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Giacomo Calzolari, Leonardo Felli, Johannes Koenen, Giancarlo Spagnolo, Konrad O. Stahl

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Trust and Complexity in Vertical Relationships

Abstract

We investigate the role of mutual trust in long-term vertical relationships involving trades of complex goods. High complexity is associated with high contract incompleteness and hence the increased relevance of trust-based relational contracts. Contrary to expectations, we find that changes in trust do not impact the quality of highly complex objects. Instead, higher trust improves the quality of less complex objects. Even more surprisingly, trust is associated with more competition in procurement, again for low tech objects. This complexity-based difference persists even when the same supplier provides both types of objects, suggesting relational contracting may be object-specific. These findings are derived from a comprehensive survey of buyers and critical suppliers in the German automotive industry. We explain these results with a relational contracting model, where the cost of switching suppliers is technology-specific and increases with object complexity, shifting bargaining power and altering the effects of trust on each party's incentives.

JEL-Codes: D860, L140, L620, O340.

Keywords: relational contracts, complexity, bargaining power, trust, high-tech industries.

*Giacomo Calzolari**
European University Institute
Via Badia dei Roccettini 11
Italy – 50014 Fiesole FI
Giacomo.Calzolari@eui.eu

Leonardo Felli
University of Cambridge
Cambridge / United Kingdom
lf454@cam.ac.uk

Johannes Koenen
ARC Econ
Limburgerhof / Germany

Giancarlo Spagnolo
Department of Economics and Financ
University of Rome Tor Vergata / Ital
spagnologianca@gmail.com

Konrad O. Stahl
University of Mannheim / Germany
konrad.stahl@uni-mannheim.de

*corresponding author

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1 Introduction

Relational contracts between suppliers and buyers, trust-based informal agreements enforced by the value of future cooperation, are key to business relationships. By complementing formal contracts, they are important not only in emerging economies, but also in economies with well developed legal systems.[1] Such an informal agreement recently led to a crucial medical breakthrough. After building mutual trust over two years of collaboration, BioNTech and Pfizer worked together for more than twelve months sharing valuable intellectual property in the development of Comirnaty, one of the first successful vaccines against Coronavirus SARS-CoV-2, before eventually signing a formal contract.[2]

This example involves cooperation in both development and production in a high-tech industry. Indeed, in a celebrated contribution, Williamson (1975) emphasizes the increased complexity of the traded object as a cause of greater contractual incompleteness, which implies an increased importance of trust-based relational contracts.[3] This should, in turn, lead to empirical outcomes such as a stronger association between high trust and high quality for traded objects of higher complexity. In this paper, however, we document no such effect. By contrast, we find that an increase in mutual trust effectively improves the quality of the traded object only when its technological complexity is relatively *low*.[4]

Furthermore, from existing theory and evidence (Calzolari and Spagnolo, 2009; Macchiavello and Morjaria, 2021), one would expect that increased competition between suppliers for procurement contracts would be detrimental to the relationship with a given buyer. We find, however, that high trust in the relationship allows the buyer to invite *more* suppliers to compete in development and to *more* frequently co-source production without compromising on quality –again only for objects of relatively low complexity.

Key to our arguments is that different levels of trust determine the outcomes. Towards those, we provide broad support for our identifying assumption that the *current*

[1]See Gibbons and Henderson (2013) for a survey on empirical evidence.

[2]Based on BioNTech founder Uğur Şahin's keynote address at the 2021 conference *Relational Contracts: Theory and Practice*. The importance of trust-based relationships was further stressed by high-level participants from firms including Boeing, GM, Kraft Foods, Procter & Gamble, and Rolls Royce.

[3]Segal (1999) formalizes the relationship between complexity and contractual incompleteness.

[4]As we will see, even low-tech parts in our industry require substantive investment in R&D, much of which is buyer-specific.

state of trust can be considered exogenous.[5]

The stark observed differences between high and low-complexity traded objects persist even when considering objects of different complexity that a buyer sources from the same supplier.[6] This contrasts with the presumption that the benefits from relational contracting should be associated with the quality of the partner-specific relationship. We find instead that in our environment they are specific to the conditions in the relevant market, implying that they are part- rather than partner-specific.

To interpret these unexpected findings, we resort to a novel theoretical analysis. In our model, we show that the marked differences observed for high- and low-tech parts can be attributed to (i) natural variations in the trading partners' bargaining power, which fundamentally alter their incentives, and (ii) the distinct role of trust in the relationships, contingent on who holds the bargaining power. After discussing key aspects of our data, we will describe the model and relate it to the empirical evidence.

Our empirical insights are based on the results of a high-level benchmarking survey on the quality of buyer-supplier relationships in the German automotive industry, that was motivated by the long shadow of a deep disruption of mutual trust and run by the Verband der Automobilindustrie (VDA), Germany's powerful central association of the industry.[7] Our data generation involves all German automotive producers and their largest first-tier suppliers, amongst them the world's largest ones. With one exception, they supply parts involving any level of complexity.

While the data so generated are limited to a cross-section, they directly address in previously unseen detail delicate issues in the relationship between key players in an industry that produces one of the most complex consumer goods to date. It is hard to imagine that direct observations on such delicate issues can be obtained with an instrument other than a survey whose generation is backed up by the mutual commitment of buyers and suppliers wishing to resolve their frictions by learning about their causes.

As clarified by our model, which reflects the observed features of the industry but is rather generic in elucidating a principle cause-effect relationship, it is the shift in bargaining power from the buyer to the leading supplier that changes incentives between low and high-tech parts. In the model, a buyer repeatedly invites a subset of potentially many competing suppliers for the development and production of a part, including a blueprint requiring buyer- and part-specific non-contractible investment. The investment

[5] We document that the buyer-supplier relationships are very long-lasting, but procurement for parts for any given car model out of many models provided by a given buyer is repeated every 12-18 months in the course of model-updates.

[6] The low-tech/high-tech difference survives several alternative specifications.

[7] We sketch key elements of that disruption in Subsection 3.1.

cost involved in developing the blueprint of a part is compensated by a contractible lump-sum payment, and by expected rents generated from eventual production. These rents are sustained by limiting competing suppliers' access to the procurement contest.

With our model, we show that the attribution of benefits arising from higher trust depends on the allocation of bargaining power. This is associated with the buyer's costs of training a supplier from outside the original subset of developers to produce the part according to the selected blueprint, which we refer to as *switching costs*.[8] These costs are substantially smaller for low-tech than for more complex high-tech parts. For low switching costs, the bargaining power naturally rests with the buyer. In this case, a higher common discount factor that indicates the level of mutual trust between buyer and supplier relaxes the typical supplier's incentive constraint, allowing the buyer to increase both the number of suppliers involved in the development phase and the required investment. Honoring that incentive constraint as part of the relational contract ensures that the invited suppliers invest during the development phase despite increased competition.

For high switching costs, the leading supplier invited by the buyer holds the bargaining power. This supplier controls the necessary investment, which, if trust is sufficiently high, remains constant despite increasing mutual trust.[9] However, this does not mean that mutual trust plays no role in the procurement of high-tech parts. Our survey indicates that trust is equally crucial in each of the different part categories, consistent with the model where trust is essential to uphold a relational contract even when the supplier has the bargaining power.

While our analysis reflects the specifics of an important economic sector in one country, we believe it provides insights relevant to procurement environments in other industries and countries. Key examples involve the procurement of parts for the production of aircraft and trains, as well as for defense and aerospace procurement.[10]

[8] This notion of switching costs relates back to Monteverde and Teece (1982) or Demski, Sappington, and Spiller (1987).

[9] The influence of switching costs on bargaining power results from the buyer's tendency to expropriate suppliers' investment and intensify competition. When this temptation is strong, the buyer's payoff is bound by the potential gains from such actions, which decrease with rising switching costs. In contrast, a supplier with bargaining power gains from higher switching costs because they lessen the cost of enforcing discipline on the buyer. Consequently, with low (high) switching costs, the benefits to the buyer from possessing bargaining power surpass (fall below) those to a supplier. In any bidding process that allocates bargaining power beforehand, the buyer (supplier) would prevail.

[10] Gibbons and Henderson (2013) provide many other relevant examples.

Related literature We contribute empirically and theoretically to the growing literature on relational contracts pioneered by Macauley (1963), MacLeod and Malcomson (1989) and Baker et al. (1994).[11] We extend this literature by uncovering how the complexity of the exchanged good may affect bargaining power, and through it the interaction between trust, investment and competition within the relationship. Williamson (1975) and Segal (1999) highlighted the importance of increased complexity as source of increased contractual incompleteness, and with it, of the increased importance of trust and relational contracts. We show that the argument is subtle as the comparative statics may depend on technological conditions, such as the cost of switching suppliers and with it, the parties' bargaining power. The economic relevance of part complexity has also been addressed in the supply chain literature. In particular, Gosh, Dutta, and Stremersch (2006) argue that the vendor should take control in customizing complex products. By our argument, the vendor takes control because the buyer's costs of switching across vendors are high. Beyond that, we are not aware of any theoretical or empirical analysis differentiating the impacts of relational contracts by product characteristics and production technologies.

The importance of relational contracts is by now widely empirically documented for a variety of industries, ranging from the US and Japanese automotive sectors (Helper and Henderson, 2014; Bernstein, 2015) to airlines (Gil, Kim, and Zanarone, 2022), US highway procurement (Gil and Marion, 2013), movies (Barron et al., 2020), and the oil industry (Paltseva, Toews, and Troya-Martinez, 2023). Relational contracts are particularly important for trading relationships when legal enforcement is weak, such as in developing countries and in international trade (see, e.g., Antràs and Foley, 2015). Although they do not discuss exchanged goods' complexity, the focus on competition makes McMillan and Woodruff (1999) and Macchiavello and Morjaria (2021) the closest empirical studies to our paper. They show that within a weak legal system, an exogenous increase in competition leads mutually beneficial relational contracting to degenerate. Macchiavello and Morjaria (2022) link this effect directly to a decrease in reported mutual trust towards their trading partners. In contrast to their setting, ours involves a strong and effective legal system and one where competition (among suppliers competing for a procurement contract) is endogenous. Here, for low tech goods, the causality is reversed: an improvement in the relationship measured by increasing mutual trust allows buyers to increase competition between these suppliers, without undermining procured quality.

[11] Malcomson (2013) and Gibbons and Henderson (2013) provide complementary surveys highlighting theoretical and institutional/empirical aspects, respectively. See also MacLeod (2007).

Many authors have studied the automotive industry as one of the most interesting examples of vertical relationships involving complex products. Grossman and Hart (1986), Milgrom and Roberts (1992), Taylor and Wiggins (1997), Holmström and Roberts (1998) and Malcomson (2013), among many others, refer to the classic Fisher-GM vertical integration case, or to Asanuma (1989)'s case-based description of upstream supplier-buyer relationships in the Japanese automotive industry. Our evidence is in the same spirit.

As to relating trust and the discount factor, Kvaloy and Olsen (2009) argue in a model of relational contracts with endogenous verification that the discount factor is a good indicator of trust in a relationship. They also perform comparative statics to understand how their results change with different levels of trust.[12] Our notion of trust does not encompass the multi-faceted sociological and psychological constructs that can also be associated with the term. While we agree with Williamson (1993) that there are good reasons for a more general view, our interpretation is likely to be the relevant one when looking at procurement issues involving sizeable firms.

In theoretically addressing relational contracts between a buyer and several sellers repeatedly competing for supply contracts, our model is close to a number of recent contributions including Calzolari and Spagnolo (2009), Board (2011), Andrews and Barron (2016), and De Chiara (2020).[13] However, none of these models fits the relationships we observe nor exhibits the comparative statics relevant to our data, including the role played by the complexity of the procured good. The influence of the cost of replacing a supplier on the allocation of bargaining power connects our model to MacLeod and Malcomson (1998), where the competitive conditions in the labour market affect the allocation of the surplus between employer and employees and the shape of the prevailing relational contracts. We obviously relate to the literature on incomplete contracts following Grossman and Hart (1986) and Hart and Moore (1988), and in particular the analysis of the role that competition plays in that setting (Rajan and Zingales, 1998; Felli and Roberts, 2016).

We sketch the mode of procurement in the industry and the relational contracting aspects in Section 2. Data and descriptives are provided in Section 3. Section 4 contains our empirical analysis, and Section 5 the model and results. We conclude in Section 6. An empirical and two theoretical appendices provide additional details.

[12]Bodoh-Creed (2019) defines trust and its relationship to the discount rate similarly, as does Kartal (2018). Cabral (2005) interprets the folk theorem as a model of trust.

[13]Less related are studies of relational contracts with teams of agents working together, such as Che and Yoo (2001), Levin (2002) and Kvaløy and Olsen (2006).

2 Procurement in the Industry

We begin by detailing the typical first-tier procurement process observed in the German automotive industry.[14] We then derive elements of a relational buyer-supplier contract in this industry.

2.1 Description

The German automotive producer (buyer, OEM) features many models. Every fall, a subset of these models is phased out and replaced by a new design. The typical model is produced for 6 to 8 years, with annual to biannual uplifts in which key parts are updated typically by the same supplier. At the level of the OEM, this results in an overlapping generations (OLG) structure of model lifetimes.

Upstream firms, amongst them the world's number one and two, develop and supply their parts to multiple buyers rather than being vertically integrated, allowing them to both carry out cutting-edge research and development and to exploit economies of scale. Thus, unlike elsewhere, upstream R&D is an important driver in this industry in Germany.[15] Vertical collaborative relationships have lasted for decades, with only one major disruption introduced below in Subsection 3.1, on which we base our analysis.

In the supply of a part, the industry distinguishes between pre-development, which in Germany involves the typical supplier's R&D which is most often not attributable to a specific buyer and car model; car model- and thus buyer-specific development; series production; and the after-sales supply of parts for about 15 years after the model is phased out. Thus, including all phases, the economic life-time of a part may extend to up to 30 years.

When developing a car model, the typical buyer chooses a subset from her shortlist of suppliers she considers capable of developing and producing a specific part. The chosen suppliers compete in developing the best blueprint based on the buyer's performance requirements and beyond, each drawing from their buyer- and model-unspecific pre-development efforts. That naturally includes their patented and unpatented intellectual property rights (IPR).

[14] The context of development and production is described in detail in Müller, Stahl, and Wachtler (2016).

[15] German automotive suppliers tend to be more research oriented than in the U.S. and Japan, where innovation is centered around manufacturers. Koppel, Puls, and Röben (2018) report that in 2015, the two largest German suppliers filed about as many patent applications as the five most research intensive automotive producers.

Development requires model-, and thus buyer-specific investment –and this for all types of parts distinguished in this paper. In principle, the resulting blueprint should enable other competent suppliers to produce the part. However, switching the supplier is costly. The cost increases in the complexity of the part for technical and administrative reasons as this necessarily involves the development-specific transfer of production skills to a competitor and the competitor's use of the developer's IPR. The development of blueprint-specific production tools further increases these switching costs. Thus, parts are supplied by one or at most two suppliers on the basis of their own blueprints.

Since the typical supplier's R&D efforts are impossible to attribute to a buyer- and model-specific part, only a fraction of the development effort is directly compensated. The fraction indirectly compensated is embedded in the buyer's promise that the winning model-specific design is contracted for at least the first years of series production. This incentivizes the supplier to be included in the buyer's shortlist, and if selected, to develop a good part. The incentive increases with a decreasing number of suppliers chosen by the buyer to compete with.

The buyer's shortlist of part suppliers is private information but is known to be small. Both the OLG structure in bringing new models to the market and uplifting current models necessitate procurement of functionally the same part several times a year, and this often from the same supplier. Therefore it appears unsurprising that this mode of procurement, while eventually fiercely competitive across suppliers, rests on trust built within long term cooperative buyer-supplier relationships. Within these relationships, we don't observe monetary ex-post buyer-supplier transfers.[16]

The supplier winning the procurement contest and the buyer sign a letter of intention that indicates their mutual interest in trading the part over the entire 6 to 8 years of series production period of the automotive model. Verifiable transaction details, including quantities and prices for the part, are specified in annual or, at most, bi-annual formal contracts. Since the demand for the automotive model is uncertain, they foresee quantity/price intervals, allowing the buyer and the supplier to share the rents involved in producing and selling larger quantities. The agents negotiating the part specific contract differ across parts, with the parties informally agreeing to Chinese walls across contracts –even when involving the same buyer-supplier pair.

[16] In very rare exemptions typically reported by the media, automotive producers use transfers to assist suppliers in a battle for survival.

2.2 Elements of an interfirm relational contract

To produce an innovative part requires deep technical insight. Therefore, it is natural that the developing firm also produces the part. This natural link was threatened on the buyer side in the disruptive phase provoking the collection of our data. Our version of a relational contract, that we argue is typical for the development and trade of complex products between innovation oriented suppliers and buyers, involves the buyer's promise not to open procurement of production for non-developing suppliers, and in turn, the typical supplier's promise to invest and develop cutting-edge technology towards a reliably functioning part. Mutual trust then is associated with the probability that the relational contract is sustained. Other promises include not passing on a supplier's IPR to competing suppliers, and treating each other fairly, e.g., by helping to identify a problem that may involve the particular part or its interfaces with other parts.[17]

3 Data and Descriptives

Our empirical analysis is mainly based on the benchmarking survey that focuses on eliciting the mutual trust between a supplier providing a specific part and its buyer, and its implications for the German automotive industry. We complement this data with data from the international commercial database *Who Supplies Whom* (WSW) offered by supplierbusiness.com that collects data on such relationships more broadly, but in less depth. We first sketch the generation of our database and then, in the interest of paper length, only summarize descriptives of our variables of interest. More detail on the latter is contained in Appendix A.

3.1 Data gathering process

The benchmarking survey originated from an incident back in the early 1990s that left a long-lasting imprint on the buyer-supplier relationships in the German automotive industry. Ignacio Lopez, (in)famously known for implementing aggressive, cost-saving procurement practices in the U.S. at GM, was poached with his entire team by German

[17] A typical violation of a relational contract on the supplier side: Kiekert, a specialized producer of car locks, claimed a serious problem in its process computing facilities during contract negotiations with Ford. This stalled Ford's assembly lines for weeks, until a continuation contract favorable to Kiekert was signed. In response, Kiekert was excluded by Ford from future contracts. Thus, Ford chose a relational form of punishment instead of pursuing damages in court. See Wachtler (2002).

carmaker VW.[18] With the intention to push parts prices toward marginal production costs, Lopez used the winning blueprint from competitive development procurement without compensation to its originator to procure worldwide for production, thereby expropriating the originator's intellectual property.[19] As a result, VW's short run profits substantially increased. Lopez' strategy was adopted to varying degrees by VW's German competitors. The long-term supplier-buyer relationships, however, suffered overall dramatic decay. The long shadow of this unique disruption led to a serious deterioration of part quality. This prompted the board of the German Association of Car Manufacturers (VDA) that includes the CEOs of all German automotive producers and of their leading suppliers, all key players in the world's automotive industry, to unanimously commit to a detailed and costly benchmarking study on diminished supplier-buyer trust and its effects. That the lasting "trust-shock" prompted this major study underscores its importance for the entire industry.[20]

A steering committee consisting of researchers as well as chief engineers and managers of the participating manufacturers and suppliers –all on the VDA board– supervised the study. Focal to the study was our survey, designed to identify the state of trust as well as disruptions up to violations of legally enforceable contracts.The survey was carried out between Fall of 2007 and Summer of 2008. The committee participated in the questionnaire design and phrasing of key items, ensuring a common understanding of definitions which is crucial to our identification strategy, and monitored the respondents in their respective firms.[21] The data generation was so costly that the industry participants felt unable to repeat this process for a subsequent survey wave. While the analysis of cross-sectional survey data poses obvious limitations, the richness of the data allows us to shed a unique light on fundamental relational contracting issues in an important industry.

All 10 German automotive producers (7 producers of passenger cars and 3 truck makers) as well as all 13 leading German parts suppliers participated in the survey.[22]

[18]The dramatic consequences for GM's buyer-supplier relationships are well described in Helper and Henderson (2014).

[19]See Moffett and Youngdahl (1999) for a detailed description of Lopez's procurement strategy. For a discussion of Lopez's long shadow over Opel, a German daughter company of GM, see *here* while a collection of articles on Lopez's case is found *here*.

[20]The study was preceded by case studies carried out between November 2005 and May 2006 that involved interviews with high-ranking representatives of first-tier suppliers' R&D, production and marketing departments, and automotive producers' procurement departments. Müller, Stahl, and Wachtler (2016) summarise the results of these case studies.

[21]Their participation also ensured complete anonymity of data collection and reporting. It prohibits us from the identification of individual firms' responses or profiles.

[22]While VW, Audi and Porsche belong to the same group, their procurement is completely independent, and they often compete fiercely in the output market. For benchmarking purposes, the set of buyers included one outsider.

While the survey included all German buyers, our supplier sample tends towards large participants, reporting average revenues in 2007 of 9.4 bn, and minimally 700 m euros. Yet the survey covers relationships involving the essential volume of all transactions involving tier 1 suppliers, and focuses on the longest enduring relationships, many of which had extended over several decades.[23]

The questionnaire contains 185 questions plus 150 sub-questions and covers the phases *Pre-development*, *development*, and *series production.*Suppliers' specialists in these phases spent significant time evaluating their relationship w.r.t. a specific part to a particular buyer, selected from one of the four product groups, *systems, modules, components*, and *commodities*, that are industry standard: components are high-tech and systems an assembly thereof; commodities are low-tech and modules an assembly thereof. To capture also the buyer perspective, key managers of the buyers' procurement divisions were asked essentially the same questions.

An observation is defined as *a given supplier's report on a given buyer's procurement practice for a specific part supplied to that buyer at the time of the survey.*[24] In order to obtain a clear view of relationships at the supplier-part-buyer level, we used the arithmetic mean of the responses of the supplier's specialists, whenever they answered identical questions for a given part.[25] Since any such aggregation tends to blur the analyzed relationship, we consider it encouraging to have arrived at the clear picture below on relationships and effects.

3.2 Measure of trust

Trust is an elusive concept. But in the present business context, trust is given a specific meaning. Trust in a counterpart is conceived as belief about the counterpart's type. In particular, higher trust implies an increased belief that the counterpart places high value on future bilateral interactions and thus will not behave opportunistically to increase

[23] 61% of our observed *part-specific* buyer-supplier relationships had lasted longer than 15 years. Among the remaining 39% shorter relationships, the average duration is 8.7 years. Only 1% of our part-specific observations stated a duration of the relationship of less than 4 years.

[24] While the suppliers' responses were buyer- and part-specific, the buyers' responses were only part-specific to preserve anonymity in the procurement relationships, which imposes limits on exploiting both sides' views on the same relationship.

[25] Appendix A, subsection 7.1 contains details on the aggregation. While theoretically, this results in 572 relationships (13 suppliers x 4 product groups x 11 buyers), our sample is reduced to 308 relationships because not all suppliers provide parts from all product groups to all buyers. The number of analyzable observations is further reduced by incomplete responses.

short-run profits.[26] In order to be effective in a transaction, such a belief must be high and mutual.

The focal question asked specialists in all phases and for all parts selected for the survey to *evaluate the importance of mutual trust in the buyer's selection of a supplier.* This question was unanimously agreed upon by the steering committee after intensive discussion. Nevertheless, we need to exclude an unexpected alternative interpretation of that question that could result in measurement error: respondents might state the importance of trust in the relationship to be high in principle (so that we measure a high value) while considering it to be lacking in practice (which we would not observe). We first relate the responses to questions included in the questionnaire that link trust directly to behavior in key decisions. Second, we regress statements indicating past unilateral friendly vs. opportunistic actions that should affect the trust level. The results are as expected and significant throughout, and thus support our interpretation of the chosen measure.[27]

3.3 Other key variables

A focal point in our analysis is that buyer-supplier relationships differ across part categories. The descriptives in Table I reflect differences between these. The relevant definitions are specified in Appendix A, Subsection A.1. Before all, the frequency of observations across the four parts categories corresponds rather well to the relative number of suppliers as presented in the WSW data (lines 1 & 2).

High-tech vs. low-tech parts By lines 3 and 4 of Table I, the share of development to total costs and to part revenue differs as expected between low- and high-tech parts, as do the shares of more than 20 patent applications by product group in the preceding 5 years in line 5. Surprisingly, however, more than three quarters of low-tech parts are associated with 5 or more patent applications (line 6). We will return below to the apparent discrepancy between development cost shares and patenting.

Part-specific trust Lines 7 & 8 in Table I show trust indices by part categories. The second index is normalized by responses to a corresponding question on the relevance

[26]This is akin to the notion introduced by Gambetta (1988) and endorsed by Williamson (1993). See also Cabral (2005). In repeated games, the notion corresponds to the partner's expectation about the counterpart's discount rate.

[27]Appendix A, Subsection A.2 contains details rationalizing the choice of this index, and robustness checks for its interpretation.

of prices. Neither part-specific trust index varies significantly across parts categories.[28] Rather than the idea that trust should be more important for the trade of high-tech parts, this seems to reflect the critical importance of most parts to the functionality of an automobile.[29] Furthermore, as shown in Figure I, the means of the trust measure vary only insignificantly across buyers. In view of all these small variations, our finding that changes in trust have effects that differ between low- and high-tech parts appears even more surprising.

Part quality is of strategic concern for manufacturers. Part quality contributes to and determines the quality and utility of the final product. Yet even the manufacturer may observe part quality only when operating within its interfaces, and often only after (ab-)use by the buyer. Publicly reported and known to the researcher are typically only recalls of the entire automobile. By contrast, our questionnaire response provides us with an insider measure that is part-specific and much more sensitive. The frequency of quality issues reported in line 9 varies between 10 and 25%. As expected, lower frequencies are reported for the physically smaller commodities and high-tech components compared to the larger modules and systems. But frequencies do essentially not differ between high-tech and low-tech.

[28]On both the buyer and the supplier side, separate agents are in charge of specific parts or part groups rather than for specific buyer-supplier pairs, and so are the respondents to our questionnaire survey.

[29]For example, the failure of an o-ring in a combustion engine is as critical as the failure of an entire electronic system.

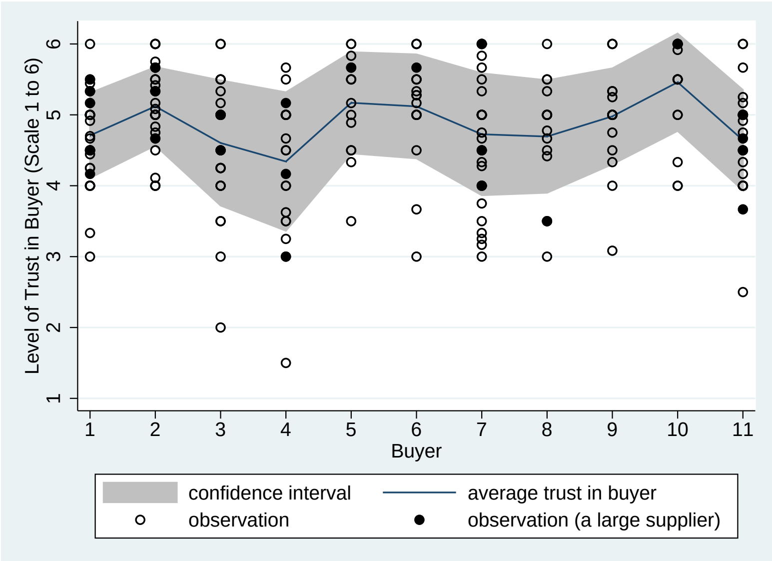
Table I

Descriptive statistics, differentiated by type of part

Variable	Systems		Modules		Components		Commodities		High-Tech		Low-Tech		
	Mean	std. err.	Mean	std.err.	Mean	std.err.	Mean	std.err.	Mean	std.err.	Mean	std.err.	Obs.
(1) Freq. of Obs. Questionnaire	**16.4%**		**22.4%**		**24.3%**		**33.2%**		**40.7%**		**55.6%**		
(2) Freq. of Obs. WSW-Data	**10.7%**		**27.4%**		**23.3%**		**31.6%**		**34.0%**		**59.0%**		562
Variables rationalizing categorization of parts:													
(3) Share development costs of total part costs	**9.9%**	0.048	**7.5%**	0.038	**10.3%**	0.044	**7.0%**	0.032	**10.1%**	0.046	**7.2%**	0.034	211
(4) Share development costs of total part revenue	**6.6%**	0.033	**2.5%**	0.03	**6.0%**	0.026	**3.3%**	0.018	**6.2%**	0.027	**3.2%**	0.020	44
(5) Share more than 20 patents in last 5 years	**70.0%**		**9.8%**		**38.0%**		**29.6%**		**49.4%**		**23.0%**		207
(6) Share less than 5 patents in last 5 years	**6.7%**		**17.1%**		**22.8%**		**35.8%**		**29.5%**		**16.5%**		207
Key Variables:													
(7) Trust index	**4.82**	0.79	**4.83**	0.71	**4.89**	0.72	**4.80**	0.87	**4.86**	0.75	**4.81**	0.82	296
(8) Trust index normalized (n)	**-0.7**	0.95	**-0.61**	1.09	**-0.63**	1.04	**-0.63**	1.10	**-0.66**	1.01	**-0.62**	1.10	295
(9) Freq. of quality issues	**19.9%**	0.121	**24.3%**	0.308	**12.8%**	0.188	**10.3%**	0.138	**15.5%**	0.168	**16.2%**	0.231	193
(10) Number competing suppliers ...in pre-devt.	**2.34**	0.85	**1.92**	0.51	**2.22**	0.84	**2.14**	0.88	**2.10**	0.82	**2.27**	0.84	124
(11) ...in model spec. detailed development	**1.26**	0.70	**1.50**	1.12	**1.39**	0.61	**1.66**	0.96	**1.60**	1.02	**1.35**	0.63	194
(12) ...in series production (SOP)	**1.09**	0.30	**1.05**	0.22	**1.08**	0.27	**1.4**	0.87	**1.28**	0.73	**1.09**	0.28	216
Share devt. costs absorbed by OEM:													
Suppliers' view													
(13) via lump-sum payment	**27%**	0.261	**43%**	0.324	**26%**	0.25	**22%**	0.234	**28%**	0.279	**29%**	0.287	193
(14) via markup on parts procured	**59%**	0.264	**60%**	0.299	**57%**	0.291	**48%**	0.333	**56%**	0.253	**53%**	0.325	186
OEMs' view													
(15) via lump-sum payment	**27%**	0.261	**43%**	0.324	**26%**	0.25	**22%**	0.234	**28%**	0.279	**29%**	0.287	193
(16) via markup on parts procured	**59%**	0.264	**60%**	0.299	**57%**	0.291	**48%**	0.333	**56%**	0.253	**53%**	0.325	186

Descriptive statistics of the main variables employed in our empirical analysis by type of part. High-Tech includes systems and components, Low-Tech modules and commodities. Questions employed for measures: Freq. of quality issues: "For the part in question, how often do quality issues arise?"; risk sharing: "Who absorbs risks for higher development costs?" (1 - always supplier to 5 - alway OEM); freq. IPR conflicts: "How frequently do conflicts arise with respect to IPR?"; freq. IPR pass-on: "How frequently does the OEM leak information to competing suppliers?"

Figure I
Variation in the trust measure.



Assessments of importance of trust in part-specific buyer-supplier relationship (supplier's perspective). Assessments by a large supplier in solid black dots. Confidence interval of suppliers' assessments in gray.

Number of suppliers. It varies across the product life-cycle. In pre-development, inasmuch pursued in cooperation with a specific buyer (line 10), on average more than two competing suppliers are tasked with developing the underlying technology. In the final development phase (line 11), the number of suppliers drops to 1.60 (low-tech) and 1.35 (high-tech parts). At the start of series production (line 12), the number of parallel suppliers reaches its nadir. Multiple sourcing is immediately implemented in only a tenth of all high-tech, and in less than a third of low-tech procurement relationships.[30]

Supplier compensation By the suppliers' responses (lines 13 & 14), only about 25% of their development costs are covered by a lump sum transfer –except for modules that are arguably the most model-specific product group. Only for the latter, the development costs are covered *in toto* by the suppliers' responses. By the OEMs' responses (lines 15 & 16), total compensation is substantially higher, ranging from 96% (components) to 110% (systems). The difference is likely due to differing –and difficult– attributions of model- and buyer-specific development expenses. Suppliers and buyers agree, though, on the share of compensation that is attributable to lump-sum vs. markups: Lump-sum

[30]See Appendix A, Subsection A.3 for more detail.

payments contribute 34% of total compensation according to suppliers (33% according to OEMs), mark-ups on parts produced 66% (67% according to OEMs).

4 Empirical Results

We show that an increase in mutual buyer-supplier trust increases both the quality of the typical part supplied and, perhaps more surprisingly, the intensity of competition between its suppliers as determined by the buyer. In contrast to what one might expect, the effect shows up in the exchange of only low-tech rather than of high-tech parts –and the difference arises even when involving the same buyer-supplier-pair.

Our primary identifying assumption for the causality that changes in trust affect trades is that developing a high level of mutual trust takes many successful interactions and, thus, many years. Trust is destroyed very quickly, and re-building it takes even more years. (Our data were generated within such years.) By contrast, decisions about the supply of parts are taken anew at least once a year.

There are two rather obvious alternative causalities, however. Part quality could backward influence trust; alternatively, competition between suppliers could influence quality –and with it, trust. It is hard to imagine other alternative causalities involving these variables. Thus, in subsections 4.1 and 4.2 we use the variation in the key variables' rate of change as our identifying assumption, and defend it against these alternative causalities in subsection 4.3. As both the positive relationship between trust and competition and the limits of all effects to low-tech parts defy standard reasoning involving relational contracting, we seek a novel theoretical explanation for this, in Section 5.

4.1 Trust and part quality

Part quality is the outcome of the supplier's effort –his investment. Since that is very difficult to attribute to the specific part, we follow the standard established in the literature (Taylor and Wiggins, 1997; Womack, Jones, and Roos, 1991) and use an unequivocally observable outcome –problems involving part quality– as a proxy for the input –investment. The empirical assessment of problems involving part quality typically lacks identification of origin and/or originator. Unlike most of the literature, our survey allows to address origin by looking at quality issues involving the part as the smallest item traded between the supplier and the buyer, and this over all phases, including its (pre-) development. We account for the originator of the problem by introducing buyer and supplier dummies. By introducing a supplier dummy, we also account for the fact that the same supplier may provide parts in different categories but under possibly different conditions.

Our baseline specification is

$$y_{ijs} = \beta * x_{ijs} + \gamma * Z_{ijs} + \kappa + \alpha_j + \gamma_s + \epsilon_{ijs}, \quad (1)$$

where y_{ijs} is the frequency of quality problems arising for part i supplied to buyer j by supplier s, x_{ijs} is part-specific mutual buyer-supplier trust, Z_{ijs} are controls, κ is a constant, and α_j and γ_s are buyer and supplier fixed-effects, respectively. Controls include part size and complexity, supplier revenues in 2007 proxying size and market power, and N, the number of potential competitors in Germany extracted from the WSW database. We estimate a fractional probit model, thus accounting for the non-linear nature of the dependent variable. As in all the following specifications, we estimate robust standard errors clustered at the level of buyer-supplier pairs.[31]

Table II contains the results. By columns 1 (without) and 2 (with buyer fixed effects), higher levels of trust are associated with significantly fewer quality problems. That the strength of the trust/quality (or the suppliers' investment) relationship is underestimated in the absence of buyer fixed effects indicates that a trusting buyer co-invests more in quality. Quality problems arise obviously with significantly and substantially higher frequency for larger parts (systems and modules). Neither supplier size matters, nor the number of competitors supplying the given part. The incidence of quality issues per standard deviation of the trust index (0.79) is between 2.77 and 3.95 percentage points lower, compared to the observed average incidence of quality issues of 14.1%. A one standard deviation increase in the trust index is therefore associated with a relative reduction in the incidence of quality issues of between 19.6% and 28.0%.

Columns 3 to 6 of Table II provide more detail. In column 3, we interact the trust index with the tech indicator variable. The positive relationship between trust and quality continues to matter significantly *only* for low-tech parts. Importantly, this relationship is sustained when we include the supplier fixed effect. In principle, we would like to include buyer times supplier fixed effects. The sample size does not allow this, as it would involve 141 dummies combining each buyer with each supplier. Yet, 67.2% of all trades in our sample involve supplies of both low- and high-tech parts by the given supplier to the same buyer. This indicates rather clearly that the effects vary across

[31] All results are robust to alternative specifications of clusters, in particular clustering at the level of buyer and part-type to account for differences in procurement strategies.

Table II
Trust and quality issues (proxy for investment): Fractional Probit results

Variables	**Frequency of Quality Problems** **Fractional Probit**					
	(1)	(2)	(3)	(4)	(5)	(6)
Trust index	**-.0344****	**-.0430*****				
	(.01)	(.02)				
Trust index (low-tech)			**-.0499*****	**-.0536****		
			(.02)	(.02)		
Trust index (high-tech)			-.0283	-.0179		
			(.03)	(.03)		
Trust index (low dev. costs)					**-.0124****	
					(.01)	
Trust index (high dev. costs)					-.00292	
					(.01)	
Trust index (below median patents)						**-.0159****
						(.01)
Trust index (above median patents)						**-.0184****
						(.01)
product type						
system (D)			reference category			
module (D)	-.019	-.021	.083	.106	-.021	-.028
	(.034)	(.039)	(.040)	(.048)	(.042)	(.055)
component (D)	**-.139****	**-.148*****	**-.145*****	-0.0654	**-.155*****	**-.146*****
	(2.43)	(2.64)	(2.63)	(1.08)	(2.94)	(2.85)
commodity (D)	**-.154*****	**-.157*****	-.0531	0.109	**-.170*****	**-.178*****
	(2.95)	(2.96)	(.26)	(.47)	(3.35)	(3.47)
supplier revenues (bln)	-.001	-.001	-.001	-0.01	-.002	-.001
	(.081)	(1.01)	(.88)	(.42)	(1.15)	(.97)
N	.001	.001	.001	-.001	.002	.002
	(.98)	(.99)	(.99)	(.88)	(1.46)	(1.33)
Buyer-FE	**no**	**yes**	**yes**	**yes**	**yes**	**yes**
Supplier-FE	**no**	**no**	**no**	**yes**	**no**	**no**
Number observations	126	126	126	126	126	126

Dependent variable: Frequency of quality problems arising (in percent). Avg. marginal effects and (std.err.) reported. Robust standard errors clustered at the level of buyer-seller pairs. * sign. at 10%; ** sign. at 5%; *** sign. at 1%.

parts categories, even for the same buyer-supplier pair. We conclude that differences in technological or market conditions across parts cateogies must cause this variation.

As to columns 5 and 6, recall that low- and high-tech parts differ, especially w.r.t. R&D-efforts entering their development, but less so w.r.t. patenting intensity. However, patented research (R) can be enforced in the courts, while relationship-specific development (D) efforts cannot, that embed the part into a specific car model.[32] Furthermore, patents contain public information that is transferable at low cost, while experience in development efforts is not. In column 5, we interact trust with an indicator of whether a part incorporates a share of development to total costs above or below the observed median, and likewise in column 6, with one indicating whether the number of patents is higher or lower. The trust/quality association is significant only when the development cost share is relatively low. By column 6, the difference in patent protection cannot be responsible for the difference in results by part groups, as the coefficients are almost identical. We will rationalize this perhaps puzzling finding within our theoretical model.[33]

4.2 Trust and competition

Recall that the average number of suppliers the buyer employs to develop and produce the part differs along the auto model's life-cycle. Therefore, the dependent variable in our Poisson regressions is the count variable n_{ijs}, the number of parallel suppliers involved in developing or producing part type i for buyer j from the perspective of supplier s in pre-development, in detailed development, and at the start of series production. The independent variables are as before. Sometimes, we include responses to the question on the impact of price in selecting the supplier, hypothesizing that price plays a larger role in the selection process if the buyer wants to induce intense competition among suppliers.

Table III contains the results. In pre-development (columns 1 through 3) involving little relationship-specific investment, there is no association between trust and the number of competitors the buyer chooses. This does not change when the role of price (column 3) is brought in.

By contrast, the association between trust and supplier competition is significant and large in both development and series production involving substantial relation-ship-

[32] Even if patented, the supplier's IPRs are much less well protected than one might expect, which is reflected by buyers passing on supplier IPRs in about 31% of the observed development relationships.

[33] The results reflected in columns 5 and 6 are qualitatively sustained when including the supplier fixed effect.

Table III
Trust and Competition: Poisson-regressions

Variables	Pre-Dev.♠				Dev.♣			Ser. Prod.♡	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
trust index	-.026	-.002	-.007	**.116****	**.157****	**.167****	**.133*****	**.121****	**.129*****
	(.047)	(.059)	(.064)	(.054)	(.064)	(.065)	(.038)	(.049)	(.050)
role of price			.033			**.132****			.105
			(.043)			(.060)			(0.075)
supplier revenues	.001	.003	.002	**.016*****	**.019*****	**.019*****	.001	.002	.001
	(.003)	(.004)	(.004)	(.006)	(.005)	(.005)	(.004)	(.004)	(.004)
# suppliers overall	-.003	-.003	-.003	**-.017*****	**-.018*****	**-.018*****	**-.014*****	**-.013*****	**-.014*****
	(.004)	(.392)	(.000)	(.000)	(.000)	(.000)	(.641)	(.641)	(.641)
product type									
system (D)				reference category					
module (D)	-.063	.021	.000	**.695*****	**.743****	**.683****	.122	.161	.144
	(.178)	(.187)	(.179)	(.271)	(.215)	(.195)	(.157)	(.148)	(.149)
component (D)	.009	.014	.005	.327	**.347***	**.328***	.167	.181	.193
	(.152)	(.165)	(.159)	(.224)	(.196)	(.180)	(.157)	(.144)	(.150)
commodity (D)	.128	.125	.126	**.660*****	**.668*****	**.630*****	**.532*****	**.556*****	**-.538*****
	(.145)	(.150)	(.143)	(.201)	(.179)	(.168)	(.173)	(.147)	(.144)
const	.874	.521	.319	-.532	-.912	-1.623	-.514	-.673	-1.274
	(.274)	(.328)	(.417)	(.273)	(.302)	(.497)	(.258)	(.289)	(.616)
Buyer-FE (11)	**no**	**yes**	**yes**	**no**	**yes**	**yes**	**no**	**yes**	**yes**
# observations	77	77	75	126	126	126	126	126	126

Column group header: **Number of suppliers at different phases**

Dependent variables: ♠ number of suppliers employed during pre-development ♣ number of suppliers during final phase of development ♡ number of suppliers at start of series production – coefficients and (std.err.) reported; robust standard errors clustered at the level of buyer-seller pairs; * sign. at 10%; ** sign. at 5%; *** sign. at 1%.

specific investment. In the development phase (columns 4 through 6), an increase in trust by one standard deviation (0.79) is related to about 0.13 or 8.4% more suppliers compared to the average of 1.55 suppliers involved in this phase. Furthermore, the importance of price is significantly and positively associated with the number of suppliers (column 6). Finally, in the series production phase (columns 7 through 9), an increase of the trust index by one standard deviation is associated with 0.11 or 14% more suppliers when compared to the average of 1.27 suppliers engaged in production. Yet, the correlation between the importance of price and the number of suppliers is insignificant.

Note also that larger suppliers (measured by revenues) tend to face significantly more competition: buyers may attempt to countermand larger suppliers' better relative bargaining position. By contrast, a larger N indicating more external market competition for a given part is associated with significantly fewer suppliers selected in both the development and production phases. This could indicate that competition for a given part-procurement among the chosen suppliers and in the wider market are substitutes.

As in the trust/quality regressions, we interact the trust index with a high tech-dummy in the regressions of each development phase in Table IV. As before, the association between trust and competition remains significant only for low-tech parts (commodities and modules), and only in development and series production phases. Joint F-tests reveal that for high-tech parts, the effect is insignificant.[34]

4.3 Trust, quality and competition: alternative causalities

Recall the two alternative causalities between our key variables introduced above: First, under-investment quality problems could burden trust, especially on the buyer-side. Second, tougher competition between suppliers could allow the buyer to select higher quality suppliers and/or force the chosen suppliers to exert more effort.

To address the first, direct reverse causality, we require an instrument that contributes to building or diminishing long-term trust, but does not directly affect the quality of the currently provided part. The frequency of pass-on of the supplier's IPR in pre-development without his consent is such an instrument, as pass-on arose years before the start of production, while the reported quality issues arise years after that start and are reported by separate agents. Furthermore, quality issues correlate hardly (.196) with past IPR pass-on.

In Table V, we use pass-on as a reduced-form instrument in columns 1 and 2, and

[34] Table B.3 in Appendix B gives the results when employing the trust index normalized by the importance of price.

Table IV
Trust and competition for low- vs. high-tech parts: Poisson-regressions

	Number of Suppliers		
	Pre-Dev.	**Dev.**	**Ser. Prod.**
Variables	(1)	(2)	(3)
trust index (low-tech)	.033	**.185*** **	**.174*** **
	(.674)	(.007)	(.001)
trust index (high-tech)	-.053	.100	-.004
	(.597)	(.363)	(.946)
supplier revenues (bln)	.003	**.019*** **	.001
	(.470)	(.000)	(.852)
# suppliers overall	-.003	**-.018*** **	**-.013*** **
	(.442)	(.000)	(0.000)
product type			
system (D)		omitted	
module (D)	-.405	.293	**-.746** **
	(.570)	(.543)	(.042)
component (D)	.021	**.331* **	.141
	(.895)	(.097)	(.277)
commodity (D)	-.300	.232	.141
	(.674)	(.646)	(.130)
const	.768	-.618	-.358
	(.142)	(.179)	(.311)
Buyer-FE (11)	**yes**	**yes**	**yes**
# observations	78	127	126
Pseudo-R^2	.013	.083	.047

Dependent variables: number of parallel suppliers at the different development phases; coefficients and (p-values) reported; robust standard errors clustered at level of buyer-seller pairs; * sign. at 10%; ** sign. at 5%; *** sign. at 1%.

instrument the trust index in columns 3 and 4. Its use as a reduced-form instrument shows that more frequent pass-on of IPR in the past is associated with a significantly higher incidence of quality issues occurring today. Employing it as an instrumental variable is feasible (first-stage F-statistics are above 10 for each specification) despite the limited number of observations; the association between instrumented trust and quality becomes slightly stronger and remains significant. Therefore, the empirical evidence is in favor of our suggested causality.[35]

To address the second, indirect alternative causality by which tougher competition would push up quality, we regress the incidence of quality problems on the number of

[35] Appendix B contains further robustness checks. The result also holds when alternative trust indices are used: the one normalized by the impact of prices on the buyer's procurement decision (Table B.1); and one that captures the directional trust of the supplier in the buyer that neutralizes the possible reverse causality channel (Table B.2).

Table V
Trust and quality issues (proxy for investment): Reduced form instrument and IV results

Variables	Frequency of Quality Problems Fractional Probit		IV	
	(1)	(2)	(3)	(4)
Freq. IPR pass on	**0.022***	**0.023***		
	(0.012)	(0.012)		
Trust index (instrumented)			**-0.048****	**-0.051***
			(0.023)	(0.030)
product type				
system (D)		reference category		
module (D)	-0.020	-0.023	0.002	-0.011
	(0.075)	(0.077)	(0.082)	(0.073)
component (D)	**-0.151****	**-0.160****	**-0.133***	**-0.154*****
	(0.066)	(0.066)	(0.068)	(0.059)
commodity (D)	**-0.179*****	**-0.185*****	**-0.159****	**-0.170*****
	(0.062)	(0.064)	(0.072)	(0.063)
supplier_revenues (bln)	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
N	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Constant			0.454***	0.544***
			(0.137)	(0.167)
First stage F stat			31.3	10.6
Buyer-FE (11)	**no**	**yes**	**no**	**yes**
# observations	122	122	109	109
R-squared			0.225	0.257

Fractional Probit and IV regressions; dependent variable: frequency of quality problems arising (in percent). IV-approach: trust instrumented by frequency of supplier IPR passed on by the OEM in the past, reported by supplier. Fractional Probit: Marginal effects and (std.err.) reported. IV: Coefficients and (std.err.) reported. Robust standard errors clustered at level of buyer-seller pairs. * sign. at 10%; ** sign. at 5%; *** sign. at 1%.

suppliers in the different phases, including the familiar set of controls and fixed effects. Table VI, columns 1, 3 and 5 contain the results. In columns 2, 4 and 6 we add trust as additional control, which should be of no influence if the alternative causality holds.

For the two phases involving relationship-specific investment, there is no significant effect in columns 3 and 5, and for pre-development, we even get a sign opposite to the one claimed within the alternative causality. By contrast, the trust measure, when included, becomes highly significant, while the relationship between competition and quality problems remains unchanged. This clearly indicates that the driver of the observed pattern is trust. That we do not observe a significant positive correlation between competition and quality issues can be explained by our theory below, by which buyers use additional slack from higher trust to alternatively induce additional competition or enforce higher investment by suppliers.

Table VI
Quality, competition and trust: Fractional Probit-regressions

	Frequency of Quality Problems					
	Pre-Dev.		**Dev.**		**Ser. Prod.**	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
# suppliers	**.039****	**.045*****	-.004	.004	-.010	-.001
	(.018)	(.014)	(.015)	(.015)	(.023)	(.025)
trust index		**-.052****		**-.044*****		**-.041****
		(.022)		(.015)		(.018)
supplier revenues	**.002****	**.002***	-.001	-.001	**-.002***	**-.003***
	(.001)	(.001)	(.002)	(.001)	(.001)	(.001)
# suppliers overall	**.005*****	**.005*****	.001	.001	.001	.001
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
product type						
system (D)			reference category			
module (D)	.067	.018	-.020	-.038	**-0.133***	-0.140
	(.104)	(.090)	(.071)	(.082)	(.079)	(.092)
component (D)	**-.208*****	**-.209*****	**-.163****	**-.179****	**-.234*****	**-.243*****
	(.062)	(.055)	(.064)	(.074)	(.072)	(.081)
commodity (D)	**-.157*****	**-.149*****	**-.176*****	**-.188*****	**-.243*****	**-.247*****
	(.058)	(.056)	(.061)	(.073)	(.079)	(.090)
Buyer-FE (11)	**yes**	**yes**	**yes**	**yes**	**yes**	**yes**
# observations	73	73	126	126	126	126

Dependent variable: Frequency of quality issues arising for the part in question (percent); coefficients and (std.err.) reported; standard errors (reported) clustered at the level of buyer-seller pairs; *sign. at 10%; ** sign. at 5%; *** sign. at 1%

5 A Model of Buyer-Supplier Relations

We use a repeated game framework to model critical aspects of relational contracts within the German automotive industry and beyond, focusing on the long-term supply of parts involving substantial buyer-specific development, which is challenging for uninvolved suppliers to adapt to. We analyze how the relational contract variables are set by either the buyer or the leading supplier. We determine the best equilibrium for the buyer or supplier, further exploring how bargaining power is assigned based on the switching costs to alternative suppliers.

5.1 The model

A buyer procures an innovative intermediate product in each period t of an infinite sequence of periods. This entails first the development of a buyer-specific blueprint for such a product, which requires substantive specific investment $I > 0$ by the typical supplier and, subsequently, the manufacturing of that product. In line with our empirical analysis, the investment I is neither observable nor contractible. The investment cost is sunk and normalized to I for I investment units.

There are $N > 1$ firms capable of developing and supplying the intermediate product.[36] To simplify our analysis, we assume that at the outset, the N firms are identical from the buyer's viewpoint. If amongst those, $n > 1$ suppliers decide to develop a blueprint for the buyer, they invest independently and competitively. As the development investment is buyer-specific, it has no value for buyers other than those for whom the intermediate product is developed.

Following the development phase, a single supplier is chosen within a process described below, that produces the part for the buyer.[37] The value to the buyer of the final product with embedded investment I is $v(I)$, where $v(\cdot)$ is increasing, strictly concave and satisfying Inada conditions.[38] The value of procurement to the buyer if she stays in the relationship but $I = 0$ is denoted by v_0, and the buyer's outside option by v_S. The suppliers' outside option is normalized to zero. Investment fully depreciates.

Supplier i's cost of production in period t is θ_{it}, assumed to be i.i.d. across suppliers and periods, and drawn by nature from a time-invariant commonly known distribution $F(\theta_{it})$ with support $[\theta_{\min}, \theta_{\max}]$. The realization of each supplier's production cost is unknown to the buyer, although, for simplicity, it is known to the other n suppliers.

Within the current period t, supplier i can produce the intermediate product using the blueprint developed by another supplier j. Yet, for suppliers that did not participate in the development phase, the buyer must pay a switching cost k, which is private information to her.[39]

This procurement process is repeated over an infinite number of periods, with the following stage-game:

$-t_1$ *(Contracting)*: When the buyer has the bargaining power, she chooses n suppliers for blueprint development, sets a minimum investment level $\underline{I}$, and commits to a transfer w to each developer, paid at t_2. Conversely, when the leading supplier has the bargaining

[36]In our data, we have verified that $N > 1$, so there is potential competition among suppliers for each part considered.

[37]See the Theoretical Appendix for the case of multiple sourcing.

[38]We take $v(I)$ to be closely related to the quality outcome of the investment and, as such, related to the inverse of the frequency of part-related quality problems in our empirical analysis. This aligns with the relational contracting framework: a party's action is not observable by the counterpart, yet some of its outcomes are.

[39]This is a cost of training a non-developing supplier and naturally reflects the idea that the production of parts not developed in-house requires the costly adaptation of skills and tools. Indeed, it corresponds to Lopez' strategy of sending teams of engineers for weeks on-site to non-developing outsiders to train them to reliably produce the part based on a competing supplier's blueprint.

power, he pledges to invest at least $\underline{I}$ and specifies the transfer payment w he expects from the buyer for his investment.

$-t_2$ *(Development)*: Each supplier i participating in the development stage incurs investment I_i. Investment remains unobserved by the buyer until the end of t_4. The buyer pays the transfer w to each developing supplier.

$-t_3$ *(Selection for production)*: When $\tilde{n} > 1$ suppliers compete for the production contract, they observe the realized production costs θ_i and participate in a second-price auction to select a unique producer. The price p paid upon delivery of the intermediate product is determined by the mechanism preferred by the party with bargaining power. The buyer faces the cost $k \geq 0$ if she allows a non-developing supplier to compete with the blueprint from another supplier.

$-t_4$ *(Production)*: The producing supplier h produces at cost θ_h and receives p from the buyer. The buyer observes the investment of the n developing suppliers.[40]

Consistent with our survey findings and relational contracting literature, the transfer w is contractible and enforceable by courts, whereas the investment level I_i and the number $\tilde{n}$ of suppliers effectively competing—potentially different from n—are not contractible. The infinite repetition of the stage game allows the buyer and the suppliers to rely on relational contracting, threatening to enact mutual punishments at the end of t_4 after deviations. In particular, the buyer excludes from future procurement any supplier who, as observed in the last stage of the game, has not complied with the performance requirements $I \geq \underline{I}$. Similarly, the suppliers collectively refuse to fulfill their requirements in future stage games if, in the previous stage game, they faced the buyer's decision to procure from (any of) the $N - n$ non-investing suppliers.[41]

Empirically, there is significant duplication of investment in the development phase. The expected adjustment costs $E(k)$ appear to be large enough to have the buyer avoid unbundling blueprint development and production altogether, i.e., not having just one firm invest for a blueprint and all firms compete for production on its basis.[42] In line with

[40] We could consider an alternative scenario where investments in blueprints not utilized in production may remain non-observable. This requires considering an additional incentive compatibility constraint necessary to deter firm i from adopting a strategy where $I_i = 0$, aiming not to win the auction but to systematically profit from w (if positive). The inclusion of this constraint would not alter our findings.

[41] The steering committee overseeing the survey for our empirical analysis chose not to query investment details. This decision was informed by experts' difficulty distinguishing between general and specific investment aspects in part development. Additionally, including non-developing suppliers in production would hinge on the adaptation cost k. However, given that k is private information to the buyer and only ascertainable post-blueprint selection, the buyer could under-report k to artificially increase the auction competition by including non-developing suppliers.

[42] See the Theoretical Appendix for the optimality of bundling when $E(k)$ is large enough. Even

our empirical observations, we do not consider the buyer to make contingent payments such as discretionary bonuses.

The discount factor is unity across all phases of the same stage game and $\delta \leq 1$ across stage games. In line with the literature on trust and relational contracts discussed in Section 1 , we interpret δ, common to both the buyer and the suppliers, as an indicator of the mutual trust of the participants in the game associated with future co-operation. The common δ directly reflects the relevant question in the questionnaire survey: mutual trust is the commonly understood level of trust between the buyer and the suppliers of a given part.

In what follows, we focus on symmetric stationary strategies of the infinitely repeated game.[43] The game, as described, has a continuum of equilibria. In Subsection 5.2, we focus on the equilibrium most profitable for the buyer, and in Subsection 5.3 on the one most profitable for the typical supplier that participates in the development stage and obtains the production contract. In Subsection 5.4, we identify which of these two cases we expect to observe for a given level of trust in the buyer-supplier relationship, conditional on the supply of low-tech vs. high-tech parts.

5.2 Leading buyer

Here we consider relational contracts in which the buyer regularly invites the same n suppliers to develop the required blueprint by making an investment $I \geq \underline{I}$. The buyer refrains from inviting additional suppliers beyond this set of n to compete for the production contract.

In the development phase, each of these suppliers decides how much to invest, anticipating the expected rent $\beta(n)\pi(n)$ associated with the production contract in this stage game, where $\beta(n)$ denotes the probability that a supplier will obtain the production contract among the n suppliers, and $\pi(n)$ the expected rent to that supplier accruing from production. Since by assumption, the suppliers are *ex-ante* identical, $\beta(n) = 1/n$.

If $n > 1$, the expected rent obtained by the winning supplier is $\pi(n) = \theta^e_{(2)}(n) - \theta^e_{(1)}(n)$, where $\theta^e_{(1)}(n)$ is the expected cost of the efficient supplier and $\theta^e_{(2)}(n)$ that of the second-most efficient one. In the second price auction, the suppliers reveal their costs in

Lopez did not factually procure production from non-developing suppliers, but incurred k to train them and used their price quotation to depress the winning developer's price.

[43]Stationarity is without loss of generality with a single agent-supplier (Levin, 2003). Board (2011) has shown that a principal-buyer may want to follow a non-stationary initial phase, leading to a stable group of preferred agents-suppliers. The equilibria we consider here can be seen as the long-run steady state of this transition.

their bids. The winning supplier then sells his product at price $p = \theta_{(2)}(n)$. If instead $n = 1$, then $\beta(1) = 1$, the single supplier's expected rent is $\pi(1) = p - \theta^e(1)$ where $\theta^e(1) = E(\theta)$, and p is the price the buyer and the supplier agree to at t_3.

Suppliers optimally satisfy the buyer's requirement by investing just $I = \underline{I}$. A supplier's expected payoff over the infinite horizon game is then,

$$[w - \underline{I} + \beta(n)\pi(n)]\frac{1}{1-\delta}.$$

If, instead, the supplier decides to deviate and invest less than required, then he knows that the buyer will observe the deviation at the end of the stage game and will exclude him from all future procurement. Accordingly, when deviating, it is optimal for him to set $I = 0$, and his expected profit is $w + \beta(n)\pi(n)$. The supplier prefers not to deviate and invest $\underline{I}$ if the incentive compatibility constraint,

$$w + \beta(n)\pi(n) \geq \frac{\underline{I}}{\delta} \tag{IC_s}$$

is satisfied. He chooses $\underline{I}$ as required if the sum of the transfer w and the expected rent from winning production $\beta(n)\pi(n)$ is not smaller than the contemporary cost of the required investment $\underline{I}/\delta$. This cost is high if δ is small. In such a case, the typical supplier would face a stronger temptation to cheat in the investment phase.

Consider now the buyer. Let

$$p^e(n) = \begin{cases} \theta^e(1) & \text{if } n = 1 \\ \theta^e_{(2)}(n) & \text{if } n > 1 \end{cases}$$

be the price the buyer expects to pay. When the n suppliers choose the required investment $\underline{I}$, the buyer's infinite horizon payoff at t_3 is,

$$v(\underline{I}) - p^e(n) + [v(\underline{I}) - nw - p^e(n)]\frac{\delta}{1-\delta}.$$

At time t_3, the buyer has the option to deviate by inviting more suppliers than initially planned, $\tilde{n} > n$, to the competition, thereby reducing the expected price paid to $p^e(\tilde{n})$. Anticipating the potential punitive measures from suppliers in response to deviations, the optimal strategy for the buyer involves inviting all available suppliers, denoted by $\tilde{n} = N$, to maximize competition. When suppliers refrain from investment, the buyer optimally adjusts the transfers to $w' = \beta(N)\pi(N)$ that captures all informational rents from the sellers (with $I = 0$, there is no point in leaving rents to the sellers). The buyer's expected discounted payoff from deviating would then be

$$\{v(\underline{I}) - p^e(N) - k[1 - n\beta(N)]\} + [v_0 - Nw' - p^e(N)]\,\frac{\delta}{1-\delta}, \tag{2}$$

where the terms in the first bracket reflect her return in the current period, accounting for the cost k associated with supply procurement from a non-developer; and those in the second bracket her returns in the future stage games where she would have to rely on zero investment, maximal competition and transfer w'.[44]

The buyer prefers not to deviate by inviting to the auction more than the n participants in the development stage if the incentive compatibility constraint,

$$\delta\,[v(\underline{I}) - nw - (v_0 - w'N)] + (1-\delta)k\frac{N-n}{N} \geq p^e(n) - p^e(N) \tag{IC_b}$$

is satisfied. Here, the right-hand side represents the expected savings in the buyer's payment for the production of the intermediate good when all N firms, rather than just n, compete. The left-hand side quantifies the future loss in procurement value, adjusted by the net difference between the equilibrium transfers nw and the deviation transfers $w'N$, and the cost of adaptation.

The optimal procurement program $\mathcal{P}_B$ of the buyer requires to identify $\underline{I}, w, n$ that maximize the (per-period) payoff $v(\underline{I}) - wn - p^e(n)$ subject to the two constraints (IC_s) and (IC_b).

Considering the optimal w, which makes constraint (IC_s) binding, increasing the number n of competing suppliers has two effects. First, it reduces the expected price $p^e(n)$ the buyer has to pay and limits the buyer's temptation to deviate by reducing the r.h.s. in (IC_b). Second, it negatively impacts the typical supplier's motivation to invest, as the expected rent $\beta(n)\pi(n)$ available to the supplier diminishes with n, thus reducing the l.h.s. in (IC_s).

In line with our empirical analysis, we aim to examine here the impact of a change in δ on two critical procurement variables: competition level n and investment $\underline{I}$. Initially, an increased discount factor δ offers the buyer flexibility in managing suppliers' incentives, effectively improving procurement terms by fostering greater competition (resulting in lower production costs) and/or encouraging higher investment (leading to enhanced product value). However, the comprehensive effects of different values of δ on

[44] The expected cost of adaptation, $k[1 - n\beta(N)]$ in (2), reflects the idea that all N firms are treated equally in the auctions. Although the expression of this cost would be different if the buyer treated those in n and the others differently, the idea and the consequences of the adaptation costs would remain the same.

procurement terms, as determined by solving $\mathcal{P}_B$, are complex. For instance, imagine a rise in δ elevates investment levels. The influence of δ on n encompasses both a direct effect on n for a given $\underline{I}$ and an indirect effect via increased investment. If the indirect effect is significant, a higher δ might necessitate a decrease in the number of competing firms to afford larger informational rents, incentivizing suppliers to invest further. This intricate relationship necessitates solving the buyer's procurement program $\mathcal{P}_B$ to fully understand these dynamics, as we do in the Theoretical Appendix. The relevant results are as follows.

Proposition 1 *In the equilibrium optimal for the buyer, an increase of the discount factor δ necessarily induces an increase of at least one of the two optimal procurement variables n_B^* and $\underline{I}_B^*$. Both n_B^* and $\underline{I}_B^*$ increase in δ if $v(\cdot)$ is sufficiently concave, that is if the indirect effect is not too strong.*

Since trust is commonly associated with intimate relationships and is often undermined by competition, these comparative static results may appear counterintuitive. Yet, they emerge naturally when the buyer has bargaining power, and align with our empirical findings on low-tech parts. In these cases, both the investment and competition solicited by the buyer increase in tandem with trust.

In the Theoretical Appendix, we also show that the results of Proposition 1 carry over to the case of multiple sourcing (Proposition 4) and that, consistent with our findings (see Subsection 4.2), a larger δ induces the buyer to move from single-sourcing to multiple sourcing.

5.3 Leading supplier

We now identify the leading supplier's most profitable equilibrium procurement relational contract. More specifically, we characterize the equilibrium where $n = 1$, while the buyer can still deviate and open the competition for the production contract to the N suppliers. To motivate the assumption that $n = 1$, we have to realistically change our assumption that all N suppliers are *ex-ante* symmetric. Especially when it comes to high-tech parts such as components and systems, the buyer typically has one favorite supplier that is usually selected for the development of the part.[45] We then discuss the case $n > 1$.

[45] A typical example for systems was the selection of Bosch by Daimler, or that of Conti-Teves by BMW, to develop ESP, the electronic stabilization program for their top models.

The optimal procurement contract is now such that $n_S^* = 1$, and the procurement program $\mathcal{P}_S$ involves the maximization of the supplier's (per-period) payoff $w + p^e(1) - \theta^e(1) - I$ with respect to I and w and subject to the constraints (IC_s) and (IC_b) evaluated with $n = 1$. Optimal procurement is specified in:

Proposition 2 *In the equilibrium optimal for the leading supplier, $n_S^* = 1$, the optimal investment I_S^* is at the efficient level I^*, independent of the discount factor δ, as long as k is large enough.*

This proposition is consistent with our empirical finding that investment and competition do not increase with trust when high-tech parts are traded. Although we have considered the case with a single supplier, $n = 1$, and that supplier's optimal relational contract, the idea is the same when $n > 1$ suppliers collectively have bargaining power. As above, they would set w so that the buyer's incentive constraint (IC_b) is binding, and from this, a result similar to Proposition 2 applies (see the first part of the Online Appendix).

5.4 Switching-costs and bargaining power

Relating our findings to the procurement of parts by German car manufacturers, the analysis in the preceding subsections leads to a crucial conclusion. When there is a positive correlation between the level of trust among suppliers and the buyer with both the investment in the development stage and the number of suppliers involved, as observed with low-tech products, the buyer should hold the bargaining power. Conversely, when the trust level does not correlate with either investment during the development stage or the number of participating suppliers, as seen with high-tech products, the bargaining power is likely to reside with the suppliers.

Why is there a difference in the allocation of bargaining power for high-tech versus low-tech products? We propose a theoretical rationale: the cost k of switching suppliers for production influences which party holds the bargaining power and, consequently, who dictates the terms of the relational contract. Suppose that before establishing the relational contract for a part, the buyer and suppliers partake in a bidding game where the party with the highest potential payoff from assuming the role of the principal gains the bargaining power. Formally, let $V_B(k)$ and $V_S(k)$ represent the buyer's and suppliers' payoffs, respectively, from solving problems $\mathcal{P}_B$ and $\mathcal{P}_S$ when they hold the bargaining power. Instead of explicitly modeling this bidding game, we assess the parties' optimal payoffs across different part types. We adopt a realistic assumption that the cost k, which represents the buyer's expense of switching production to a non-developing supplier, is low for low-tech parts and high for high-tech parts.

Proposition 3 *The buyer's payoff of problem $\mathcal{P}_B$, $V_B(k)$, is weakly decreasing in k; the suppliers' payoffs of problem $\mathcal{P}_S$, $V_S(k)$, is strictly increasing in k. For v_0 sufficiently high, there exists a threshold value $\bar{k} > 0$ such that $V_B(k) \geq (\leq) V_S(k)$ if $k \leq (\geq) \bar{k}$.*

By the proposition, an increase in the switching cost k elevates the supplier's payoff while diminishing that of the buyer. This is because an increase in k diminishes the buyer's potential gains from actions such as increasing the number of suppliers, thereby reducing the need for the supplier to compensate the buyer to prevent that. In the last part of the proposition, we prove that the payoff functions $V_B(k)$ and $V_S(k)$ cross when procurement offers significant value, implying that for low values of k, the buyer's payoff surpasses that of the supplier, and vice versa.

6 Concluding Remarks

We analyse survey data, providing unique evidence on the role of relational contracting in the German automotive industry, in which intermediate products are traded that involve highly different degrees of complexity. We show first that, not unexpectedly, higher levels of trust result in an increased quality of parts. Opposite to what one might expect from established theory, however, this benefit arises only for relatively less complex parts. Furthermore, we show that higher levels of trust induce buyers to promote competition between suppliers –and this again only for relatively low complexity parts. None of these are instead observed for highly complex parts. This drastic distinction extends even to trades between the same buyer-supplier pair.

Our results are not driven by variations in trust *across* part categories, as trust retains its importance across those. All this strongly suggests that part-specific market conditions on the supply side exercise a strong impact.

We develop a model incorporating elements of formal and relational contracts that helps to explain these puzzling empirical results. If the costs of switching suppliers are low, as for parts involving low complexity, buyers retain bargaining power and can use enhanced trust to foster both relationship-specific investment and competition among suppliers during development and production. If these switching costs are high, as for highly complex parts, the leading supplier gains bargaining leverage, limiting the buyer's ability to capitalize on trust to boost investment or competition.

These insights may extend beyond the specific industry and country analyzed. In particular, as manufacturers increasingly collaborate with innovative IT firms to develop and produce complex digital solutions as inputs into final products, the insights from our study may offer guidance for understanding these highly complex collaborative ventures.

Appendix A: Data and Descriptives

A.1 Aggregation

Recall that an observation is defined as a given supplier's report reflecting a given buyer's procurement practice for an individual part supplied to that buyer. The following aggregations created the focus on the tuple buyer-part-supplier:

- Responses by supplier's specialists on the same question. The questionnaire was addressed to respondents from seven departments: *pre-development*, *development*, *series production*, *quality control*, *sales*, *logistics*, and *aftermarket production*. Respondents had to indicate their association with one of those. For each part and buyer, they would then answer a subset of questions suited to their function.[46] When they responded to identical questions –as they did on the critical trust relationship– we used the arithmetic mean of those.

- Responses w.r.t. individual parts. The first respondent of a supplier had first to specify both a part currently supplied to the respective buyer, and the product category (industry standard) to which that part belongs:

  (Low-tech) Commodities: technologically relatively unsophisticated parts requiring little model-specific investment, e.g., o-rings;

  (High-tech) Components: technologically sophisticated parts, often combining mechanical and electronic functionalities, e.g., distance sensors;

  (Low-tech) Modules: technologically relatively unsophisticated part groups designed and assembled by suppliers, e.g., front-ends (body);

  (High-tech) Systems: technologically sophisticated part groups designed and assembled by suppliers, e.g., brake systems or electronic stabilization programs.

  Table A.1 lists typical parts by type and number of suppliers from the WSW database.

A.2 Measure of trust

The focal question on trust was asked specialists of each phase of the part's life-cycle within a number of factors, with importance to be evaluated on a six-point scale from 1

[46] See Müller, Stahl, and Wachtler (2016) for a detailed description of the individual functions and the automobile development and production process.

Table A.1
Part categories, part descriptions, number of suppliers.

	Number of suppliers			
Part description	Pre-Dev.	Dev.	Ser. Prod.	German market overall
Systems (high tech)				
Brake system	1.8	1.4	1.0	11
Drive assist system	3	1.5	1.0	9
Engine cooling system	2.7	1.1	1.2	9
HVAC system	1.5	1.0	-	8
Injection system	2.0	1.25	1.0	7
Steering system	-	-	1.4	11
Transmission system	3.5	1.0	1.0	5
Modules (low tech)				
Axle module	1.0	1.3	1.5	9
Body module	-	5.0	1.0	9
Brake module	2.0	1.0	-	8
Chassis module	2.0	1.3	1.2	6
Cockpit	-	1.0	-	5
Dashboard	-	-	1.0	9
Filter module	-	1.3	-	15
Gearshift module	2.0	1.8	1.0	26
HVAC module	2.0	1.4	1.0	10
Piston module	-	1.5	1.1	3
Roof module	2.0	1.0	1.0	34
Wiper module	2.0	1.0	1.0	20
Components (high tech)				
Brake component	2.3	1.0	1.0	10
Clutch component	2.1	1.2	1.0	11
Drive assist component	2.3	1.1	1.0	19
Gearshift component	2.0	1.0	1.0	32
HVAC component	-	1.3	1.2	13
Injection component	2.5	1.5	1.0	8
Injection component	2.5	1.5	1.0	8
Piston component	2.5	2.4	1.3	5
Transmission component	2.3	1.2	1.1	25
Commodities (low tech)				
Axle commodity	-	1.0	1.3	16
Bearings	1.6	1.9	1.3	27
Body commodity	2.2	1.0	1.0	25
Brake commodity	3.0	1.7	2.2	22
Clutch commodity	2.0	1.5	1.0	12
Engine cooling commodity	-	1.0	1.0	18
Gasket commodity	1.5	1.7	1.3	14
Starter	3.0	3.0	1.0	8
Steering commodity	2.5	1.3	1.0	8
Transmission commodity	2.0	1.1	1.0	50
V-belt	1.5	2.0	1.2	17

Descriptions of the parts assessed in the benchmarking study sorted by corresponding type; for each part: (average, if applicable) number of suppliers in pre-development, development and series production; last column: overall number of suppliers providing this kind of part in the German market at the time of the survey, according to industry procurement database "Who supplies whom".

(no relevance) to 6 (very important). The mean of the responses represents the aggregate of the views of multiple representatives of a particular supplier w.r.t. a buyer-part pair. By taking the mean of the responses, we exclude idiosyncratic influences.

To defend our measure against the possible interpretation of responses as to the importance of trust in principle, while possibly lacking in practice, we relate the responses to other trust questions that link trust directly to behavior on specific topics: *What is the importance of trust for your firm's decision to initialize a pre-development with the OEM?* and *How do you evaluate mutual trust between OEM and supplier with respect to honoring each other's intellectual property rights?* While the first measure is unilateral, both measures are highly correlated with the chosen trust index (0.43, p-value 0.000; 0.47, p-value 0.000).

Furthermore, we use responses related to buyer behavior in the distant past that should be detrimental (first five items) or beneficial (last item) to the supplier's trust. For pre-development and development, respectively, suppliers were asked to assess, for the past five years, the frequency of conflicts with the buyer with regard to the supplier's IPR, as well as how often supplier IPR were leaked by the buyer to competing suppliers.[47] For series production, the buyer's most confrontational behavior is on past price renegotiations (”pay to play”). On the positive side, the buyer's financial assistance in development cost overruns in the past should contribute to building trust. All answers are such that we can convert them to frequencies.

Table A.2 shows that passing on IPR without the supplier's consent occurs frequently in both pre-development and development, in between 27% and 44% of all part-specific relationships. That this results in less frequent IPR conflict, especially in pre-development, may be due to differences in the ability to document IPR: Much of undocumented –and yet unpatented– IPR is contained in pre-development, whence in development, documentation is improved by resorting to the blueprint. That the buyer reneges on past contracts also arises frequently, in between 21% and 31% of all relationships. All five variables are associated with opportunistic, Lopez-type behavior that should be detrimental to trust. By contrast, the trust measure should be positively affected by the buyer's financial assistance in development cost overruns, reported to arise much less frequently, and thus to vary between relatively low frequencies.

We add a seventh prediction. Next to the role of mutual trust, respondents also evaluated the role that price played in the supplier selection process, which may indicate the buyer's opportunistic, if not confrontational, incentive to cut costs and supplier

[47] Note that in the desire to maintain the relationship, suppliers tend to enforce the IPR in court only in exceptional cases.

Table A.2

Variables reflecting impacts of trust

Variable	**Systems**		**Modules**		**Components**		**Commodities**		**High-Tech**		**Low-Tech**		
	Mean	std. err.	**Mean**	std.err.	**Mean**	std.err.	**Mean**	std.err.	**Mean**	std.err.	**Mean**	std.err.	Obs.
Pre-Development:													
(1) Frequency IPR pass-on	**37.5%**	.233	**37.4%**	.247	**33.6%**	.228	**27.20%**	.249	**35.10%**	.229	**30.5%**	.252	245
(2) Frequency IPR conflicts	**6.8%**	.114	**22.7%**	.236	**8.6%**	.130	**10.7%**	.150	**7.9%**	.124	**12.8%**	.172	123
Development:													
(3) Frequency IPR pass-on	**38.2%**	0.305	**37.5%**	.285	**43.6%**	.313	**35.8%**	.336	**41.9%**	.309	**36.3%**	.322	162
(4) Frequency IPR conflicts	**36.4%**	.206	**37.9%**	.194	**31.2%**	.195	**26.2%**	.211	**32.7%**	.198	**29.5%**	.212	182
Production:													
(5) Frequency price renegotiations	**31.1%**	.279	**28.1%**	.276	**20.6%**	.255	**22.6%**	.28	**24.5%**	.267	**24.5%**	.279	193
(6) Assistance in Cost Overruns	**1.83**	.57	**2.16**	.9	**2.01**	.73	**1.70**	.75	**1.94**	.67	**1.86**	.83	222

Questions employed for measures: freq. IPR conflicts: "How frequently do conflicts arise with respect to IPR?"; freq. IPR pass-on: "How frequently does the OEM leak information to competing suppliers?"; freq. price renegotiations:"How often are prices renegotiated with the following justification: Procurement of an additional product by the OEM?" : risk sharing: "Who absorbs risks for higher development costs?" (1 - always supplier to 5 - always OEM).

prices. We use this response in two different ways: First, the relationship between the role of trust and the role of price should be negative. Second, we use it to construct a "normalized" trust index as an alternative trust measure by subtracting the response on the role of price from that on the role of trust, thus capturing the role of trust relative to price in supplier selection. Table A.3 offers the relevant pairwise correlations.

Table A.3
Correlation Frequency of quality issues and trust determinants (p-values in parentheses).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Freq. of quality issues	1.00						
(p-level)							
(2) IPR conflicts PD	.478	1.00					
(p-level)	(.000)						
(3) IPR pass-on PD	.196	.178	1.00				
(p-level)	(.023)	(.053)					
(4) Risk sharing	.129	.083	.048	1.00			
(p-level)	(.143)	(.448)	(.490)				
(5) IPR conflicts DEV	.320	.495	.445	.216	1.00		
(p-level)	(.000)	(.000)	(.000)	(.013)			
(6) IPR pass-on DEV	.205	.269	.526	.073	.507	1.00	
(p-level)	(.034)	(.007)	(.000)	(.437)	(.000)		
(7) Lump-sum rebates	-.034	-.033	.144	.002	.142	.268	1.00
(p-level)	(.714)	(.774)	(.056)	(.974)	(.120)	(.005)	

PD = Pre-development; DEV = Development

Controlling for product category, suppliers' revenues as a proxy for size and bargaining power, and total number of suppliers offering this type of product in the German market at the time of the inquiry extracted from the WSW-database as potentially confounding factors, Table A.4 exhibits a clear and unambiguous pattern. Reported Lopez-type opportunistic behavior in the past is associated with significant and substantial reductions of the trust index reported today, with IPR conflicts in pre-development (column (1)) exhibiting the strongest effect. Vice versa, financial assistance by the OEM (column (3)) has a significant positive association with the trust index. Further, the significant negative sign in column (7) of Table A.4 indicates that there is in fact a tension between the roles of trust and price in supplier selection. All associations are sustained when employing the trust index normalized by the importance of price. Summarizing, this creates confidence in our interpretation of the trust measure.

Table A.4
Determinants of the Trust Index: OLS regressions

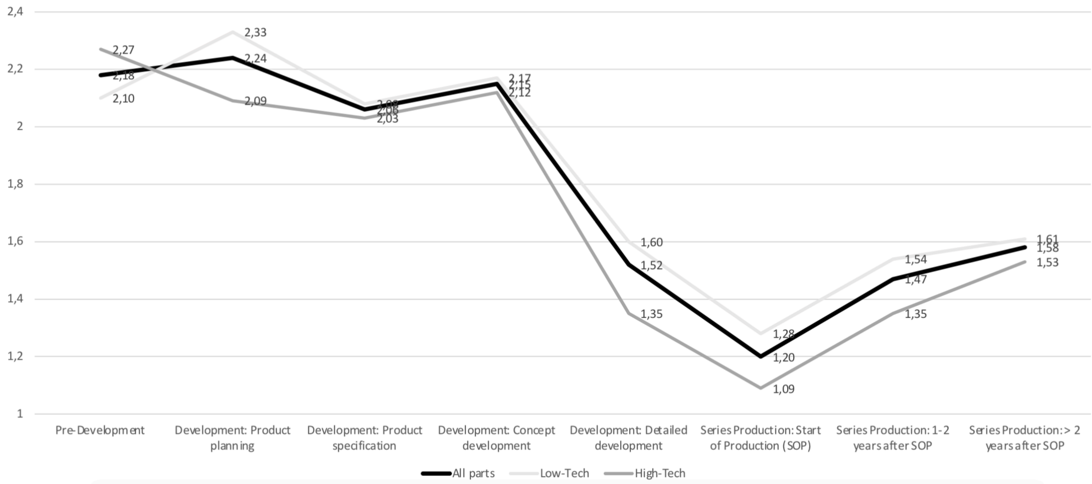
Variables	**Trust Index**						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IPR Conflicts PD	**-.470*** **						
	(.124)						
IPR pass-on PD		**-.273*** **					
		(.067)					
Risk sharing			**.134** **				
			(.065)				
IPR Conflicts DEV				**-.231*** **			
				(.067)			
IPR pass-on DEV					**-.132** **		
					(.054)		
Lump-sum rebates						**-.165*** **	
						(.052)	
Role of Price							**-.241** **
							(.120)
supplier revenues (bln)	.005	.004	.007	**.011** **	.008	**.008* **	.014
	(.006)	(.004)	(.004)	(.005)	(.005)	(.004)	(.009)
# suppliers overall	-.001	-.001	.000	.002	.003	-.005	-.001
	(.006)	(.004)	(.005)	(.004)	(.004)	(.005)	(.006)
product type							
system (D)				reference category			
module (D)	.069	.106	.116	.009	-.011	.171	.196
	(.313)	(.170)	(.194)	(.256)	(.284)	(.210)	(.319)
component (D)	.062	.201	.227	.027	.131	.170	0.170
	(.218)	(.154)	(.167)	(.224)	(.237)	(.189)	(.310)
commodity (D)	.027	-.037	.109	-.138	-.017	.154	.244
	(.229)	(.183)	(.197)	(.238)	(.253)	(.201)	(.285)
const	5.431	5.350	4.398	5.253	4.973	5.059	5.815
	(.269)	(.237)	(.216)	(.282)	(.261)	(.218)	(.694)
Observations	121	241	220	179	159	193	126
R-squared	.143	.121	.033	.087	.068	.093	.059

Dependent variable: Trust index; coefficients and (p-values) reported; robust standard errors clustered at level of buyer-seller pairs. PD = Pre-development; DEV = Development; * sign. at 10%; ** sign. at 5%; *** sign. at 1%.

A.3 Other key variables

Part quality Suppliers were asked with regard to a specific part supplied to a specific buyer: *With respect to the part considered, how often do quality problems occur?*, measured on a 5-point scale, with 1 identifying the lowest and 5 the highest frequency, and the middle of the scale anchored at 50%. The points on the scale are therefore interpreted as probabilities increasing from 0 to 100% in steps of 25%.

Figure A.1
Mean number of parallel or competing suppliers along product lifecycle.



Mean number of suppliers employed by phase of the product lifecycle (black line), and differentiated by low-tech (light-gray) vs. high-tech (dark-gray) parts.

Number of suppliers Table I, and in more detail Table A.1 and Figure A.1 display the number of suppliers working in the different phases for a given OEM and part selected for the survey. Table A.1 gives the number of suppliers by part, and Figure A.1 over the phases of the product life cycle. While in pre-development, the average number of suppliers per high-tech part exceeds that of low-tech parts, the order is reversed from all phases of development to all phases of series production.

Appendix B: Robustness Checks

Table B.1
Robustness: Normalized trust index and investment proxied by quality issues
(Fractional probit results)

	Frequency of Quality Problems			
Variables	(1)	(2)	(3)	(4)
trust index (n)	-.014	**-.024****	**-.027****	**-.037****
	(.250)	(.038)	(.041)	(.014)
supplier revenues (bln)	-.001	-.002	omitted	omitted
	(.352)	(.253)		
# suppliers overall	.001	.001	-.002	-.002
	(.390)	(.418)	(0.321)	(.135)
product type				
system (D)	reference category			
module (D)	-.032	-.042	-.087	.018
	(.683)	(.593)	(.205)	(.823)
component (D)	**-.165****	**-.175****	-.076	.053
	(.020)	(.013)	(.212)	(.626)
commodity (D)	**-.181*****	**-.189*****	-.084	-.005
	(.007)	(.006)	(.123)	(.819)
Buyer-FE (11)	**no**	**yes**	**yes**	**yes**
Supplier-FE (13)	**no**	**no**	**yes**	**yes**
Buyer-Part-FE	**no**	**no**	**no**	**yes**
# observations	127	127	127	127

Dependent variable: Frequency of quality problems arising (in percent). average marginal effects (p-values). Trust index (n): difference in importance between mutual trust and price; Robust standard errors clustered at the level of buyer-seller pairs; ** significant at 5%; *** significant at 1%.

Table B.2
Robustness: Directed trust and quality issues (proxy for investment): Fractional probit results

	Frequency of Quality Problems	
Variables	(1)	(2)
$trust_{PD}$	**-.027*** **	**-.027** **
	(.009)	(.012)
supplier revenues (bln)	-.001	-.001
	(.621)	(.711)
# suppliers overall	.001	.001
	(.477)	(.452)
product type		
system (D)	reference category	
module (D)	-.018	-.017
	(.866)	(.875)
component (D)	**-.183***	**-.192** **
	(.063)	(.046)
commodity (D)	**-.186** **	**-.195** **
	(.045)	(.039)
Buyer-FE (11)	**no**	**yes**
# observations	107	107

Dependent variable: Frequency of quality problems arising (in percent); average marginal effects (p-values); $trust_{PD}$: supplier's trust in the buyer in the context of initiating pre-development; standard errors clustered at the level of buyer-seller pairs; ** significant at 5%; *** significant at 1%.

Table B.3
Robustness: Normalized trust index and competition: Poisson-regression results

Variables	**Number of suppliers at different stages**					
	Pre-Dev.♠		**Dev.♣**		**Ser. Prod.♡**	
	(1)	(2)	(3)	(4)	(5)	(6)
trust index (n)	-.042	-.032	**.059***	**.103***	**.115*******	**.128*******
	(.195)	(.429)	(.066)	(.052)	(.007)	(.007)
supplier revenues	.002	.004	**.024*******	**.027*******	.005	.006
	(.588)	(.240)	(.000)	(.000)	(.260)	(.122)
product type						
system (D)			reference category			
module (D)	-.080	-.003	**.707****	**.775*******	0.139	0.207
	(.629)	(.429)	(.023)	(.003)	(.424)	(.193)
component (D)	0̇04	.018	.292	.313	.135	.151
	(.979)	(.913)	(.265)	(.225)	(.428)	(.307)
commodity (D)	.106	.116	**.564****	**.584****	**.443****	**.484*******
	(.448)	(.433)	(.018)	(.011)	(.015)	(.001)
const	.689	.426	-.271	-.509	-.053	-.275
	(.000)	(.031)	(.337)	(.088)	(.785)	(.116)
Buyer-FE (11)	**no**	**yes**	**no**	**yes**	**no**	**yes**
# observations	78	78	127	127	126	126
Pseudo-R^2	.005	.013	.036	.055	.025	.035

Dependent variables: ♠ Number of suppliers employed during pre-development, ♣ number of suppliers during the final stage of development; ♡ number of suppliers at the start of series production; coefficients (p-values); trust index (n): differences in importance between trust and price; robust standard errors clustered at the level of buyer-seller pairs. * significant at 10%; ** significant at 5%; *** significant at 1%.

Appendix C: Proofs

Lemma 1 *In the equilibrium optimal for the buyer, a higher discount factor δ is associated with*

(i) a higher level of investment $\underline{I}$, for given n,

(ii) a larger number of suppliers n, for given $\underline{I}$.

Proof: Consider the case $n \geq 2$ and take the binding constraint (IC_s) :

$$w + \frac{\theta^e_{(2)}(n) - \theta^e_{(1)}(n)}{n} = \frac{\underline{I}}{\delta}$$

We have

$$\frac{\theta^e_{(2)}(n) - \theta^e_{(1)}(n)}{n} = \int_{\underline{\theta}}^{\overline{\theta}} F(\theta)[1 - F(\theta)]^{n-1} d\theta$$

with a slight abuse of notation, we obtain

$$\frac{\partial \left(\frac{\theta^e_{(2)}(n) - \theta^e_{(1)}(n)}{n} \right)}{\partial n} = \int_{\underline{\theta}}^{\overline{\theta}} F(\theta)[1 - F(\theta)]^{n-1} \ln(1 - F(\theta)) d\theta < 0$$

The result in this case follows from the observation that

$$\frac{\partial I}{\partial \delta} = \frac{\underline{I}}{\delta} > 0$$

together with

$$\frac{\partial w}{\partial \delta} = -\frac{\underline{I}}{\delta^2} < 0$$

and

$$\frac{\partial n}{\partial \delta} = -\frac{\underline{I}}{\delta^2} \left[\frac{\partial \left(\frac{\theta^e_{(2)}(n) - \theta^e_{(1)}(n)}{n} \right)}{\partial n} \right]^{-1} > 0.$$

Consider now the case $n = 1$ the binding (IC_s) is then:

$$w = \frac{\underline{I}}{\delta} - \pi(1) \tag{3}$$

since $\pi(1) = p(1) - E(\theta)$. Clearly in this case we still have

$$\frac{\partial \underline{I}}{\partial \delta} = w > 0$$

and

$$\frac{\partial w}{\partial \delta} = -\frac{\underline{I}}{\delta^2} < 0$$

To identify the effect of an increase of δ on n in the case $n = 1$ we need to compare the buyer objective function in the case $n = 1$ and $n = 2$. For a given level of investment I (as contemplated in the proposition), once we substitute the binding (IC_s) in the buyer's objective function we have that $n = 2$ is preferred by the buyer to $n = 1$ if and only if:

$$\left[v(I) - \frac{2\underline{I}}{\delta} - \theta^e_{(1)}(2)\right]\frac{1}{1-\delta} \geq \left[v(I) - \frac{\underline{I}}{\delta} - E(\theta)\right]\frac{1}{1-\delta}$$

which can be written as:

$$\left[E(\theta) - \theta^e_{(1)}(2)\right] \geq \frac{\underline{I}}{\delta}$$

Clearly, for given I, this condition is more likely to be satisfied the higher δ is.

Q.E.D.

Proof of Proposition 1

Since w is implicitly defined by (IC_s), we can rewrite the buyer's per-period objective function as a function of the two main decision variables $\underline{I}$ and n,

$$H(\underline{I}, n) \equiv v(\underline{I}) - n\frac{\underline{I}}{\delta} - \theta^e_{(1)}(n), \tag{4}$$

where the *actual cost of development* $(n\underline{I})/\delta$ encompasses the cost of providing the n suppliers with the incentives to invest (and clearly $\theta^e_{(1)}(1) = \theta^e(1)$). For a given n, the maximizer of $H(\underline{I}, n)$ with respect to $\underline{I}$ — denoted $\underline{I}^n$ — is defined by

$$v'(\underline{I}^n) = \frac{n}{\delta}. \tag{5}$$

This condition shows that if δ increases and the optimal number of firms n^*_B remains unaffected, then the optimal level of investment increases.

Notice first that equation (5) implies that if δ increases, either n^*_B or $\underline{I}^*_B$ have to increase. Consider next the overall effect of δ on both endogenous variables n^*_B and $\underline{I}^*_B$. We proceed in steps and start from the effect of δ on the optimal number of suppliers n^*_B. Notice that given some n at the optimal level of investment $\underline{I}^n$ defined in (5) above it could be that

$$H(\underline{I}^n, n)\delta \geq v_0\,\delta + (1-\delta)p^e(n) - p^e(N),$$

i.e., constraint (IC_b) could never be satisfied even considering different values of I. Clearly, in the proof, we disregard these values of n and restrict attention to (and explicitly consider only) those values of n that can allow to satisfy constraint (IC_b).

We first show that when comparing the buyer's payoff associated with any two different numbers of suppliers $n > \tilde{n}$, there exists conditions on $v(\cdot)$ such that an increase of the discount factor δ makes the buyer prefer procurement with a larger number n rather than a smaller number $\tilde{n}$ of suppliers. Recall that we are considering $n > \tilde{n}$ which implies $\underline{I}^{\tilde{n}} \geq \underline{I}^n$ where $\underline{I}^n$ and $\underline{I}^{\tilde{n}}$ are the associated optimal level of investments defined by (5). The solution to program $\mathcal{P}$ is such that n is preferred to $\tilde{n}$ if:

$$\left[v(\underline{I}^n) - \frac{n\underline{I}^n}{\delta} - \theta^e_{(1)}(n)\right]\frac{1}{1-\delta} \geq \left[v(\underline{I}^{\tilde{n}}) - \frac{\tilde{n}\underline{I}^{\tilde{n}}}{\delta} - \theta^e_{(1)}(\tilde{n})\right]\frac{1}{1-\delta}$$

or equivalently

$$\theta^e_{(1)}(\tilde{n}) - \theta^e_{(1)}(n) \geq \left[v(\underline{I}^{\tilde{n}}) - \frac{\tilde{n}\underline{I}^{\tilde{n}}}{\delta}\right] - \left[v(\underline{I}^n) - \frac{n\underline{I}^n}{\delta}\right].$$

We show next how the r.h.s. varies with δ. Using the envelope theorem,

$$\frac{d}{d\delta}\left\{\left[v(\underline{I}^{\tilde{n}}) - \frac{\tilde{n}\underline{I}^{\tilde{n}}}{\delta}\right] - \left[v(\underline{I}^n) - \frac{n\underline{I}^n}{\delta}\right]\right\} = \frac{1}{\delta}[v'(\underline{I}^{\tilde{n}})\underline{I}^{\tilde{n}} - v'(\underline{I}^n)\underline{I}^n]$$

and, using the Lagrange Residual of the Taylor series,

$$v'(\underline{I}^{\tilde{n}})\underline{I}^{\tilde{n}} - v'(\underline{I}^n)\underline{I}^n = [v''(\zeta)\zeta + v'(\zeta)]\,(\underline{I}^{\tilde{n}} - \underline{I}^n)$$

where $\zeta = (1-\theta)\underline{I}^{\tilde{n}} + \theta\underline{I}^n$. If $v''(\cdot)$ is sufficiently negative, the r.h.s. is negative, which proves our claim.

Consider now the effect of δ on the optimal investment $\underline{I}^*_B$. If n^*_B were a continuous variable, then equation (5) above immediately would imply that whenever an increase of δ induces a larger n^*_B then $\underline{I}^*_B$ might decrease. However, when n changes with unitary increments and δ is in the $[0, 1]$ range, the r.h.s. of (5) must increase when n^*_B increases. In other words, if the increase of δ is not large enough to affect n^*_B, then necessarily $\underline{I}^*_B$ must increase with δ. Increases of the discount factor δ are associated with possibly infrequent and (relatively) small reductions of $\underline{I}^*_B$ when n^*_B "jumps up" and more frequent and (relatively) large increases $\underline{I}^*_B$ when n^*_B remains constant. This follows from the observation that, for the same change $\Delta\delta$ of δ, the (absolute value of the) change of the r.h.s. in (5) is smaller when n^*_B increases than when it remains constant.

Q.E.D.

Proof of Proposition 2

The supplier optimally increases w up to the point where the other side's incentive compatibility constraint (IC_b) is binding, similarly to when the buyer has bargaining power. Substituting this binding (IC_b) constraint, the objective becomes $[v(I) - I - K]\frac{1}{1-\delta}$ where

$$K \equiv v_0 - N\beta(N)\pi(N) + \frac{1}{\delta}\left[p^e(1) - p^e(N) - (1-\delta)k\frac{N-1}{N}\right] \tag{6}$$

which does not depend on I, and constraint (IC_s) becomes $v(I) - K \geq I/\delta$. We can now identify two alternative characterizations of the most profitable equilibrium relational contract for the supplier. Denote by I^* the first-best investment defined by

$$v'(I^*) = 1. \tag{7}$$

The first case is such that

$$[v(I^*) - \frac{I^*}{\delta} - K] \geq 0, \tag{8}$$

in which case $I_S^* = I^*$ and an increase of the discount factor δ is not associated with any change in the optimal level of investment I_S^*.

The second case is such that

$$[v(I^*) - \frac{I^*}{\delta} - K] < 0. \tag{9}$$

In this case $I_S^* = I_S$ where I_S is defined by

$$[v(I_S) - \frac{I_S}{\delta} - K] = 0. \tag{10}$$

From (10) given (17) above we have that

$$\frac{dI_S}{d\delta} = -\frac{I_S + \left[p^e(1) - p^e(N) - k\frac{N-1}{N}\right]}{\delta^2\left(v'(I_S) - \frac{1}{\delta}\right)}. \tag{11}$$

Consider first the numerator of (11). A necessary condition for the buyer to consider a deviation at t_4 that opens the auction to $\tilde{n} = N$ sellers is that the expected reduction in the price due to opening the auction, $p(1) - p^e(N)$, exceeds the expected cost of asking one of the $(N-1)$ sellers that did not participate in the development stage to produce the commissioned part, $k(N-1)/N$, that is

$$\left[p^e(1) - p^e(N) - k\frac{N-1}{N}\right] > 0$$

In the other case, the (IC_b) constraint would not be binding.

Consider now the denominator of (11). We need to identify the sign of $[v'(I_S) - (1/\delta)]$. Denote $\hat{I}$ the value of I such that

$$v'(\hat{I}) = \frac{1}{\delta},$$

that is the value of $\underline{I}$ that maximises the function $[v(I_S) - (I_S/\delta)]$. Notice also that the strict concavity of $v(\cdot)$ implies that equation (10) or

$$[v(I_S) - \frac{I_S}{\delta}] = K$$

has two solutions whenever $I_S \neq \hat{I}$. Denote these solutions $I_{S,1}$, $I_{S,2}$ with $I_{S,1} < \hat{I} < I_{S,2}$. The seller will choose the investment $I_S^* = I_{S,i}$, $i \in \{1, 2\}$ that maximises $[v(I_S^*) - I_S^*]$.

We can then conclude that necessarily

$$I_{S,2} < I^*. \tag{12}$$

Assume by way of contradiction that this is not the case, that is $I_{S,2} > I^*$. Since the seller's problem is such that the (10) holds then,

$$[v(I_{S,2}) - \frac{I_{S,2}}{\delta}] = K$$

and from (9) above

$$[v(I^*) - \frac{I^*}{\delta}] < K,$$

that is

$$[v(I_{S,2}) - v(I^*)] > \left[\frac{I_{S,2}}{\delta} - \frac{I^*}{\delta}\right] \tag{13}$$

while from the definition of I^* we have that

$$[v(I^*) - I^*] > [v(I_{S,2}) - I_S^2]$$

or

$$[v(I_{S,2}) - v(I^*)] < [I_{S,2} - I^*].. \tag{14}$$

Inequalities (13) and (14) then imply

$$[I_{S,2} - I^*] > \left[\frac{I_{S,2}}{\delta} - \frac{I^*}{\delta}\right]$$

which if $I_{S,2} > I^*$ contradicts $\delta < 1$.

We therefore conclude from the definition of I^*, the fact that $I_{S,1} < I_{S,2} < I^*$ and the strict concavity of $v(\cdot)$ that the seller will choose $I_S^* = I_{S,2}$. Since $\hat{I} < I_{S,2}$ and $v'(\cdot)$ is a decreasing function, we then have

$$v'(I_{S,2}) < v'(\hat{I}) = \frac{1}{\delta},$$

which implies

$$\frac{dI_S}{d\delta} = -\frac{I_S + \left[p^e(1) - p^e(N) - k\frac{N-1}{N}\right]}{\delta^2\left(v'(I_S) - \frac{1}{\delta}\right)} > 0.$$

This concludes the proof of Proposition 2.

Q.E.D.

Proof of Proposition 3

Consider first the situation where the bargaining power rests with the buyer. Using the binding (IC_s) constraint and (4) above we have that:

$$\begin{aligned} V_B(k) = \quad & \max_{\underline{I},n} \quad H(\underline{I},n)\tfrac{1}{1-\delta} \\ & s.t. \quad H(\underline{I},n)\tfrac{1}{1-\delta} \geq H(0,N)\tfrac{1}{1-\delta} + \tfrac{1}{\delta}\{p^e(n) - p^e(N) - k[1-n\beta(N)]\} \end{aligned} \tag{15}$$

where $H(0,N) = v_0 - Nw' - p^e(N)$ is the per period payoff of procuring with all N suppliers. Let $\underline{I}^*, n^*$ be the solution to the (unconstrained) problem

$$\max_{\underline{I},n} H(\underline{I},n)$$

Then, as discussed in Subsection 5.2 above, there are two possible cases. The first case is the one where (IC_b) does not bind

$$H(\underline{I}^*, n^*)\frac{1}{1-\delta} > H(0,N)\frac{1}{1-\delta} + \frac{1}{\delta}\{p^e(n^*) - p^e(N) - k[1 - n^*\beta(N)]\}$$

then the value function of the program $V_B(k) = H(\underline{I}^*, n^*)\frac{1}{1-\delta}$ does not depend on k. The second case is such that

$$H(\underline{I}^*, n^*)\frac{1}{1-\delta} < H(0,N)\frac{1}{1-\delta} + \frac{1}{\delta}\{p^e(n^*) - p^e(N) - k[1 - n^*\beta(N)]\}$$

and then at the optimum (IC_b) binds and the value function $V_B(k)$ is

$$V_B(k) = H(0,N)\frac{1}{1-\delta} + \frac{1}{\delta}\{p^e(n^*_S(k)) - p^e(N) - k[1 - n^*_S(k)\beta(N)]\}.$$

Recall that $n^*_B(k)$ is the optimal choice of n in problem (15). Therefore, by Envelope Theorem, the effect of an increase in k is to reduce $V_B(k)$ since $1 - n\beta(N) \geq 0$. In other words, if the buyer has the bargaining power, then $V_B(k)$ weakly decreases in k.

Consider now the case where the bargaining power rests with the supplier. In line with Subsection 5.3 above, we focus only on the specific case $n^*_S = 1$.

Substituting the necessarily binding (IC_b) constraint we have that

$$\begin{aligned} V_S(k) = \quad & \max_{\underline{I}} \quad [v(\underline{I}) - \underline{I} - K(k)]\frac{1}{1-\delta} \\ & s.t. \quad v(\underline{I}) - K(k) \geq \underline{I}/\delta. \end{aligned} \tag{16}$$

where

$$K(k) \equiv v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N) - (1-\delta)k\frac{N-1}{N}\right] \tag{17}$$

As we have seen above,e there are two possible cases. The first case where (IC_s) does not bind at the optimum, then the investment is at the first best level $\underline{I}^*_S = \underline{I}^*$ and the value function of the program $V_S(k)$ is (directly) increasing in k since clearly $K(k)$ is decreasing in k. The second case where the (IC_s) constraint binds, then substituting the binding (IC_s) in the objective function we have

$$V_S(k) = v(\underline{I}^*_S(k)) - K(k) \tag{18}$$

that allows us to conclude, by Envelope Theorem, that $V_S(k)$ is also increasing in k.

From problem (16) and (15) above that the lower is k the more likely is the case that both (IC_s) and (IC_b) are binding.

Now we show that for v_0 sufficiently high the two functions $V_B(k), V_S(k)$ have overlapping supports. In the seller's program, when $k = 0$ the (IC_s) constraint is:

$$v(I) - \frac{I}{\delta} \geq v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N)\right] \tag{19}$$

Recall now that I^* is the first-best investment

$$v'(I^*) = 1.$$

If for $I = I^*$ the (IC_s) is not satisfied:

$$v(I^*) - \frac{I^*}{\delta} < v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N)\right]$$

then necessarily the (IC_s) has to bind at $k = 0$ and the optimal investment $I^*(0)$ is such that

$$v(I^*(0)) - \frac{I^*(0)}{\delta} = v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N)\right] \tag{20}$$

Notice that necessarily this must be the case for v_0 large enough $v_0 \geq \hat{v}_0^s$ where:

$$v(I^*) - \frac{I^*}{\delta} = \hat{v}_0^s - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N)\right]$$

Therefore, substituting in the seller's problem above we have that in the case $k = 0$ when $v_0 \geq \hat{v}_0^s$

$$V_S(0) = v(I^*(0)) - v_0 + Nw' - \frac{1}{\delta}\left[p^e(1) - p^e(N)\right] \tag{21}$$

Consider now the case in which the buyer has the bargaining power, problem (15) above. The (IC_b) constraint can be written as:

$$v(I) - n\frac{I}{\delta} - \theta^e_{(1)}(n) \geq v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N) - k\frac{N-n}{N}\right]$$

Therefore when $k = 0$ the (IC_b) constraint becomes:

$$v(I) - n\frac{I}{\delta} - \theta^e_{(1)}(n) \geq v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right] \tag{22}$$

Denote now $\hat{I}_b$ to be the investment level that maximizes with respect to I the objective function in problem (15) above:

$$v'(\hat{I}_b) = \frac{n}{\delta}. \tag{23}$$

If for $\hat{I}_b$ the (IC_b) is not satisfied:

$$v(\hat{I}_b) - n\frac{\hat{I}_b}{\delta} - \theta^e_{(1)}(n) < v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right]$$

then necessarily the (IC_b) has to bind at $k = 0$ or

$$v(I) - n\frac{I}{\delta} - \theta^e_{(1)}(n) = v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right] \tag{24}$$

Notice that necessarily this must be the case for v_0 large enough, that is $v_0 \geq \hat{v}_0^b$ where:

$$v(\hat{I}_b) - n\frac{\hat{I}_b}{\delta} - \theta^e_{(1)}(n) = v_0^b - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right]$$

Therefore, substituting in the buyer's problem above, we have that in the case $k = 0$ when $v_0 \geq \hat{v}_0^b$,

$$V_B(0) = v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right] \tag{25}$$

Therefore, for values of $v_0 \geq \max\{v_0^s, v_0^b\}$ we have that a large enough v_0 guarantees:

$$V_B(0) > V_S(0)$$

that is

$$v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right] > v(I^*(0)) - v_0 + Nw' - \frac{1}{\delta}\left[p^e(1) - p^e(N)\right]$$

or

$$v(I^*(0)) < 2\left[v_0 - Nw' - \frac{p^e(N)}{\delta}\right] + \frac{1}{\delta}p^e(1) + \frac{1-\delta}{\delta}p^e(n) \tag{26}$$

Consider now the values of $V_S(k)$ and $V_B(k)$ for k sufficiently large. Notice first that in the supplier's problem, when the investment equals to the first-best level $I = I^*$ for k large enough, then the (IC_s) constraint is not binding:

$$v(I^*) - \frac{I^*}{\delta} > v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N) - (1-\delta)k\frac{N-1}{N}\right]$$

Similarly, in the buyer's problem above, when investment equals the value that maximizes the objective function, i.e. $I = \hat{I}_b$, then for k large enough the (IC_b) constraint is not binding:

$$v(\hat{I}_b) - n\frac{\hat{I}_b}{\delta} - \theta^e_{(1)}(n) > v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N) - k\frac{N-n}{N}\right].$$

Therefore, for k large enough so that constraint (IC_s) in the seller's bargaining power problem and (IC_b) in the buyer's bargaining power problem are not binding, we have:

$$V_S(k) = \left\{v(I^*) - I^* - v_0 + Nw' - \frac{1}{\delta}\left[p^e(1) - p^e(N) - (1-\delta)k\frac{N-1}{N}\right]\right\}\frac{1}{1-\delta}$$

and

$$V_B(k) = \left[v(\hat{I}_b) - n\frac{\hat{I}_b}{\delta} - \theta^e_{(1)}(n_b)\right]\frac{1}{1-\delta}$$

It follows that there exists a value of k, denoted $\overline{k}$ such that:

$$v(I^*) - I^* - v_0 + Nw' - \frac{1}{\delta}\left[p^e(1) - p^e(N) - (1-\delta)\overline{k}\frac{N-1}{N}\right] = v(\hat{I}_b) - n\frac{\hat{I}_b}{\delta} - \theta^e_{(1)}(n_b).$$

Hence, for any $k > \overline{k}$ we have

$$V_S(k) > V_B(k). \tag{27}$$

Summarizing, we have shown that when $v_0 \geq \max\{v_0^s, v_0^b\}$, for k sufficiently small then $V_B(k) > V_S(k)$, while for larger k we have $V_B(k) < V_S(k)$, which concludes what we wanted to prove.

Incidentally, we observe that for low-tech products we expect the value of procurement with nil investment, that is v_0, to be relatively high, thus leading to the previous case where $V_B(k)$ and $V_S(k)$ have overlapping ranges. For high-tech products, instead, we expect v_0 to be relatively low, so that $V_B(k) < V_S(k)$ for any k.

Q.E.D.

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Online Appendix

Several Suppliers with Bargaining Power

Let $n > 1$ suppliers, rather than one supplier only as considered in the main text, approach the buyer for procurement and propose a level of investment I in exchange of an ex-ante payment w. When it comes to production, the buyer has the possibility to exploit the best blueprint procured by the n suppliers and towards selecting a supplier to run an auction with more, possibly all N suppliers, that identifies an (expected) price $p^e(N)$. As with $n = 1$ the suppliers will optimally set w so that the (IC_b) binds, that is

$$w = \frac{1}{n}\left[v(I) - (v_0 - Nw')\right] + \frac{1}{\delta n}(1-\delta)k\frac{N-n}{N} - \frac{1}{\delta n}(p^e(n) - p^e(N)). \tag{28}$$

We focus here on the case where the (IC_s) constraint does not bind. Substituting (28) in the suppliers' expected-discounted profit, the optimal level of investment I^* must satisfy the following condition

$$v'(I^*) = n. \tag{29}$$

This clearly shows that if, when δ changes, the number of suppliers n does not change, as observed in the data for high-tech products. The optimal investment I^* does not change either. This is different from the case where the buyer has the bargaining power: By Proposition 1, if n does not change, then an increase of δ necessarily induces an increase in I^*. It is also immediate to see from (29) above that n and I^* are negatively related, as $v(\cdot)$ a monotonously increasing strictly concave function.

Bundling Development and Production

The relational contract that we have considered in the main text contemplates bundling development and production and is motivated by the evidence in our industry. Substituting the supplier's binding incentive constraint, the associated buyer's payoff is

$$\left[v(\underline{I}) - n\frac{\underline{I}}{\delta} - \theta^e_{(1)}(n)\right]\frac{1}{1-\delta}.$$

The buyer and the suppliers may in principle, agree to rely on a different relational contract where $n' \geq 1$ suppliers develop n' possibly different blueprints and competition for production involves all the N suppliers. Such type of procurement would allow to minimize the cost of production but would involve incurring the adjustment cost k.

Considering that the $N-n'$ suppliers excluded from development would be requested to pay an ex-ante participation fee w', similarly as to w for those developing, the buyer's objective function can be written as,

$$\left[v(\underline{I'}) - n'\frac{\underline{I'}}{\delta} - \theta^e_{(1)}(N) - E(k)(1-n'\beta(N))\right]\frac{1}{1-\delta},$$

where the expected cost of adjustment $E(k)$ is multiplied by the probability $(1-n'\beta(N))$ that the producing most efficient supplier did not develop its blueprint.[48] Maximizing this objective with respect to n' the buyer faces a trade-off. On one hand fewer developing suppliers (that is lower n') avoid the duplication of investment costs (the second term in the parenthesis). On the other hand, this increases the probability of facing adjustment costs. As seen, this trade-off (and the associated one on the optimal choice of I) is similar to that with bundling. Here, the fewer developing suppliers imply a higher adjustment cost $E(k)\beta(N)$, with bundling, they imply a higher production cost $\theta^e_{(1)}(n)$. Hence, whether at the optimum the buyer employs more or fewer suppliers at the developing stage with unbundling also depends on these different costs.

Considering that the two relational contracts may be associated with different levels of investment I and I', bundling dominates unbundling for the buyer if the following is satisfied,

$$E(k)(1-n'\beta(N)) + \left[\theta^e_{(1)}(n) - \theta^e_{(1)}(N)\right] \geq \left[v(\underline{I}) - \frac{n\underline{I}}{\delta}\right] - \left[v(\underline{I'}) - \frac{n'\underline{I'}}{\delta}\right]. \quad (30)$$

The left-hand side indicates the production-adjustment cost of unbundling. The two terms on the right-hand side reflect the fact that two relational contracts may be associated with different levels of investment. Even if this is not the case, employing fewer developing firms allows the buyer to save on duplication costs here captured by the second terms in each parenthesis. What matter to our purposes, however, is that if $E(k)$ is large, then condition (30) implies the buyer prefers to bundle development and the possibility to produce.

Notice that the cost of developing a blueprint is unrelated to the cost of developing a production technology based on a particular blueprint, including specific labor skills and expensive tools. The adjustment costs k may therefore be substantially higher than those of developing the blueprint. For example, the development cost for a front-end module

[48] We are not allowing the relational contract to be conditioned on the ex-post realization of k because adjustment costs are typically private information of the parties, which would make the relational contract unrealistically complex.

may be minimal compared to its adjustment cost. Also, besides the cost of instructing the producing firm to use another firm's blueprint and to delay production to do so, the adjustment cost k may also include the cost of managing the free-riding problem and the conflicting incentives of the developer and the producer under unbundling. For example, when a firm i wins the production contract but did not develop the blueprint used for production, he can claim that ensuing problems with production follow from poor blueprint design rather than little care in adapting it in production.

Finally, two further considerations are in order. First, a relational contract may, in principle, condition the intensity of competition on the realization of k. However, this possibility is precluded because, realistically, only the buyer has a clear idea of the realization of the adjustment cost k that she will have to bear. Second, for some products, the expected adjustment cost $E(k)$ may not be very high, and the buyer and the sellers may agree on a relational contract that explicitly relies on several competing suppliers at production $\tilde{n}$ larger than n, that at the investment stage, e.g. in a ratio two to one. Although the model would differ from the one studied here, the main results would also qualitatively hold in this case, as long as $\tilde{n} < N$. In fact, we can identify conditions such that an increase in δ may now reflect into higher investment, larger n and $\tilde{n}$. The latter case of multiple sourcing is further discussed in the next appendix.

Several suppliers in series production (multiple sourcing)

The management literature regards "supply assurance" as a crucial motive behind multiple-sourcing, that is, simultaneously procuring an input from different suppliers. The buyer hedges against the risk that her assembly line is brought to an expensive halt because the single supplier is not forthcoming with the parts at the right time or in the required quantity.[49] On the other hand, Riordan and Sappington (1989) and Rogerson (1989) stressed early on that, by reducing suppliers' production rents, second sourcing may undermine incentives for R&D.

In our environment, an adverse event (observable) may occur with probability α, in which case the unique supplier could procure just a fraction $1-\gamma$ of the required production. Facing this risk of incomplete procurement—the costs of which we do not explicitly model, for simplicity—dual-sourcing and two production contracts may be preferable to single-sourcing. The first-source contract exhausts the entire production with probability $1-\alpha$. With complementary probability α the adverse event realizes and the first-source contract will only provide the fraction $1-\gamma$ of production. In this

[49]See Yu et al. (2009) or Wang et al. (2010).

case, the second-source contract, under which the complementary fraction γ is supplied, will be executed.

We mainly focus here on the case where the buyer designs the procurement contract. Since the buyer will never allocate the two contracts to the same supplier, dual-sourcing corresponds here to a multi-unit auction where firms are not allowed to win both contracts and are thus interested in winning just one of the two. With at least three competing suppliers, the buyer's selection mechanism is assumed to be a uniform-price auction (which is efficient here and involves truthful bidding).

With dual-sourcing, the buyer pays more for production since the price paid to the two winners of the first- and second-source contracts is the production cost $\theta^e_{(3)}(n)$ of the third- rather than the second-most efficient firm as in the case of single sourcing (Section 5.2). Yet dual-sourcing almost surely guarantees complete production even when the adverse event is realized. The higher buyer's price translates into higher expected information rents to suppliers. To see this, note that from the analysis above, the expected rent with single-sourcing is $\beta(n)\pi(n)(1-\alpha\gamma)$. With dual-sourcing, it is instead

$$\beta(n)\pi_1(n)(1-\alpha\gamma)+\tilde{\beta}(n)\pi_2(n)\alpha\gamma$$

where $\beta(n)$ and $\tilde{\beta}(n)$ are respectively the probabilities of being the most efficient and the second-most efficient supplier—both equal to $(1/n)$—with associated rents $\pi_1(n)$ and $\pi_2(n)$.[50] Since $\pi_1(n) \geq \pi(n)$, dual-sourcing guarantees a larger expected rent to suppliers. With an argument similar to that in Section 5.2, we obtain:

Proposition 4 *Assume the function $v(\cdot)$ is sufficiently concave. If δ has an effect on the type of procurement, then an increase in δ induces the buyer to switch from single-sourcing to dual-sourcing.*

Proof: From the binding suppliers' incentive compatibility constraint, as in (IC_s), and coherently with w being paid *ex-ante* with respect to production, whether a producer delivers full production or not, we obtain an equivalent optimal procurement program $\mathcal{P}_d$ with dual-sourcing and associated per-period payoff for the buyer:

$$H_d(\underline{I}^*_d, n^*_d) = v(\underline{I}^*_d) - n^*_d\frac{\underline{I}^*_d}{\delta} - (1-\alpha\gamma)\theta^e_{(1)}(n^*_d) - \alpha\gamma\theta^e_{(2)}(n^*_d).$$

[50]To simplify notation we assume that a firm i that procures a fraction of total (unitary) production faces a production cost, which is the corresponding fraction of its cost θ_i. Then we have $\pi_1(n) = \theta^e_{(3)}(n) - \theta^e_{(1)}(n) \geq \pi_2(n) = \theta^e_{(3)}(n) - \theta^e_{(2)}(n) \geq 0$.

We now compare dual-sourcing to single-sourcing when the buyer has the bargaining power. The latter is now associated with a buyer's expected (per-period) payoff:

$$H(\underline{I}_B^*, n_B^*) = (1-\alpha\gamma)v(\underline{I}_B^*) - n_B^* \frac{\underline{I}_B^*}{\delta} - (1-\alpha\gamma)\theta^e_{(1)}(n_B^*).$$

where, as above, $\underline{I}_B^*$ denotes the optimal investment under single-sourcing, and the buyer has the bargaining power and n_B^* the number of developers.

To make the analysis interesting so that a change δ can have an impact on the type of sourcing, we assume that (i) if the buyer can only procure nil investment, as when $\delta = 0$, then it is optimal to procure with single-sourcing, which formally requires

$$H_d(0, N) = v_0 - (1-\alpha\gamma)\theta^e_{(1)}(N) - \alpha\gamma\theta^e_{(2)}(N) < H(0, N) = (1-\alpha\gamma)v_0 - (1-\alpha\gamma)\theta^e_{(1)}(N)$$

or equivalently

$$v_0 < \theta^e_{(2)}(N);$$

(ii) if the investment is perfectly contractible, as when $\delta = 1$, then it is optimal to procure with dual sourcing, which formally requires:

$$H_d(\hat{\underline{I}}_d, \hat{n}_d) = v(\hat{\underline{I}}_d) - \hat{n}_d\hat{\underline{I}}_d - (1-\alpha\gamma)\theta^e_{(1)}(\hat{n}_d) - \alpha\gamma\theta^e_{(2)}(\hat{n}_d) >$$

$$> H(\hat{\underline{I}}, \hat{n}) = (1-\alpha\gamma)v(\hat{\underline{I}}) - \hat{n}\hat{\underline{I}} - (1-\alpha\gamma)\theta^e_{(1)}(\hat{n})$$

where the variables $\hat{n}$ and $\hat{\underline{I}}$ are the optimal choices with contractibility. When $\hat{n}_d = \hat{n} = \tilde{n}$ this is equivalent to:

$$\left[v(\hat{\underline{I}}_d) - \tilde{n}\hat{\underline{I}}_d - \left(v(\hat{\underline{I}}) - \tilde{n}\hat{\underline{I}}\right)\right] + \alpha\gamma\left[v(\hat{\underline{I}}) - \theta^e_{(2)}(\tilde{n})\right] > 0$$

where the first square bracket is positive, and the condition is then implied by:

$$v(\hat{\underline{I}}) > \theta^e_{(2)}(\tilde{n}).$$

These two assumptions are consistent with the facts that if procured investment is nil, the value of complete procurement is relatively low, and the buyer is ready to minimize its cost with single sourcing. On the other hand, when the buyer wants to procure a very large investment, then risking incomplete procurement is very costly, and dual-sourcing should be optimal.

Now notice first that if the investment is the same $\underline{I}_B^* = \underline{I}_d^* = \hat{I}$, for any given δ the buyer, when indifferent between single- and dual-sourcing, will choose a larger number of developing firms under dual-sourcing than under single-sourcing. In other words:

$$H_d(\hat{I}, n_d^*) = H(\hat{I}, n_B^*) \quad \text{implies} \quad n_d^* > n_B^*.$$

With dual sourcing, the buyer can leverage the larger expected rent for suppliers, thus affording more competing firms. Notice also that for any given δ and equal number of developing firms $n_d^* = n_B^* = \hat{n}$, the optimal target investment under dual- and single-sourcing are such that:

$$\underline{I}_d^* > \underline{I}_B^*$$

because the optimal target investment under single-sourcing is such that:

$$v'(\underline{I}_B^*) = \frac{\hat{n}}{\delta(1-\alpha\gamma)}$$

while the optimal target investment under dual sourcing is given by:

$$v'(\underline{I}_d^*) = \hat{n}\frac{1}{\delta}.$$

Following the same steps as in the proof of Proposition 1, it now follows immediately that for any given δ if the function $v(\cdot)$ is sufficiently concave when the buyer is indifferent between single- and dual-sourcing: $H_d(\underline{I}_d^*, n_d^*) = H(\underline{I}_B^*, n_B^*)$ hence we have $n_d^* \underline{I}_d^* > n_B^* \underline{I}_B^*$

Moreover, the envelope theorem implies that, as in Subsection 5.2 above, the effects of δ on the optimal value of the buyer's per-period payoff under both dual- and single-sourcing are:

$$\frac{\partial H_d}{\partial \delta} = \frac{(n_d^* \underline{I}_d^*)}{\delta^2}, \qquad \frac{\partial H}{\partial \delta} = \frac{(n_B^* \underline{I}_B^*)}{\delta^2} \tag{31}$$

If $v(\cdot)$ is concave enough, $\frac{\partial H_d}{\partial \delta} > \frac{\partial H}{\partial \delta}$, and since $H_d(0, N) < H(0, N)$ and $H_d(\hat{\underline{I}}_d, \hat{n}_d) > H(\hat{\underline{I}}, \hat{n})$, by continuity there is a threshold for δ such that $H = H_d$. We can then conclude that when the function $v(\cdot)$ is sufficiently concave, if δ increases, the buyer moves from optimally choosing single-sourcing to choosing dual-sourcing: dual-sourcing is more likely the higher the level of δ. This concludes the proof.

Q.E.D.

Although the thresholds for concavity of Proposition 4 and of Proposition 1 are not the same, the result is based on a similar mechanism. First, dual-sourcing guarantees a larger rent to suppliers than single-sourcing. Hence, as in the model in the main test, the "slackness" in suppliers' incentive compatibility translates into a larger optimal number of developing suppliers n_d^* *and* higher investment $\underline{I}_d^*$ (d denotes dual-sourcing) compared with single-sourcing, if the function $v(\cdot)$ is sufficiently concave. Second, the higher investment and larger number of suppliers imply that the actual cost of development with dual-sourcing $(n_d^* \underline{I}_d^*)/\delta$ is higher than that with single-sourcing. This finally implies that an increase of δ benefits the buyer (in reducing the actual cost of development) more with dual-sourcing than with single-sourcing, so that if a larger δ has an effect, it induces the buyer to move from single-sourcing to dual-sourcing.

When procurement design is in the hands of suppliers, dual sourcing seems less relevant and natural. If the buyer's value significantly reduces in case of production halt, a "main" supplier with bargaining power may involve one (or more) additional supplier with the type of step-in contract described above. This sub-contract would allow an increase the buyer's expected value, which the leading supplier can then extract. At the same time, the difficulty is that, in addition to his incentives, the leading supplier must also guarantee the sub-contractors incentive compatibility constraints with appropriate transfers. The optimality of subcontracting very much depends on this subtle comparison, and, what is more, for our purposes, the effect of a larger δ is ambiguous.