NOTA DI LAVORO

78.2009

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INSTITUTIONS AND MARKETS Series
Editor: Fausto Panunzi

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Summary

We provide a general framework in which to determine the optimal penalty fee inducing the contractor to respect the contracted delivery date in public procurement contracts (PPCs). We do this by developing a real option model that enables us to investigate the contractor's value of investment timing flexibility which the penalty rule - de facto - introduces. We then apply this setting in order to evaluate the range of penalty fees in the Italian legislation on PPCs. According to our calibration analysis, there is no evidence that the substantial delays recorded in the execution times of Italian PPCs are due to incorrectly set penalty fees. This result opens the way for other explanations of delays in Italian PPCs: specifically, we extend our model to investigate the probability of enforcing a penalty which we assume negatively affected by the "quality" of the judicial system and the discretionality of the court in voiding the rule. Our simulations show that the penalty fee is highly sensitive to the "quality" of the judicial system. Specifically referring to the Italian case, we show that the optimal penalty should be higher than those set according to the present Italian law.

Keywords: Public Procurement Contracts, Penalty Fee, Investment Timing Flexibility, Contract Incompleteness, Enforceability of Rules

JEL Classification: L33, H57, D81

We would like to thank Maria Bigoni, Piermaria Piacentini, Pippo Ranci, Giancarlo Spagnolo, Ugo Trivellato, Tommaso Valletti, Laura Zanettini, the seminar participants at the 2007 Cofin Workshop in Padua, EAERE 2007, EARIE 2008, EEA 2008, for very useful comments and suggestions. We are also grateful to Gianluca Marino, Valerio Longo, Renato Oliva and Raffaele Tortora (Autorità per la Vigilanza sui Contratti Pubblici di Lavori, Servizi e Forniture) for the data-set provided. Part of this research was conducted while the third author visited the European University Institute and she would like to thank the Florence School of Regulation and the Schuman Center for their great hospitality. We acknowledge the financial support provided by the MIUR under project no.2004134814_005 and by the University of Padova under the two-year fellowship no. CPDR055419. The usual disclaimer applies.

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"It is never too late": Optimal penalty for investment delay in Italian public procurement contracts

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July 30, 2009

Abstract

This paper provides a general framework to determine the *optimal* penalty fee to induce a contractor to respect the contracted delivery date in public procurement contracts (PPCs). We did this by i) developing a real option model to evaluate the investment timing flexibility that the inclusion of a penalty clause in the contract gives the contractor; ii) investigating the probability of enforcing the penalty rule which is here assumed to be negatively affected by the 'quality' of the judicial system and by the discretionality of the court in voiding the penalty rule itself. Our model shows that the *optimal* penalty fee increases as the uncertainty over the contract's investment costs increases and the probability of the penalty enforcement decreases.

Using parameters which mimic the Italian context, we then calibrate the model to evaluate the range of penalties set by the Italian legislation on PPCs. According to our calibrations, the optimal penalty fees result highly sensitive to the 'quality' of the judicial system and to the discretional power of courts of law: in particular, the *optimal* penalty for delay in PPCs should be of different level in the different Italian macro-regions and, in some cases, much higher than that set according to the present Italian law.

Keywords: public procurement contracts, penalty fee, investment timing flexibility, contract incompleteness, enforceability of rules.

JEL: L33; H57; D81

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¶We would like to thank M. Bigoni, P. Piacentini, P. Ranci, G. Spagnolo, U. Trivellato, T. Valletti, L. Zanettini, H. Paarsh, D. Perez Castrillo, I. Macho Stadler, P. Garella, the seminar participants at the 2007 Cofin Workshop in Padua, EARIE 2008, EEA 2008, EAERE 2009, Workshop on Industrial Organization 2009 - University of Salento for very useful comments and suggestions. We are also grateful to Gianluca Marino, Valerio Longo, Renato Oliva and Raffaele Tortora (Autorità per la Vigilanza sui Contratti Pubblici di Lavori, Servizi e Forniture) for the data-set provided. Part of this research was conducted while the third author visited the European University Institute and she would like to thank the Florence School of Regulation and the Schuman Center for their hospitality. We acknowledge the financial support provided by the MIUR under project no. 2004134814_005 and by the University of Padova under the two-year fellowship no. CPDR055419. The usual disclaimer applies.

1 Introduction

The deterioration of public finance and increase in global competition have forced governments and public institutions to obtain "the best value for money" through the purchase of goods, works and services in the form of procurement contracts. Efficient public procurement contracts (henceforth PPCs) are thus emerging as a "core necessity for ... the public sector's effectiveness in obtaining resources for social spending and/or lowering taxes" (Dimitri *et al.*, 2006). These contracts have recently recorded a rapid increase both in number and value, reaching 16% of the GDP in the EU, and around 20% in the United States.[1] However, PPCs have both benefits and costs: the benefits (e.g. allocative and productive efficiency) can be quickly erased by the costs and all the other consequences that usually arise from contractual incompleteness.[2]

Delays in PPC execution times are often a negative by-product; therefore, penalties for delay in delivering are specifically addressed in the contract by the procurer to provide the contractor the *right* incentive to prevent such default.[3] Indeed, delays in delivering negatively affect many of the actors involved, e.g. they may determine direct costs for the procurer and reduce consumers' utility. A typical illustrative example is a PPC for roadway resurfacing, rehabilitation and restoration: if these activities are undertaken in heavily urbanized areas, they may cause extreme traffic congestion and severe inconvenience to the travelling public and the business community. Thus, delays in the completion of these works prolong the negative impact on users (i.e. a social cost), and also cause overruns in the planned execution costs.[4] To avoid these inconveniences, the procurer - a Contracting Authority, henceforth CA - usually includes in the PPC a penalty fee for each day of delay the contractor produces in the delivery date.[5] However, a contractor may be unwilling to respect contractual times if its gain from defaulting is larger than the penalty to be paid. The recent Italian experience of PPCs has highlighted that this issue is relevant: there is puzzling evidence that consistent delays are still present regardless of the fact that explicit penalty clauses are included in the contract. Indeed, our simple descriptive analysis[6] shows that out of 45,370 completed contracts in the period 2000-2006, about 78% were completed with delays.This discrepancy raises the following research questions: a) is there something wrong with the defintion of penalty fees currently set? b) how should this penalty be *optimally* set to induce the contractor to respect the contracted delivery date?

In order to answer these questions, this paper provides a general framework to determine the *optimal* penalty fee in a PPC contract. Our starting point is that the inclusion of a penalty clause gives the contractor - to some extent - the option of deciding the investment timing for the contract's execution. In order to be effective, the penalty fee should consider the value of the investment timing flexibility which, *de facto,* increases the contract value. To correctly approach

[1] Note that between 1995 and 2002 PPCs in the EU underwent a 31% increase in value (Dimitri, *et al.*, 2006; Ch.1.)
See also: http://europa.eu.int/comm/internal_market/publicprocurement/index_en.htm

[2] The economic and engineering literature give different explanations for the main issues arising in PPCs. Most of the economic analysis on this topic focuses on the information asymmetry concerning production costs between the supplier and the procurer (Laffont and Tirole, 1993) while engineering and construction management analysis concentrates on the uncertainty which affects the contract after it has been signed and its effects on both the supplier and the procurer (Bartholomew, 1998). For a methodological discussion on contract incompleteness and unforeseen contingencies see Maskin and Tirole (1999).

[3] In the economic literature on PPCs, delivery delays in contract execution are often considered along with the issue of the supplier's performance regarding contracted aims (i.e. quality). See on this Engel A.R. *et al.* (2006).

[4] Cost overruns in different procurement contracts have been specifically addressed in the seminal paper by Bajari and Tadelis (2001) and, more recently, by Ganuza (2007).

[5] According to the actual practice in PPCs, the penalty for delay in contracts execution is a fee per day of delay usually defined as a percentage of the contract value. As an example, in Italy penalty fees range from 0.03% to 0.1% of the contract value for each day of delay (see Government Decree n. 163/2006 and DPR n. 554/1999). As far as the united States are concerned, Herbsaman *et al.* (1995, Table 6, p. 276) show that for PPCs in highway construction, the Kansas Department of Transportation usually sets penalties ranging from 0.03% to 0.3% of the contract value for each day of delay. Arditi *et al.* (1997) show that a similar range of penalty is applied by the Illinois Department of Transportation.

[6] See details in Section 2 below, where we present our analysis on the database compiled by the Italian Authority in charge of controlling PPCs (i.e. *Autorità per la Vigilanza sui Contratti Pubblici di Lavori, Servizi e Forniture - AVCP*). See also AVLP (2005).

the issue, we propose a simple Real Option model which makes it possible to ascertain the value of option to delay induced by the inclusion of a penalty clause in the contract.[7]

Moreover, to correctly address the above research questions, we should take into consideration elements affecting the enforcement of the penalty rule itself. Following results generally acknowledged in the - scarce - literature on judicial enforcement of contracts, a low probability of penalty enforcement can arise when:[8] *i)* the court of law - to which the parties refer to for settlement of the dispute on the penalty payment - has discretionality in reducing, or even in not enforcing, the committed fee;[9] *ii)* default by the contractor triggers costly and time-consuming litigation. We include these elements in our model setting the probability of penalty enforcement as related both to the level of the penalty (as discretionality in enforcement of PPCs by a court of law increases with the committed penalty's amount) and to a measure of the 'quality' of the judicial system.

This paper mainly refers to two different strands of literature. On a formal level, it builds on the value of flexibility in contract investment timing (Dixit and Pindyck, 1994). In regard to economic literature on judicial enforcement of contracts, our paper stems from studies on the probability of a penalty rule's enforcement. Referring to Guash *et al.* (2006) - who investigated the probability of renegotiation of concession contracts when corruption is present - in our model we assume that the probability of enforcing the penalty is affected by the 'quality' of the judicial system. Specifically, in the calibration of our model we rely - as in Bianco *et al.* (2005) - on an indicator of judicial inefficiency which measures the length of ordinary civil trials. The source of the court's discretionality in enforcing the penalty is discussed by Anderlini *et al.* (2007) as a way to recognize ex-post some ex- ante unforseen events[10]: in our model we assume that the court's discretionality in enforcing the rule increases with the amount of the committed penalty; that is, the higher amount of the penalty to be paid by the contractor, the greater the court's probability of deciding whether to void or enforce the contract.

Our paper shows that the *optimal* penalty fee to be set in a PPC - i.e. the penalty which should induce the contractor to respect the contracted delivery date - increases as the uncertainty over the contract's investment costs increases and the probability of the penalty's enforcement decreases. The model's theoretical predictions are supported by our calibration results: using parameters which mimic the Italian context for PPCs, our findings show that, first, in accordance with Real Option Theory, the higher the uncertainty over the future realization of the investment costs, the higher the penalty fee should be; and, second, the penalty fee should be set by considering the probability of penalty enforcement which - in turn - is correlated to the discretionality of the court and to the 'quality' of the judicial system.

The paper is organized as follows. Section 2, summarizes a variety of empirical evidence dealing with delays and the probability of judicial enforcement in Italian PPCs. Section 3 first describes a basic model for procurement contracts which includes a penalty rule for delay in completion, and further then presents simulations carried out adopting a range of parameters which refer to the Italian empirical evidence in procurement. Finally, Section 4 provides a brief summary of our findings policy. Appendix A shows how our base model can be extended to consider a penalty/premium scheme where the contractor is punished (or rewarded) if it decides to delay (or anticipate) the delivery date. Appendix B contains additional tables for evidence discussed in Section 2, and further simulations and figures referring to key parameters of the model.

[7] As Brennan and Schwartz (1985) and McDonald and Siegel (1985; 1986) highlighted in their seminal works, there is a close analogy between security options and investment timing flexibility.

[8] In our analysis we assume that delays in delivering the project are always verifiable; our focus is not on verifiability of delays. A non-verifiable task could threaten contract enforceability itself (Laffont and Martimort, 2002, p.348). To our knowledge, since the seminal paper by Manelli and Vincent (1995), analysis on non-verifiable tasks in procurement (and concession) contracts has been carried out - with differing emphases - by Dalen et al. (2004), Calzolari and Spagnolo (2006) and Moretto and Valbonesi (2007). Usman (2002) presents a model where the judicial enforcement of the contract depends on the judge's cost in verifying tasks.

[9] See Eggleston *et al.* (2000) for a general discussion of the role of courts in enforcing contract clauses; and Legros *et al.* (2002) specifically on the effects of courts enforcement on parts' investment, when imperfections in the "technology of communication" are present.

[10] Usman (2002) shows that the discretional nature of the court's effort can act strategically in verifying the contract's contingencies.

2 Delays and penalty enforcement in Italian PPCs

2.1 Empirical evidence of delays in Italian PPCs

To investigate delays in PPCs we accessed the database compiled by the Italian Authority in charge of controlling these contracts (*Autorità per la Vigilanza sui Contratti Pubblici di Lavori, Servizi e Forniture - AVCP*). This database records all public works contracts of a value between 150,000 and 15,000,000 Euros awarded by municipalities, local/regional public authorities and public firms. At first glance, our examination of this database highlights that out of 45,370 fully completed contracts in the period 2000-2006, about 35,312 (corresponding to about 78%) were completed with delays.

In Table 1A in the Appendix, these contracts are presented with respect to *i)* the awarding procedure (open, negotiated and non-classified - n.c.); *ii)* their values (from € 150,000 to € 500,000; from € 500,000 to € 1,000,000; from € 1,000,000 to € 5,000,000; from € 5,000,000 to € 15,000,000; larger than € 15,000,000) and *iii)* the regional area where they were carried out (Northern, Central and Southern Italy).[11] It is interesting to note that the number of awarded PPCs is higher in the Northern part of Italy than in the Central and Southern parts (about three times more than those awarded in Central and in Southern Italy), and most of these contracts fall in the smallest range of values (more than 60% of the total PPCs recorded fall in the range between 150,000 and 500,000 Euros).

Italian data shows that the PPCs awarded with an open procedure are more than double those with a negotiated one. Moreover, the average days of delay does not appear to differ according to the nature of the awarding procedure itself:[12] out of the 30,244 contracts awarded with an open procedure, about 80% had delays while out of the 13,189 contracts awarded with a negotiated procedures, 75% had delays.[13]

Figure 1 illustrates the ratio between the average recorded delay over contracted days for different ranges of contract values. Although in Central and Northern Italy this ratio deacreses as the value of the contract increases, the correlations between the average recorded delays over the contract value results (though statistically significant) very low in any of the three macro-regions (0.03 in Central Italy, 0.1 in Southern Italy and 0.05 in Northern Italy).[14] This suggests that there is not a functional relationship between delays and contract value; the reduction in the ratio, illustrated in Figure 1, could simply be due to the reduction in the average days of delay (numerator) or to an increase in contracted days (denominator) or to a combination of the two.[15]

[11] The distinction among these three macro-regions has been made by referring to the definition by the Italian National Institute of Statistics (Istat) according to which, Italy can be divided in: Northern Italy (which comprises Piemonte, Valle d'Aosta, Liguria, and Lombardia, Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Emilia Romagna); 2) Central Italy (Toscana, Umbria, Marche, Lazio); 3) Southern Italy (Abruzzo, Molise, Campania, Puglia, Basilicata e Calabria, Sicilia, Sardegna).

[12] Italian regulation on PPCs is slowly adopting the EU rules in force. The four EU procedures for awarding procurement are: open procedure, restricted procedure, negotiated procedure and competitive dialogue (see about:http://europa.eu/scadplus/leg/en/lvb/l22009.htm). Note that prior than the promulgation of Government Decree n. 163/2006, in Italy there was a different classification for the awarding procedures which comprised a longer list of procedures than the one set in the EU regulation, therefore the AVCP database records them accordingly to the legislation in force during the period 2000-2006 (i.e. Law n. 109/1994 and D.P.R. n. 554/1999). We have here aggregated these data according to the EU classification which is currently in force in Italy.

[13] In principle, delays in the PPC completion time weigh differently on the contract value depending on the procedure adopted in awarding. In the "negotiated" procedure, the contract value is directly agreed between the parties and includes an explicit trade-off between the contract value and the investment's delivery time. Instead, in the "open" procedure, the investment's execution time can itself be part of the successful bid, thus representing a strategic variable in the competition among bidders. Bajari and Lewis (2009) investigated theoretically and empically the effects of awarding separately completion time and contract costs in Minnesota highway procurements. They highlighted that large improvements in social welfare are possibile through the adoption of the scoring rule where contractors bid for the two items separately with respect to the case where contractors bid only for contract costs.

[14] All these three correlations are stastically significant at 0.01 level.

[15] Inspections of the database highilight that the high ratio recorded for PPCs in Southern Italy for the range between 5,000,000 and 15,000,000 Euros seems mainly driven by only one contract for road resurfacing awarded by the municipality of Naples: this contract records a delay in execution which corresponds to about eleven times the contracted completion time.

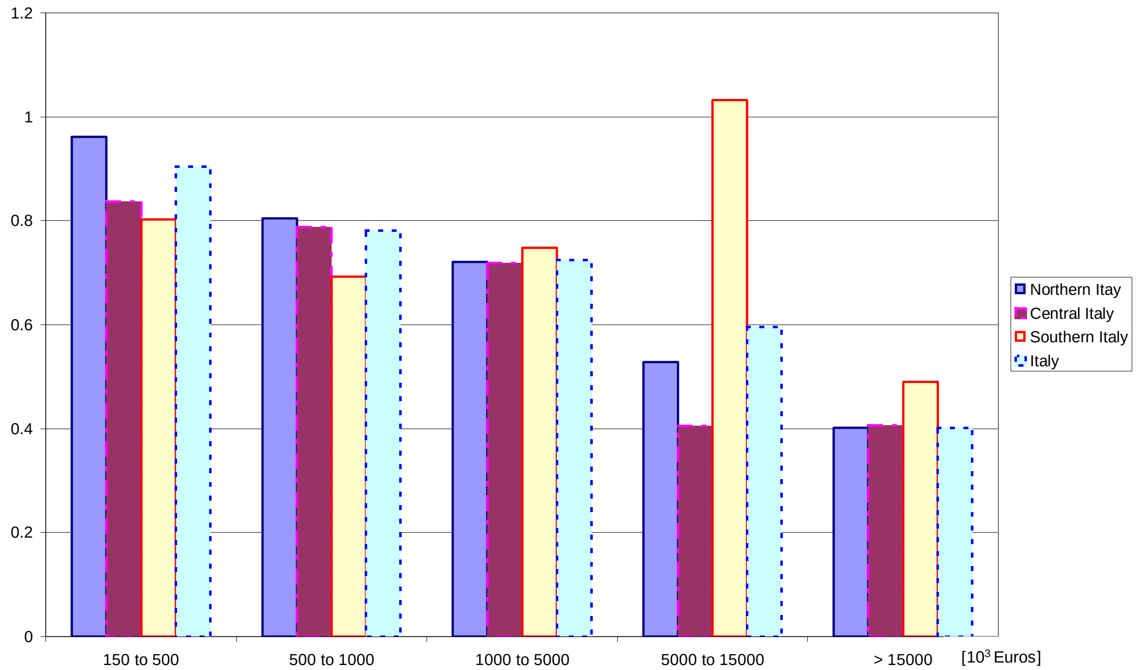

Figure 1: Average delayed days over contracted days according to contract location and value

2.2 Judicial enforcement of penalty for delay in Italian PPCs

In the following, we specifically address the probability of judicial enforcement of the rule for delay in PPC execution. We first refer to previous analyses where judicial enforcement is related to the 'quality' of the judicial system and provide empirical evidence for the Italian case. We then discuss how judicial enforcement is affected by the discretionality of the court of law in voiding the penalty rule for delay and, specifically, we refer the discretionality of the court to the amount of the penalty committed.

Guash *et al.* (2006) developed a theoretical model where the probability of contract enforcement is affected by a parameter referring to the 'quality' (efficiency) of the judicial system: the higher the judicial inefficiency, the lower the probability of contract enforcement. These theoretical predictions are broadly consistent with the empirical results obtained by the same authors on concession contracts for building infrastructure in Latin America (Guasch *et al.*, 2003). Bianco *et al.* (2005), investigating credit markets**,** offered a simple theoretical model showing that improvements in judicial efficiency reduce credit rationing and increase lending; their results are supported by national and international empirical evidence. Indeed, Bianco *et al.* (2005) empirically highlight that in Italian provinces with longer trials - or large backlogs of pending trials - credit for firms is less available.[16]

In a procurement setting, the key function of a court of law is essentially to force contractors to pay penalties when they fail to do so. Therefore, poor judicial enforcement - if foreseen - will increase the contractor's opportunistic behaviour, i.e. the contractor will have *de facto* an incentive to delay the completion of the PPC. Thus, in our analysis, we assume that the enforcement of a penalty is directly related to the average length of judicial processes as the threat of long trials reduces the probability of enforcement itself.[17] Following Bianco *et al.* (2005), in Table 1 below

[16] Moreover, at an international level, Bianco *et al.* (2005) found that the depth of mortgage markets is inversely related to the costs of mortgage foreclosure and other proxies for judicial efficiency.

[17] A long trial increases the contractor's and the CA's legal expenses; moreover, for a disputed penalty, the contract execution may even be suspended, increasing the direct negative externality inflicted on consumers by slow completion. For a disputed penalty there could be a further negative effect for the contractor depending on the

we show the average length of ordinary civil trials (i.e. the time elapsing between the date of initial recording of a trial and that of the court's final sentence) in the three main geographical macro-regions in Italy as reported by data-sets provided by the Italian Ministry of Justice in 2005.[18]

Location	**Average days**
Italy	850
Northern Italy	646
Central Italy	648
Southern Italy	1015

Table 1: Average length of ordinary civil trials in Italy, 2005

The average length for Italian civil justice to reach a final sentence is equal to 850 days, i.e. more than 2 years. Nevertheless, this inefficiency is distributed differently across the geographical macro-regions of Italy. More precisely, the judicial inefficiency in civil trial is very marked in Southern Italy (1015 average days to reach a final sentence) compared to both the Northern and Central regions (respectively 646 and 648 days on average).

A further issue affecting the probability of enforcement of rules in PPCs is related to the role played by the court of law as an active player in observing *ex-post* unforeseen contingencies: in this context the court could decide whether to void or enforce a contract's rule. If we apply Anderlini *et al.*'s (2007) analysis to our procurement setting, we can observe similar effects when committed penalties for delays in delivery date are significant: in these cases the court can choose to not enforce the penalty rule and apply the "principle of liquidated damage" which only considers enforceable the penalty corresponding to the "reasonable damage" suffered by the procurer (and/or consumers, etc.). In other words, the probability of enforcement of the penalty by the court is here related to the level of the committed penalty since the court's discretionality in contract enforcement increases with the amount of the penalty.

Referring to Italian PPCs, unfortunately, the AVCP database does not provide information about the level of penalties which have been committed for delays in execution and which have actually been paid by contractors. However, using the information provided on the delayed days for each contract's execution and the minimum and maximum level of penalty fees as defined by the Italian Law (respectively 0.03% and 0.1% of the contract value for each day of delay in delivering the asset),[19] we present in Table 2 the average penalty that should have been committed in Italian PPCs by range of contract value and macro-regional area. This was done by multiplying the average number of delayed days for each range of contract values by 0.03% and 0.1% respectively (i.e. for the minimum and maximum penalty fee for each day of delay set by the Italian Law).

The data in Table 2 show that the percentage of the estimated penalty over the total value of the PPC tends to increase with contract value except for the very high value projects (over 15,000,000 Euros). This is due to two main facts: first, according to Italian Law, the penalty is calculated as a percentage of the contract's value; second, as noted in Figure 1, the ratio of average delayed days over contracted days decreases with a contract's value. In particular, for very high value contracts, a reduction in the average delayed days more than compensates for an increase in the penalty amount.

payment rules adopted: if the payment to the contractor is divided up into the contract's execution stages, a direct cost for the contractor arises as - given the halt in the PPC execution - it is not fully rewarded.

[18] For further details, see the following link: http://www.giustizia.it/statistiche/statistiche_dog/2002/civile/distretti_civ.htm.

[19] This range of penalties belongs to the D.P.R . n. 554/1999, art. 117. See also Government Decree n. 163/2006.

By range value (10^3 euro)	Geog. Region	Average delayed days	Average contract value (euro)	Minimum penalty amount (euro)	Maximum penalty amount (euro)	% Minimum penalty over total value	% Maximum penalty over total value
150 to 500	Italy	131.84	273192	15584	51948	5.7%	19.0%
	N. Italy	131.63	273942	15338	51129	5.6%	18.7%
	C. Italy	204.48	271378	15886	52955	5.9%	19.5%
	S. Italy	133.68	272857	15999	53333	5.9%	19.5%
500 to 1000	Italy	173.24	694654	47284	157613	6.8%	22.7%
	N. Italy	166.68	696045	46472	154907	6.7%	22.3%
	C. Italy	201.71	694666	51806	172687	7.5%	24.9%
	S. Italy	167.28	689813	45266	150889	6.6%	21.9%
1000 to 5000	Italy	219.98	1886735	160390	534636	8.5%	28.3%
	N. Italy	208.86	1897885	153413	511377	8.1%	26.9%
	C. Italy	235.53	1908249	178208	594026	9.3%	31.1%
	S. Italy	250.01	1825213	169889	566298	9.3%	31.0%
5000 to 15000	Italy	267.13	7808002	803379	2677931	10.3%	34.3%
	N. Italy	258.18	7601970	732416	2441389	9.6%	32.1%
	C. Italy	220.05	8173845	814588	2715293	10.0%	33.2%
	S. Italy	344.94	8306584	1069027	3563424	12.9%	42.9%
> 15000	Italy	213.93	33941171	3611694	12038981	10.6%	35.5%
	N. Italy	184.16	33952771	3164290	10547634	9.3%	31.1%
	C. Italy	262.83	44470151	7215423	24051410	16.2%	54.1%
	S. Italy	294.75	27977296	3178474	10594914	11.4%	37.9%
Total	Italy	150.55	698157	54949	183163	7.9%	26.2%
	N. Italy	149.04	734957	55349	184497	7.5%	25.1%
	C. Italy	152.65	622972	53353	177843	8.6%	28.5%
	S. Italy	153.47	659764	55402	184674	8.4%	28.0%

Table 2: Minimum and maximum penalty in level and percentage over the total amount of contracts defined according to the DPR n. 554/1999

Given the lack of information in the AVCP database about committed penalties which have actually been paid - i.e. enforced - we looked at other recent investigations into PPC enforcement in Italy. These investigations (Albano *et al.* (2008) and Spagnolo *et al.* (2008)) which were carried out on smaller datasets, documented that committed penalties in Italy are enforced in very few cases.[20]

3 A model for *optimal* penalty fee in PPCs

In this section, we consider the case where a Contracting Authority (CA) awards a public procurement contract (PPC) to an economic operator (i.e. a contractor firm) to build a public infrastructure with exogenous and ex-ante defined technical characteristics.[21] We assume that the contractor is selected according to a 'negotiated' procedure: that is, the CA first consults some economic operators of its choice and then agrees on the terms of the contract with only one of them.[22] Moreover, the project (e.g. the building of a public infrastructure) is of a fixed size.[23]

[20] Albano *et al.* (2008) investigated the quality of public expenditure for Italian public administrations and showed that out of 800 inspectoral checks between September 2006 and April 2007, 437 cases did not comply with the ex-ante defined standard: of these, in only 16 cases were penalties enforced (3.66%). Spagnolo *et al.* (2008) reported that out of 4,095 inspections commissioned by the Italian Public Procurement Agency (CONSIP) in the period 2005-2008, a total of 1,455 contractual infringements by the contractor were ascertained, but penalties were only exercised in 64 cases (about 4.42%).

[21] This context does not deal with the issue of delay caused by an erroneous original project. To investigate this issue, one would have to extend this model with *i)* a preliminary stage where the CA evaluates the contractor's proposal and *ii)* a further stage where the CA controls ex-post the infrastructure's execution.

[22] This assumption seems to be neutral: indeed, by evidence from the Italian AVCP database, delays are not correlated to the awarding procedure adopted (see Section 2 above).

[23] This assumption is in line with our findings from data on the Italian PPCs - see previous Section 2.1 - about recorded delays and the contracts's average range value: we found a very low correlation index which results slighty

According to the PPC, the contractor commits itself to constructing the infrastructure at time t in return for a fixed payment p, which is agreed on by both parties. To keep the model as simple as possible, we assume that the infrastructure can be built instantaneously, at the estimated cost $C_t \leq p$. Furthermore, the contract includes the contractor's liability for completion on time, i.e. if the contractor delays the contracted delivery date it will pay a constant penalty c for each period (i.e. for each day) of delay. In Appendix A we present an extension of our model to the - realistic, but not frequent - case where the contractor is punished/rewarded if it decides to delay/anticipate the delivery date, i.e. to the case where the PPC includes a penalty/premium rule.

Under these assumptions, the net benefit for a risk-neutral contractor (i.e. the project's Net Present Value, NPV henceforth) that complies with the contract delivery time is given by:[24]

$$F_t = p - C_t \ , \tag{1}$$

where $C_t \leq p$ is the estimated cost of building the infrastructure at time t, when the contract is signed.

However, the introduction of the penalty clause gives - *de facto* - the contractor some flexibility in deciding its optimal time-to-completion. This investment timing flexibility has a value that should be added to the project's NPV as expressed in (1). In particular, for the sake of simplicity, we assume that the project's cost C_t evolves over time according to a geometric Brownian motion:[25]

$$dC_t = \alpha C_t dt + \sigma C_t dz_t \ , \tag{2}$$

where $\alpha \gtreqless 0$ is the drift and $\sigma > 0$ is the volatility of the cost process. Under this assumption, the contractor's possibility of deferring the infrastructure's completion date becomes analogous to a Perpetual Put Option whose value is equal to:

$$P_t \equiv \Phi_t - \pi \Lambda_t. \tag{3}$$

where $\Phi_t \equiv E_t(e^{-r(\tau-t)})F_\tau$ and $\Lambda_t \equiv E_t\left[\int_t^\tau ce^{-r(s-t)}ds\right]$. Φ_t is the expected and discounted net benefit from investing at a general cost $C_\tau < C_t$, Λ_t is the expected value of the penalty at time t, $\pi \in [0,1]$ is the probability that a third party - i.e. a court of law - is able to enforce the penalty, r is the risk-adjusted expected rate of return that investors would require to invest in the project,[26] and τ is the exercise time of the option.

According to (3), since $\Lambda_t = \left[1 - E_t(e^{-r(\tau-t)})\right]\frac{c}{r}$, the ex-ante value of the procurement contract for the contractor is (Dixit and Pindyck, 1994):[27]

$$P_t = E_t(e^{-r(\tau-t)})\left(F_\tau + \pi\frac{c}{r}\right) - \pi\frac{c}{r}. \tag{4}$$

different according to geographic area where the PPC is executed (from 0.03 in Central Italy to 0.1 in Southern Italy, and to 0.05 in Northern Italy).

[24] The assumption that the project is built instantaneously can be relaxed without substantially altering the results. Let us assume that it takes "time-to-build" the project but there is a maximum rate k at which the firm can invest in every period (year). Therefore, denoting the total expenditure with C_t, it takes $T = C_t/k$ periods (years) to complete the project. Assuming that the expenditures are made continuously over T, their present value is:

$$\hat{C}_t = \int_0^{C_t/k} ke^{-rs}ds = (1 - e^{-rC_t/k})\frac{k}{r}$$

However, noting that $e^{-rC_t/k} \simeq 1 - r\frac{C_t}{k} + ...$, we get $\hat{C}_t \simeq C_t$ and the analysis can proceed pretty much as in the text.

[25] In the following equation, dz_t is the increment of a standard Brownian process with mean zero and variance dt (Dixit, 1993; Dixit and Pindyck, 1994).

[26] The discount rate r can either be adjusted for risk or the expectation for the discount factor can be taken with respect to a risk-adjusted probability measure with r as the risk-free discount rate (Cox and Ross, 1976; Harrison and Kreps, 1979).

[27] When it is established in the PPC that the CA can revoke the contract if the total penalty reaches an upper bound G, the previous Perpetual Put Option in (2) turns into an American Put Option, with maturity time T, as follows:

$$\int_0^T ce^{-rs}ds \equiv \frac{c}{r}(1 - e^{-rT}) = Gp$$

Modelling this option is more complicated than the previous (2) but the results do not substantially differ.

Furthermore, since F_t is also driven by a geometric Brownian motion, i.e. $dF_t = \alpha(F_t - p)dt + \sigma(F_t - p)dz_t$, the discount rate can be expressed as $E_t(e^{-r(\tau - t)}) = \left(\frac{F_t - p}{F_\tau - p}\right)^\beta$, where $\beta < 0$ is the negative root of the quadratic equation $\frac{1}{2}\sigma^2 x(x-1) + \alpha x - r = 0$.[28] By substituting the expression for the discount rate into (4), we obtain the final expression for P_t as:

$$P_t = \left(\frac{F_t - p}{F_\tau - p}\right)^\beta \left(F_\tau + \pi\frac{c}{r}\right) - \pi\frac{c}{r}. \tag{5}$$

Equation (5) states that for any fixed p, whenever $P_t > F_t$, it will be profitable for the contractor to infringe the contract's provision on the investment's delivery date. In particular, the contractor will be better off by maximizing (5) with respect to F_τ in order to determine its optimal delay. The net benefit that will trigger the firm's investment is:[29]

$$F_\tau = \frac{1}{1-\beta}(p + \beta\pi\frac{c}{r}). \tag{6}$$

Equation (6) yields the following investment rule: if $F_\tau \leq F_t$, it is optimal for the contractor to invest immediately, while if $F_\tau > F_t$, it is optimal to wait until the net benefit is equal to F_τ. Finally, if the CA wishes to incentivate the firm to respect the contractual time, it must fix a penalty fee such that $F_\tau = F_t$. From (6), the optimal penalty fee is now:

$$c^*(\pi) = \frac{r}{\pi}\left(\frac{\beta - 1}{\beta}C_t - p\right) \tag{7}$$

which, *ceteris paribus*, depends on π, σ (via β) and C_t.

According to (7), if the CA expects a low probability π and/or a high current investment cost C_t (i.e. for decreasing NPV), it should increase the value of the penalty fee to discourage the firm from delays. Futhermore, since $d((\beta - 1)/\beta)/d\sigma > 0$, according to (7) an increase in uncertainty would induce the CA to set a higher penalty fee.

We now investigate the probability of the penalty enforcement more deeply: specifically, we assume that a low probability of penalty enforcement may arise from at least two different sources. First, if the court of law - to which the parties refer in case of dispute - considers the committed penalty to be "excessive", it may decide not to enforce it or to reduce it to an extent estimated as reasonably covering the damages caused by the contractor's breach.[30] In order to include this case in our model, we assume that the probability of enforcement by the court π depends on the value of penalty c with the properties that $\pi'(c) < 0$, $\pi(\underline{c}) = 1$ and $\lim_{c\to\infty} \pi(c) = 0$, where $\underline{c} \geq 0$ represents the minimum time unit value (i.e. fee per day) considered *reasonable* by the court of law as *ex ante* foreseen by the CA.[31]

A second element affecting the enforceability of the penalty clause is the 'quality' (efficiency) of the judicial system. Following Guasch *et al.* (2006, p.60), we thus multiply the probability $\pi(c)$

[28] See Dixit and Pindyck (1994), p. 315-316.

[29] The first order condition is:

$$\begin{aligned}\frac{\partial P}{\partial F_\tau} &= \beta\left(\frac{F_t - p}{F_\tau - p}\right)^{\beta - 1}\left(-\frac{F_t - p}{(F_\tau - p)^2}\right)\left(F_\tau + \pi\frac{c}{r}\right) + \left(\frac{F_t - p}{F_\tau - p}\right)^\beta \\ &= \left(\frac{F_t - p}{F_\tau - p}\right)^\beta \left[\beta\left(-\frac{1}{F_\tau - p}\right)\left(F_\tau + \pi\frac{c}{r}\right) + 1\right] = 0\end{aligned}$$

[30] In the literature on firm breach of contract, this discretionality by the court of law is commonly referred to as the "liquidated damage principle". Delay in delivering the contracted investment should be referred to as a specific case of the firm's breach of the contract, and the court can apply the above principle to cover the reasonable damage caused to society by delays. For a discussion of the application of the "liquidate damage principle" in PPCs, see Dimitri *et al.* (2004, Ch. 4, pp. 85-86); for an analysis of the economic incentives pertaining to it, see Anderlini *et al.* (2007).

[31] In the US experience of PPC in the highway construction industry, the "unit time value" is typically expressed as a cost per day. It is calculated by the State highway agency (the CA in our model) referring to the "daily road-user cost", which include items such as travel time, travel distance, fuel expense, etc. See Herbsman *et al.* (1995) for an example of the "daily road-user cost" calculation used by the Kansas Department of Transportation.

by a parameter $\theta \in [0, 1]$ which refers to the average time that the court of law takes to resolve disputes.[32]

According to these assumptions on the probability of the penalty's enforcement, the optimal penalty design (7) is now given by the implicit function:

$$\pi(c^*)c^* - \frac{r}{\theta}\left(\frac{\beta-1}{\beta}C_t - p\right) = 0, \qquad for \;\; c^* \geq \underline{c}. \tag{8}$$

In order to illustrate the properties of (8) with reference to the Italian case, in what follows, we first provide some numerical solutions (see Tables 3, 4, 5, 6 below) and discuss them referring to the maximum and minimum value of the penalty fee set by Italian legislation. We further specify different values for θ according to data on the average length of ordinary civil trials in different Italian regional areas (see previous Table 1) and compare results for (8) according to the macro areas where the contracts are executed - Northern and Central Italy *vs* Southern Italy (see Figures 2, 3, 4, 5 below).

Let us calculate (8). Regarding the probability of enforcement, we assume $\pi(c) = (\underline{c}/c)^\eta$ for $c \geq \underline{c}$. In other words, when the CA sets a penalty higher than $\underline{c}$, an increase in elasticity η determines a rapid decrease in probability π. If the elasticity is less than one, so that higher values of $\underline{c}$ are deemed excessive by the court, increasing values of both σ and C_t lead to higher optimal penalties. In the calibration, $\underline{c}$ takes the values of 0.03% and 0.1%, which are respectively the lower and upper limits of the penalty fee in PPC as set by Italian legislation while elasticity η takes two different values, $\eta = 0.3$ and $\eta = 0.5$, respectively.

All the above assumptions allow us to rewrite equation (8) as follows:

$$c^* = \max\left\{\underline{c} \;\; , \;\; \frac{\left[r/\theta\left(\frac{\beta-1}{\beta}C_t - p\right)\right]^{1/1-\eta}}{(\underline{c})^{\eta/1-\eta}}\right\}. \tag{9}$$

The choice of parameters for the calibration is made following as much as possible indications from related studies (Dixit and Pindyck, 1994; Herbsman *et al.*, 1995; Arditi *et al.*, 1997). The price of the contracted investment is normalized to one, i.e. $p = 1$, and the parameters of the model take the following values: the discount rate[33] $r = 0.05$;[34] the investment cost $C_t = 0.7, 0.8, 0.9; \alpha = 0$;[35] and $\sigma = 0.3, 0.4, 0.5$.

Finally, interpreting θ as the probability that a court of law is able to resolve a dispute in a year, in order to gauge the effect of the 'quality' of the judicial system throughout Italy we set $1/\theta = 3$ so as to refer to the average number of years the Italian courts take to resolve legal disputes.[36]

The results of the simulations show that, according to the Real Option Theory, the higher the investment cost, C_t, and/or the uncertainty, σ, the higher the optimal penalty c^*. In other words, both the investment cost C_t and the uncertainty σ incentivate the firm to defer the contracted investment which, in turn, would call for higher penalties to make the firm comply with the contracted execution time.

[32] We are aware that the quality of justice is often discussed in the economic literature with reference to many other dimensions, such as accuracy and costs in pursuing legal actions. Considering only the timing dimension, we would stress here the relevance of the common saying "justice delayed is justice denied".

[33] Although r should be the return that an investor can earn on other investments with comparable risk characteristics, throughout our analysis we simply refer it to the social rate of discount that the Italian government suggests should be usedto evalute most public projects. For Italy this ranges between 8% and 12%, with the possibility of dropping to 5% for projects undertaken in the southern regions (see Pennisi and Scandizzo, 2003).

[34] We performed other simulations by changing the value of the discount rate, for r = 8%, 10%, 15%. The simulations for r = 10% are in the Appendix while the others are available from the authors on request.

[35] Note here that because of the Markov property of (2), the quality of all subsequent results does not change for any non-zero trend of costs as long as $\alpha < r$. In fact, the presence of any non-zero trend would change the option to wait. Therefore a $\alpha < 0$ would strenghten the firm's desire not to comply with the contractual time.

[36] Here we refer to the average duration of a civil trial in Italy (Table 1) because the civil court of law is the forum authorized to deal with these disputes. Note that the average duration of a civil trial adopted in the calibration is consistent with the period our dataset on Italian PPCs refers to.

Tables 3 and 4 below show the optimal penalties obtained by simulations of (9) for $\underline{c} = 0.03\%$, and $\eta = 0.3$ and $\eta = 0.5$ respectively, while Tables 5 and 6 show the optimal penalties obtained by simulations of (9) for $\underline{c} = 0.1\%$, and $\eta = 0.3$ and $\eta = 0.5$ respectively. In all these Tables it can be observed that the higher the values of C_t and σ, the higher the optimal penalty c^*. In addition, it is evident that the optimal penalties are highly sensitive to the values of both $\underline{c}$ and η. Specifically, when the value of the penalty considered reasonable by the court of law is $\underline{c} = 0.03\%$, if the elasticity of the probability is $\eta = 0.3$ or $\eta = 0.5$ (Table 3 and 4), the optimal penalty c^* always exceeds $\underline{c}$. In these cases $\underline{c}$ is sub-optimal, and would induce the contractor to delay the investment. This delay would increase as the NPV decreases (Tables 3 and 4). By contrast, when the value of the reasonable penalty by the court of law is $\underline{c} = 0.1\%$, if the elasticity of the probability is $\eta = 0.3$ (Table 5), the optimal penalty c^* is higher than 0.1% only for a high value of C_t and/or σ. In all the other cases, the CA will find it convenient to set the penalty fee equal to 0.1% and the contractor will find it convenient to comply with the contractual delivery date. In olther words, the penalty fee is correctly set and the probability of enforcement is equal to 1 (perfect enforceability). Note that all the results according to which the CA finds it convenient to set the fee equal to $\underline{c}$ are in the Tables highlighted in yellow.

The results displayed in Table 6 show that for $\eta = 0.5$, the CA finds it convenient to set the fee which presumes reasonable for the court (i.e. to set $\underline{c} = 0.1\%$) only when $C_t = 0.7$ and $\sigma = 0.3$ (i.e for greater NPV and lower volatility); in all other cases the optimal penalty is always greater than 0.1%.

To sum up, if a firm's profitability on signing a contract is high and the volatility on future investment costs, C_t, is low, the contractor will not defer the investment. This allows the CA to set the penalty equal to the one proposed by the court. On the contrary, if the NPV is low and the volatility is high, the contractor will find it convenient to defer the investments, and by contrast the CA will set a penalty higher than $\underline{c}$ in order to induce the contractor to comply with the contracted delivery date.[37]

α=0		c*			
		r=5%			
		σ=20%	σ=30%	σ=40%	σ=50%
C_t	0,9	0,0607%	0,1459%	0,2787%	0,4708%
	0,8	0,0383%	0,1060%	0,2145%	0,3731%
	0,7	0,03%	0,0703%	0,1556%	0,2826%

Table 3: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = 0$, $r = 5\%$, $\eta = 0.3$ expressed in percentage and in terms of days

α=0		c*			
		r=5%			
		σ=20%	σ=30%	σ=40%	σ=50%
C_t	0,9	0,1720%	0,5864%	1,4521%	3,0249%
	0,8	0,0904%	0,3753%	1,0061%	2,1842%
	0,7	0,0348%	0,2111%	0,6418%	1,4801%

Table 4: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = 0$, $r = 5\%$, $\eta = 0.5$ expressed in percentage and in terms of days

[37] All the results still hold if we consider $\alpha < 0$ (see Appendix). Assuming $\alpha < 0$ emphasizes the results according to which the optimal penalty is always greater than $\underline{c}$ except when $\underline{c} = 0.1\%$, $\eta = 0.3$, $C_t = 0.7$ and $\sigma = 0.3$. In this case the optimal penalty is always less than $\underline{c} = 0.1\%$, so that the CA finds it optimal to set the penalty equal to $\underline{c}$.There is only one case where the optimal penalty is less than 0.1%: when $\underline{c} = 0.03\%$, $\eta = 0.5$, $C_t = 0.7$ and $\sigma = 0.3$.

α=0		c^*			
		r=5%			
		σ=20%	σ=30%	σ=40%	σ=50%
C_t	0,9	0,1%	0,1%	0,1664%	0,2810%
	0,8	0,1%	0,1%	0,1280%	0,2227%
	0,7	0,1%	0,1%	0,1%	0,1687%

Table 5: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = 0$, $r = 5\%$, $\eta = 0.3$ expressed in percentage and in terms of days

α=0		c^*			
		r=5%			
		σ=20%	σ=30%	σ=40%	σ=50%
C_t	0,9	0,1%	0,1759%	0,4356%	0,9075%
	0,8	0,1%	0,1126%	0,3018%	0,6553%
	0,7	0,1%	0,1%	0,1925%	0,4440%

Table 6: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = 0$, $r = 5\%$, $\eta = 0.5$ expressed in percentage and in terms of days

Finally, we perform simulations to test the effects of the quality of the judicial system on the optimal penalty (Figure 2, 3, 4, 5). As outlined in Section 2.2, the average length of ordinary civil trials in the three Italian macro-regions are very similar for Northern and Central Italy (which can be therefore considered together) and shorter than in the South. Therefore, referring to Table 1, we assumed $\theta = 0.5$ for Northern and Central Italy (NCI henceforth), and $\theta = 0.25$ for Southern Italy (SI henceforth) respectively. These parameters imply that the average length of ordinary civil trials is respectively $1/\theta = 2$ years for NCI and $1/\theta = 4$ years for SI.

The results obtained for the case of Italy do not vary qualitatively if we consider NCI and SI separately: the optimal penalty in both cases increases monotonically in C_t and σ. However, it is important to stress here that the optimal penalty decreases for increasing value of θ: indeed, note that in the Figures below the plane for $\theta = 0.5$ lays always below that for $\theta = 0.25$. Figures 2, 3, 4, 5, show that *i)* the optimal penalty set for PPCs awarded and executed in SI should always be greater than the one set in NCI; *ii)* the spread between the optimal penalty in NCI and the one in SI increases for increasing values of C_t (i.e. decreasing NPV) and σ.

These findings are consistent with the empirical evidence on delays reported in the AVCP's survey on Italian PPCs. Indeed, according to the AVCP's dataset, the SI records on average the highest number of delayed days. This reveals that, because the penalty fee is not differentiated by regional areas, in SI contractors find it optimal to delay the delivery date more frequently than in NCI.[38]

[38] As shown in the Appendix, the results for NCI and SI respectively still hold if we consider $\alpha < 0$. Analogous considerations hold for $\theta = 0.5$ and $\theta = 0.25$.

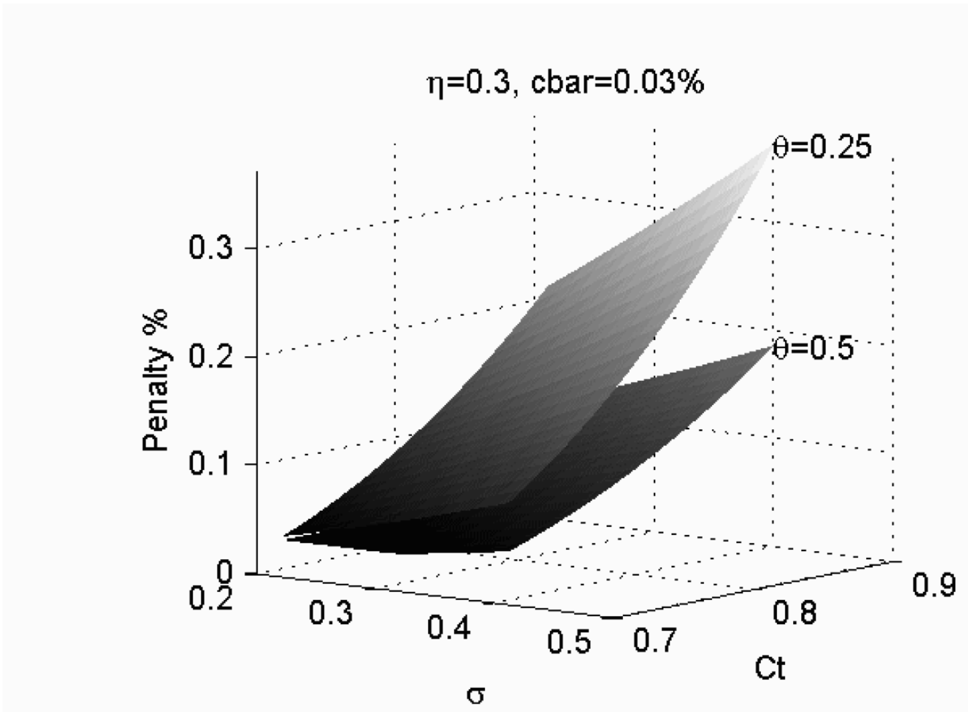

Figure 2: Optimal penalties expressed in percentage and in terms of days for $\underline{c} = 0.03\%, \eta = 0.3$, with respect to increasing σ and C_t

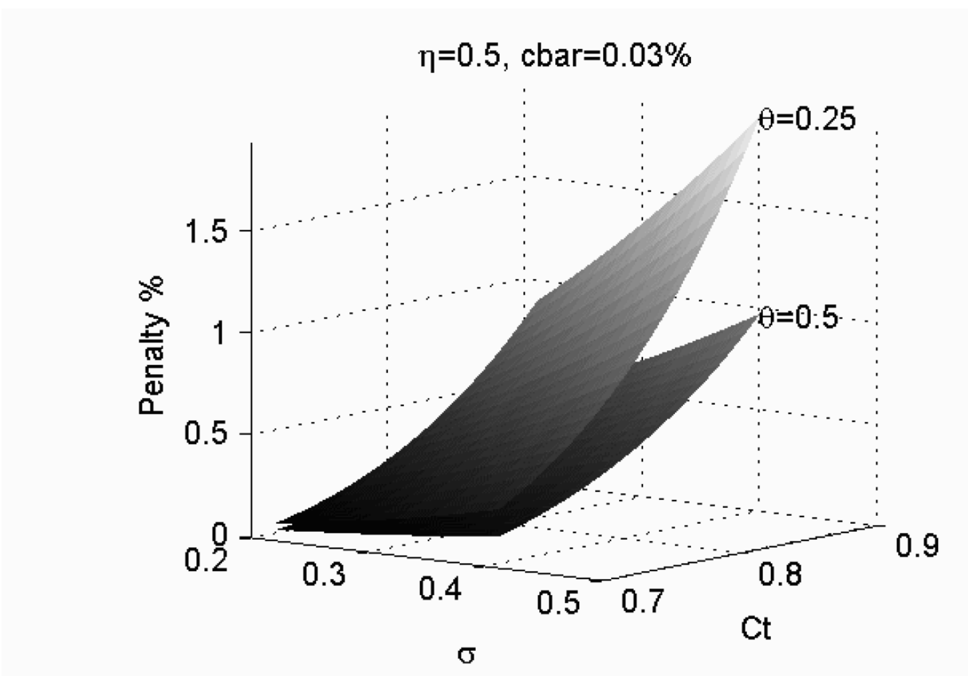

Figure 3: Optimal penalties expressed in percentage and in terms of days for $\underline{c} = 0.03\%, \eta = 0.5$, with respect to increasing σ and C_t

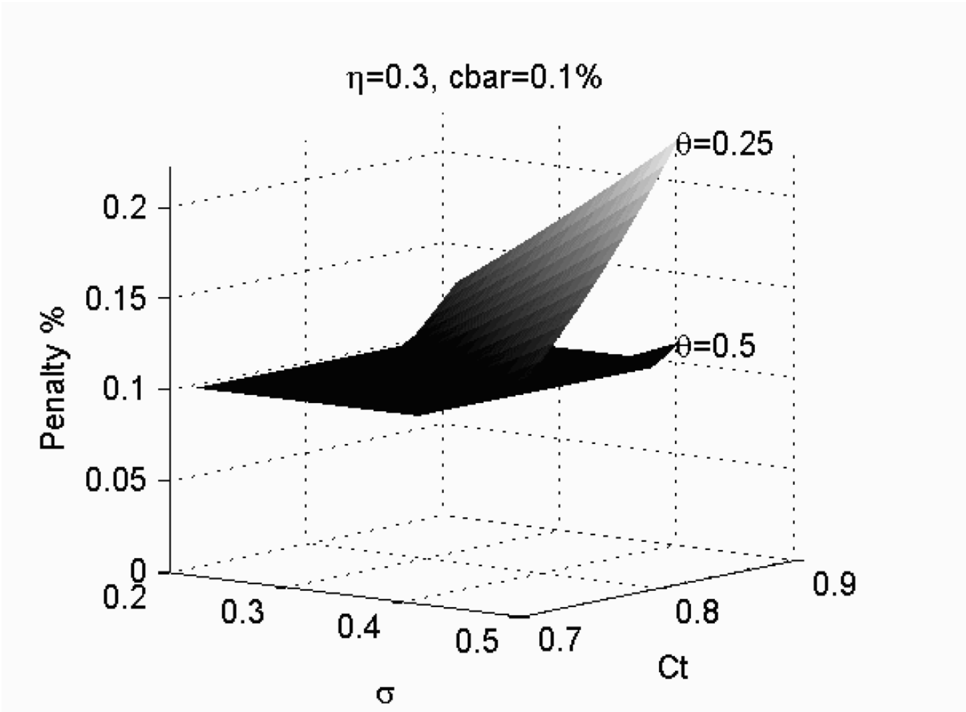

Figure 4: Optimal penalties expressed in percentage and in terms of days for $\underline{c} = 0.1\%, \eta = 0.3$, with respect to increasing σ and C_t

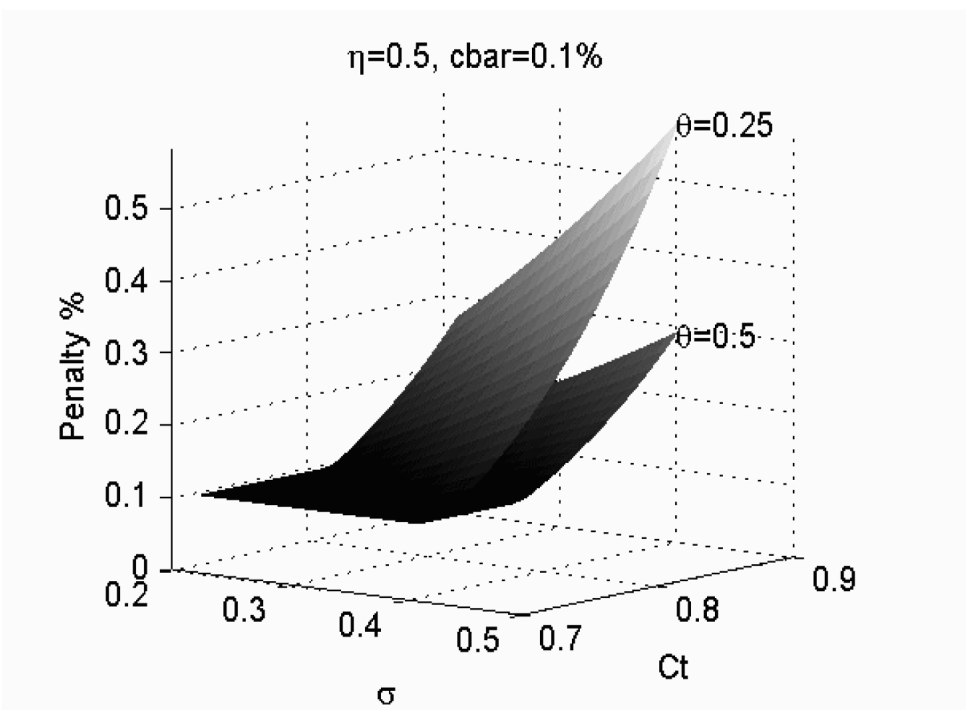

Figure 5: Optimal penalties expressed in percentage and in terms of days for $\underline{c} = 0.1\%, \eta = 0.5$, with respect to increasing σ and C_t

Finally, it is important to consider the dynamics of the optimal penalties specifically considering the two variables analysed here: the NPV $(p - C_t)$ and the uncertainty effect (σ) focusing on the spread between NCI and SI optimal penalties. In this regard, it can be noted that the profitability effect is stronger than the uncertainty effect (the plane with $\theta = 0.25$ increases more sharply than the plane with $\theta = 0.5$). This seems to suggest that the lower the NPV (the higher C_t), the longer the delay and, consequently, the higher the optimal penalty should be. Referring to the Italian macro-regions, this means that a low profitability contract in the SI exhibits more delayed days than in NCI, *ceteris paribus:* this result is explained in our model by a less efficient judicial system in SI, which implies a low probability that the penalty will be enforced and, consequently, paid.

4 Final remarks

Delays in investment execution are a negative by-product of public procurement because they can: i) increase the original costs of the contract, thus producing direct negative effects for the CA; ii) inflict a negative externality on consumers which would directly benefit from the contract's completion. This is a relevant issue for the performance of PPCs in Italy where - as documented in Section 2 - about 78% of contracts awarded in the period 2000-2006 were executed with delays.

In many countries procurement contracts usually include penalty clauses for each day of delay to induce the contractor to respect the contracted delivery timing. To date, the effectiveness of penalty rules for delay in PPC, has never been specifically investigated. Our paper takes a step in this direction, answering the following research questions: given the evidence of long delays, is there something wrong with the definition of these penalty clauses? How should the optimal penalty fee be determined?

We presented a model starting from the assumption that penalty clauses give - to some extent - the contractor the option of deciding the investment timing for the PPC's execution. To be "optimally" set, these penalties should take into account the value of this investment timing flexibility, which then affects the contract's value. Adopting a Real Option approach, our model illustrates that uncertainty over investment costs increases the penalty fee set to induce the contractor to respect the delivery timing.

Moreover, our model investigates whether the inefficiency of penalty rules is caused by difficulties in their enforcement. For this purpose, we specifically explored judicial inefficiency of the penalty enforcement in two directions. First of all, we assumed that the court's discretionality in enforcing the penalty increases with the committed penalty, and this - in turn - reduces the probability of penalty enforcement. Secondly, we assumed that the penalty enforcement is lower as the 'quality' of the judicial system decreases. As a measure of the 'quality' of the judicial system we adopted the average length of ordinary civil trials: the longer the average length of trials, the lower the 'quality' of the judicial system.

The model's predictions on penalty enforcement received support from calibrations we perform on the Italian case: our findings show that *i)* the higher the investment cost, C_t, and/or the uncertainty, σ, the higher the optimal penalty c^* and *ii)* the optimal penalty is highly sensitive to the 'quality' of the judicial system and to the discretional power of the court. As the average 'quality' of the judicial system differs among the Italian macro-regions (see Table 1), our results record different levels of *optimal* penalty for the Northern and Central parts of Italy (NCI) and the Southern part (SI). Specifically, the optimal penalty to be set for PPCs in SI should always be greater than the one to be set in NCI, *ceteris paribus*.

We also found that the spread between the optimal penalty in NCI and in SI increases for increasing values of the investment cost C_t (i.e. decreasing profitability) and uncertainty σ. Nevertheless, the profitability of investments weighs more than the uncertainty (the spread increases more slightly with respect to σ than C_t). This means that when the profitability decreases, the delay increases, and consequently this would call for a higher optimal penalty in SI than in NCI.

Thus, as for the Italian case, the theoretical predictions of our simple model and its calibration seem to explain the evidence of the puzzling inefficiency of the penalty rule for delays in the PPCs. At present, the excessive length of ordinary civil trials in Italian judicial districts is common knowledge for all the economic agents: on this ground, if a contractor expects that the CA will not apply to the court to enforce a disputed penalty for delay in completion, it will optimally delay the investment, looking forward - at best - to a renegotiation of the contract with the CA. Moreover, if the contractor considers the case where the CA will apply to the court to enforce the disputed penalty, it knows that the higher the value of the committed penalty, the larger the discretionality of the court in reducing, or even in not enforcing, the committed penalty. These effects would invalidate the direct incentives produced by the rule itself and would - in some cases - call for higher *optimal* penalties than those set according to the Italian regulation on public procurement contracts.

A Appendix

A.1 A penalty/premium model

In Section 3 we investigated how a PPC should comprise a penalty clause for delay designed to optimally induce the contractor to invest at contracted time t. Many PPCs, however, commit the contractor to invest at a future date $t' > t$ and also include an incentive/disincentive (I/D) clause stating that, on the one hand, if the contractor is able to complete the project ahead of schedule t' it will be entitled to premium fee I whilst, on the other hand, if the contractor delays completion, a penalty D will be imposed.

Although the CA may introduce different and alternative I/D designs, we consider here the simplest one where the firm receives a constant premium/penalty fee c for each period (day, month, year, etc.) with which it anticipates/delays the investment with respect to $t' > t$.[39] In other words, the present section investigates how this I/D rule - where the premium and the penalty are identically defined in their amounts, but with opposite signs - should be optimally designed.

Following the approach presented in section 3, the current NPV, say N, of the project for the contractor complying with the contractual delivery time now becomes:[40]

$$\begin{aligned} N(F_t, t') \equiv \; & N_t = e^{-r(t'-t)}p - e^{-\delta(t'-t)}C_t \\ = \; & e^{-\delta(t'-t)}F_t + \left[e^{-r(t'-t)} - e^{-\delta(t'-t)}\right]p \end{aligned} \tag{10}$$

where $\delta = r - \alpha$.[41]

The inclusion in the procurement contract of an I/D rule makes the contractor's investment decision equivalent to exercising a Perpetual Put Option whose value is now given by $P_t \equiv \Phi_t - \pi\Lambda_t$, where Φ_t and π are as in (3) and Λ_t (i.e. the expected value of the premium/penalty at time t) is now equal to:

$$\Lambda_t = \mathcal{E}_t \left[\begin{array}{c} \int_t^{\min(\tau,t')} 0e^{-r(s-t)}ds + \int_{\min(\tau,t')}^{t'} ce^{-r(s-t)}ds + \\ -\int_{t'}^{\max(\tau,t')} ce^{-r(s-t)}ds \end{array} \right] \tag{11}$$

where the expected value $\mathcal{E}_t$ is calculated with respect to both τ and the probability that τ is lower (greater) than t'.

[39] Herbsman *et al.*, 1995 pointed out that in the real world when CAs adopt the I/D rule, the same value for both the incentive and the disincentive fee is generally used.

[40] Note that if t' is set by the CA to allow the contractor to maximize the NPV (10), depending on the parameter values, t' is greater than t only if $r < \delta$. In particular, maximizing (10) we obtain:

$$t' = \max\left[\frac{1}{r-\delta}\log\left(\frac{\delta}{r}\frac{C_t}{p}\right), 0\right] + t$$

which is an increasing function of the current investment cost C_t and is always greater than t if $\frac{\delta}{r} < \frac{p}{C_t}$. In the case of $r = \delta$, we get $N_t = e^{-r(t'-t)}F_t$. Since $F_t > 0$ it is optimal to invest immediately, i.e. $t' = t$. If $r > \delta$ the solution of the first order condition represents a minimum as $\frac{\partial^2 N_t}{\partial (t')^2} > 0$ and the optimal value coincides with one of the boundaries, i.e. it is given by $\max\left[F_t, \lim_{t'\to\infty} N_t\right]$. However, since $\lim_{t'\to\infty} N_t = 0$ it is still optimal to invest immediately.

[41] The term $r - \delta$ can be interpreted as the certainty-equivalent rate of return (see Mc Donald and Siegel, 1984; Dixit and Pindyck, 1994).

By rearranging **(11),** we get**:**

$$\begin{aligned}
\Lambda_t &= E_t\left[\int_t^{\min(\tau,t')} 0e^{-r(s-t)}ds + \int_{\min(\tau,t')}^{t'} ce^{-r(s-t)}ds - \int_{t'}^{\max(\tau,t')} ce^{-r(s-t)}ds\right] \qquad (12)\\
&= E_t\left[c\left(-\frac{1}{r}e^{-r(t'-t)}+\frac{1}{r}e^{-r(\min(\tau,t')-t)}\right) - c\left(-\frac{1}{r}e^{-r(\max(\tau,t')-t)}+\frac{1}{r}e^{-r(t'-t)}\right)\right]\\
&= \frac{c}{r}E_t\left[-e^{-r(t'-t)}+e^{-r(\min(\tau,t')-t)}+e^{-r(\max(\tau,t')-t)}-e^{-r(t'-t)}\right]\\
&= \frac{c}{r}E_t\left[e^{-r(\min(\tau,t')-t)}+e^{-r(\max(\tau,t')-t)}\right] -2\frac{c}{r}e^{-r(t'-t)}
\end{aligned}$$

where the optimal exercise time τ is defined as

$$\tau = \min\left(t \geq 0 \mid F_\tau = \arg\max P_t\right) \tag{13}$$

According to (13), at time t, the probability of having a bonus is the probability of having an optimal exercise time τ less than (or equal to) the contractual time t'. In other words, this is the probability of the geometric Brownian motion F_t reaching the critical value F_τ^* within $[t,\ t']$ starting from an initial condition $F_t < F_\tau^*$. This can be expressed as (Harrison, 1985)

$$\Pr\left(\tau \leq t'\right) = N(s_1) + \left(\frac{F_\tau^*}{F_t}\right)^{2(r-\delta)/\sigma^2-1} N(s_2) \tag{14}$$

where:

$$\begin{aligned}
s_1(F_t, F_\tau^*) &= \frac{\ln(F_t/F_\tau^*) + (r-\delta-\sigma^2/2)(t'-t)}{\sigma\sqrt{t'-t}}\\
s_2(F_t, F_\tau^*) &= s_1 - \left(\frac{2(r-\delta)}{\sigma^2}-1\right)\sigma\sqrt{(t'-t)}.
\end{aligned}$$

By (14), we rewrite (12) as:

$$\begin{aligned}
\Lambda_t &= \frac{c}{r}E_t\left[\Pr\left(\tau \leq t'\right)\left(e^{-r(\tau-t)}+e^{-r(t'-t)}\right) + \left(1-\Pr\left(\tau \leq t'\right)\right)\left(e^{-r(t'-t)}+e^{-r(\tau-t)}\right)\right] +\\
&\quad -2\frac{c}{r}e^{-r(t'-t)}\\
&= \frac{c}{r}E_t\left[e^{-r(t'-t)}+e^{-r(\tau-t)}\right] -2\frac{c}{r}e^{-r(t'-t)}\\
&= \frac{c}{r}E_t\left[e^{-r(\tau-t)}\right] -\frac{c}{r}e^{-r(t'-t)}
\end{aligned}$$

According to (3) and (4) the PPC's ex-ante value where an I/D rule is included is now**:**

$$P_t = \left(\frac{F_t - p}{F_\tau - p}\right)^\beta \left(F_\tau + \pi\frac{c}{r}\right) - \pi\frac{c}{r}e^{-r(t'-t)} \tag{15}$$

which should be maximized with respect to F_τ. From (15), if the contractual time is very long, i.e. $t' \to \infty$, the second term on the left hand side (l.h.s.) disappears and the contractor will get the premium by investing before t' with probability one. If, conversely, the contractual time t' is very short, i.e. $t' \to t$, the second term on the l.h.s. of (15) decreases to $\frac{c}{r}$ as in (5). The contractor will then incur a penalty since, with probability one, it invests when the contractual time is over. Finally, because the term $\frac{c}{r}e^{-r(t'-t)}$ enters (15) as a constant, the optimal investment trigger F_τ is still given by (6) as well as the firm's investment decision rule. In other words, the contractor defers the infrastructure delivery date until F_t reaches trigger F_τ for the first time. In this respect, if exercise time τ is lower than t', the contractor gains a premium, otherwise it must pay a fee.

As in the text, whenever $P_t > N_t$ it will be profitable for the contractor to infringe the contractual time t'. Thus, the difference $P_t - N_t$ represents the contractor's opportunity cost in delivering the investment according to the contracted date t' instead of taking advantage of the investment timing flexibility which pertains to the I/D clause.

We complete the analysis by calculating the optimal I/D fee which induces the contractor to respect the completion date t'. In this regard, since the exercise time τ is stochastic and c is constant (i.e. c is not contingent on τ), the CA must set a policy-rule referring to the probability distribution of τ. For the sake of simplicity, we follow the simple average-time rule[42]:

$$E(\tau) = t' \tag{16}$$

In this case, the mean time that F_t, with starting point $F_t > F_\tau$, takes to reach the upper trigger F_τ for the first time is given by:

$$E(\tau) = m^{-1} \log\left(\frac{C_t}{C_\tau}\right) + t, \tag{17}$$

with $m \equiv (\frac{1}{2}\sigma^2 - (r-\delta) > 0$ and $C_\tau = p - F_\tau$.[43]

To obtain (17), we consider the process C_t on an interval $0 < a < C_t < b < \infty$, with left boundary a and right boundary b. Defining $t_{a,b}$ as the stochastic variable that describes the time it takes C_t to hit for the first time either a or b, we are able to evaluate the first moment (Saphores, 2002):

$$E(t_{a,b}) = \frac{2}{\kappa^2\sigma^2}\left\{\frac{C_t^\kappa - a^\kappa}{b^\kappa - a^\kappa}\left[\left(\frac{b}{C_t}\right)^\kappa - 1 - \kappa\log\left(\frac{b}{C_t}\right)\right] + \frac{b^\kappa - C_t^\kappa}{b^\kappa - a^\kappa}\left[\kappa\log\left(\frac{C_t}{a}\right) + \left(\frac{a}{C_t}\right)^\kappa - 1\right]\right\}$$

where $\kappa = 1 - \frac{2(r-\delta)}{\sigma^2}$.Since $\kappa > 0$, for $b \to \infty$ and $a \to C^* < C_t$ we obtain the expected time that the construction cost will take to reach the lower boundary C^* starting from C_t.

$$\lim_{a \to C^*, b \to \infty} E(t_{a,b}) = E(t_{C^*}) =$$

$$\begin{aligned}
&= \frac{2}{\kappa^2\sigma^2}\left\{\frac{C_t^\kappa - a^\kappa}{b^\kappa - a^\kappa}\left[\left(\frac{b}{C_t}\right)^\kappa - 1 - \kappa\log\left(\frac{b}{C_t}\right)\right] + \frac{b^\kappa - C_t^\kappa}{b^\kappa - a^\kappa}\left[\kappa\log\left(\frac{C_t}{a}\right) + \left(\frac{a}{C_t}\right)^\kappa - 1\right]\right\} \\
&= \frac{2}{\kappa\sigma^2}\log\left(\frac{C_t}{C^*}\right)
\end{aligned}$$

To prove this limit, let us consider the first and second term separately:

$$\lim_{b\to\infty} \frac{b^\kappa - C_t^\kappa}{b^\kappa - a^\kappa}\left[\kappa\log\left(\frac{C_t}{a}\right) + \left(\frac{a}{C_t}\right)^\kappa - 1\right] = \kappa\log\left(\frac{C_t}{a}\right) + \left(\frac{a}{C_t}\right)^\kappa - 1$$

$$\begin{aligned}
&\lim_{b\to\infty} \frac{C_t^\kappa - a^\kappa}{b^\kappa - a^\kappa}\left[\left(\frac{b}{C_t}\right)^\kappa - 1 - \kappa\log\left(\frac{b}{C_t}\right)\right] \\
= &\lim_{b\to\infty} \frac{C_t^\kappa - a^\kappa}{b^\kappa - a^\kappa}\left(\frac{b}{C_t}\right)^\kappa - \lim_{b\to\infty} \frac{C_t^\kappa - a^\kappa}{b^\kappa - a^\kappa} - \lim_{b\to\infty} \frac{C_t^\kappa - a^\kappa}{b^\kappa - a^\kappa}\log\left(\frac{b}{C_t}\right)^\kappa \\
= &\lim_{b\to\infty} \frac{b^\kappa}{b^\kappa - a^\kappa}\frac{C_t^\kappa - a^\kappa}{C_t^\kappa} - 0 - 0 = \frac{C_t^\kappa - a^\kappa}{C_t^\kappa} = 1 - \left(\frac{a}{C_t}\right)^\kappa
\end{aligned}$$

Putting the two limits together, we get:

$$\frac{2}{\kappa^2\sigma^2}\left\{1 - \left(\frac{a}{C_t}\right)^\kappa + \kappa\log\left(\frac{C_t}{a}\right) + \left(\frac{a}{C_t}\right)^\kappa - 1\right\} = \frac{2}{\kappa^2\sigma^2}\left\{\kappa\log\left(\frac{C_t}{a}\right)\right\}$$

[42] Depending on different assumptions about the CA's risk aversion, this rule can be made more stringent by giving greater weights to different moments in the delivery timing distribution.

[43] Obviously m should be positive; otherwise $E(\tau) = \infty$ (see Cox and Miller, 1965, p. 221-222).

According to (17) and (16), the optimal penalty is then equal to:

$$c^*(\pi) = \frac{r}{\pi}\left(\frac{\beta-1}{\beta}C_t e^{-m(t'-t)} - p\right) \tag{18}$$

Since when $t' = t$ and $t' > t$, (18) is respectively equal to or smaller than (7), the results obtained in the previous section can be replicated for the I/D scheme as well. It is worth noting that as $(t' - t)$ increases, the optimal I/D fee diminishes. In other words, when the contractual time t' is a long way from the current time t, the incentive for the contractor to delay the investment decreases and the CA is able to minimize premium outpayment by undercutting the I/D fee. When the interval $t' - t$ is very long, we have the paradox that the contractor must somehow be incentivated, by means of an incentive fee, to respect the contracted delivery date for the investment.

A.2 Other Tables and Simulations

This Appendix includes: Tables on the empirical evidence discussed in Section 2; simulations and figures which complement those presented in Section 3.

A.2.1 Tables

Procedure	By range value (euro)	Geogr Region	N° of contracts	Delayed contracts (%)	Average Days	Average delayed days	S. d. delayed days	Delayed Days Ratio	S.d. Delayed Days ratio
Open	150 to 500	Italy (4)	20679	16060 (78%)	380.3	135.4	188.2	0.89	1.56
		N. Italy	11737	9136 (78%)	369.1	134.1	180.6	0.95	1.75
		C. Italy	3963	3082 (78%)	389.7	138.0	197.3	0.87	1.39
		S. Italy	4975	3841 (77%)	399.4	136.3	198.4	0.79	1.10
	500 to 1000	Italy (2)	5482	4516 (82%)	512.2	171.1	209.9	0.78	1.79
		N. Italy	3359	2768 (82%)	501.8	169.0	207.2	0.81	2.13
		C. Italy	941	790 (84%)	537.5	190.5	212.6	0.77	0.98
		S. Italy	1180	958 (81%)	521.2	162.0	214.5	0.68	1.11
	1000 to 5000	Italy (7)	3793	3230 (85%)	676.3	221.6	256.7	0.74	1.5
		N. Italy	2458	2070 (84%)	651.2	207.4	242.3	0.73	1.47
		C. Italy	587	507 (86%)	720.5	244.4	265.4	0.78	1.98
		S. Italy	741	649 (88%)	724.9	252.3	290.6	0.74	1.13
	5000 to 15000	Italy (0)	226	189 (84%)	867.5	246.5	276.2	0.57	0.84
		N. Italy	160	133 (83%)	862.4	240.5	246.8	0.50	0.62
		C. Italy	30	24 (80%)	804.1	150.6	261.7	0.32	0.47
		S. Italy	36	32 (89%)	936.1	353.6	370.3	1.06	1.52
	> 15000	Italy (0)	64	52 (81%)	951.6	209.2	273.2	0.43	0.71
		N. Italy	53	43 (81%)	927.3	192.8	265.0	0.42	0.76
		C. Italy	5	4 (80%)	1433.5	339.4	383.1	0.48	0.61
		S. Italy	6	5 (83%)	774.6	246.2	265.9	0.47	0.43
	Total	Italy (13)	30244	24047 (80%)	449.93	153.64	205.27	0.85	1.59
		N. Italy	17767	14150 (80%)	442.69	152.00	198.22	0.89	1.78
		C. Italy	5526	4407 (80%)	457.51	158.46	211.74	0.84	1.40
		S. Italy	6938	5485 (79%)	462.68	154.29	217.44	0.77	1.14
Procedure	**By range value (euro)**	**Geograp hic Region**	**N° of contracts**	**Delayed contracts (%)**	**Average Days**	**Average delayed days**	**S. d. delayed days**	**Delayed Days Ratio**	**S.d. Delayed Days ratio**
Negotiated	150 to 500	Italy (0)	9410	6842 (73%)	383.6	131.5	198.1	0.90	1.62
		N. Italy	5517	4128 (75%)	377.5	137.2	191.2	0.96	1.65
		C. Italy	2832	1962 (69%)	391.8	123.2	214.5	0.80	1.63
		S. Italy	1061	752 (71%)	395.4	123.8	186.1	0.82	1.47
	500 to 1000	Italy (0)	2137	1739 (81%)	539.8	179.6	262.6	0.80	1.35
		N. Italy	1445	1139 (79%)	523.3	162.8	254.9	0.79	1.44
		C. Italy	490	421 (86%)	573.5	222.0	278.0	0.82	1.04
		S. Italy	202	179 (89%)	565.6	197.1	267.0	0.77	1.27
	1000 to 5000	Italy (4)	1470	1199 (82%)	711.2	220.6	271.4	0.69	1.10
		N. Italy	996	814 (82%)	696.6	217.5	268.2	0.70	1.06
		C. Italy	308	250 (81%)	744.1	222.4	286.9	0.61	0.79
		S. Italy	162	134 (83%)	742.0	241.6	262.7	0.78	1.68
	5000 to 15000	Italy (0)	140	121 (86%)	979.0	308.4	302.5	0.65	1.12
		N. Italy	86	77 (90%)	953.7	296.0	264.6	0.57	0.58
		C. Italy	26	21 (81%)	1026.5	322.1	334.7	0.55	0.54
		S. Italy	28	23 (82%)	1020.6	333.8	381.7	1.00	2.23
	> 15000	Italy (0)	32	25 (78%)	1148.0	249.3	492.5	0.40	0.64
		N. Italy	12	10 (83%)	927.9	191.3	219.8	0.32	0.32
		C. Italy	7	5 (71%)	1493.8	208.1	688.0	0.35	0.68
		S. Italy	13	10 (77%)	1195.2	325.0	578.7	0.51	0.84
	Total	Italy (4)	13189	9926 (75%)	459.72	151.38	223.91	0.86	1.53
		N. Italy	8056	6168 (77%)	454.65	153.50	217.50	0.89	1.55
		C. Italy	3663	2659 (73%)	460.80	146.34	237.15	0.79	1.50
		S. Italy	1466	1098 (75%)	485.81	152.75	224.73	0.81	1.48

Table 1A- part I: Contracts awarded by procedure, range value, and location

Procedure	By range value (10^3 euro)	Geographic Region	N° of contracts	Delayed contracts (%)	Average Days	Average delayed days	S. d. delayed days	Delayed Days Ratio	S.d. Delayed Days ratio
"n. c."	150 to 500	Italy (3)	1748	1213 (69%)	294.35	92.17	154.85	1.03	8.79
		N. Italy	1486	1047 (70%)	284.74	91.45	146.30	1.06	9.45
		C. Italy	137	83 (61%)	364.94	84.76	184.21	0.72	1.80
		S. Italy	122	83 (68%)	344.92	112.13	211.00	0.96	2.84
	500 to 1000	Italy (1)	99	72 (73%)	500.43	153.23	225.26	0.63	1.03
		N. Italy	81	57 (70%)	467.67	137.46	197.54	0.59	1.01
		C. Italy	12	10 (83%)	718.40	251.67	373.93	0.88	1.29
		S. Italy	5	5 (100%)	438.00	204.00	186.30	0.84	0.83
	1000 to 5000	Italy (7)	73	46 (63%)	475.85	123.88	213.03	0.77	1.88
		N. Italy	59	36 (61%)	465.17	122.75	209.60	0.84	2.06
		C. Italy	9	6 (67%)	468.67	102.89	210.32	0.42	0.75
		S. Italy	5	4 (80%)	582.75	175.00	295.11	0.53	0.79
	5000 to 15000	Italy (0)	7	3 (43%)	1074.33	105.71	456.86	0.41	1.19
		N. Italy	5	3 (60%)	1074.33	174.40	538.76	0.65	1.36
		C. Italy	2	0 (0%)	0	-66.00	93.34	-0.18	0.26
		S. Italy	0	0	0	0	0	0	0
	> 15000	Italy (0)	10	5 (50%)	1101.00	130.70	301.98	0.20	0.47
		N. Italy	9	4 (44%)	1191.75	123.78	319.46	0.18	0.49
		C. Italy	0	0	0	0	0	0	0
		S. Italy	1	1 (100%)	738.00	193.00	0	0.35	0
	Total	Italy (4)	1937	1339 (69%)	316.42	96.73	164.86	0.99	8.34
		N. Italy	1640	1147 (70%)	304.72	95.28	155.60	1.02	9.01
		C. Italy	160	99 (62%)	406.93	96.41	207.96	0.70	1.71
		S. Italy	133	93 (70%)	364.38	118.56	212.08	0.93	2.73
Procedure	**By range value (10^3 euro)**	**Geographic Region**	**N° of contracts**	**Delayed contracts (%)**	**Average Days**	**Average delayed days**	**S. d. delayed days**	**Delayed Days Ratio**	**S.d. Delayed Days ratio**
Total	150 to 500	Italy (7)	31837	24115 (76%)	376.94	131.84	189.80	0.90	2.56
		N. Italy	18740	14311 (76%)	365.39	131.63	181.71	0.96	3.13
		C. Italy	6932	5127 (74%)	390.15	204.48	204.48	0.84	1.50
		S. Italy	6158	4676 (76%)	397.80	133.68	196.65	0.80	1.26
	500 to 1000	Italy (3)	7718	6327 (82%)	519.66	173.24	225.96	0.78	1.67
		N. Italy	4885	3964 (81%)	507.52	166.68	222.25	0.80	1.93
		C. Italy	1443	1221 (85%)	551.42	201.71	238.71	0.79	1.00
		S. Italy	1387	1142 (82%)	527.84	167.28	223.00	0.69	1.13
	1000 to 5000	Italy (11)	5336	4475 (84%9	683.58	219.98	260.50	0.72	1.41
		N. Italy	3513	2920 (83%)	661.54	208.86	249.67	0.72	1.38
		C. Italy	904	763 (84%)	726.25	235.53	272.72	0.72	1.66
		S. Italy	908	787 (87%)	727.06	250.01	285.66	0.75	1.25
	5000 to 15000	Italy (0)	373	313 (84%)	912.59	267.13	291.70	0.60	0.96
		N. Italy	251	213 (85%)	898.39	258.18	260.79	0.53	0.62
		C. Italy	58	45 (78%)	907.89	220.05	307.12	0.40	0.52
		S. Italy	64	55 (86%)	971.45	344.94	372.42	1.03	1.85
	> 15000	Italy (0)	106	82 (77%)	1020.56	213.93	353.90	0.40	0.67
		N. Italy	74	57 (77%)	945.96	184.16	262.72	0.38	0.68
		C. Italy	12	9 (75%)	1467.00	262.83	562.31	0.41	0.63
		S. Italy	20	16 (80%)	1035.19	294.75	481.73	0.49	0.71
	Total	Italy (21)	45370	35312 (78%)	447.62	150.55	209.65	0.86	2.31
		N. Italy	27463	21465 (78%)	438.75	149.04	202.29	0.90	2.73
		C. Italy	9349	7165 (77%)	458.03	152.65	222.17	0.82	1.45
		S. Italy	8537	6676 (78%)	465.11	153.47	218.64	0.78	1.24

Table 1A- part II: Contracts awarded by procedure, range value, and location

A.2.2 Other simulations

Here we report other simulations of the optimal penalty by changing some key parameters. Tables 2A, 3A, 4A, 5A display the results of simulations obtained for the Italian case (i.e. $1/\theta = 3$) when $\alpha < 0$, $r = 0.1\%$ and $\sigma = 0.3, 0.4, 0.5$. Tables 6A, 7A, 8A, 9A display the results of simulations obtained for the Italian case (i.e. $1/\theta = 3$) when $\alpha < -0.05$ and $r = 0.5\%$. Tables 10A, 11A, 12A, 13A display the results of simulations obtained for the Italian case (i.e. $1/\theta = 3$) when $\alpha < -0.05$ and $r = 0.5\%$. Tables 10A, 11A, 12A, 13A.

Figures 1A illustrates the optimal penalty obtained for the NCI (i.e. $1/\theta = 2$) and SI (i.e. $1/\theta = 4$) when $\alpha = 0$ and $r = 0.1\%$. Figures 2A and 3A illustrate the optimal penalty obtained for the NCI (i.e. $1/\theta = 2$) and SI (i.e. $1/\theta = 4$) when $\alpha < 0$ and $r = 5\%, 10\%$ respectively.

α=0		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,1378%	0,2563%	0,4207%
	0,8	0,0894%	0,1836%	0,3169%
	0,7	0,0479%	0,1186%	0,2225%

Table 2A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = 0$, $r = 10\%$, $\eta = 0.3$ expressed in pecentage and in terms of days

α=0		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,4102%	0,9786%	1,9584%
	0,8	0,2238%	0,6132%	1,3172%
	0,7	0,0934%	0,3328%	0,8027%

Table 3A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = 0$, $r = 10\%$, $\eta = 0.5$ expressed in pecentage and in terms of days

α=0		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,1%	0,1530%	0,2511%
	0,8	0,1%	0,1096%	0,1892%
	0,7	0,1%	0,1%	0,1328%

Table 4A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = 0$, $r = 10\%$, $\eta = 0.3$ expressed in percentage and in terms of days

α=0		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,1231%	0,2936%	0,5875%
	0,8	0,1%	0,1840%	0,3952%
	0,7	0,1%	0,1%	0,2408%

Table 5A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = 0$, $r = 10\%$, $\eta = 0.5$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=5%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,2780%	0,4388%	0,6604%
	0,8	0,2139%	0,3466%	0,5306%
	0,7	0,1551%	0,2612%	0,4098%

Table 6A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = -0.05$, $r = 5\%$, $\eta = 0.3$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=5%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	1,4467%	2,7409%	4,8576%
	0,8	1,0021%	1,9700%	3,5760%
	0,7	0,6390%	1,3260%	2,4903%

Table 7A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = -0.05$, $r = 5\%$, $\eta = 0.5$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=5%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,1659%	0,2619%	0,3942%
	0,8	0,1277%	0,2069%	0,3167%
	0,7	0,1%	0,1559%	0,2446%

Table 8A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = -0.05$, $r = 5\%$, $\eta = 0.3$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=5%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,4340%	0,8223%	1,4573%
	0,8	0,3006%	0,5910%	1,0728%
	0,7	0,1917%	0,3978%	0,7471%

Table 9A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = -0.05$, $r = 5\%$, $\eta = 0.5$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,2328%	0,3713%	0,5568%
	0,8	0,1646%	0,2767%	0,4284%
	0,7	0,1042%	0,1909%	0,3107%

Table 10A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = -0.05$, $r = 5\%$, $\eta = 0.3$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,8550%	1,6444%	2,8990%
	0,8	0,5266%	1,0891%	2,0085%
	0,7	0,2774%	0,6478%	1,2809%

Table 11A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.03\%$, $\theta = 1/3, \alpha = -0.05$, $r = 10\%$, $\eta = 0.5$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,1389%	0,2217%	0,3323%
	0,8	0,1%	0,1651%	0,2557%
	0,7	0,1%	0,1139%	0,1854%

Table 12A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = -0.05$, $r = 5\%$, $\eta = 0.3$ expressed in percentage and in terms of days

α=-0,05		c*		
		r=10%		
		σ=30%	σ=40%	σ=50%
C_t	0,9	0,2565%	0,4933%	0,8697%
	0,8	0,1580%	0,3267%	0,6025%
	0,7	0,1%	0,1943%	0,3843%

Table 13A: Optimal penalty for different values of C_t and σ, $\underline{c} = 0.1\%$, $\theta = 1/3, \alpha = -0.05$, $r = 5\%$, $\eta = 0.5$ expressed in percentage and in terms of days

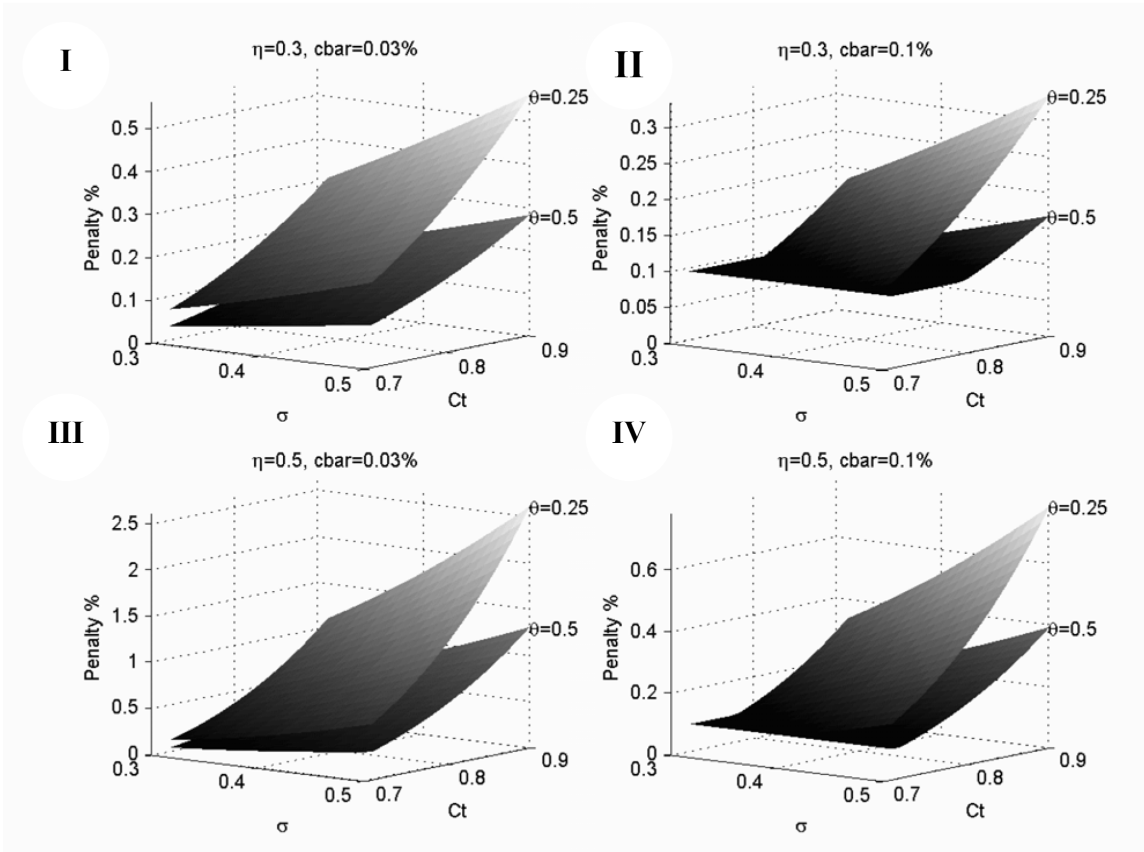

Figure 1A: Optimal penalty expressed in percentage and in terms of days for $r = 0.1$, $\alpha = 0$ and $\theta = 0.25$ (SI), $\theta = 0.5$ (NCI) by increasing volatility σ and C_t. In quadrant I $\eta = 0.3$, $\underline{c} = 0.03\%$; in quadrant II $\eta = 0.3$, $\underline{c} = 0.1\%$; in quadrant III $\eta = 0.5$, $\underline{c} = 0.03\%$; in quadrant IV $\eta = 0.5$, $\underline{c} = 0.1\%$

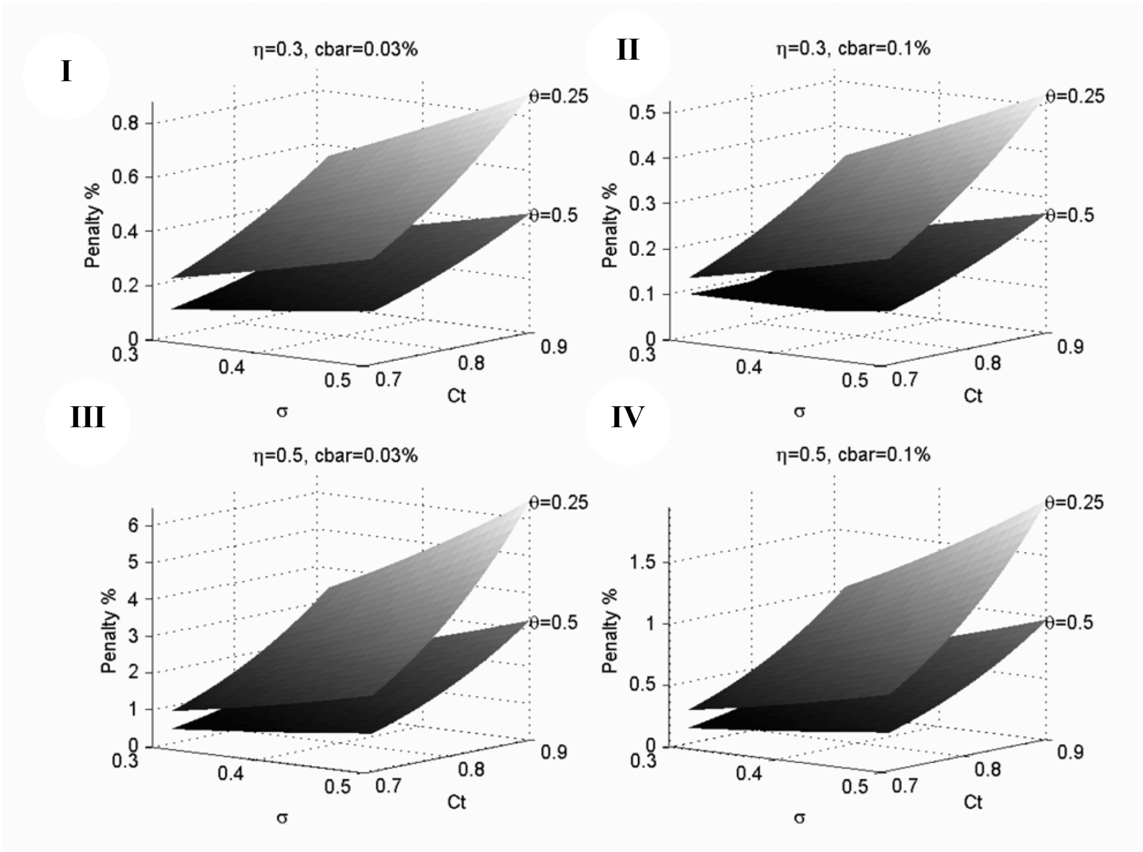

Figure 2A: Optimal penalty expressed in percentage and in terms of days for $r = 0.05$, $\alpha = -0.05$ and $\theta = 0.25$ (SI), $\theta = 0.5$ (NCI) by increasing volatility σ and C$_t$. In quadrant I $\eta = 0.3$, $\underline{c} = 0.03\%$; in quadrant II $\eta = 0.3$, $\underline{c} = 0.1\%$; in quadrant III $\eta = 0.5$, $\underline{c} = 0.03\%$; in quadrant IV $\eta = 0.5$, $\underline{c} = 0.1\%$

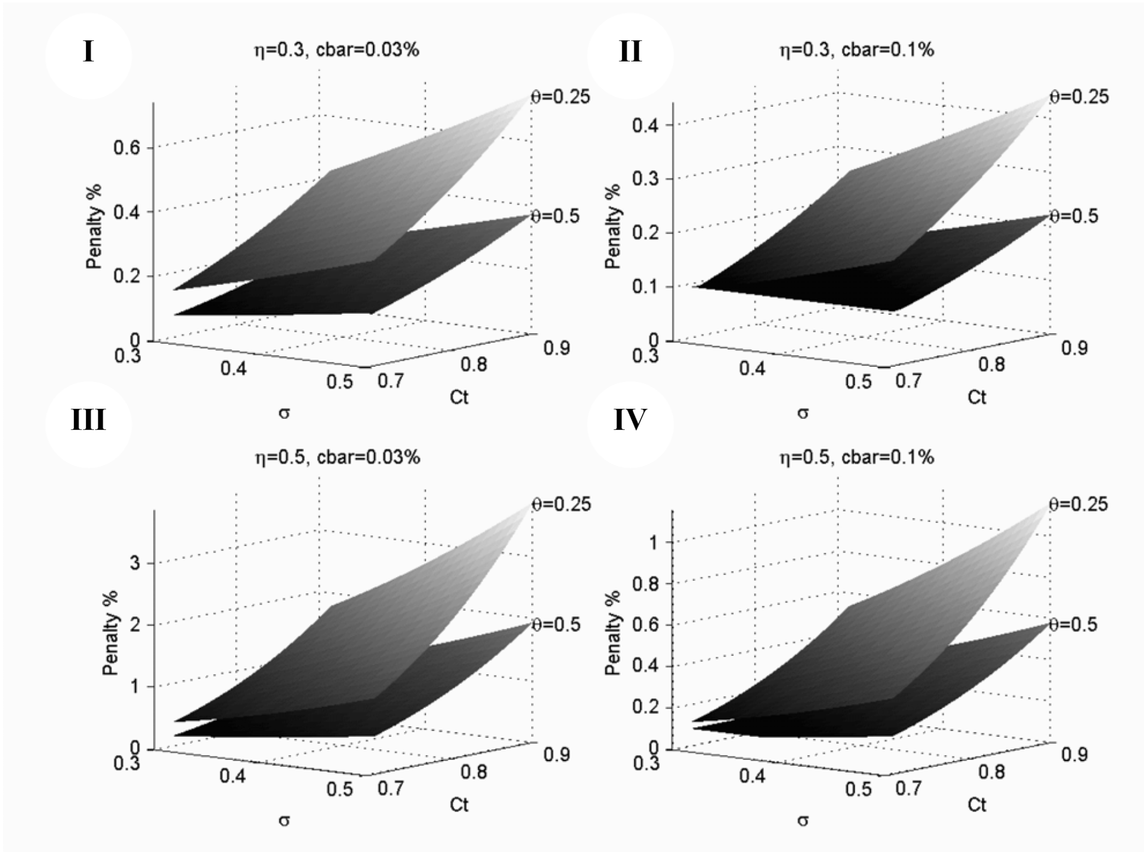

Figure 3A: Optimal penalty expressed in percentage and in terms of days for $r = 0.1$, $\alpha = -0.05$ and $\theta = 0.25$ (SI), $\theta = 0.5$ (NCI) by increasing volatility σ and C_t. In quadrant I $\eta = 0.3$, $\underline{c} = 0.03\%$; in quadrant II $\eta = 0.3$, $\underline{c} = 0.1\%$; in quadrant III $\eta = 0.5$, $\underline{c} = 0.03\%$; in quadrant IV $\eta = 0.5$, $\underline{c} = 0.1\%$

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(lxxxv) This paper has been presented at the 14th Coalition Theory Network Workshop held in Maastricht, The Netherlands, on 23-24 January 2009 and organised by the Maastricht University CTN group (Department of Economics, http://www.feem-web.it/ctn/12d_maa.php).