases the economic resources that the policy-maker needs to spend on monitoring. That is, even though both types of hyperbolic discounting individual-farmers have the same policy function $f_h(\theta)$, the presence of beliefs regarding the consistency of their decisions determines the penalty that the policy-maker imposes in order to motivate compliance towards the target, and hence beliefs determine the impact of dynamic inconsistencies as it reflected in the cost of monitoring. More precisely, one can easily verify that $f_h(\theta_h^*) = f(\theta^*)$, and so the cost for the *principal* of having a *sophisticated agent* is $\xi\Big(f_h(\theta_h^*)\Big) - \xi\Big(f(\theta^*)\Big) = 0$. On the other hand, $f_h(\theta^*) > f(\theta^*)$ and therefore the presence of a *naive agent* creates a cost for the *principal* equals

$$DI^M \equiv \xi\Big(f_h(\theta^*)\Big) - \xi\Big(f(\theta^*)\Big) = \frac{\overline{p}}{\theta^*}\bigg(\frac{1-\beta}{\beta}\bigg)$$

In other words, the impact of dynamic inconsistencies into contract design when *moral hazard* also exists (DI^M) equals

$$DI^M = \frac{DI}{\theta^*} = \frac{d^*}{\beta\theta_h^*}$$

given that $\theta_h^* = \theta^*/\beta$.

PROPOSITION 7: The presence of different beliefs regarding the consistency of an agent's decisions will determine the impact of a hyperbolic discounting individual-farmer into contract design when moral hazard exists. More precisely, *a) If an agent is naive, then* $\{\theta^*, f_h(\theta^*)\}$ *is the optimal policy, which creates a cost to the principal equals* DI^M*,*

b) If an agent is sophisticated, then $\{\theta_h^*, f_h(\theta_h^*)\}$ *is the optimal policy, which creates zero cost to the principal.*

The interesting point is that, the *principal* does not necessarily needs to detect *naive agent* with the higher probability $f_h(\theta^*)$. In cases where participants are unaware of their intertemporal inconsistency of their decisions, the policy maker can always impose a policy $\{\theta^*, f(\theta^*)\}$, allowing to them to partially comply on the contract begins. However, at $t = 0$ a *naive agent* behaves of being an exponential discounting individual-farmer, and therefore she falsely believes that under such policy scheme, $self$-1 is going to comply with the contract. Thus, the *principal* needs to overcompensate her, in a sense that he needs to offer a subsidy that corresponds to compliance (i.e. $\overline{p} \geq \phi_E$) for a degree that corresponds to partial compliance. As a consequence, *principal's* decision on whether to impose the policy $\{\theta^*, f(\theta^*)\}$ or $\{\theta^*, f_h(\theta^*)\}$ to a *naive* hyperbolic discounting individual-farmer is determined by:

$$\xi(f_h(\theta^*)) \leq \underbrace{[U(e^*) - U(\beta e^*)]}_{\text{utility loss}} \tag{4.5}$$

That is, the Agricultural Agency has an incentive to bear the cost associated with the higher monitoring if and only such cost does not exceed *principal's* utility loss by allowing to *naive* individual-farmer to partially comply with the contract.

In this section of our theoretical analysis we developed our framework for the adaption of a predetermine degree to organic farming practices under imperfect information, when the contractual agreement between the Agricultural Agency and individual-farmers is of one period. Our key finding is that the presence of a hyperbolic discounting individual-farmer does not necessarily creates serious problems for the policy-maker, as this problems are reflected into monitoring costs. Given that the *principal* can always impose a policy $\{\theta^*, f(\theta^*)\}$ the impact of dynamic inconsistencies determines exclusively by the *principal's* ability to observe and identify the beliefs of an hyperbolic discounting individual-farmer regarding the consistency of her time-preferences.

However, when the duration of such contracts are more than one periods, participants either choose to play the same strategy every period or they may choose to play a different strategies depending on the time period. For this reason, the next part of this section is dedicated to present both the impact of time itself and dynamic inconsistencies into contract with *moral hazard.*

4.3 A Two-Periods Theoretical Framework under Imperfect Information

In the previous section we presented how hyperbolic discounting *agents* affects contracts for the provision of agri-environmental goods and services under imperfect information and when the duration of such contract is only for one period. Here, we are going to relax this assumption by expanding time horizon into two periods ($T = 2$), keeping at the same time all the other assumptions and simplifications constant. For the same reasons as we explained in two-periods contracts under perfect information, our analysis concerns only the incentives under which a two-periods contract becomes *incentive-feasible* for an intertemporal time-inconsistent individual-farmer.

When the policy-maker offers a two-period contract, participants have a set of strategies Ω^2, which does not necessarily consist by the same strategies period after period. As a consequence, the problem for the him is to determine the *incentive-feasible* contract for an j type intertemporal time-inconsistent individual-farmer, by choosing a menu of policies which are consisted by penalties $\theta_{j,t}$ and detection probabilities $q = f_{j,t}(\theta)$, and so the *principal* imposes the policy vector $F_j = \Bigg(\{\theta, f_{j,1}(\theta)\}; \{\theta, f_{j,2}(\theta)\}\Bigg)$.

The stages of this two-periods framework with moral hazard can be presented by figure 4, where at $t = 0$ the *principal* offers the contract, at period $t = 1$ participants choose current and future strategies, from which current actions will be observed and verified at the next period. At $t = 2$, individuals choose again their new actions, which in turn will be observed and verified when contract ends ($t = 3$). Thus, we obtain the *incentive-feasible* contract by solving the intertemporal game between the *principal* and $self_j$-t backwards.

At $t = 2$, both *sophisticated* and *naive* individual-farmers have discounted present value of their expected net benefits:

$$DPVE\Big[\Pi_{h2}(e)\Big] = -\psi(e) + (I + pe^* - q\theta(e^* - e))\beta\delta \tag{4.6}$$

One can easily observe that (4.6) is identical with (4.3). Hence, an intertemporal time-inconsistent self-2 exerts effort $\underline{e}_2 = q\theta\beta\delta = \underline{e}$, and so compliance becomes her dominant strategy under a policy function $\{\theta, f_{j,2}(\theta)\}$, where $f_{j,2}(\theta) = f_h(\theta) = \overline{p}/\beta\theta$.

Going one period back ($t = 1$), an intertemporal time-inconsistent $self_j$-1 has discounted present value of expected her net benefits

$$DPVE[\Pi_{h1}(e_1, e_2)] = \underbrace{-\psi(e_1) + (I + pe^* - q\theta(e^* - e_1))\beta\delta}_{\text{current effort}} - \underbrace{\psi(e_2)\beta\delta + (I + pe^* - q\theta(e^* - e_2))\beta\delta^2}_{\text{future effort}} \tag{4.7}$$

where e_2 denotes $self_j$-1 plans for future effort. That is, (4.7) states that $self_j$-1 expected profits depend not only on her current degree of compliance, but also on what $self$-2 is going to do. Therefore, maximizing (4.7) with respect to both e_1 and e_2 we obtain the optimal conditions $\psi'(e_1) = q\theta\beta\delta$ and $\psi'(e_2) = q\theta\delta$, respectively, which in turn provides the optimal relationship between current and future degree of compliance towards the contract: $e_1 = \beta e_2$. However, at that point of time an individual-farmer is either aware or unaware of her intertemporal time-inconsistency of her decisions, and so she has different beliefs up to which point her current plans (that is, e_2) actually carried out by $self$-2. Thus, $self_j$-1 does not choose her optimal strategy directly on e_2, but rather on another effort that takes into account her beliefs regarding $self$-2 actions. Using $\varepsilon_{j,1}$ to denote such effort, we have that $\varepsilon_{j,1} = b_j e_2$. Thus, a $self_j$-1's optimal strategy is $\underline{e}_{j,1} = \beta b_j e_2$, which in turn becomes

$$\underline{e}_{j,1} = \begin{cases} q\theta\delta\beta & \text{if } j = N \\ q\theta\delta\beta^2 & \text{if } j = S \end{cases}$$

As a consequence, a $self_N$-1 complies with the contract under a policy $\{\theta, f_{N,1}(\theta)\}$, where $f_{N,1}(\theta) = f_{j,2}(\theta)$, whereas a *sophisticated agent* complies with the contract under a policy $\{\theta, f_{S,1}(\theta)\}$, where $f_{S,1}(\theta) = \overline{p}/\theta\beta^2$. As a consequence, the *principal* offers the policy vector $F_S = \Big(\{\theta, f_{S,1}(\theta)\}; \{\theta, f_{S,2}(\theta)\}\Big)$ and $F_N = \Big(\{\theta, f_{N,1}(\theta)\}; \{\theta, f_{N,2}(\theta)\}\Big)$ to a *sophisticated* and to *naive agent*, respectively in order to motivate compliance at every period.

4.3.1 The Impact of Time into j-Type Optimal Strategies

When contracts expand to more than one periods, dynamic inconsistency reveals some interesting aspects of individual-farmer's behaviour: (i) we can easily verify that

$\underline{e}_{N,1}>\underline{e}_{S,1}$ $\forall\beta(0,1)$. That is, $self_N$-1 is willing to do more (and hence to comply more) than a $self_S$-1 at any possible pair of $(\theta, f(\theta))$; (ii) $\underline{e}_{N,1} = \underline{e}_2$, and so an unaware intertemporal time-inconsistent decision-maker plays the same strategy over compliance among periods, once the contract begins; (iii) in contrast with *naive* optimal decisions, a *sophisticated agent* has the tendency to comply more as times approaches the end of the contract ($\underline{e}_{S,1} < \underline{e}_2$). In addition, given that her optimal effort takes continuous values, a *sophisticated* decision-maker never plays the same strategy period after period, unless the policy vector F_S is feasible. We can present these results by considering the following scenarios, in which the *principal* chooses the policy function $f_{j,t}(\theta)$, (i.e. the detection probability that enforces participants to comply with the contract) which will be imposed at every period t, and *agent's* optimal strategy set is defined as $\omega_j^* = \{\underline{e}_{j,1}, \underline{e}_2\} \subset \Omega^2$:

(a) *the principal imposes a policy function $f(\theta) = \overline{p}/\theta$ at every period:*

Once the contract begins, an unaware individual-farmer exerts effort $\underline{e}_{1,N} = \underline{e}_2$, and so both $self_N$*-1* and self-2 choose to partially comply with the contract at $t = 1$ and $t = 2$, respectively. In addition, an aware participant also chooses to partially comply with the contract at both periods, but the effort she provides at $t = 1$ is lower than that of $self_N$-1's. That is, $self_S$-1chooses to comply by the degree of $\underline{e}_{S,1} = \beta^2 e^* < \underline{e}_{N,1} = \beta e^*$. Thus, optimal strategy sets for a *naive* and a *sophisticated* individual-farmer under such policy scheme is

$$\omega_N^* = \{\beta e^*, \beta e^*\} \text{ and } \omega_S^* = \{\beta^2 e^*, \beta e^*\}$$

respectively,

(b) *the principal imposes a policy function $f_{N,1}(\theta) = f_{j,2}(\theta) = \overline{p}/\beta\theta$ at every period:*

In that case, an unaware individual-farmer exerts effort $\underline{e}_{1,N} = \underline{e}_2$, and so both $self_N$*-1* and self-2 comply with the contract at every period. On the other hand, an aware participant exerts effort equals $\underline{e}_{S,1}$ and $\underline{e}_2$ at $t = 1$ and $t = 2$, respectively. Thus, her best response to such policy function is to partial comply at the first period, but she finds optimal to comply at the second one. Thus, optimal strategy sets for a *naive* and a *sophisticated* individual-farmer under such policy scheme is

$$\omega_N^* = \{e^*, e^*\} \text{ and } \omega_S^* = \{\beta e^*, e^*\}$$

respectively,

(c) *the principal imposes a policy function* $f_{S,1}(\theta) = \overline{p}/\beta^2\theta$ *at the first period and* $f_{j,2}(\theta)$=$\overline{p}/\beta\theta$ *at the second period:*

Here, both *naive* and *sophisticated* individual-farmers comply with the contract at every period. The reason is that $\underline{e}_{N,1}, \underline{e}_2 \leq e^*$, and so any for any detection probability $q \geq f_{j,2}(\theta)$ a *naive agent* has an incentive to comply with the contract. In addition, we can easily verify that under a detection probability $q = f_{S,1}(\theta)$ a *sophisticated* $self$-1 finds optimal to comply at the first period (i.e. $\underline{e}_{S,1}(f_{S,1}(\theta) = e^*)$. Moreover, we saw that a *sophisticated agent*, also complies with the contract at $t = 2$ under a policy function $f_{j,2}(\theta)$. Thus, optimal strategy sets for a *naive* and a *sophisticated* individual-farmer under such scheme is:

$$\omega_N^* = \{e^*, e^*\} \text{ and } \omega_S^* = \{e^*, e^*\}$$

respectively,

The above three different scenarios regarding the policy functions (i.e. detection probabilities) that the *principal* chooses to impose in order to motivate a hyperbolic discounting individual-farmer to comply with the contract at every period highlight an important result: When it comes to actual degrees of compliance towards the contract, time itself has zero impact into compliance decisions for a *naive agent*, since for a given policy function she chooses the same degree of compliance at every period. On the other hand, if *agents* are *sophisticated,* then the total duration of the contract affects her decisions over the pre-period degree of compliance, since a *sophisticated agent* has the tendency to comply less during the first period of the contract. In other words, we could say that time itself has zero impact into *naive agent's* decisions towards compliance with the contract.

4.3.2 The Impact of Time into Participation Decisions

Going back one period ($t = 0$) , a time-inconsistent $self_j$-0 does not need to exert any effort at all. The only decision she needs to take is whether participation is profitable for her. At that point of time, $self_j$-0 discounted present value of her expected net benefits is

$$DPVE\Big[\Pi_{h0}(e_{01}, e_{02})\Big] = \sum_{t=1}^{2} \beta\delta^t[-\psi(e_{0t}) + (I + pe^* - q\theta(e^* - e_{0t}))\delta] \tag{4.8}$$

and so she plans to comply at $t = 1$ and $t = 2$ by $\psi'(e_{01}) = \psi'(e_{02}) = q\theta\delta$. However, at that point of time an individual-farmer is either *naive* or *sophisticated*, and thus a hyperbolic discounting $self$-0 has different beliefs on whether such plans actually fulfilled by $self_j$-1 and $self$-2, respectively. In addition, we saw that $self_j$-1 either *sophisticated* or *naive,* and therefore $self_j$-1 has different beliefs regarding the consistency of her plans with $self$-2 actual actions. Thus, $self_j$-0's pre-period "believed" efforts are ε_j=($b_j^2 e_2$,$b_j e_{02}$), where $e_2 = e_{02}$. Since the *principal* can perfectly observe the type of a hyperbolic discounting individual-farmer, he has no interest of imposing a different policy vector than F_S or F_N, when *agents* are *sophisticated* or *naive,* respectively. Thus, a hyperbolic discounting $self_j$-0 signs the contract if and only if

$$E\Big[DPV\Pi_{h0}\Big(e^*, e^*\Big)\Big] \geq DPVA$$

$$\sum_{t=1}^{2}\Big(-\psi(e^*)\beta\delta^t + (I + pe^*)\beta\delta^{t+1}\Big) \geq A\beta\delta^2(1+\delta)$$

$$p \geq 2(A - I)/e^* + e^*/2\delta \tag{4.9}$$

That is, inequality (4.9) is $self_j$-0 incentive-rationality constraint, and for $p = \overline{p}$ it is given by $\overline{p} \geq \phi_E$. In other words, both in one-period and in two-periods contract, the *principal* needs to "secure" that a pre-period subsidy such that $\overline{p} \geq \phi_E$ is feasible, and so we could conclude that time itself has zero impact into participation decisions, provided that the policy-maker can observe and identify the type of a hyperbolic discounting individual-farmer, and hence to impose the necessary policy vector F_j.

4.3.3 The Impact of Beliefs into Two-Periods Contracts

Suppose that $\overline{p} \geq \phi_E$ is satisfied, and so both *naive* and *sophisticated* individual-farmers sign the contract at $t = 0$. In addition, let's recall that the maximum feasible penalty for a j type intertemporal time-inconsistent decision-maker is

$$\begin{cases} \theta_N^{max} \equiv \theta_E^{max} = \theta^* & \text{if } j = N \\ \theta_S^{max} = \theta_h^* & \text{if } j = S \end{cases}$$

At $t = 0$ the *principal* knows the type of a hyperbolic discounting individual-farmer, and hence he can impose either F_S or F_N. However, neither of such policy vectors come at zero cost for the policy-maker. The reason lies again on different beliefs that *naive* and *sophisticated agents* have at that point of time. More precisely, a $self_N$-0 behaves exactly the same with an exponential discounting individual-farmer, and so the *principal* cannot impose to him a penalty higher than θ^*. As a consequence, the policy-maker can motivate compliance towards the contract if at every period he can bear the cost of monitoring $\xi\Big(f_h(\theta^*)\Big)$. On the other hand, a *sophisticated agent* also creates a cost for the *principal.* The reason is that at $t = 1$, the maximum penalty that the *principal* can impose is θ^*_h, and therefore he needs to bear the cost for motivating *sophisticated agent* to comply with the contract by imposing a detection probability $f_{S,1}(\theta^*_h)$, which is higher than that in one-period contract ($f_{S,1}(\theta^*_h) > f(\theta^*_h)$). However, this cost does not hold fo too long, since at the next period the policy-maker can shift it to the side of participants by imposing again a penalty θ^*_h, but now a lower detection probability $f_{S,2}(\theta^*_h)$. As a consequence, a *sophisticated* hyperbolic discounting decision-maker has strong incentives to report of being *naive,* and hence she enforces the *principal* to bear entirely the cost of compliance both at two periods.

In conclusion, this dynamic analysis under *moral hazard* highlights that: (i) time itself has zero impact into participation decisions for both *naive* and *sophisticated* individual-farmers, and hence the *principal* always offer $\overline{p} \geq \phi_E$, independently the consistency of an *agent's* decisions; (ii) the degree of self-awareness (i.e. beliefs) determine optimal efforts (and hence strategies) during the first period of the contract, and so the Agricultural Agency does not necessarily impose the same policy vector to both *sophisticated* and *naive* participants; (iii) time itself matters only for *sophisticated* individual-farmers, since the degree of compliance during the first periods becomes lower and lower as the duration of the contract increases, and so the higher is the duration of the contract, the higher is the detection probability (i.e. the higher is the policy function) that the policy-maker needs to impose in order to motivate compliance towards the contract; (iv) the impact of an intertemporal time-inconsistent decision-maker into contract design -as it reflected in monitoring costs- is determined by her beliefs at $t = 0$, and hence by which penalty the *principal* can impose;

Chapter 5

Does Inter-Temporal Time-Inconsistency Matters?

5.1 A Discussion of the Results

The purpose of this dissertation was to present the impact of an intertemporal time-inconsistent decision-maker into contract design for the provision of agri-environmental goods and services, under perfect and imperfect information, respectively.

Unfortunately, we cannot give a straight answer on whether hyperbolic discounting individual-farmers creates serious problems for the policy-maker. What we can say for sure, is that their impact depends on her beliefs regarding the intertemporal consistency of their time-preferences and the duration of the contract, both when the Environmental Agency has perfect and imperfect information on their true actions.

More precisely, we proved that under perfect information[27]:

(a) Both a time-consistent and a time-inconsistent decision-maker (*naive* and *sophisticated*) make the same plans for future the future,

(b) If $T = 1$, then both a *naive* and a *sophisticated* individual-farmer exert the same effort once the contract begins. If, however, $T > 1$ (e.g. $T = 2$) then, a *naive* individual-farmer always provide more effort in the first period than a *sophisticated*, but the latter always increases her performance in the second one, whereas the performance of the former remains the same,

(c) An unaware individual-farmer has lower opportunity cost than an aware individual-farmer ($\phi_N < \phi_S$), and so participation of the former does not necessarily implies that the latter will also abandon her conventional agricultural activities in favour

[27] These results hold for both one-period and two-period contracts, unless it specifies different.

of the contract, but the opposite always holds. In addition, we presented that the opportunity cost for a *sophisticated* participant increases as the duration of the contract increases ($\phi_S(2) > \phi_S(1)$), but the opportunity cost of a *naive* participant remains unaffected,

(d) Results (b) and (c) states that under perfect information time itself matters only for *sophisticated* individual-farmers,

(e) The Environmental Agency can overcome the problems of a hyperbolic discounting decision-maker by imposing a commitment mechanism, which its value depends on the *present bias ratio* ($(1 - \beta)/\beta$). The higher is the degree of *present bias* (i.e. low values of β), the stricter (i.e. higher value) is the commitment mechanism,

(f) The impact of a hyperbolic discounting decision-maker depends on whether a penalty d^* is feasible. In one-period contracts if $d \geq d^*$, then a contract $y^1(e^*) = \langle \overline{p}; d^* \rangle$ is *incentive compatible* for both *naive* and *sophisticated* individual-farmers. In that case, their presence creates zero problems for the policy-maker, whereas in any other case the *principal* pays entirely the cost of their presence (DI). On the other hand, in a two-periods contracts the situation is more complex, since the beliefs of the participant determines which of the penalty vectors d^*_S or d^*_N the policy-maker imposes, and hence which is the impact of an intertemporal time-inconsistent decision-maker into contract design,

(g) The above result states that when the *principal* perfectly observes the actions of the participants and $T = 1$, then beliefs do not matter for the policy-maker. As long as T increases, the higher is the role of beliefs for the determination of the consequences of intertemporal time-inconsistent decision-makers into contract design,

However, it is more realistic to consider situations where the *principal* has limited information on the degree in which participants actually comply with the contract. Due to this information asymmetry, the penalty that the *principal* imposes does not only try to solve *agents'* strategic actions, but also to eliminate problems that individual-farmer's behavioural failures creates into contract design.

More precisely, we proved that when *moral hazard* exists[28]:

(a) Under imperfect information, both planned and actual strategies depend on participant's expected marginal cost of cheating, and hence on which policy function

[28] Again, these results hold for $T \geq 1$, unless it specifies differently

the Environmental Agency imposes,

(b) For $T \geq 1$, the type of a time-inconsistent decision-maker determines the impact of dynamic inconsistencies, since a *naive agent* requires a higher detection probability than a *sophisticated agent,*

(c) Both time-consistent and time-inconsistent individual-farmers plan to play the same strategy (i.e. to provide the same effort) at $t = 0$, and both *naive* and *sophisticated* participants comply by the same degree once the contract begins,

(d) Intertemporal time-inconsistency of an individual decisions does not affect the trade-off between the policy tools for the elimination of *moral hazard,*

(e) Since strategies (i.e. efforts) for both exponential and hyperbolic discounting decision-makers do not depend on the price, the *principal* needs to ensure that the targeted outcome itself generates profits to participants that are least equal to profits from conventional agricultural activities. Hence, the Environmental offers the same price to everyone, which it equals to the price for the provision of e^* under perfect information,

(f) Result (e) states that for $T \geq 1$, dynamic inconsistencies affect only compliance conditions, and so its consequences for the policy-makers reflect in the values of the policy tools that the *principal* must implement,

(g) The existence of maximum ethical penalties implies that even when $T = 1$, the identification of $self_j$-0 beliefs matters because the *principal* might need to apply different penalty (or detection probability) between *naive* and *sophisticated* individual-farmers. In other words, beliefs determine the impact of dynamic inconsistencies under *moral hazard* even for one-period contracts,

(h) When $T > 1$, then *naive agents* do not have necessarily the same optimal strategy set with *sophisticated agents.* What we presented in this dissertation is that in dynamic contracts, *naive* have the tendency to comply more during the first periods of the contract, and this decision over the degree of compliance remains the same throughout T. In other words, the optimal strategy set for an unaware individual-farmer consists by the same pre-period strategy. On the other hand, the optimal strategy set for a *sophisticated* individual-farmer consists of different strategies, unless a decreasing policy vector F_S is feasible,

(i) The above results imply highlight that time itself matters only for aware inter-temporal time-inconsistent decision-makers. We also saw that the higher is the duration of the contract, the higher is the tendency for a *sophisticated agent* to cheat during the first period of the contract, and hence the cost of their presence into contract design increases as the duration of the contract increases,

The main result that comes straightforward from this brief presentation of our key findings between perfect and imperfect information is that hyperbolic discounting individual-farmers do not necessarily create serious problems for the policy-maker, independently how symmetric is the information that the Environmental Agency has on participant actual performance. What we say for sure is that individua-farmer's beliefs regarding the intertemporal consistency of her time-preferences, the existence of maximum feasiblel penalties, and the duration of the contract are the key factors that determines the impact of dynamic inconsistencies into contract design.

The reason is that both under perfect and imperfect information beliefs determine actual performance during the first period of the contract (i.e. when $T > 1$) and participation decisions (under perfect information, when also $T \geq 1$).

If for the sake of simplicity we take as granted that an intertemporal time-inconsistent decision-maker signs the contract, then the problem for the Agency is to specify the penalty scheme that motivates either provision of the targeted outcome (perfect information) or compliance (imperfect information) with it. Whether such policy scheme is feasible depends on whether its value exceed the maximum ethical penalty for a hyperbolic discounting decision-maker.

However, we saw that not every type of intertemporal time-incosistent individual-farmers have necessarily the same maximum tolerance levels towards penalization, and hence not every type creates the same problems for the policy-makers. That is, beliefs provide the necessary information on the *principal* on which is the maximum penalty he can impose to every type of hyperbolic discounting individual-farmer, and hence to determine whether the presence of a j types creates problems for the policy-maker.

If we extend the duration of the contract to more than one periods, then the role of the maximum feasible penalty -and hence of beliefs- becomes even crucial, because *sophisticated agents* requires even a higher penalty in the beginning of the contract in order to provide (or to comply with) the targeted outcome.

However, the importance of the time itself is so high relative to beliefs. The validity of this argument lies on the assumptions of our theoretical framework, and more precisely on the assumption that both planned and actual effort take continues values in an interval $[0, e^*]$, instead of between two values $\{0, e^*\}$, as it is the case in many theoretical frameworks that analyse the impact of *moral hazard* into contract design (e.g Fraser (2002, 2012, 2004); Choe and Fraser (1999); Heyes (2000); Hölmstrom (1979)). As a consequence, for any $T \geq 1$ the *principal* can impose d^*(or $f_h(\theta)$ under imperfect information) at every period, allowing to *sophisticated agents* to under provide (or partially comply with) the targeted outcome. In that case, we could claim that time itself is a minor factor into contract design for the provision of an (agri)environmental outcome.

Another implication of the assumption of continues effort is that one could argue that in cases where (agri)environmental policy is not a priority, then the *principal* can always offer exactly the same contract to both exponential and hyperbolic discounting individual-farmers, obtaining from the latter a positive outcome that can be interpreted as second-best outcome. Thus, intertemporal time-inconsistent decision-makers do not make *moral hazard* even a more serious problem.

We favour this argument in the context that beliefs determine the consequences of dynamic inconsistencies into contract design, and so when (agri)environmental policy is a top priority for the Environmental Agency, then *principal* economic resources must primarily spend in the identification of the beliefs of an intertemporal time-inconsistent decision-maker, rather than in these resources (i.e. monitoring expenses) that makes compliance her dominant strategy. In other words, we favour the claim that *adverse selection* on the type of an intertemporal time-inconsistent decision-maker seems to create more serious problems for the *principal,* rather than the problems that *moral hazard* creates by itself.

5.2 Problems and Areas for Further Research

In this dissertation we tried to analyse the impact of dynamic inconsistencies into (agri)environmental contracts, in which the *principal* delegates to participants the provision of a predetermine target, under a compensation scheme.

In our framework, we assume that participants are individuals, whose the primary source of income comes from conventional agricultural activities, and hence every single individual needs to provide the target. However, one might argue that in reality the provision of an (agri)environmental target is too costly for a single person. Instead, farmers have the tendency to organise in unions and the delegation is between the *principal* and the union. In that case, the union as a form of an institution, behaves consistently, and hence its choices over provision (or compliance) are the same at any point of time. As a consequence, dynamic inconsistencies of individula decisions are "irrelevant" when it comes to (agri)environmental policy.

Another problem that might arise is that non every individual-farmer has the same degree of *present bias*, and the assumption that individuals lack of self-learning processes from previous actions is unrealistic. Thus, an *naive agent* may becomes *sophisticated* somewhere in between the duration of the contract.

A third opposition to our theoretical analysis could on the assumption that e^* is the per-period outcome. One could claim that in cases where individuals have all the necessary means to provide the targeted outcome by themselves, however they may not provide it every single period. In other words, a more realistic approach could to assume that e^* is the cumulative targeted outcome. Even though such modification has zero impact into one-period contracts, it might have serious implications in multi-periods contracts, even in cases where participants are *naive.*

A fourth "drawback" of our theoretical analysis is that we internally assume that actual effort of an individual does not affect -either positive or negative- the utility of another individual, who may not participate in the agreement. In other words, in this dissertation we do not take into account neither positive nor negative externalities of participant actual performance. However, many agri-environmental targets have spatial implication -even in cases where they concern the use and development of a land that is privately owned-, and so these must also be included into the frame.

Finally, in our frame both compensation and penalty schemes (i.e. both commitment mechanism and the penalty for cheating) are expressed in monetary terms. However, individual-farmers may be positive intrigue towards environmental protection, and therefore the implementation of a mix policy with non-monetary (i.e. certificates) and monetary incentives may provide to the *principal* a more efficient solution to the problem of behavioural failures.

Chapter 6

Conclusion

Closing this dissertation, one needs take into consideration that our purpose was not to present a theoretical framework that captures all the parameters that might affect individual's decision-processes, but rather to emphasize on the incentives that a dynamic inconsistencies individual requires in order to provide (or comply) a predefine (agri)environmental target, and how these incentives differentiate relative to the classical assumption that individual's decisions are intertemporal consistent.

In the introduction we stated that "... our purpose is to provide a reliable answer on how agricultural contracts for the adaptation to organic farming practices should be designed when dynamic inconsistencies on participant decisions and moral hazard exists?". Our main key finding is that when the policy-maker has perfect information on participants actual action, the policy-maker either offers a higher price or he imposes a commitment mechanism. The choice between these two alternatives depends on the feasibility of a commitment mechanism, independently the duration of the contract. However, when contracts extend to more than one periods, someone's belies regarding her self-awareness on the consistency of her decisions becomes a major factor, because they indicate to the policy-maker the value of the commitment mechanism. As a consequence, the policy-makers ability to perfectly observe and verify the type of a hyperbolic discounting decision-maker is the factor that determines the extent of the impact of dynamic inconsistencies into multi-period contracts.

Similar result holds when the *principal* can only observe and verify participant's actions by some probability. However, information asymmetry on *agent's* performance indicates that beliefs becomes an important factor, even for when contracts are of one period. Even though beliefs do not determine optimal strategies, they -however- determine the penalty that the policy-maker can impose, and hence the detection probability, which in turn will show the impact of a dynamic inconsistent individual-farmer. The need for the identification of beliefs becomes even higher when the duration of the contract extend to multiple periods. In that case, a *sophisticated* participant has the tendency to comply lower and lower during the first periods as T increases. The implication is that if we assume that T is high enough, then compliance during the first periods becomes too costly for the *principal,* since the probability of monitoring becomes too high and hence, the cost of monitoring increases as well. As a consequence, it is reasonable to argue that when participants are *sophisticated* and T approaches to infinity, *incentive-feasible* contracts do not exists for such type of individual-farmers, since the cost of monitoring during the first periods approaches the infinity.

To sum up, we claim that in cases where penalties are restricted to some maximum value and the *principal* cannot perfectly observe and verify participants actions, the impact of dynamic inconsistencies into contract design depends on whether the *principal* can also perfectly observe and verify the type of an intertemporal time-inconsistent individual-farmer, and hence he can identify participant's beliefs regarding the consistency of their time-preferences. That is, the intertemporal consistency of someone's decisions is of high importance for the policy-maker only in cases where the policy-maker cannot perfectly observe and verify the type of a hyperbolic discounting individual-farmer. The less information on participant's actual action the policy-maker has, the higher is the need for him to identify the type of a participants. In other words, *moral hazard* creates serious failures into (agri)environmental contract design up to that point in which *adverse selection* on the type of a participant also exists.

References

Ainslie, G. (1975). Specious reward: a behavioral theory of impulsiveness and impulse control. *Psychological bulletin 82*(4), 463.

Ainslie, G. (1992). Picoeconomics: The strategic interaction of successive motivational states within the person (studies in rationality and social change).

Akerlof, G. A. (1991). Procrastination and obedience. *American Economic Review 81*(2), 1–19.

Anthoff, D., R. S. Tol, and G. Yohe (2009). Discounting for climate change. *Economics: The Open-Access, Open-Assessment E-Journal 3*.

Arnott, R. and J. E. Stiglitz (1986). Moral hazard and optimal commodity taxation. *Journal of Public Economics 29*(1), 1–24.

Arrow, K. J. (1963). Uncertainty and the welfare economics of medical care. *The American economic review*, 941–973.

Barnard, C. (1938). *The Functions of the Executive*. Harvard University Press.

Besanko, D. and G. Kanatas (1993). Credit market equilibrium with bank monitoring and moral hazard. *Review of Financial studies 6*(1), 213–232.

Cabe, R. and J. A. Herriges (1992). The regulation of non-point-source pollution under imperfect and asymmetric information. *Journal of Environmental Economics and Management 22*(2), 134–146.

Chabris, C. F., D. I. Laibson, and J. P. Schuldt (2006). Intertemporal choice. *The new Palgrave dictionary of economics 2*.

Challinor, A. J., F. Ewert, S. Arnold, E. Simelton, and E. Fraser (2009). Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. *Journal of experimental botany 60*(10), 2775–2789.

Chapman, G. B. and A. S. Elstein (1995). Valuing the future temporal discounting of health and money. *Medical Decision Making 15*(4), 373–386.

Chapman, G. B., R. Nelson, and D. B. Hier (1999). Familiarity and time preferences: Decision making about treatments for migraine headaches and crohn's disease. *Journal of Experimental Psychology: Applied 5*(1), 17.

Choe, C. and I. Fraser (1999). Compliance monitoring and agri-environmental policy. *Journal of agricultural economics 50*(3), 468–487.

Chung, S.-H. and R. J. Herrnstein (1967). Choice and delay of reinforcement1. *Journal of the experimental analysis of behavior 10*(1), 67–74.

Dasgupta, P. (2008). Discounting climate change. *Journal of risk and uncertainty 37*(2-3), 141–169.

DellaVigna, S. (2007). Psychology and economics: Evidence from the field. Technical report, National Bureau of Economic Research.

Eichengreen, B. J. (1999). Toward a new international financial architecture: a practical post-asia agenda. *Peterson Institute Press: All Books*.

Engel, E. and R. Fischer (2008). Optimal resource extraction contracts under threat of expropriation. Technical report, National Bureau of Economic Research.

Fearnside, P. M., D. A. Lashof, and P. Moura-Costa (2000). Accounting for time in mitigating global warming through land-use change and forestry. *Mitigation and Adaptation Strategies for Global Change 5*(3), 239–270.

Foster, A. D. and M. R. Rosenzweig (1994). A test for moral hazard in the labor market: Contractual arrangements, effort, and health. *The Review of Economics and Statistics*, 213–227.

Fraser, R. (2002). Moral hazard and risk management in agri-environmental policy. *Journal of Agricultural Economics 53*(3), 475–487.

Fraser, R. (2004). On the use of targeting to reduce moral hazard in agri-environmental schemes. *Journal of agricultural economics 55*(3), 525–540.

Fraser, R. (2012). Moral hazard, targeting and contract duration in agri-environmental policy. *Journal of Agricultural Economics 63*(1), 56–64.

Fraser, R. (2013). To cheat or not to cheat: Moral hazard and agri-environmental policy. *Journal of Agricultural Economics 64*(3), 527–536.

Frederick, S., G. Loewenstein, and T. O'donoghue (2002a). Time discounting and time preference: A critical review. *Journal of economic literature*, 351–401.

Frederick, S., G. Loewenstein, and T. O'donoghue (2002b). Time discounting and time preference: A critical review. *Journal of economic literature 40*(2), 351–401.

Fuchs, V. R. (1980). Time preference and health: an exploratory study.

Fudenberg, D. and J. Tirole (1990). Moral hazard and renegotiation in agency contracts. *Econometrica: Journal of the Econometric Society*, 1279–1319.

Giné, X., D. Karlan, and J. Zinman (2010). Put your money where your butt is: a commitment contract for smoking cessation. *American Economic Journal: Applied Economics*, 213–235.

Green, L., N. Fristoe, and J. Myerson (1994). Temporal discounting and preference reversals in choice between delayed outcomes. *Psychonomic Bulletin & Review 1*(3), 383–389.

Green, L. and J. Myerson (2004). A discounting framework for choice with delayed and probabilistic rewards. *Psychological bulletin 130*(5), 769.

Hart, R. and U. Latacz-Lohmann (2005). Combating moral hazard in agri-environmental schemes: a multiple-agent approach. *European Review of Agricultural Economics 32*(1), 75–91.

Heal, G. (1997). Discounting and climate change; an editorial comment. *Climatic Change 37*(2), 335–343.

Hepburn, C. (2003). Hyperbolic discounting and resource collapse.

Hepburn, C., S. Duncan, and A. Papachristodoulou (2010). Behavioural economics, hyperbolic discounting and environmental policy. *Environmental and Resource Economics 46*(2), 189–206.

Herrnstein, R. J. (1981). Self-control as response strength. *Quantification of steady-state operant behavior*, 3–20.

Heyes, A. (2000). Implementing environmental regulation: enforcement and compliance. *Journal of Regulatory Economics 17*(2), 107–129.

Hirshleifer, J. and P. Hall (1970). *Investment, interest, and capital.* Prentice-Hall Englewood Cliffs, NJ.

Hölmstrom, B. (1979). Moral hazard and observability. *The Bell journal of economics*, 74–91.

Horowitz, J. K. and E. Lichtenberg (1993). Insurance, moral hazard, and chemical use in agriculture. *American Journal of Agricultural Economics 75*(4), 926–935.

Jensen, M. C. and W. H. Meckling (1979). *Theory of the firm: Managerial behavior, agency costs, and ownership structure*. Springer.

Jevons, H. S. (1905). *Essays on economics*. Macmilan.

Jevons, W. S. (1884). *Investigations in currency and finance*. Macmillan and Co.

Kahneman, D., J. L. Knetsch, and R. Thaler (1994). Fairness as a constraint on profit seeking: Entitlements in the market. *1994b, Quasi Rational Economics,(Russel Sage, New York)*, 199–219.

Karl, T. R. and J. M. Melillo (2009). *Global climate change impacts in the United States*. Cambridge University Press.

Kirby, K. N. (1997). Bidding on the future: evidence against normative discounting of delayed rewards. *Journal of Experimental Psychology: General 126*(1), 54.

Kirby, K. N. and R. J. Herrnstein (1995). Preference reversals due to myopic discounting of delayed reward. *Psychological Science 6*(2), 83–89.

Kirby, K. N. and N. N. Maraković (1995). Modeling myopic decisions: Evidence for hyperbolic delay-discounting within subjects and amounts. *Organizational Behavior and Human Decision Processes 64*(1), 22–30.

Koopmans, T. C. (1960). Stationary ordinal utility and impatience. *Econometrica: Journal of the Econometric Society*, 287–309.

Koopmans, T. C., P. A. Diamond, and R. E. Williamson (1964). Stationary utility and time perspective. *Econometrica: Journal of the Econometric Society*, 82–100.

Laffont, J.-J. and D. Martimort (2009). *The theory of incentives: the principal-agent model*. Princeton University Press.

Laibson, D. (1997). Golden eggs and hyperbolic discounting. *The Quarterly Journal of Economics*, 443–477.

Lambert, R. A. (1983). Long-term contracts and moral hazard. *The Bell Journal of Economics*, 441–452.

Latacz-Lohmann, U. and C. P. Hamsvoort (1998). Auctions as a means of creating a market for public goods from agriculture. *Journal of Agricultural Economics 49*(3), 334–345.

Loewenstein, G. and D. Prelec (1991). Negative time preference. *The American Economic Review*, 347–352.

Loewenstein, G., R. Weber, J. Flory, S. Manuck, and M. Muldoon (2001). Dimensions of time discounting. In *Conference on survey research on household expectations and preferences*, Volume 31.

MacKenzie, I. A., M. Ohndorf, and C. Palmer (2011). Enforcement-proof contracts with moral hazard in precaution: ensuring permanence in carbon sequestration. *Oxford economic papers*, gpr057.

Mazur, J. (1987). An adjustment procedure for studying delayed reinforce% ment, ch. 2 in commons. *ML, Mazur, JE, Nevins, JA and Rachlin, H., Quantitative Analysis of Behavior: The effect of Delay and of Intervening Events on Reinforcement Value, Ballinger, Hillsdale.*

McClure, S. M., K. M. Ericson, D. I. Laibson, G. Loewenstein, and J. D. Cohen (2007). Time discounting for primary rewards. *The Journal of Neuroscience 27*(21), 5796–5804.

Milgrom, P. and J. Roberts (1994). Economics, organization and management/p. milgrom, j. roberts.

Millar, A. and D. J. Navarick (1984). Self-control and choice in humans: Effects of video game playing as a positive reinforcer. *Learning and Motivation 15*(2), 203–218.

Olson, M. and M. J. Bailey (1981). Positive time preference. *The Journal of Political Economy*, 1–25.

Owen, N. A., O. R. Inderwildi, and D. A. King (2010). The status of conventional world oil reserves: Hype or cause for concern? *Energy policy 38*(8), 4743–4749.

Ozanne, A., T. Hogan, and D. Colman (2001). Moral hazard, risk aversion and compliance monitoring in agri-environmental policy. *European review of agricultural economics 28*(3), 329–348.

Persson, T. and G. Tabellini (1996). Federal fiscal constitutions: Risk sharing and moral hazard. *Econometrica: Journal of the Econometric Society*, 623–646.

Phelps, E. S. and R. A. Pollak (1968). On second-best national saving game-equilibrium growth. *Review of Economic Studies 35*(2).

Rachlin, H., A. Raineri, and D. Cross (1991). Subjective probability and delay. *Journal of the experimental analysis of behavior 55*(2), 233–244.

Rae, J. and C. W. Mixter (1905). *The sociological theory of capital.* Macmillan Company.

Ramsey, F. P. (1928). A mathematical theory of saving. *The Economic Journal*, 543–559.

Read, D. (2001). Is time-discounting hyperbolic or subadditive? *Journal of risk and uncertainty 23*(1), 5–32.

Rubinstein, A. (2003). Economics and psychology? the case of hyperbolic discounting. *International Economic Review 44*(4), 1207–1216.

Rubinstein, A. and M. E. Yaari (1983). Repeated insurance contracts and moral hazard. *Journal of Economic Theory 30*(1), 74–97.

Salas, P. C. and B. E. Roe (2012). The role of cooperation and reciprocity in structuring carbon sequestration contracts in developing countries. *American Journal of Agricultural Economics 94*(2), 411–418.

Salois, M. J. (2008). *Intertemporal preferences and time-inconsistency: The case of farmland values and rural-urban land conversion.* University of Florida.

Salois, M. J. and C. B. Moss (2011). A direct test of hyperbolic discounting using market asset data. *Economics Letters 112*(3), 290–292.

Samuelson, P. A. (1937). A note on measurement of utility. *The Review of Economic Studies 4*(2), 155–161.

Segerson, K. (1988). Uncertainty and incentives for nonpoint pollution control. *Journal of environmental economics and management 15*(1), 87–98.

Senior, N. W. (1836). *An outline of the science of political economy.* Verlag Wirtschaft und Finanzen.

Settle, C. and J. F. Shogren (2004). Hyperbolic discounting and time inconsistency in a native–exotic species conflict. *Resource and Energy Economics 26*(2), 255–274.

Shafiee, S. and E. Topal (2009). When will fossil fuel reserves be diminished? *Energy policy 37*(1), 181–189.

Shavell, S. (1979). On moral hazard and insurance. *The Quarterly Journal of Economics*, 541–562.

Shogren, J. F. and L. O. Taylor (2008). On behavioral-environmental economics. *Review of Environmental Economics and Policy 2*(1), 26–44.

Smith, A. (1801). *An Inquiry Into the Nature and Causes of the Wealth of Nations*. Number v. 1-2 in An Inquiry Into the Nature and Causes of the Wealth of Nations. J. Decker.

Smith, V. H. and B. K. Goodwin (1996). Crop insurance, moral hazard, and agricultural chemical use. *American Journal of Agricultural Economics 78*(2), 428–438.

Solnick, J. V., C. H. Kannenberg, D. A. Eckerman, and M. B. Waller (1980). An experimental analysis of impulsivity and impulse control in humans. *Learning and Motivation 11*(1), 61–77.

Sopher, B. and A. Sheth (2006). A deeper look at hyperbolic discounting. *Theory and Decision 60*(2-3), 219–255.

Thaler, R. H. and H. M. Shefrin (1981). An economic theory of self-control. *The Journal of Political Economy*, 392–406.

Varian, H. R. (1980). Redistributive taxation as social insurance. *Journal of Public Economics 14*(1), 49–68.

von Böhm-Bawerk, E. (1890). *Capital and interest: A critical history of economical theory*. Macmillan and Co.

Wilkinson, N. and M. Klaes (2012). *An Introduction to Behavioral Economics*. Palgrave Macmillan.

Xepapadeas, A. P. (1991). Environmental policy under imperfect information: incentives and moral hazard. *Journal of environmental economics and management 20*(2), 113–126.

Zweifel, P. and W. G. Manning (2000). Moral hazard and consumer incentives in health care. *Handbook of health economics 1*, 409–459.

Appendix A

Derivation of Optimal Efforts

The reader must have two important things in mind: (1) The convnexity of our cost function implies that profits are a concave function in the level of effort. Thus, given that profits are also increasing function in the level of effort, the steady-state point will maximize our profit function; (2) In addition, the introduction of penalty scheme (both under perfect and imperfect information) is a linear function in the level of effort. As a consequence, it does not affect the concavity of our profit function, making the effort that derives from the first-order condition the maximum; (3) hyperbolic and exponential discounting individual-farmers have similar profits, where the only difference lies on the discounting function. Therefore, we are going to derive optimal efforts under a general discount function $D(t)$.

A.1 One-Period Contracts

A.1.1 Perfect Information

At every period, an individual-farmer chooses effort that maximizes her discounted present value of her net benefits. Given that efforts at $t = 0$ denotes individual's plans, we can focus our derivation exclusively at $t = 1$. Thus, self-1 has:

$DPV\Pi(e) = -\psi(e) + (I + pe)D(1)$, where $D(1)$ is the discount function used by her at $t = 1$.

From the first-order condition (F.O.C.) we have that:

$dDPV\pi_1(e)/de = -\psi'(e) + pD(1) = 0 \Rightarrow \psi'(e) = pD(1)$, which given the quadratic form of our cost function. $\psi(e) = e^2/2$, we have that $e = pD(1)$

Recall that for $t > 1$, time-consistent individual-farmer discount function is $D_E = \delta^t$, whereas time-inconsistent discount function is $D_H = \beta\delta^t$, and so g the former chooses optimal effort $\overline{e} = p\delta$, whereas the latter chooses optimal effort $\underline{e} = p\beta\delta$.

A.1.1.1 Derivation of optimal commitment mechanism

The reader can recall that the commitment mechanism has the following scheme

$$P(e) = \begin{cases} 0 & \text{if } e = e^* \\ d(e_{h0} - e) & \text{if } < e^* \end{cases} \text{, where } d > 0$$

At $t = 0$, the Agency offers $\overline{p} = e^*\delta^{-1}$, and so at $t = 1$, a time-inconsistent self-1 has discounted present value of net benefits:

$DPV\Pi_{h1}(e) = -\psi(e) + (I + \overline{p}e - d(e^* - e))\beta\delta.$

The F.O.C. is

$dDPV\pi_{h1}(e)/de = -\psi'(e) + (p_e + d)\beta\delta = 0 \Rightarrow \psi'(e) = (\overline{p} + d)\beta\delta$

where again given the quadratic form of our cost function $\psi(e) = e^2/2$, self-1 chooses effort $\underline{e} = (\overline{p} + d)\beta\delta.$

Thus, self-1 provides the targeted outcome if

$e^* = (\overline{p} + d)\beta\delta \Rightarrow e^*(\beta\delta)^{-1} = \overline{p} + d \Rightarrow d = e^*(\beta\delta)^{-1} - \overline{p}$

$d = \overline{p}(\beta^{-1} - 1) \Rightarrow d^* = \overline{p}(1 - \beta)/\beta$

A.1.2 Imperfect Information

The reader can recall that the Agency penalizes cheaters according to the following penalty scheme

$$\Theta(e) = \begin{cases} 0 & \text{if } e = e^* \\ \theta(e^* - e) & \text{if } < e^* \end{cases} \text{, where } \theta > 0$$

At $t = 1$ the expected discounted present value of self-1's net benefits is

$DPVE[\Pi(e)] = -\psi(e) + (I + \overline{p}e^* - q\theta(e^* - e))D(1)$

From the first-order condition (F.O.C.) we have that

$dDPVE[\Pi(e)]/de = -\psi'(e) + q\theta D(1) = 0 \Rightarrow \psi'(e) = q\theta D(1)$

Given $D_E = \delta^t$, $D_H = \beta\delta^t$, and $\psi(e) = e^2/2$, an exponential discounting individual-farmer exerts effort $\overline{e} = q\theta\delta$, whereas a hyperbolic discounting individual-farmer exerts effort $\underline{e} = q\theta\beta\delta$.

A.2 Two-Periods Contract (only for hyperbolic discounting agents)

A.2.1 Perfect Information

At $t = 1$, an intertemporal time-inconsistent self-1 has discounted present value of her net benefits:

$DPV\Pi_{h1}(e_1, e_2) = -\psi(e_1) + (I + pe_1)\beta\delta - \psi(e_2)\beta\delta + (I + pe_2)\beta\delta^2$

From the first-order conditions (F.O.C.) we have that:

$\partial DPV\Pi_{h1}/\partial e_1 = -\psi'(e_1) + p\beta\delta = 0 \Rightarrow \psi'(e_1) = p\beta\delta$

and

$\partial DPV\Pi_{h1}/\partial e_2 = -\psi'(e_2) + p\delta = 0 \Rightarrow \psi'(e_2) = p\delta$

where given that $\psi(e) = e^2/2$, we finally obtain $e_1 = p\beta\delta$ and $e_2 = p\delta$, respectively.

As a consequence, the optimal relationship between current effort and future plans is $e_1 = \beta e_2$.

A.2.2 Imperfect Information

Again, the Agency penalizes cheaters according to the following penalty scheme

$$\Theta(e) = \begin{cases} 0 & \text{if } e = e^* \\ \theta(e^* - e) & \text{if } < e^* \end{cases} \text{, where } \theta > 0$$

At $t = 1$, a time-inconsistent self-1 has

$DPVE[\Pi_{h1}(e_1, e_2)] = -\psi(e_1) + (I + pe^* - q\theta(e^* - e_1))\beta\delta - \psi(e_2)\beta\delta + (I + pe^* - q\theta(e^* - e_2))\beta\delta^2$

where again e_2 denotes self-1 plans for the future.

From the first-order conditions (F.O.C.) we have that

$\partial DPVE[\Pi_{h1}]/\partial e_1 = -\psi'(e_1) + q\theta\beta\delta = 0 \Rightarrow \psi'(e_1) = q\theta\beta\delta$

and

$\partial DPVE[\Pi_{h1}]/\partial e_2 = -\psi'(e_2) + q\theta\delta = 0 \Rightarrow \psi'(e_2) = q\theta\delta$

and so given that $\psi(e) = e^2/2$, we have $e_1 = q\theta\beta\delta$ and $e_2 = q\theta\delta$, respectively.

As a consequence, the optimal relationship between current effort and future plans is $e_1 = \beta e_2$.

Appendix B

Derivation of Incentive-Rationality Constraints (IR)

The reader must note that at $t = 0$, a *naive agent* behaves exactly the same with an intertemporal time-consistent decision-maker, and so the IR of the latter will be the same with IR of the former. Therefore, we are going to derive the incentive-rationality constraint only for a j type intertemporal time-inconsistent decision-maker.

B.1 Perfect Information

B.1.1 Time-inconsistent Individual-Farmers in an One-Period Contract

At $t = 0$, $self_j$-0 "considering" effort is $\varepsilon_j = b_j p\delta$, and so her incentive-rationality constraint is

$$DPV\Pi_{h0}(\varepsilon_j) \geq DPVA$$

$$-\psi(\varepsilon_j)\beta\delta + (I + p\varepsilon_j)\beta\delta^2 \geq A\beta\delta^2 \Rightarrow -\psi(\varepsilon_j) + p\varepsilon_j\delta \geq \delta(A - I)$$

$$-(pb_j\delta)^2/2 + b_j(p\delta)^2 \geq \delta(A - I) \Rightarrow -(pb_j\delta)^2 + 2b_j(p\delta)^2 \geq 2\delta(A - I)$$

$$b_j(p\delta)^2(-b_j + 2) \geq 2\delta(A - I) \Rightarrow p^2 b_j\delta(2 - b_j) \geq 2(A - I)$$

$$p^2 \geq 2(A - I)/b_j\delta(2 - b_j) \Rightarrow p \geq \left[2(A - I)/b_j\delta(2 - b_j)\right]^{1/2}$$

and so,

$$IR_j = \begin{cases} p \geq \left[2(A - I)/\delta\right]^{1/2} & j = N \\ p \geq \left[2(A - I)/\beta\delta(2 - \beta)\right]^{1/2} & j = S \end{cases}$$

B.1.2 Time-inconsistent Individual-Farmers in a Two-Periods Contract

At $t = 0$ an inter-temporal time-inconsistent decision-maker signs the contract if and only if

$DPV\Pi_{h0}(\varepsilon_{01,j}, \varepsilon_{02,j}) \geq DPVA \Rightarrow -\psi(\varepsilon_{01,j})\beta\delta + (I + p\varepsilon_{01,j})\beta\delta^2 - \psi(\varepsilon_{02,j})\beta\delta^2 + (I + p\varepsilon_{02,j})\beta\delta^3 \geq A\beta\delta^2(1+\delta)$

$$-\psi(\varepsilon_{01,j}) + (I + p\varepsilon_{01,j})\delta - \psi(\varepsilon_{02,j})\delta + (I + p\varepsilon_{02,j})\delta^2 \geq A\delta(1+\delta)$$

$$-\psi(\varepsilon_{01,j}) - \psi(\varepsilon_{02,j})\delta + p\varepsilon_{01,j}\delta + p\varepsilon_{02,j}\delta^2 \geq \delta(1+\delta)(A-I)$$

However, $\varepsilon_{01,j} = b_j^2 e_{02}$ and $\varepsilon_{02,j} = b_j e_{02}$, and so we can express the former as a function of the latter as follows: $\varepsilon_{01,j} = b_j\varepsilon_{02,j}$.

Thus, incentive-rationality constraint becomes:

$$-b_j^2\psi(\varepsilon_{02,j}) - \psi(\varepsilon_{02,j})\delta + p\delta b_j\varepsilon_{02,j} + p\varepsilon_{02,j}\delta^2 \geq \delta(1+\delta)(A-I)$$

$$-\psi(\varepsilon_{02,j})(b_j^2 + \delta) + p\delta\varepsilon_{02,j}(b_j + \delta) \geq \delta(1+\delta)(A-I)$$

$$-(b_j p\delta)^2(b_j^2 + \delta)/2 + (p\delta)^2 b_j(b_j + \delta) \geq \delta(1+\delta)(A-I)$$

$$-(b_j p\delta)^2(b_j^2 + \delta) + 2(p\delta)^2 b_j(b_j + \delta) \geq 2\delta(1+\delta)(A-I)$$

$$(p\delta)^2 b_j[2(b_j + \delta) - b_j(b_j^2 + \delta)] \geq 2\delta(1+\delta)(A-I)$$

$$p^2 \geq 2(1+\delta)(A-I)/\delta b_j[2(b_j + \delta) - b_j(b_j^2 + \delta)]$$

$$p \geq \Big[2(1+\delta)(A-I)/\delta b_j[2(b_j + \delta) - b_j(b_j^2 + \delta)]\Big]^{1/2}$$

However, $\phi_N = \phi_E = \Big[2(A-I)/\delta\Big]^{1/2}$, and so

$$\phi_S(2) = \phi_N\Big[(1+\delta)/b_j\Big(2(b_j + \delta) - b_j(b_j^2 + \delta)\Big)\Big]^{1/2}$$

B.1.3 Incentive-rationality Constraint under Imperfect Information

$$DPVE[\Pi_0(\varepsilon_j)] \geq DPVA$$

$$-\psi(\varepsilon_j)\delta + (I + pe^* - q\theta(e^* - \varepsilon_j))\delta^2 \geq A\delta^2$$

$$pe^*\delta \geq (A-I)\delta + \psi(\varepsilon_j) + q\theta\delta(e^* - \varepsilon_j)$$

However, given the quadratic form of our cost function, the the right-hand side can be written as

$(A-I)\delta + \varepsilon_j^2/2 + q\theta\delta(e^* - \varepsilon_j) = (A-I)\delta + b_j^2 e_0^2/2 + e_0(e^* - b_j e_0)$

$(A-I)\delta + b_j^2 e_0^2/2 + e_0 e^* - b_j e_0^2 = (A-I)\delta + b_j e_0^2(b_j/2 - 1) + e_0 e^*$

$(A-I)\delta + b_j e_0[e_0(-2 + b_j)/2 + e^*]$

and so,

$pe^*\delta \geq (A-I)\delta + b_j e_0[e_0(-2 + b_j)/2 + e^*]$

$p \geq (A-I)/e^* + b_j e_0[e_0(b_j - 2) + 2e^*]/2e^*\delta$

$p \geq (A-I)/e^* + b_j q\theta[2e^* - q\theta\delta(2 - b_j)]/2e^*$

Therefore, for a *naive agent* ($b_N = 1$)

$p \geq (A-I)/e^* + q\theta/\delta - (q\theta)^2\delta/2e^*$

whereas for a *sophisticated agent* ($b_S = \beta$)

$p \geq (A-I)/e^* + \beta q\theta[2e^* - q\theta\delta(2-\beta)]/2e^*$

and so, given that the principal can identify the type of a participant, he imposes either $f_h(\theta)$ or $f(\theta)$, and so incentive-rationality constraint for both these two policy functions becomes

$pe^* \geq (A-I) + -\psi(e^*)\delta^{-1} + q\theta(e^* - e^*)$

$pe^* \geq (A-I) + (e^*)^2/2\delta$

$p \geq (A-I)/e^* + e^*/2\delta$

Appendix C

More Proofs and Derivations

A Comparison Between $\phi_N(1)$ and $\phi_S(1)$

Recall that $\phi_N(1) = \Big(2(A-I)/\delta\Big)^{1/2}$ and $\phi_S(1) = \Big(2(A-I)/\beta\delta(2-\beta)\Big)^{1/2}$

Then,

$\phi_N(1)/\phi_S(1) = \Big[(2(A-I)/\delta)\Big/(2(A-I)/\beta\delta(2-\beta))\Big]^{1/2}$

$\phi_N(1)/\phi_S(1) = [\beta(2-\beta)]^{1/2}$

Let's assume that

$[\beta(2-\beta)]^{1/2} < 1 \Rightarrow \beta(2-\beta) < 1$

$\beta^2 - 2\beta + 1 > 0 \Rightarrow (\beta-1)^2 > 0$which is true for all $\beta \in (0,1)$

Hence,

$\phi_N(1)/\phi_S(1) < 1 \Rightarrow \phi_N(1) < \phi_S(1)$

Comparison Between $\phi_S(1)$ and $\phi_S(2)$

Recall that $\phi_S(1) = \phi_N\Big[1/\beta(2-\beta)\Big]^{1/2}$ and $\phi_S(2)$=$\phi_N\Big[(1+\delta)/(2\beta(\beta+\delta)$-$\beta^2(\beta^2+\delta))\Big]^{1/2}$

Thus,

$$\phi_S(1)/\phi_S(2) = \phi_N\Big[1/\beta(2-\beta)\Big]^{1/2} \Big/ \phi_N\Big[(1+\delta)/(2\beta(\beta+\delta) - \beta^2(\beta^2+\delta))\Big]^{1/2}$$

$$\phi_S(1)/\phi_S(2) = \Big[(2\beta(\beta+\delta) - \beta^2(\beta^2+\delta))\Big/\beta(2-\beta)(1+\delta)\Big]^{1/2}$$

Let's assume that the $\Big[\phi_S(1)/\phi_S(2)\Big] < 1$, and so

$$\Big[(2\beta(\beta+\delta) - \beta^2(\beta^2+\delta))\Big]^{1/2} < \Big[\beta(2-\beta)(1+\delta)\Big]^{1/2}$$

$$2\beta(\beta+\delta) - \beta^2(\beta^2+\delta) < \beta(2-\beta)(1+\delta)$$

$$2\beta^2 + 2\beta\delta - \beta^4 - \beta^2\delta < 2\beta - \beta^2 + 2\beta\delta - \beta^2\delta \Rightarrow \beta^4 - 3\beta^2 + 2\beta < 0$$

$$\beta^4 - 3\beta^2 + 2\beta > 0 \Rightarrow \beta(\beta^3 - 3\beta + 2) > 0$$

Given that $\beta \in (0,1)$, then the 3rd degree polynomial must positive. Thus,

$$\beta^3 - 3\beta + 2 = \beta^3 - 2\beta - \beta + 2 = \beta(\beta^2 - 1) - 2(\beta - 1) = \beta(\beta+1)(\beta-1) - 2(\beta-1)$$

$$(\beta-1)(\beta(\beta+1) - 2) = (\beta-1)(\beta^2+\beta-2)$$

Hence,

$$\beta^2 + \beta - 2 = \beta^2 - 1 + (\beta - 1) = (\beta-1)(\beta+1+1) = (\beta-1)(\beta+2)$$

Finally, we have that

$$\beta(\beta^3 - 3\beta + 2) = \beta(\beta-1)(\beta^2+\beta-2) = \beta(\beta-1)^2(\beta+2) > 0 \;\forall\beta \in (0,1)$$

As a consequence,

The assumption that $\Big[\phi_S(1)/\phi_S(2)\Big] < 1$ is true, and hence $\phi_S(1) < \phi_S(2)$

A Comparison Between $\phi_N^M(1)$ and $\phi_S^M(1)$

Recall that $\phi_N^M(1) = (A - I)/e^* + q\theta[2e^* - q\theta\delta]/2e^*$ and $\phi_S^M(1)$=(A-I)/e^*+βqθ[2e^*-q$\theta\delta$(2-β)]/2e^*

Then,

$\phi_N^M - \phi_S^M = [q\theta(1-\beta) - \delta(q\theta)^2(1-\beta(2-\beta))]/2e^*$

$\phi_N^M - \phi_S^M = q\theta[(1-\beta) - q\theta\delta(1-\beta)^2]/2e^*$

$\phi_N^M - \phi_S^M = q\theta(1-\beta)[1 - q\theta\delta(1-\beta)]/2e^*$

Thus, $\phi_N^M \gtreqless \phi_S^M$ depends on whether $1 - q\theta\delta(1-\beta) \gtreqless 0$

If $1 - q\theta\delta(1-\beta) > 0$, then

$1 > e_0(1-\beta) \Rightarrow e_0 < 1/(1-\beta)$

If $1 - q\theta\delta(1-\beta) < 0$, then

$1 < e_0(1-\beta) \Rightarrow e_0 > 1/(1-\beta) > 1$

However, this is wrong since $e_0 \in [o, e^*]$ and $e^* \in [0,1]$

Derivation of the elasticity of the policy functions f and f_h

The reader can recall that $f(\theta) = \overline{p}/\theta$ and $f_h(\theta) = \overline{p}/\beta\theta$. In addition, the elasticity of a policy function for an exponential and a hyperbolic discounting agent is defined as $\eta_e = \theta f'(\theta)/f(\theta)$ and $\eta_h = \theta f_h'(\theta)/f_h(\theta)$, respectively.

Thus, the elasticity of $f(\theta)$ is:

$\theta f'(\theta)/f(\theta) = (-\overline{p}/\theta^2)(\theta/(\overline{p}/\theta))$

$\eta_e = (-\overline{p}/\theta^2)(\theta^2/\overline{p}) \Rightarrow \eta_e = -1$

whereas the elasticity of $f_h(\theta)$ is

$\theta f'_h(\theta)/f_h(\theta) = (-\overline{p}/\beta\theta^2)(\theta/(\overline{p}/\beta\theta))$

$\eta_h = (-\overline{p}/\beta\theta^2)(\beta\theta^2/\overline{p}) \Rightarrow \eta_h = -1$

Relationship Between d^* and θ^*

The principal imposes a policy function $q \equiv f(\theta^*) = \overline{p}/\theta^*$

However, $q \in (0, 1)$, and so

$f(\theta^*) < 1 \Rightarrow \overline{p} < \theta^* \Rightarrow \overline{p}r_\beta < \theta^* r_\beta$, where $r_\beta = (1-\beta)/\beta > 1$

Thus,

$d^* < \theta^* r_\beta \Rightarrow \theta^*/d^* > r_\beta$

As a consequence:

if $r_\beta > 1$, then $\theta^* > d^*$

if $r_\beta < 1$, then $\theta^* \gtrless d^*$ depending on the value of β.