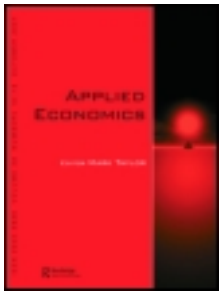

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Ex post adaptations and hybrid contracts in software development services

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Ex post adaptations and hybrid contracts in software development services

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We follow the recent literature on *ex post* adaptations in procurement and argue that highly volatile specifications result in multiple variations of fixed price (FP) and time and materials (T&M) contracts. Specifically, placing a cap on specification change in FP contracts prevents specification volatility, similar to the way that placing a cap on the price in T&M contracts prevents price escalation. We argue that these hybrid mechanisms are particularly important in software development contracting, a new critical business capability involving frequent and costly *ex post* adaptations to specification change. The level of completeness in these contractual archetypes is hypothesized to be determined by contracting costs and benefits, where costs are related to project uncertainty and benefits are related to the likelihood of vendor opportunism. We test this hypothesis with a unique data set of 270 software development contracts entered into by a leading international bank. The analysis confirms the existence of multiple hybrid contracts that mitigate both price escalation and specification volatility. It also shows that contracting costs and benefits explain more variance in contract choice when these hybrids are included, uncovering the detailed mechanisms used to curb opportunism when the vendor is less familiar to the client.

Keywords: incomplete contracting; *ex post* adaptations; hybrid contracts; software development

JEL Classification: D23; L14; L24; L86

I. Introduction

It is accepted that more complete contracts mitigate *ex post* opportunism, but at the cost of additional *ex ante* contracting cost (Williamson, 1985). Empirical studies generally show that the balance between contracting costs and benefits is accommodated within the fixed price (FP) and time and materials (T&M) dichotomy (Bajari and Tadelis, 2001; Corts and Singh, 2004). However, Kalnins and Mayer (2004) argue that in addition to FP and T&M, hybrid contracts are used to balance incentives for cost efficiency and quality. Specifically, T&M contracts with a price cap are used when uncertainty is at an intermediate level and *ex post* measurement costs are moderate. Such hybrid contracts are efficient because of the weaker incentives for the supplier to under-provide quality and because the relationship between the buyer and supplier has not yet developed.

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The current study builds on this argument and reports an additional type of contract that caps specification change to achieve a balance between contracting costs and benefits in a context where specification changes are common and their cost is significant. The context is development services for custom software (Banerjee and Duflo, 2000; Ethiraj *et al.*, 2005), where standard FP contracts provide a mechanism for specification change. We show that capped FP contracts that allow no specification changes are used when uncertainty is very low and the relationship between the buyer and supplier has yet to be established.

The article thus builds on recent empirical studies of adaptation costs (e.g. Bajari *et al.*, 2009; Guccio *et al.*, 2012) and their influence on contract choice (Bajari and Tadelis, 2001). We reason that clients protect themselves from supplier opportunism related to adaptation costs when specification changes are common. Specifically, we report that the standard FP contract for software development services includes an implicit contract to renegotiate for specification change at a reasonable mark up over the supplier's costs (Corts, 2012). We argue that this implicit contract is removed when the likelihood of opportunism is high.

The current study is also closely related to the analysis by Crocker and Reynolds (1993) of a contract typology for jet engine procurement. We present the two FP and two T&M contract types as a typology that balances contracting costs and benefits. We also report a mixed contract type that includes system components with highly complete specifications that are priced on an FP basis and system components with less stringent specifications that are priced on a T&M basis. Although the typology of Crocker and Reynolds (1993) is concerned with the pricing of a fully specified product, and therefore that typology either allows or disallows *ex post price* changes, our analysis includes contract types that either allow or disallow both price and *specification* changes.

The first goal of this article was to describe the observed typology of software development contracts in our research site, a leading international bank. Software development is of special interest because it is common to leave the specification of system functionality incomplete, in particular when contracting on a T&M basis (Banerjee and Duflo, 2000; Gopal *et al.*, 2003; Ethiraj *et al.*, 2005). In addition, uncertainty is exceptionally high in software development projects. Recent industry research reports that 24% of projects are considered failures and 44% are considered challenged in terms of time, cost or functionality (Standish Group, 2009). This work extends recent analysis of non-standard contracts in this context that include performance-based and profit-sharing contracts (Dey *et al.*, 2010). Interestingly, our evidence goes beyond earlier data reported in the literature, showing that software development contracts are either FP or T&M, at least for Indian vendors (Banerjee and Duflo, 2000).

However, the main goal of this article was to provide a theoretical rationale for the observed contract typology. We rely on the malleability of software and the fact that about two-thirds of projects either fail or are significantly challenged to assert that *ex post* adaptations are central to software development. We then argue that the capping of specification change in FP contracts is required under certain circumstances, similar to the practice of capping the price of T&M contracts (Kalnins and Mayer, 2004). Finally, we offer contractual completeness as the main analytical perspective (Grossman and Hart, 1986; Crocker and Reynolds, 1993). We thus posit that the costs and benefits of contracting depend on both project uncertainty and the likelihood of *ex post* opportunism on the part of the vendor. This hypothesis is then tested on a portfolio of 270 software development contracts for a leading international bank.

The rest of this article is organized as follows. We present a brief overview of software development outsourcing in Section II. We present the main theoretical considerations, including the description of the observed typology and the formulation of a model-based hypothesis, in Section III. In Section IV, we describe the research site and data set. We present the empirical analysis in Section V and discuss the findings and their implications in Section VI.

II. Software Development Outsourcing

Software development outsourcing involves the development of custom-made software by external vendors. The National Academy of Engineering (2008) estimated that 2003 global spending on application development was 184 billion US dollars. In outsourcing, software development activities are managed by the vendor and performed outside the client's premises. This definition differentiates software development outsourcing from other forms of software-related outsourcing; contracting for consulting services is typical of projects managed by the client, and contracting for licencing of off-the-shelf software packages usually does not involve significant software development.

The Standish Group annually publishes the CHAOS report that provides an integrative assessment of success rates in software development projects. The 2009 report showed that 32% of software development projects are considered successful, 44% are considered challenged in terms of time, cost or scope and 24% are considered failed before completion (Standish Group, 2009). Project failure rates do not decrease as the software engineering

discipline matures, and the 2009 report showed the highest rate of failure in the last decade.

These failure rates reflect the high level of uncertainty in software development, where frequent changes in business and technological environments require frequent changes in system specification. Therefore, a major challenge in software development outsourcing is bridging the gap between the frequent need to modify the functionality and design of the system under development and the binding nature of the contract governing the relationship between the parties (Sia *et al.*, 2008).

The contracts governing software development have generally been classified as either FP or T&M (Whang, 1992; Banerjee and Duflo, 2000; Gopal *et al.*, 2003; Lichtenstein, 2004). With FP contracts, the price for completing the project is predetermined. Conversely, T&M contracts do not specify a price, but rather reimburse the vendor for its costs plus a predetermined profit. The common practice in the industry is to have very detailed system specifications only for FP contracts and to keep specifications loosely defined for T&M contracts (Dey *et al.*, 2010). The detailed specifications are needed in FP contracts to allow agreement on the content of work and the price, whereas the loose specifications in T&M contracts serve the purpose of leaving functionality issues to be resolved during the development process. While the themes of the literature on software development contracting are quite diverse, including risk sharing, project profitability, the role of trust and company reputation and capabilities, it is universally recognized that contract choice is the key managerial decision.

III. Theoretical Considerations

Procurement contracting

Economic theory models procurement as a problem of *ex ante* asymmetric information, uncertainty that persists beyond the contracting date and results in hold-up, and unobservable effort that results in moral hazard (Williamson, 1975; Laffont and Tirole, 1993; Bolton and Dewatripont, 2005). Theory predicts that menus of contracts are offered by buyers to reduce private information and potential hold-up and to create incentives to exert effort.

However, most relevant to the current study is research that focuses on *ex post* uncertainty and adaptations. Bajari and Tadelis (2001) observe that most contracts are variants of simple FP and T&M contracts, since the buyer and seller have little *ex ante* private information but they share uncertainty about many important *ex post* design changes. They argue that an FP contract is used because it does not require the measurement of production costs that a cost-sharing contract requires. Similarly, T&M contracts are used because they reduce the need to verify quality; even partial incentives to reduce costs require expensive quality verification mechanisms.

The persistence of uncertainty beyond the contracting date is also argued to result in the use of hybrid contracts, which combine the features of FP and T&M contracts to balance incentives for cost efficiency and quality (Kalnins and Mayer, 2004). Capping the price of T&M contracts maintains their renegotiation benefits. As long as the price cap is not exceeded, the supplier is guaranteed a profit and changes are incorporated without renegotiation. This type of hybrid contract also maintains some of the incentives of FP contracts, because the supplier has an incentive to contain costs when it approaches the price cap. Therefore, capped T&M contracts are likely to be used at intermediate levels of *ex ante* cost uncertainty. Similarly, at intermediate levels of *ex post* measurement costs, capped T&M contracts are more attractive than FP contracts because of the weaker incentive for the supplier to reduce quality. Finally, capped T&M contracts may be used when the relationship between the parties has not yet developed and the benefits of repeated interaction have yet to be realized.

Finally, a major influence on the present study is the empirical investigation of contractual completeness in the US Air Force engine procurement by Crocker and Reynolds (1993). They reason that had contracting been costless, it would have been possible to write sufficiently complete contracts to circumscribe all *ex post* opportunism. However, the costs of identifying contingencies, devising responses and reaching agreements are considerable. Thus, the parties *balance* the costs of *ex post* opportunism against the costs of crafting more complete contracts *ex ante*. The result is a contract typology, which represents a continuum of balance points of *price* completeness and includes price adjustments, price ceilings and successive negotiations on price targets. Specifically, the costs of a more complete contract are related to environmental uncertainty, because uncertainty leads to more contingencies and responses. The benefits to the client of completeness are related to the likelihood of opportunistic behaviour on the part of the seller.

The observed contract typology

The current article stems from a careful analysis of a contract portfolio of one of the largest banks in the world, which contracts out system development through about 100 vendors. Custom systems are tailored to specific client needs, which, at least in banking, are highly volatile and require frequent *ex post* adaptations. In this context, specification volatility is a major concern in addition to cost uncertainty and quality measurement difficulty (Kalnins and Mayer, 2004). While price escalation is a

major hazard in T&M contracts, specification volatility is a major hazard in FP contracts. Therefore, placing a cap on specification change in FP contracts can serve as a mechanism of reducing renegotiation costs, in addition to the mechanism created by placing a price cap on T&M contracts. When specification volatility is very low, placing a cap on specification change can curb renegotiation opportunities and limit *ex post* adaptations in FP contracts. When specification volatility is somewhat higher, *ex post* adaptations may be allowed by using the standard FP contract that includes a change mechanism. Finally, T&M contracts are likely to be used when specification volatility is high and frequent *ex post* adaptations are expected.

Our analysis of this contract portfolio shows that about one-third of the contracts are neither FP nor T&M but significant variations of these archetypes. In addition to the introduction of mixed contracts, FP contracts are divided into those that allow changes and those that disallow them, and T&M contracts are divided into those that include a binding price cap and those that do not. Two of the archetypes are widely used in the industry, FP without a cap on specification change and T&M without a cap on price, so we label them just as FP and T&M to get the following typology:

- Firm FP (specification changes are not allowed)
- FP (with an explicit procedure for specification changes)
- Mixed (both FP and T&M components)
- Not-to-exceed T&M (a price cap that may not be exceeded is agreed *ex ante*)
- T&M (without a price cap)

Table 1 presents the issues negotiated *ex ante* and *ex post* for each of the five archetypes. In contrast to many procurement contracts (e.g. engine procurement), where the specification is given and the level of completeness is related only to production price, the level of completeness in software development is related to both specification and price. The following paragraphs describe each of the archetypes in the new typology and explain their relative completeness.

Firm FP. In firm FP contracts, price and specifications are fully predetermined *ex ante*, and contracts do not include a mechanism to accommodate change in the specifications. Managers at the bank explain that the exclusion of a change mechanism is infrequent because it requires the highest level of design completeness. The contracting consequences of disallowing change are important, because *ex post* negotiation is costly and creates a contractual hazard (Bajari and Tadelis, 2001; Bolton and Dewatripont, 2005). The costs and risks of renegotiation are of special importance because of the difficulty to verify the quality and maintainability of the system. Under this archetype, a high level of trust in the vendor is not warranted (Mayer *et al.*, 1995), and bidding becomes highly competitive (Iacovou and Nakatsu, 2008).

FP. Although price and specifications are fully predetermined *ex ante*, the FP contract includes a clause with an explicit change management procedure that allows changing both specifications and price. Managers in the industry explain that it is standard practice to include a change provision in FP contracts, as is indeed reflected in the research literature (Saunders *et al.*, 1997; Sia *et al.*, 2008; Chen and Bharadwaj, 2009). Such clauses can be viewed as safeguards (Williamson, 1985), specifically as contingency planning used to protect a vulnerable party (Argyres *et al.*, 2007). Furthermore, these clauses explicitly open the possibility of an augmented FP contract that allows the vendor to perform modifications on a T&M basis (Corts, 2012).

Mixed. The mixed archetype covers contracts that include both FP and T&M work packages. Mixed software development contracts have been reported by Dey *et al.* (2010). Banerjee and Duflo (2000) explain that in these contracts the work involved in writing the full functional specification and technological design tends to be performed on a T&M basis and the rest of the work, including programming and testing, tends to be done on

Table 1. Contractual archetypes of software development outsourcing

	Specification		Price	
Archetype	Negotiated *ex ante*	Negotiated *ex post*	Negotiated *ex ante*	Negotiated *ex post*
Firm FP	Full specification		Price	
FP	Full specification	Changes to the specification	Price	Price of changes
Mixed	Full specification (FP components)	Changes to the specification (FP components)	Price (FP components)	Price of changes (FP components)
	Rough specification (T&M components)	Detailed implementation (T&M components)	Daily rates (T&M components)	
Not-to-exceed T&M	Rough specification	Detailed implementation	Price cap, daily rates	
T&M	Rough specification	Detailed implementation	Daily rates	

an FP basis. An interesting consequence of the mixed archetype is that it leads to simple risk sharing, as T&M cost risk is borne by the client, while FP cost risk is on the vendor (Bajari and Tadelis, 2001).

Not-to-exceed T&M. In the not-to-exceed T&M contract, the client reimburses the vendor for its expenses up to a price cap that is agreed *ex ante*. This archetype is identical to the hybrid contract described by Kalnins and Mayer (2004). The price cap indicates that the client has specified the main features of the software and has estimated its development costs, as in FP contracts, but will control costs and pay, as in T&M contracts, up to the cap. The not-to-exceed T&M archetype is considered less complete than the mixed archetype, because the former mostly relies on a T&M mechanism, with loose system specifications, whereas the latter typically includes a substantial FP part, with detailed system specifications.

T&M. This archetype represents the standard T&M contract, in which the specification for the system is not fully detailed and the price for project completion is not constrained. The primary benefit of this archetype, relative to an FP contract, is the reduced negotiation cost (Bajari and Tadelis, 2001) that comes at the expense of introducing a moral hazard problem (Corts and Singh, 2004). As requirements change, the vendor is more likely to accept changes requested by the client without the need for renegotiation (Kalnins and Mayer, 2004). In contrast to the not-to-exceed T&M archetype, the standard T&M archetype poses a significant risk of cost escalation. Thus, familiar, trustworthy vendors are more likely to be granted such contracts.

Contract type selection

It is assumed that the typology described above is applied efficiently, that is the parties balance the costs of selecting a more complete contractual archetype with the benefits that completeness provides (Crocker and Reynolds, 1993). Costs are related to uncertainty, because high uncertainty requires the identification of more contingencies and responses. Benefits are related to the likelihood of opportunism by the vendor; when such likelihood is small, there is no need for complete contracts.

In our context, the costs are those of writing a detailed specification of the system and estimating the costs of its development. These costs are related to project uncertainty (w), because higher uncertainty requires more negotiation about system features and their implementation, as well as more contingency clauses; thus, contracts for uncertain projects are more costly to craft.

The benefits of a complete contract are the ability to prevent *ex post* opportunism of the vendor and *ex post* renegotiation costs. Opportunism in our context includes reducing effort on the part of the vendor and developing lower-quality software, inflating T&M costs (Dey *et al.*, 2010) and increasing costs when changes are requested by either client or vendor. The likelihood of opportunism (L) is influenced by both client and vendor characteristics; in particular, we assume that some vendors engage in opportunistic behaviour and others do not.

We use a panel data set of contracts, estimating the relationship between contractual completeness and project and vendor characteristics:

$$Y_{ij} = f\left(w_{ij}, L_{ij}\right) + \varepsilon_{ij} \tag{1}$$

where Y_{ij} is the completeness measure of the archetype chosen for contract i of vendor j, w_{ij} represents expectations of project uncertainty and L_{ij} is the expected likelihood of opportunism by vendor j before contract i is signed. The relationship (Equation 1) is modelled as a linear relationship as follows:

$$Y_{ij} = a + bw_{ij} + cL_{ij} + \varepsilon_{ij} \tag{2}$$

This model suggests that project uncertainty and likelihood of opportunism are linearly related to contractual completeness (Crocker and Reynolds, 1993). Specifically, the incomplete contracting perspective and the reasoning presented above lead to the hypothesis that project uncertainty is *negatively* related to contractual completeness and that the likelihood of opportunism is *positively* related to contractual completeness. We expect to find more complete contracts used for projects with lower uncertainty (lower cost of drafting complete contracts) and higher likelihood of opportunism (higher benefit of drafting complete contracts).

IV. Data

The research setting for this study is the financial services industry, which is considered to be the largest user of IT in the industrial sectors (Zhu *et al.*, 2004) and which tends to have the highest IT investment risk (Dewan *et al.*, 2007). We analyse the contract portfolio of a leading international bank, headquartered in Europe. It provides retail and commercial banking, wealth management and investment banking in dozens of countries and has tens of thousands of employees. The bank's IT department employs about 3000 permanent employees and 2000 contractors. The bank contracts out system development through about 100 local and international vendors. Its methods of managing software development contracts are typical of other large companies. The bank aims at using its standard software development contracts wherever possible. The standard contract is similar to contract forms described in the literature (e.g. Pearson, 1984; Kutten, 1988). This contract is about 10

Table 2. Archetype data ($N = 270$)

Archetype	Number of contracts	Percentage	Average price ($K)	Average duration (days)	Example
Firm FP	42	16%	169.64	129.45	Electronic archive
FP	139	51%	284.01	182.70	SWIFT
Mixed	32	12%	632.00	230.45	Credit process
Not-to-exceed T&M	14	5%	321.36	242.46	Global accounting
T&M	43	16%	323.61	222.49	ATM

pages in length, excluding appendices for scope and schedule. The bank's contracting guidelines permit changes to the standard contract within defined limits.

Consistent with previous research, the unit of analysis in this study is the contract (e.g. Gulati, 1995; Gopal *et al.*, 2003; Ethiraj *et al.*, 2005). We collected detailed quantitative data from the bank's contract repository. Each record in the repository represented a single contract and included the contract number, start and end dates, contract price, vendor name and an electronic scan of the contract. We were given access to 270 software development contracts signed between January 2000 and April 2003. Table 2 presents data on the contractual archetypes.

Project uncertainty is evaluated by three items gleaned from contract text. Contract price (as a proxy for size) has been identified as a factor contributing to software development uncertainty (Barki *et al.*, 1993). The relation between project size and uncertainty has been acknowledged by much of the literature on software development. Large projects are more likely to fail because of the difficulty to coordinate multiple tasks and many developers (Wallace *et al.*, 2004). *Price* is the binding price in firm FP and FP contracts, the price cap in not-to-exceed T&M contracts, the cost estimation in T&M contracts or the sum of FP and T&M prices in mixed contracts. In addition, contract *Duration* is used as a proxy for business and technology volatility; longer projects require more contingency planning and thus more costly contracts, similar to the associations between contract time-horizon, volatility and contracting cost in engine procurement (Crocker and Reynolds, 1993). The final measure of uncertainty uses the number of *Intermediate Deliverables*, as defined in the contract text. Intermediate deliverables tied to payments, also known as milestones (Sommerville, 2000), reflect uncertainty because when many such deliverables are defined, the development course is defined in minute detail and *ex ante* uncertainty is low. It should be noted that our conversations with managers at the bank showed that contract details, including the timely provision of deliverables, their acceptance and the transfer of payments, are typically followed strictly during contract execution, in accordance with the highly controlled management style of the bank.

The likelihood of opportunism is measured in terms of business familiarity (Gulati, 1995; Ryall and Sampson, 2009) using two measures (Gefen *et al.*, 2008). The first measure is *Previous Contracts*, defined as the accumulated price of previous contracts signed with the same vendor after January 2000 and up to the specific contract. The logic underlying this measure is that vendors who have a long history of work for the bank are unlikely to be opportunistic, at least because the bank continues to be a major client for IT services. Therefore, high values in this measure represent high business familiarity and thus low likelihood of opportunism. The second measure is the vendor *Locality*, which may be either international (designated by 1) or local (2). The logic underlying this measure is that local vendors are less likely to behave opportunistically with this large local client.

All the measures described above are objective and involve no subjective judgment. Descriptive statistics are given in Table 3, the correlation matrix is given in Table 4 and cross-tabulation of the measures with contractual completeness is given in Table 5.

The cross-tabulation in Table 5 suggests that project uncertainty is negatively associated with contractual

Table 3. Descriptive statistics

	Minimum	Maximum	Mean	SD
Project uncertainty				
Price ($K)	2	3490	315.65	474.77
Duration (days)	3	880	189.60	143.30
Intermediate deliverables	0	13	2.09	2.31
Likelihood of opportunism				
Previous contracts ($K)	0	21 037	4426	5883
Locality (1 = international, 2 = local)	1	2	1.79	0.41

Table 4. Correlation matrix

	1	2	3	4	5	6
1. Price (log)	1					
2. Duration (log)	0.533***	1				
3. Intermediate deliverables	0.217***	0.136*	1			
4. Previous contracts (log)	0.098	0.054	−0.066	1		
5. Locality	0.376***	0.267***	0.060	0.386***	1	
6. Contractual completeness	−0.325***	−0.231***	0.257***	−0.204***	−0.262***	1

Note: *$p < 0.05$; ***$p < 0.001$; two-tailed p-values are reported.

Table 5. Cross-tabulation of contractual completeness with project uncertainty and likelihood of opportunism

Contractual completeness		Project uncertainty			Likelihood of opportunism	
Archetype	Completeness	Price ($K)	Duration (days)	Intermediate deliverables	Previous contracts ($K)	Locality (1 = int., 2 = local)
High completeness		Low uncertainty			High likelihood	
Firm FP	5	169.64	129.45	1.95	406.02	1.33
FP	4	284.01	182.70	2.58	4594.00	1.86
Mixed	3	632.00	230.45	2.75	5754.38	1.94
Not-to-exceed T&M	2	321.36	242.46	0.93	3690.79	1.93
T&M	1	323.61	222.49	0.56	7062.47	1.86
Low completeness		High uncertainty			Low likelihood	

completeness. Specifically, larger (higher priced) and longer projects are characterized by higher uncertainty and thus use less complete contract types (i.e. mixed or T&M contracts). Similarly, higher uncertainty, as reflected by a lower number of intermediate deliverables, is associated with T&M contracts.

The effect of likelihood of opportunism on contractual completeness is not as clear when observing the full range of archetypes. With the exception of firm FP contracts, locality is similar on average for all archetypes and the effect of previous contracts with the bank is not obvious. These effects are analysed more carefully in the next section.

However, Table 5 is much clearer with respect to the differences between the two FP archetypes and between the two T&M archetypes. On average, vendors with firm FP contracts have about 10 times less experience with the bank than vendors with standard FP contracts. Similarly, vendors with not-to-exceed T&M contracts have about half the experience with the bank of vendors with open, standard T&M contracts. Therefore, the likelihood of opportunism is restricted by using capped contracts in both FP and T&M regimes. Our data set thus shows that capped variations of FP and T&M contracts are used as insurance against unfamiliar vendors, a mechanism predicted but not confirmed by Kalnins and Mayer (2004).

V. Empirical Analysis

We test the hypothesis that contractual completeness is negatively affected by project uncertainty and positively affected by the likelihood of opportunism using OLS and ordered probit models, which include controls for vendor and contract characteristics. The estimates of Equation 2 using OLS regressions are presented in Table 6. Column 1 includes the five measures of project uncertainty and likelihood of opportunism, and columns 2 and 3 add variables intended to control for potential effects of vendor and contract characteristics on contractual completeness. Specifically, column 2 adds the variables of vendor size and vendor experience, where the former represents the total number of vendor employees and the latter represents the number of years since the vendor was founded. These two vendor characteristics control for the possibility that less complete contracts are used for larger and more experienced vendors. Column 3 adds the variables of contract length and attached documents, where the former represents the number of contract pages and the latter represents the number of attached documents, such as system specifications and design, referred to in the actual contract text. These two contract characteristics control for the possibility that contract choice is affected by the volume or detail of the actual contract and attached documents.

Table 6. OLS results

		Contractual completeness		
		(1)	(2)	(3)
Project uncertainty	Price (log)	−0.305*** (−4.403)	−0.249*** (−3.733)	−0.255*** (−3.499)
	Duration (log)	−0.080 (−1.235)	−0.109^{+} (−1.715)	−0.110^{+} (−1.722)
	Intermediate deliverables	0.321*** (5.707)	0.319*** (5.945)	0.314*** (5.847)
Likelihood of opportunism	Previous contracts (log)	−0.150* (−2.515)	−0.143* (−2.258)	−0.159* (−2.503)
	Locality (1 = int., 2 = local)	−0.089 (−1.374)	−0.188** (−2.917)	−0.180** (−2.784)
Vendor characteristics	Vendor size		−0.282*** (−3.742)	−0.281*** (−3.731)
	Vendor experience		−0.023 (−0.292)	−0.022 (−0.283)
Contract characteristics	Contract length			−0.064 (−1.043)
	Attached documents			0.104^{+} (1.813)
F		17.656***	18.235***	14.692***
Degrees of freedom		5	7	9
R^2		0.265	0.344	0.354
Adjusted R^2		0.250	0.326	0.330

Notes: Estimated standardized coefficients for OLS models are shown with t values in parentheses. Columns (1)–(3) use as dependent variable our five-archetype contractual completeness typology.
$^{+}p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; two-tailed p-values are reported.

The signs of the coefficients estimated in Table 6 are consistent with our hypothesis. Specifically, the coefficients of price and duration are negative (higher price and longer duration, thus higher uncertainty, resulting in lower completeness), while the coefficient of intermediate deliverables is positive (more intermediate deliverables, lower uncertainty and higher completeness). As expected, the coefficients of previous contracts and locality are negative (higher business familiarity, lower likelihood of opportunism and lower completeness). Only three of the coefficients for the baseline model in column 1, those for price, intermediate deliverables and previous contracts, are statistically significant (at the 0.05 level). However, the inclusion of vendor and contract characteristics as additional explanatory variables in columns 2 and 3 results in statistically significant coefficients for all five measures of project uncertainty and likelihood of opportunism (the coefficient of duration is significant at the 0.10 level). The hypothesized effects thus become stronger after controlling for the effects of vendor and contract characteristics.

A concern with the OLS regressions is that they treat contractual completeness as a continuous variable. This concern is addressed by using ordered probit models, as summarized in Table 7. We estimate nine ordered probit specifications: three using our five-archetype contractual completeness typology, three using a three-archetype typology (FP, mixed and T&M) and three using a two-archetype typology (FP and mixed/T&M). The two-archetype typology is created by combining the mixed archetype with the T&M archetypes because in all three archetypes, the overall price is not determined *ex ante*, whereas in the two FP archetypes, the price is fixed *ex ante*. The three specifications for each typology are similar to those in Table 6: columns 1, 4 and 7 include the five measures of project uncertainty and likelihood of opportunism, columns 2, 5 and 8 add the two vendor characteristics and columns 3, 6 and 9 add the two contract characteristics.

The ordered probit results presented in columns 1–3 of Table 7 are generally consistent with the OLS results, with the exception that the coefficient of locality is statistically significant in the baseline ordered probit model (column 1). Similar to the OLS results, all five measures of project uncertainty and likelihood of opportunism become statistically significant once vendor and contract characteristics are included as additional explanatory variables (columns 2 and 3). The ordered probit models for the three-archetype typology (columns 4–6) and the two-archetype typology (columns 7–9) are less predictive of contract choice than our five-archetype typology. Beyond lower χ^2 and R^2 values, the coefficients of previous contracts and locality are weaker and generally not statistically significant for the narrower typologies. This finding suggests that the likelihood of opportunism explains more variance in our broader contractual completeness typology than in narrower contract typologies. Interestingly, across all OLS and ordered probit models estimated, the coefficients of vendor size are negative and statistically significant, implying that more complete contracts are used with smaller vendors.

Endogeneity analysis

The results of our analysis may be biased because of simultaneity and endogenous matching (Ackerberg and Botticini, 2002; Corts and Singh, 2004). In our context, simultaneity means that decisions relating to system specification, vendor selection and contract choice may be taken simultaneously.

Table 7. Ordered probit results

		Contractual completeness 5 archetypes			3 Archetypes			2 Archetypes		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Project uncertainty	Price (log)	−0.776***	−0.691***	−0.648***	−0.730***	−0.691***	−0.657**	−0.833***	−0.810***	−0.603**
		(27.381)	(20.142)	(14.702)	(15.750)	(12.379)	(9.299)	(17.329)	(14.439)	(6.979)
	Duration (log)	−0.222	−0.459^{+}	−0.434^{+}	−0.435	−0.561^{+}	−0.527	−0.407	−0.524	−0.528
		(0.854)	(3.207)	(2.816)	(2.159)	(3.098)	(2.666)	(1.663)	(2.409)	(2.340)
	Intermediate deliverables	0.161***	0.175***	0.173***	0.250***	0.252***	0.252***	0.209***	0.216***	0.231***
		(22.289)	(24.955)	(23.562)	(28.417)	(27.049)	(25.478)	(19.324)	(18.990)	(19.062)
Likelihood of opportunism	Previous contracts (log)	−0.141**	−0.161**	−0.190**	−0.121^{+}	−0.086	−0.115	−0.151*	−0.145^{+}	−0.168*
		(7.287)	(7.045)	(9.311)	(3.694)	(1.355)	(2.300)	(5.058)	(3.478)	(4.317)
	Locality (1 = int., 2 = local)	−0.604**	−1.209***	−1.160***	−0.015	−0.701*	−0.621^{+}	−0.011	−0.548	−0.422
		(7.460)	(21.187)	(19.277)	(0.003)	(3.862)	(3.036)	(0.001)	(2.172)	(1.328)
Vendor characteristics	Vendor size		-5×10^{-5}***	-5×10^{-5}***		-4×10^{-5}**	-4×10^{-5}**		$-3 \times 10^{-5+}$	-3×10^{-5}*
			(14.010)	(13.997)		(6.911)	(6.690)		(3.777)	(3.952)
	Vendor experience		0.006	0.006		−0.005	−0.005		0.001	0.000
			(0.679)	(0.591)		(0.370)	(0.370)		(0.008)	(0.001)
Contract characteristics	Contract length			−0.010*			−0.007			−0.015*
				(4.159)			(1.774)			(5.828)
	Attached documents			0.032			0.024			−0.003
				(2.529)			(1.083)			(0.014)
χ^2		99.376***	137.147***	141.465***	64.809***	86.167***	86.948***	60.320***	74.404***	80.050***
Degrees of freedom		5	7	9	5	7	9	5	7	9
Cox & Snell R^2		0.325	0.418	0.431	0.226	0.289	0.293	0.212	0.255	0.273
Nagelkerke R^2		0.349	0.450	0.463	0.277	0.353	0.358	0.295	0.355	0.381

Notes: Estimated coefficients for ordered probit models are shown with Wald statistics in parentheses. Columns (1)–(3) use as dependent variable our five-archetype contractual completeness typology; columns (4)–(6) use a three-archetype typology (FP, mixed and T&M); and columns (7)–(9) use a two-archetype typology (FP and mixed/T&M).
$^{+}p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; two-tailed p-values are reported.

Table 8. Definition of the system interconnectedness instrumental variable

Interconnectedness	1	2	3	4	5
Interfaces/modules	Single	Single	Single	Multiple	Multiple
Interface definitions	None	None	Well-defined	Well-defined	Ill-defined
Relation to other systems	Standalone	Standalone	Connected	Connected	Connected
Specification	Simple	Elaborated	Simple	Elaborated	Elaborated

According to industry experts we interviewed, a client may have preliminary contract preferences for a specific project. However, the final choice of contract is made only after the requirements are defined, the vendor is selected and specification and price are negotiated. Endogenous matching (Ackerberg and Botticini, 2002) may occur because of unobserved characteristics of the project that create associations among specific projects, vendors and contracts. Among the variables hypothesized in this study to affect contractual completeness, price is the most susceptible to the problems of simultaneity and endogenous matching. After the contract type has been determined, the contracting parties are not likely to make adjustments to system specification or vendor selection. The variable most susceptible to adjustments at this stage is price, because adjustments to duration or intermediate deliverables require changes in project planning, and the vendor is not likely to be replaced at this stage. Moreover, price is the variable most likely to be matched with contractual completeness as a consequence of unobserved technological characteristics. For example, a new and expensive technology may create an incentive for the client to use a T&M contract for a high-priced project.

To address these problems, we use a perceived measure of *System Interconnectedness*, which relates to the connectedness of the new system with other internal systems of the bank, as an instrumental variable. During data collection, each contract in the portfolio was reviewed and ranked on a 5-point scale by one of the authors (who had extensive experience with software development projects in both client and vendor firms). The degree of interconnectedness was determined by mapping information in the contracts to clear-cut criteria, as detailed in Table 8. We assume that interconnectedness is exogenous because the technical specifications of the connections with other bank systems are a standard part of the bank's IT infrastructure, which is relatively stable. The interconnectedness of the system under development is central to its specification, and it rarely changes during negotiation or development. It is, therefore, unlikely that interconnectedness is affected by contract choice. We further assume that interconnectedness is informative because it correlates with price – a higher degree of interconnectedness requires more development effort. According to interviews with industry experts, the careful connection of a new system to existing systems consumes significant development resources because of the need to analyse all possible interactions between systems, to specify the required inputs and outputs, to program these specifications and to test them in both synthetic and operational environments. All this work is reflected in the price of a new system in large organizations.

Consequently, interconnectedness is used as an instrumental variable in testing the endogeneity of price with a two-stage least squares (2SLS) analysis. The results of this analysis, presented in Table 9, validate our earlier findings by showing only small differences in the magnitude of coefficients for the baseline model. In particular, the predicted price using the instrumental variable maintains the highly significant effect on contractual completeness. We use the Wu–Hausman specification test for endogeneity to examine the significance of the predicted values of price when included as an additional explanatory variable in the full regression. This test shows that the predicted price has no significant effect in this case ($t = -1.24$, $p = 0.216$), indicating that the null hypothesis that price should be treated as an exogenous variable cannot be rejected. Therefore, endogeneity does not appear to be a serious concern in interpreting our results. Although our instrumentation approach is limited, it goes beyond most of the

Table 9. 2SLS results

		Contractual completeness 2SLS model
Project uncertainty	Price (log)	–0.464** (–2.604)
	Duration (log)	–0.050 (–0.453)
	Intermediate deliverables	0.385*** (6.416)
Likelihood of opportunism	Previous contracts (log)	–0.139* (–2.281)
	Locality (1 = int., 2 = local)	–0.014 (–0.190)
F		15.914***
Degrees of freedom		5
R^2		0.255
Adjusted R^2		0.239

Notes: The 2SLS model uses the instrumental variable of system interconnectedness to test the endogeneity of price. Estimated standardized coefficients are shown with *t* values in parentheses. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; two-tailed *p*-values are reported.

extant literature, which typically does not address these problems (Corts and Singh, 2004).

VI. Discussion

The main goal of this article was to provide a theoretical rationale for the combinations of FP and T&M mechanisms that create the observed contract typology. Our analysis of a large portfolio of software development contracts of a leading international bank indeed shows that archetypes are chosen by balancing the costs and benefits of crafting more complete contracts (Crocker and Reynolds, 1993). High specification volatility projects, for which complete contracts would be costly to draft, are likely to be based on the less complete archetypes. Similarly, these incomplete contracts are likely to be granted to familiar vendors for whom the likelihood of behaving opportunistically is low. The differences among archetypes in uncertainty and likelihood of opportunism are significant along the full typology and not only between the standard FP and T&M archetypes.

An additional goal of the article was to bring to light a nuanced typology of contracts for software development. Indeed, one-third of the contracts we reviewed differ significantly from the FP and T&M types on which the literature focuses (Banerjee and Duflo, 2000; Gopal *et al.*, 2003; Ethiraj *et al.*, 2005). Specifically, firm FP contracts cap specification volatility by allowing no change during the development period and thus prevent costly renegotiation (Bolton and Dewatripont, 2005). Firm FP contracts are, on average, about half the price of standard FP contracts and are more frequently awarded to unfamiliar vendors. Not-to-exceed T&M contracts define a price cap on the T&M mechanism; these contracts are similar to T&M contracts in all dimensions but one – vendors' previous experience with the client, which is, on average, half of the experience of T&M vendors. These findings confirm the expectation that capped variations of FP and T&M contracts are used as insurance against unfamiliar vendors. Finally, mixed contracts, which may be seen as the simplest form of hybrid contracts, are shown here to be a major technique of software development contracting. Although only one-eighth of the contracts are mixed, they constitute one quarter of the bank's portfolio, by price.

The limitations of the article lie in the reliance on a single organization, particularly since the large size and long experience of the bank are likely to influence its contracting practices. Although learning from such a client is laudable, our results should be generalized to other organizations with caution. Similarly, we had to rely on the contracts themselves to measure project uncertainty and likelihood of opportunism. While these measures are objective and not subject to bias, our analysis is limited by the fact that we had no access to the project managers and their considerations for selecting contact types.

The main implication of the current study for research is the need to identify additional mechanisms that address *ex post* adaptations and, more generally, other combinations or hybrids of FP and T&M mechanisms that are used in practice. The recent procurement literature describes a range of contract typologies: the single-archetype typology of unit price auctions for highway improvements (Bajari *et al.*, 2006), the prevalent two-archetype typology of FP and T&M typical of construction projects (Bajari and Tadelis, 2001; Bajari *et al.*, 2009), the three-archetype typology for IT services (Kalnins and Mayer, 2004) and the five-archetype typology for jet engine procurement (Crocker and Reynolds, 1993). The present study extends this line of research by describing a novel five-archetype typology for custom software development. Are there other hybrids and elaborate typologies used in practice?

Practical implications are mostly relevant to the software development industry. They include the need for managers to consider the full gamut of FP and T&M mechanisms to make more resources available while reducing risks in software development. Specifically, using firm FP contracts should allow clients to start working with unfamiliar vendors on short and stable projects that are not prone to renegotiation. Similarly, not-to-exceed T&M contracts should allow the client to work with vendors that are usually not trusted with standard T&M projects. The importance of software vendors in modern businesses creates new challenges in the management of technology (Applegate *et al.*, 2009). The current article shows that specification volatility and *ex post* adaptations are central to these challenges and that an elaborate contract typology is required to balance project uncertainty and vendor-related hazards.

Finally, the merits of different contractual mechanisms have recently become an issue for public debate, as the US government has encouraged agencies to use competitive bidding and FP contracts for Recovery Act 2009 projects to the maximum extent possible. However, the literature suggests that for projects in which specifications and cost are difficult to estimate, T&M contracts may be more appropriate. This article will hopefully inform this debate by extending the literature on *ex post* adaptations, presenting additional contractual mechanisms and analysing their various levels of contractual completeness.

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