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We study how informal buyer-supplier relationships in the German automotive industry affect procurement. Using unique data from a survey focusing on these, we show that more trust, the belief that the trading partner acts to maintain the mutual relationship, is associated with both higher quality of the automotive parts and more competition among suppliers. Yet both effects hold only for parts involving unsophisticated technology, not when technology is sophisticated. We rationalize these findings within a relational contracting model that critically focuses on changes in the bargaining power, due to differences in the costs of switching suppliers.

Reference Details

2154	Cambridge Working Papers in Economics
2021/01	Janeway Institute Working Paper Series
Published	2 August 2021
Key Words	Relational Contracts, Hold-up, Buyer-Supplier Contracts, Bargaining Power
JEL Codes	D86, L14, L62, O34
Websites	www.econ.cam.ac.uk/cwpe
	www.inet.econ.cam.ac.uk/working-papers

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*This is a very substantial revision of the paper by the same authors entitled *Trust, Investment and Competition: Theory and Evidence from German Car Manufacturers*. We greatly benefited from comments by James Best, Maria Bigoni, Patrick Bolton, Jeff Butler, Andrew Clausen, Liran Einav, Chaim Fershtman, Bob Gibbons, Pierre-Olivier Gourinchas, Maria Guadalupe, Tobias Klein, Shaul Lach, Rocco Macchiavello, Bentley McLeod, John Moore, Hodaka Morita, Rob Porter, Wilhelm Rall, Larry Samuelson, Klaus Schmidt, Nicolas Schutz, André Stenzel, Ina Taneva, Jonathan Thomas, Peter Vida, Luis Vasconcelos, Giorgio Zanarone, Luigi Zingales and of seminar participants at numerous institutions. We acknowledge the generous hospitality of the Studienzentrum Gerzensee. Leonardo Felli gratefully acknowledges support by the Keynes Fellowship at the University of Cambridge, and Konrad Stahl by the Deutsche Forschungsgemeinschaft through CRC TR224 (project B04).

1 Introduction

Relational contracts, informal agreements sustained by the value assigned to future interactions, are a key feature of business relationships. They complement formal contracts, and in certain cases can be considered a substitute to integration that plays an increasingly important role in many economies.[1] A recent example of such a business relationship has led to a crucial medical breakthrough: After successfully cooperating previously for two years, BioNTech and and Pfizer worked together for twelve months sharing valuable intellectual property, before even signing a formal contract to develop one of the first vaccines against the Coronavirus SARS-CoV-2.[2]

Informal relationships are particularly relevant in the German automotive industry. Independent upstream suppliers exploit economies of scale by producing parts for multiple downstream firms, while carrying out cutting-edge research and development whose results are embedded in – often buyer-specific – parts.[3] The key players in the industry, who include the world's largest part suppliers and some of the leading buyers, have been operating as vertically separate units since at least WWII, so their relationships have lasted for decades without any major interruption. To be successful, these long term relationships require each party to trust that their partner will not exploit the relationship to increase its short-term profits.

We analyze in this paper the consequences of a serious shock to the procurement relationships in the German automotive sector. In the early 1990s Ignacio Lopez, then in charge of procurement at GM, and his entire team were poached by German carmaker VW. Their mission was to implement the highly aggressive, cost-saving procurement practices that Lopez had been (in)famous for at GM, with dramatic consequences on the buyer-supplier relationship (see Helper and Henderson, 2014). In the German automotive industry, these practices threatened the entire innovation-driven business model of upstream suppliers. Until then, suppliers had willingly shared results of their expensive R&D efforts embedded in their blueprints for innovative parts with buyers, while competing for procurement contracts. This willingness was based on the expectation that their substantial efforts would be compensated at least in part through being chosen for production. An essential feature of Lopez's strategy was to use these blueprints without compensation for open procurement, pushing prices toward marginal costs and thereby expropriating the supplier's intellectual property.[4]

[1]See Gibbons and Henderson (2013) for a survey on the 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]See Müller et al. (2016). German automotive suppliers tend to be more research oriented than in the U.S. and Japan, where research is mainly carried out by the buyers. For instance, Koppel et al. (2018) report that in 2015, the two largest German suppliers filed about as many patent applications as the five most research intensive automotive producers.

[4]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*.

The drastic change in procurement practice led to a substantial increase in VW's short run profits. Moreover, Lopez' strategy was adopted – to varying degrees – by VW's German competitors. The affected long-term supplier-buyer relationships underwent dramatic transformation, threatening the underlying innovation-oriented model.

The long shadow of this disruption prompted the German Association of Car Manufacturers (VDA), whose board includes the CEOs of all German automotive producers and the leading suppliers, to unanimously commit to a detailed and costly benchmarking study in 2007 on the consequences of that disruption. At its heart was a survey developed by a steering committee involving researchers as well as representatives of the participating manufacturers and suppliers. Mostly identical questionnaires were addressed to both buyers and sellers, to capture the views from both sides. The survey respondents were procurement experts on the buyer side, and specialists in the areas of development, production, and sales on the supplier side.[5] The joint effort resulted in one of the largest and most detailed surveys to date of buyer-supplier relationships in an industry that provides complex final products.

The survey was designed primarily to identify distortions of the informal long-term relationships, and secondly to identify violations of legally enforceable contracts. The documentation of these distortions renders our data unique in capturing relational contracting issues. That these disturbances prompted the national industry association to initiate this major study underscores their importance for the entire industry. The survey was conducted between Fall 2007 and Summer 2008, more than ten years after Lopez was removed from VW. The relationships between buyers and suppliers reflected therein extend backwards well beyond that critical episode.[6]

In our empirical, and an ensuing theoretical analysis rationalizing our empirical results, we focus on two aspects important to understanding relational contracting within high tech industries: How differences in mutual trust affect the suppliers' investment into the development of buyer-specific parts; and how differences in trust affect the number of suppliers the buyer selects to compete in development and production. Trust between suppliers and buyers was *the* central and policy relevant topic of this unique survey. The notion of *mutual trust* measured in it was developed in intensive discussions within a steering committee consisting of chief procurement and sales executives nominated by the members of the VDA board.

Empirically, we find first that, not unexpectedly, higher mutual trust between a supplier and a buyer is associated with a lower incidence of quality problems, indicating higher (unobservable) buyer- and part-specific investment. The observed association is

[5] The survey contained 335 questions. Its preparation and execution cost many precious workdays.

[6] The relationships reflected in the data had been in place for more than 15 years on average (the question was censored at the top, so the actual average is higher). An indication for the importance of relational aspects is that in our data the share of litigated violations of formal contracts is negligible, below one percent. The Kiekert-Ford-Case exemplifies relational (instead of legal) punishment in the industry: Kiekert, a specialized producer of car locks, claimed a serious issue in its process computing facilities during contract negotiations with Ford. This stalled Ford assembly lines for weeks, until a continuation contract favorable to Kiekert was signed. In response, Kiekert was excluded by Ford from future contracts. Ford chose a relational form of punishment instead of pursuing damages in court. See Wachtler (2002).

significant only for low-tech parts involving low rather than high complexity, however. We find second that higher trust is associated with more suppliers invited by the buyer to compete in development, and more frequent co-sourcing of production of a given part.[7] Again, this relationship between trust and competition is significant only for low-tech, and not for high-tech parts.

It is generally challenging to establish causality on the basis of cross-sectional survey data. We use observations on past buyer behavior to instrument our measure of trust. In particular, the buyer passing on suppliers' intellectual property rights, which is detrimental to trust, should not directly affect current part quality. The reported results remain unchanged. These findings do not imply that trust is generally irrelevant for procurement relationships involving high-tech parts. Indeed, the survey responses indicate that trust is equally important in relationships involving each of the different part categories.

We develop a theoretical model to explain these puzzling observed patterns. In our model, outcomes depend not only on the beliefs of the contracting parties, but also on the complexity of the procured parts and the associated costs of switching their production to a different supplier. The level of these switching costs determines who of the two parties has the bargaining power, and with it, influences their allocation decisions.

More specifically, a buyer repeatedly procures the development and production of a part, including a blueprint requiring buyer-specific non-contractible investment.[8] Several suppliers are capable of this, but differ in production costs unknown to the buyer. At the start of the development phase, the buyer invites a subset of these suppliers to competitively invest in developing the blueprint, and formulates performance specifications requiring the typical supplier's non-contractible investment.[9] The investment cost is compensated by a contractible transfer payment from the buyer, together with expected rents generated from eventual production. The buyer awards the production contract using an efficient procedure.

Mutual bilateral trust between a buyer-supplier pair used in our empirical analysis is modeled by using a common discount factor that reflects the parties' valuation of the continued relationship. The central comparative statics result is that an increase in the discount factor allows the buyer to increase both the number of suppliers involved in the development phase and the required investment. The relational contract ensures that suppliers invest during the development phase despite increased competition; in return, buyers limit outside competitors' access to competing for the production contract. In particular, the relational contract would break down if, as in Lopez's strategy, the buyer would deviate by opening up competition to suppliers that had not previously undertaken relationship-specific development investment.

[7] By contrast, one could expect from theory and the existing empirical evidence (Calzolari and Spagnolo, 2009; Macchiavello and Morjaria, 2021) that stronger competition between suppliers for procurement contracts would be detrimental to the relationship with a given buyer.

[8] While the buyer-supplier relationships in general are very long-lasting, procurement for parts for any given car model is repeated every 12-18 months in the course of model-updates.

[9] The engineers of both buyers and suppliers in the steering group unanimously agreed that it is impossible in practice to assign supplier's development investment to individual car models, due to the large role of investment into basic research.

Which of the parties reaps the additional benefits arising from higher trust depends on the allocation of bargaining power, associated with the cost involved in taking the winning blueprint and selecting a supplier from outside the original subset to produce the part, which we refer to as "switching costs".[10] These costs are substantially smaller for low-tech than more complex high-tech parts. For low switching costs, the bargaining power rests with the buyer.[11] An increase in mutual trust allows the buyer to increase required investment and/or increase competition among suppliers in the development process. For high switching costs, the bargaining power rests instead with the supplier. Hence when mutual trust increases, the leading supplier controls required investment, but the buyer does not control the number of suppliers competing in the development process, so competition does not increase at this stage.[12]

Corresponding to our empirical analysis, this does not mean that trust is unimportant for procurement relationships involving complex products. But in those cases, the supplier, being the residual claimant of the returns from investment, has no incentive to change his choice of investment when mutual trust increases and the buyer is not able to extract the additional rent from higher trust by increasing competition. Hence, this explains our puzzling empirical result: We do not observe a relationship between trust and these variables for high-tech products.

While our analysis reflects the specifics of an important economic sector in one country, it provides insights relevant for other procurement environments across 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.[13]

In the next Section 2 we present the related literature. We describe the data generation and provide descriptives in Section 3. Section 4 is devoted to our empirical analysis. We describe and analyze our model in Section 5, and conclude in Section 6. An empirical and a theoretical appendix provide additional details.

2 Related literature

We contribute to a growing literature on managerial practice in manufacturing firms (Bloom et al., 2014), and in particular to the literature on relational contracts that by nature must be based on mutual trust. Malcomson (2013) and Gibbons and Henderson (2013) provide complementary surveys. See also MacLeod (2007). The importance of relational contracts is documented in a variety of industries, ranging from the US and Japanese automotive sectors (Helper and Henderson, 2014; Bernstein, 2015), to airlines

[10]Our notion of switching cost differs from the consumer switching cost established in the literature (see Klemperer, 1995, for a survey), that is subject to strategic manipulation by the seller.

[11]In this case, the gains to the buyer from having the bargaining power exceed the gains to the selected supplier from having it: Any competitive bidding process that allocates bargaining power ex-ante would be won by the buyer.

[12]However, the buyer retains her residual right to deviate, and procure production from all available suppliers – at the cost of provoking the suppliers' deviation to a lower investment level.

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

(Gil et al., 2016), US highway procurement (Gil and Marion, 2013), and movies (Barron et al., 2020). They are particularly important for trading relationships when legal enforcement is weak, such as in developing countries(see Macchiavello, 2018, for a survey) and in international trade (see, e.g., Antràs and Foley, 2015)). Most closely related to our paper are McMillan and Woodruff (1999), and in particular Macchiavello and Morjaria (2021). They show that within a weak legal system, an exogenous increase in competition in agricultural products leads relational contracting to shrink. In an earlier version of their paper, Macchiavello and Morjaria (2015b) link the effect of increased competition directly to a decrease in reported trust towards their trading partners. Our setting involves a strong, effective legal system, but one where competition (among suppliers competing for a procurement contract) is endogenous. Here, the causality is reversed: an improvement in the relationship allows buyers to increase suppliers' competition.

Studying a change of managerial practice in a US transportation firm, Blader et al. (2015) and Blader et al. (2020) identify complementarities between such practices and relational contracts, supporting Gibbons and Henderson's view that the reason why effective managerial practices do not spread easily across firms are difficulties involved in building and re-building relational contracts. The latter might explain why the German VDA was so worried about the negative long-run consequences of Lopez's disruption.

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) or Malcomson (2013), among many others, refer to the classic Fisher-GM vertical integration case or Asanuma (1989)'s case-based description of upstream supplier-buyer relationships in the Japanese automotive industry. Our evidence is in the same spirit, based on the most detailed benchmarking study of this industry we are aware of.

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.[14] 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 between sizeable firms.

In theoretically addressing relational contracts between one principal and several competing agents, 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).[15] However, none of these models fits the relationships we observe nor exhibits the comparative statics relevant to our data, including the allocation of bargaining power

[14]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.

[15]Calzolari and Spagnolo (2009) extend the relational contracting model of Levin (2003) to multiple competing agents, and show that restricting competition to a smaller set of agents helps limiting post-contractual moral hazard, but at the risk of inducing collusion among agents against the principal. De Chiara (2020) extends the approach to show that restricting competition/negotiations may also be optimal to sustain pre-contractual investment. These aspects are also addressed in the legal literature.

to different parties (on the latter, see MacLeod and Malcomson, 1998).

The economic relevance of part complexity is also addressed in the supply chain literature. Gosh et al. (2006) argue that the vendor should take control in customizing complex products. We obtain a similar result, resulting from a different mechanism.

Finally, our paper is closely related to the literature on incomplete contracts following Grossman and Hart (1986) and Hart and Moore (1988), and in particular to the analysis of the role that competition plays in that setting. First, by our trade-off between competition and trust, competition can reduce inefficiencies associated with hold-up (Rajan and Zingales, 1998; Felli and Roberts, 2016). Second, when bargaining power shifts to the supplier, the hold-up problem is resolved.

3 Data and Descriptives

Below we describe our data, the phases of buyer-supplier interaction, and the main variables of interest. We then discuss our concept and measurement of part specific trust in the relationship with a buyer.

3.1 Databases

The detailed questionnaire survey on which our study is based was carried out between Fall of 2007 and Summer of 2008.[16] All firms addressed by the survey had committed to participate via their CEOs sitting on the VDA's board. A steering committee supervised and monitored the study in detail. It included chief procurement and sales executives nominated by the board members. In particular, the executives participated in the questionnaire design and phrasing of key items, ensuring a common understanding of definitions which is crucial to our identification strategy. Their participation also ensured the awareness of all participants that data collection and reporting would be completely anonymous.[17] The VDA board members' commitment also included monitoring the individual respondents' participation.

Sample and observations All 10 German automotive producers (7 producers of passenger cars and 3 truck makers, henceforth called buyers, or OEMs) participated in the survey, as well as all 13 leading German parts suppliers that are members of the

A key example is Bernstein (2015). Board (2011) and Andrews and Barron (2016) study alternative models of relational contracts in procurement, focusing more on the optimal complex dynamics of these contracts than on the intensity of competition induced by the principal.

[16]It was preceded by case studies carried out between November 2005 and May 2006 that involved numerous interviews with high ranking representatives of first-tier suppliers' R&D, production and marketing departments, and automotive producers' procurement departments. Müller et al. (2016) summarise the results of these case studies. They document in detail the relationship between producers and their first-tier suppliers.

[17]This requirement also prohibits us from providing information that could identify individual firms' responses or profiles.

board. They in turn selected the survey respondents who were the firm's specialists for the topic in question.

While the survey included all German buyers, our supplier sample is not representative. It tends towards large participants, with average revenues in 2007 of 9.4 billion euros. Even the smallest participant posted revenues of more than 700 million euros. Yet the selection focuses on long-term supplier-buyer relationships, involving several decades. This ensures that the survey responses indeed reflect relational contracting issues.[18] Furthermore, the support of the VDA's board members ensured the completion of the questionnaire that required considerable commitment by the respondents.

The suppliers were asked to evaluate their relationship with each participating buyer plus, for benchmarking purposes, one outsider in relation to specified parts supplied to the buyer. Conversely, key managers of the buyers' procurement divisions were asked the same questions, but in relation to their experience in the procurement of the four parts categories defined below.

An observation is defined as a given supplier's view on a given buyer's procurement practices with respect to a given part, for example spark plugs. The same supplier's view on that buyer's procurement practice with respect to, for example, an electronic stabilization program, constitutes a different observation. Different sets of questions were addressed to the corresponding specialists in the firms.[19] We merged the answers given by all respondents on a given buyer and part across the different functions to obtain a complete observation. Whenever segments of the questionnaire overlapped, we used the arithmetic mean of the responses. Summarizing, an observation in our empirical approach represents the aggregate view of the supplier's employees on the relationship with a given buyer, with focus on a specific part.[20]

Parts categories For the purposes of benchmarking and to be able to compare responses across different part-specific relationships, industry standard product group definitions were used, involving the following four categories:

[18] 61% of the observed buyer-supplier relationships had lasted longer than 15 years. Among the remaining 39 % shorter relationships, the average duration is 8.7 years. This still covers more than 8 generations of annual introductions of new car models by each OEM. Only 1% of our part-specific observations stated a duration of the relationship of less than 4 years.

[19] Respondents were first asked to indicate their function within the company out of the following seven: *pre-development*, *vehicle development*, *series production*, *quality control*, *sales*, *logistics*, and *aftermarket production*. For each part and customer, they would then answer the set of questions suited to their function within the company. See Müller et al. (2016) for a detailed description of the individual functions and the automobile development and production process.

[20] With regard to survey participation, at the supplier/buyer/product group level, there are theoretically 13 (suppliers) x 11 (buyers) x 4 (product groups) = 572 potential relationships. In fact, out of the 13 suppliers, only 6 actually sell products from each product group, with 3 firms limited to 3 types of parts, 4 firms limited to 2 types of parts, and 1 firm only selling 1 type of part. Furthermore, since not every supplier provides parts from each product group to each buyer, the potential number of relationships is further reduced to 369. Out of these, we obtained responses for 308 different relationships. The number of complete observations is finally reduced because respondents did not necessarily answer all questions.

(Low-tech) Commodities: relatively simple, technologically unsophisticated parts requiring little specific investment; for example, wear parts such as brake linings;

(High-tech) Components: technologically sophisticated parts, often including a combination of mechanical and electronic functionalities; for example, radar distance sensors;

(Low-tech) Modules: technologically relatively unsophisticated part groups designed and assembled by suppliers; for example, front-ends (body) or shock absorbers;

(High-tech) Systems: technologically sophisticated part groups designed and assembled by suppliers; like brake systems or the electronic stabilization program, ESP.

The frequency of observations of systems (16.4%), modules (22.4%), high-tech components (24.3%) and commodities (33.2%) varies slightly. To confirm the classification, we flesh out their assignment using responses from the survey. First, we obtain the share of a part's development relative to its total costs. For a subset of products, we also observe development costs relative to total part revenue. Second, we observe the number of patent applications related to the part in question that were filed in the five years prior to the survey.

The descriptives in Table 1 show that low- and high-tech parts differ significantly w.r.t. development cost shares. Systems/components (around 10% of total costs, more than 6% of part revenues) differ clearly from modules/commodities (7-7.5% of total costs, 2.5-3.3% of part revenues), but not within each group. Figure 1 shows that the corresponding differences in patent applications (last 5 years) are not quite as clear: Perhaps surprisingly, more than 80% of low-tech parts are associated with at least 5 patent applications. The main difference is in the category of parts with more than 20 patent applications that is mainly driven by systems, the most complex part category. We will come back below to the differences between development costs and patenting.

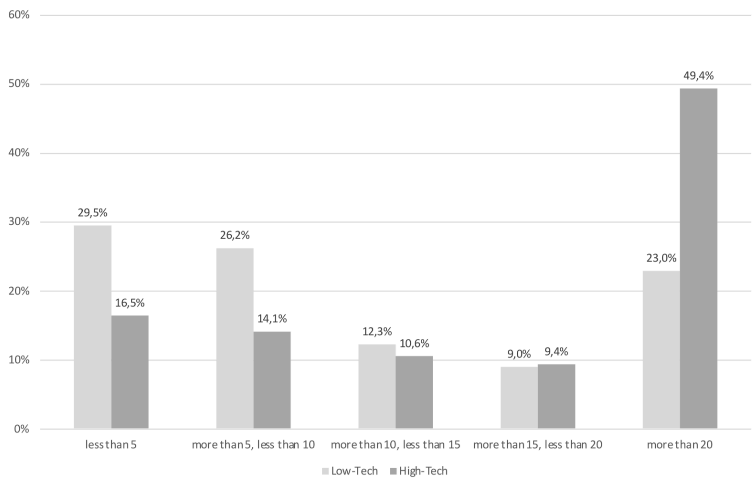
Development and production phases The full questionnaire, containing 185 questions plus 150 sub-questions, covers three distinct development phases that any part undergoes: *Pre-development*, *development*, and *series production*. Pre-development covers basic R&D activities on new technology. It is less related to individual car manufacturers and models. The design of a new fuel-efficiency technology, for example, has to be compatible with a wide range of motors from different manufacturers.

The development phase, by contrast, is focused on a given car model and buyer-specific. The corresponding investment starts with a product planning phase and continues into product specification. The general parameters of the part being developed are essentially based on the buyer's request. The suppliers competitively develop a concept for the part. This results in a blueprint, which in principle would enable competent suppliers to produce the part. But switching the supplier would entail substantial costs. A key reason is that the developing supplier's investment and learning cannot be entirely embodied in the blueprint. The more complex the part and thus a specific blueprint, the harder to have it implemented by another supplier. In the series production phase,

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.
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
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
Share more than 20 patents in last 5 years	**70.0%**		**9.8%**		**38.0%**		**29.6%**		**49.4%**		**23.0%**		207
Share less than 5 patents in last 5 years	**6.7%**		**17.1%**		**22.8%**		**35.8%**		**29.5%**		**16.5%**		207
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
Number of competing suppliers:													
Pre-Development	**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
Development: Product planning	**2.22**	1.10	**2.16**	1.13	**2.04**	0.92	**2.43**	1.22	**2.33**	1.19	**2.09**	0.97	152
Development: Product specification	**2.15**	1.10	**2.04**	1.15	**1.98**	0.92	**2.1**	1.06	**2.08**	1.08	**2.03**	0.97	162
Development: Concept development	**1.97**	0.87	**2.14**	1.08	**2.19**	0.89	**2.18**	1.25	**2.17**	1.19	**2.12**	0.88	192
Development: 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
Series Production: Start of 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
Series Production: 1-2 years after SOP	**1.31**	0.47	**1.12**	0.30	**1.37**	0.48	**1.77**	1.08	**1.54**	0.94	**1.35**	0.47	215
Series Production: > 2 years after SOP	**1.60**	0.56	**1.23**	0.42	**1.49**	0.53	**1.83**	1.11	**1.61**	0.97	**1.53**	0.54	211
Share of supplier's development costs absorbed by OEM													
… through lump-sum payment	**27%**	0.261	**43%**	0.324	**26%**	0.25	**22%**	0.234	**28%**	0.279	**29%**	0.287	193
… via markup on parts procured	**59%**	0.264	**60%**	0.299	**57%**	0.291	**48%**	0.333	**56%**	0.253	**53%**	0.325	186
… in total	**88%**	0.304	**101%**	0.289	**81%**	0.279	**69%**	0.394	**84%**	0.289	**80%**	0.390	177
Risk sharing	**1.83**	0.57	**2.16**	0.9	**2.01**	0.73	**1.70**	0.75	**1.94**	0.67	**1.86**	0.83	222
Freq, of lump-sum rebates	**31.1%**	0.279	**28.1%**	0.276	**20.6%**	0.255	**22.6%**	0.28	**24.5%**	0.267	**24.5%**	0.279	193
Pre-Development:													
Freq. IPR conflicts	**6.8%**	0.114	**22.7%**	0.236	**8.6%**	0.130	**10.7%**	0.150	**7.9%**	0.124	**12.8%**	0.172	123
Freq. IPR pass-on	**37.5%**	0.233	**37.4%**	0.247	**33.6%**	0.228	**27.20%**	0.249	**35.10%**	0.229	**30.5%**	0.252	245
Development:													
Freq. IPR conflicts	**36.4%**	0.206	**37.9%**	0.194	**31.2%**	0.195	**26.2%**	0.211	**32.7%**	0.198	**29.5%**	0.212	182
Freq. IPR pass-on	**38.2%**	0.305	**37.5%**	0.285	**43.6%**	0.313	**35.8%**	0.336	**41.9%**	0.309	**36.3%**	0.322	162

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?"

Table 1: Descriptive statistics, differentiated by type of part



Number of patent applications for the part under consideration. Shares for low-tech parts in light gray, shares for high-tech parts in dark gray.

Figure 1: Number of patent applications in 5 years prior to survey.

typically one, at most two suppliers work with their blueprints for the part selected by the buyer, and invest in (expensive) model-specific production tools.

Part quality A key variable studied is the quality of parts. Suppliers were asked with regard to a specific part and 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%. In Table 1, we observe substantial differences in quality issues arising across part-categories, arising more frequently for systems (19.9%) and modules (24.3%) than for the physically smaller components (12.8%) and commodities (10.3%).

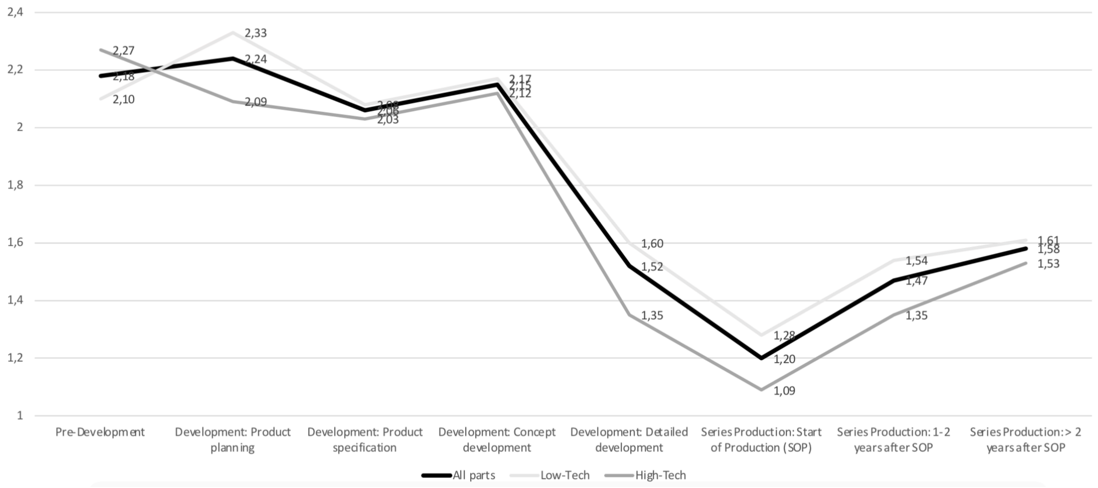
Number of suppliers Figure 2 and Table 1, and in more detail Table 2 display the number of suppliers working in the different phases for a given OEM and part selected for the survey. In the earlier sub-phases of development, more than two competing suppliers are tasked on average with development of the underlying technology. In the final development phase, the number of suppliers drops to 1.60 (low-tech) and 1.35 (high-tech parts). Alternatively speaking, in about 35-60% of part procurement processes the manufacturer invites competing suppliers to present a blueprint for part production. At the start of production, the number of suppliers reaches its nadir. In only 9% (high-tech) to 28% (low-tech) of procurement relationships multiple-sourcing is immediately implemented. In later phases of production (i.e., after 1-2 years and later) this number increases again substantially.

The evolution of the number of parallel suppliers across the product life-cycle, depicted in Figure 2 and contained in Table 1, exemplify how our data –despite resulting

Part description	Number of suppliers 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".

Table 2: Descriptives: Types, part descriptions and measures of internal and external competition.



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.

Figure 2: Mean number of parallel or competing suppliers along product lifecycle.

from a cross-sectional survey– is also longitudinal in nature. Pursuant to this, Table 3 shows pairwise correlations between the number of suppliers at the different sub-phases. Correlations are extremely high within the development and series production sub-phases, while they are substantially lower across the different phases (e.g., development and series production). Below we will focus on three of them: (unspecific) pre-development, the final phase of development resulting in the blueprints, and the start of series production.

The suppliers selected for development are typically compensated their development expenses by a fixed lump sum payment that covers only a fraction of costs, and by a mark-up on parts delivered to the buyer in the course of production. Table 1 contains the suppliers' view of compensation shares through the two channels. Between 69% (commodities) and 88% (systems) of development costs are absorbed by the OEMs in total through the two channels. From the perspective of the OEMs, these numbers are substantially higher, ranging from 96% (components) to 110% (systems). The difference is likely due to differing attributions of model and buyer-specific development expenses. Both suppliers and buyers agree, though, on the share of compensation that is attributable to lump-sum vs. markups: Lump-sum payments contribute 34% of total compensation according to suppliers (33% according to OEMs), mark-ups on parts produced 66% (67% according to OEMs). In view of this, cuts in the volume procured are costly to any supplier. This will be a major focus below.

Towards extending our picture of buyer-supplier relationships by part categories, we merged our benchmarking data with a separate commercial database, "Who supplies whom" (WSW) collected by supplierbusiness.com. Based on reports by industry participants, this database records actual part and model specific supply relationships between manufacturers-supplier pairs. We use them to specify the number suppliers by part rel-

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Pre-Development	1,00							
(p-level)								
(2) Development: Product planning	0.463	1,000						
(p-level)	(0.000)							
(3) Development: Product specification	0.443	0.861	1,000					
(p-level)	(0.000)	(0.000)						
(4) Development: Concept development	0.200	0.658	0.677	1,000				
(p-level)	(0.037)	(0.000)	(0.000)					
(5) Development: Detailed development	0.434	0.408	0.441	0.601	1,000			
(p-level)	(0.000)	(0.000)	(0.000)	(0.000)				
(6) Ser. Production: Start of production	0.412	0.336	0.319	0.255	0.519	1,000		
(p-level)	(0.000)	(0.001)	(0.001)	(0.003)	(0.000)			
(7) Ser. Production: 1-2 years after SOP	0.379	0.344	0.328	0.337	0.597	0.790	1,000	
(p-level)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
(8) Ser. Production: > 2 years after SOP	0.436	0.359	0.321	0.300	0.578	0.729	0.930	1,000
(p-level)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	

Pairwise correlations (and p-values) between number of suppliers employed at the various phases of the part life-cycle.

Table 3: Correlation between the different observed numbers of suppliers across phases (p-values in parentheses).

evant to the German market overall at the time of the survey. The last column of Table 2 contains the numbers.

3.2 A measure of trust

Selection Central to our analysis is how we measure relationship-specific trust between suppliers and buyers in the German automotive industry. We consider trust in a counterpart as a belief with regard to the counterpart's type. In particular, higher trust implies a lower subjective probability of experiencing opportunistic behavior by the party in question –or equivalently, in higher value placed on future interactions with the counterpart.[21] The industry context and the underlying motivation for the benchmarking study allow us to be very specific concerning the types of opportunistic behavior that should be conducive (or detrimental) to trust.

For each phase of the part's life-cycle (pre-development, development, production), the questionnaire included the question *Evaluate the role each of the following factors for the automotive producer's supplier selection*, followed by a number of factors, with importance to be evaluated on a six point scale from 1 (no relevance) to 6 (very important). The response of central interest for our study is to the factor *Mutual trust between the buyer and the supplier.* Therefore, we have up to three evaluations at different phases of the development and production process of how mutual trust contributed to the selection of the supplier for that part, which we can consider as a relationship- and part-specific trust variable.

We use the mean of the responses, and refer to the resulting variable as the "trust index". Constructing our central variable this way has several advantages. It covers different sub-phases of the product life cycle and thus represents the views of multiple representatives of a particular supplier. Also, it was addressed at all suppliers, as opposed to other measures discussed below that were only addressed at subsets of the suppliers, e.g., those who initiated the development process themselves.

Before a verification of our trust measure below we briefly discuss observed variation in that measure across part categories and across buyers. As to variation across parts categories, one could expect that trust is more important for complex high-tech parts whose development and production requires more know-how by the supplier. This is not reflected in our data. Table 4 displays the means for the four types systems (4.82, std. dev. 0.79), modules (4.83, std. dev. 0.71), components (4.89, std. dev. 0.72) and commodities (4.80. std. dev. 0.87). The means and standard deviations are almost identical and cannot be statistically distinguished.

The variation in the trust measure across buyers is summarized in Figure 3. On the one hand, the trust measure varies only insignificantly across buyers considering the observed means. On the other hand, for each buyer there is substantial variation of the measure across relationships with different suppliers. More than that, the example of a given large supplier (black dots) further shows that, even for a given supplier-buyer pair, trust may vary substantially across the individual part types supplied in this

[21] This is akin to the notion introduced by Gambetta (1988) and endorsed by Williamson (1993). For a more recent definition, see Cabral (2005).

Variable	Mean (Std. Dev.)	Min	Max	Obs.
Overall				
Trust index	4.83 (.79)	1.5	6	296
Trust index (n)	- .63 (1.06)	-4	2.7	295
Systems				
Trust index	4.82 (.79)	3.2	6	43
Trust index (n)	- .70 (0.95)	-2.5	1	43
Modules				
Trust index	4.83 (.71)	3.1	6	62
Trust index (n)	- .61 (1.09)	-2.6	2	62
Components				
Trust index	4.89 (.72)	3	6	72
Trust index (n)	- .63 (1.04)	-3	2.7	71
Systems				
Trust index	4.80 (.87)	1.5	6	119
Trust index (n)	- .63 (1.10)	-4	2.3	119

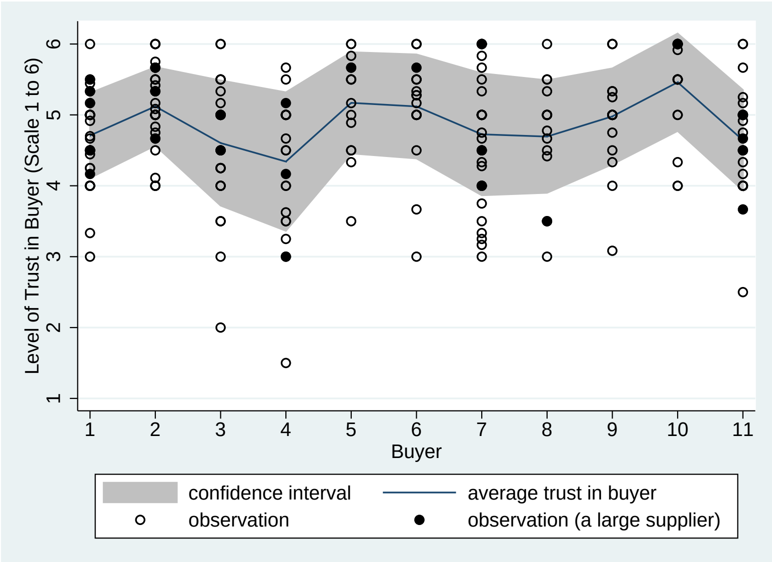
Trust indices by type of product. Trust index = arithmetic mean of the available responses to the question: *Please evaluate the importance of mutual trust between the supplier and OEM for the OEM's supplier selection*, rated on a six point scale from 1 (no relevance) to 6 (very important) across the three phases pre-development, development and series production. Trust index (n) = normalized trust index: mean of differences between importance of mutual trust and importance of price.

Table 4: Trust index summary statistics

relationship: The typical buyer's procurement officers are individually responsible for specific parts, or part groups, and variation in buyer behavior can be expected across parts even towards a given supplier, reflecting in particular the intensity of supply-side competition.

Verification The questions regarding trust were central to the entire benchmarking study, and thus were developed and discussed most intensely in the steering committee. Still, there could be alternative interpretations of the questions, potentially resulting in measurement error: In particular, respondents might state that trust is important for the relationship in principle (so that we measure a high value), while consider it to be lacking in practice (which we would not observe). Whether this interpretation matters is revealed by relating the responses to further trust questions included in the questionnaire, that link trust directly to behavior on key 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?* Both of these measures are highly correlated with the trust index (0.43, p-value 0.000; 0.47, p-value 0.000), which supports our interpretation of the measure.

To further test the validity of the measure, we make use of the longitudinal aspects of the survey, related to buyer behavior in the past that should be detrimental (five items)



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.

Figure 3: Variation in the trust measure.

or beneficial (one item) to the supplier's trust. For pre-development and development, respectively, suppliers were asked to assess the frequency of conflicts with the buyer with regard to the supplier's IPR, as well as how often supplier IPR were leaked in the past by the buyer to competing suppliers, resulting in four different items related to pre-development and development phases.[22] Answers are along a five-point scale, with option three anchored at "about 50% of cases", so that we are able to convert the answers to frequencies.

Table 1 shows that passing on IPR without the supplier's consent occurs frequently, both in the earlier and in the later phase of development. It is reported for between 30% and 44% of all part-relationships. Not every such act is associated with conflict between the OEM and the supplier, especially at the early stage in pre-development. At the stage of development in which the blueprint is generated, the correlation between IPR pass-on by the buyer and buyer-seller IPR conflicts is far larger (0.51 in development vs. a significantly lower 0.18 in pre-development). This behavior is not necessarily less problematic in the earlier phase, however. It might just be more difficult to prove, due to the lack of a blueprint. At any rate, each of these four variables is associated with opportunistic, Lopez-type behavior that should be detrimental to trust.

Two further survey items, related to suppliers' compensation, capture aspects of confrontational procurement strategy. First, for the series production phase, respondents were asked to evaluate *(e)* the frequency of price renegotiations (demands for rebates) in the past by the buyer. Prices are typically negotiated at the outset of a relationship

[22]Note that in the desire to maintain the relationship, suppliers tend not to enforce the IPRs in court.

to vary across quantity intervals produced. It is a clear indication for opportunistic behavior if an OEM demands further rebates beyond what is contractually agreed. This is reported for between a quarter and a third of part-relationships. At the positive end of the spectrum, respondents were also asked to assess *(f)* to which extent the buyer was willing to assist in case of unexpected development cost overruns in the past. Opposite of opportunistic behavior, this can be interpreted as the buyer investing in the future relationship.

For the four IPR-measures and the demands for rebates, we expect a negative correlation with a relationship-specific trust measure. For the final measure (risk-sharing), we expect a positive correlation. Given the structure of the questionnaire, we can add a seventh prediction: Next to the role of mutual trust, respondents also evaluated the role that price played in the selection process. Opportunistic confrontational procurement practices are driven by the incentive to cut costs and supplier prices. This should be captured by the role that prices played in the supplier selection process. We use this relationship in two different ways: First, if this holds, the relationship between the role of trust and the role of price should be negative. Second, we construct a "normalized" trust index as an alternative trust measure, by subtracting the evaluation of the role of price from the evaluated role of trust. This captures the role of trust relative to price in supplier selection. (See Table 4 for descriptives).

Table 5[23] exhibits regressions of the trust index onto each of the seven measures of interest. We control for potentially confounding factors, in particular the type of product in question, the suppliers' revenues as a proxy for size and bargaining power, and the number of suppliers offering this type of product in the German market at the time of the questionnaire (N).

The pattern is clear and unambiguous: Reported Lopez-type opportunistic behavior in the past is associated with significant and substantial reductions of the trust index.Vice versa, sharing the development risk by the OEM has a significant positive association with the trust index. Further, the results in column (7) of Table 5 indicate that there is in fact a tension between the roles of trust and price in supplier selection. This makes us confident that the trust index does measure what we are interested in.

4 Empirical Results

In this section, we study how the identified trust measure is related to quality issues and competition in part procurement, and separately analyze robustness and alternative causalities. We finally study the relationship between competition and quality issues as well as supplier compensation.

[23]In the Online Appendix, we also present the results for the normalized trust index; they are qualitatively identical.

Variables	**Trust Index**						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IPR Conflicts PD	**-0.470*** **						
	(0.124)						
IPR pass-on PD		**-0.273*** **					
		(0.0671)					
Risk sharing			**0.134** **				
			(0.0651)				
IPR Conflicts DEV				**-0.231*** **			
				(0.0666)			
IPR pass-on DEV					**-0.132** **		
					(0.0541)		
Lump-sum rebates						**-0.165*** **	
						(0.0520)	
Role of Price							**-0.241** **
							(0.120)
supplier revenues (bln)	0.005	0.004	0.007	**0.011** **	0.008	**0.008* **	0.014
	(0.006)	(0.004)	(0.004)	(0.005)	(0.005)	(0.004)	(0.009)
# suppliers overall	-0.001	-0.001	0.000	0.002	0.003	-0.005	-0.001
	(0.006)	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)	(0.006)
product type							
system (D)	reference category						
module (D)	0.069	0.106	0.116	0.009	-0.011	0.171	0.196
	(0.313)	(0.170)	(0.194)	(0.256)	(0.284)	(0.210)	(0.319)
component (D)	0.062	0.201	0.227	0.027	0.131	0.170	0.170
	(0.218)	(0.154)	(0.167)	(0.224)	(0.237)	(0.189)	(0.310)
commodity (D)	0.027	-0.037	0.109	-0.138	-0.017	0.154	0.244
	(0.229)	(0.183)	(0.197)	(0.238)	(0.253)	(0.201)	(0.285)
const	5.431	5.350	4.398	5.253	4.973	5.059	5.815
	(0.269)	(0.237)	(0.216)	(0.282)	(0.261)	(0.218)	(0.694)
Observations	121	241	220	179	159	193	126
R-squared	0.143	0.121	0.033	0.087	0.068	0.093	0.059

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%.

Table 5: Determinants of the Trust Index: OLS regressions

4.1 Trust and quality

The quality of individual parts is a strategic concern for manufacturers. Part quality contributes to and determines the quality and utility of the final product. It is typically not precisely observable for researchers, unless it leads to recalls of vehicles. Yet our questionnaire response provides us with a measure that is generally not observable to outsiders.

When trying to empirically assess quality issues, difficulties typically arise as (a) observed failure rates of automobiles often cannot be linked to individual parts, (b) quality problems found and solved before the parts are installed are not reported at all, and (c) buyer diligence or skill in assembling the final product may affect the contribution of a part to overall quality. Our responses are relationship and part-specific, which immediately solves (a). To overcome issue (b), the question in the survey was phrased as quality problem regarding the part, not the final product. Buyer complementary effort or skill is addressed by introducing a dummy for each of the eleven buyers in our regressions, that captures the buyer's effect on quality, taking care of issue (c). However, self-reporting of problems by suppliers –though anonymous– may lead to under-reporting. Assuming that more trust would lead to a higher likelihood of admitting problems in the questionnaire, we would only *underestimate* the actual effect.

As we will make use of below, part quality is an outcome of unobserved investment and effort by the supplier, a standard interpretation in the literature (Taylor and Wiggins, 1997; Womack et al., 1991). After controlling for factors such as part type (failure rates increasing in part complexity), market characteristics (failure rates driven down by competition), supplier size (more resources and capabilities) and buyer identity (buyer engagement in complementary investment), the remaining variation in observed part failures should be strongly associated with the supplier's effort and investment.

Our baseline specification is

$$y_{ijs} = \beta * x_{ijs} + \gamma * Z_{ijs} + \kappa + \alpha_j + \epsilon_{ijs}, \tag{1}$$

where y_{ijs} is the frequency of quality problems arising for part i supplied to buyer j by supplier s, x_{ijs} is the related trust measure Z_{ijs} are control variables, κ is a constant, and α_j a buyer fixed-effect. As motivated above, the control variables include dummies for the part type, the supplier's revenues in 2007 as a measure of size and market power, as well as the number of external competitors in Germany, N, derived from the WSW database. We estimate a fractional probit model taking the non-linear nature of the dependent variable into account as well as an OLS specification as a reference (results reported in the online appendix). As in all following specifications, we estimate robust standard errors clustered at the level of buyer-seller pairs.[24]

Table 6 contains the results. Columns 1 (without) and 2 (with buyer fixed effects) show that higher levels of trust are associated with significantly fewer quality problems. Neither supplier size nor number of competitors supplying the given part matter.

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

Variables	Frequency of Quality Problems Fractional Probit				
	(1)	(2)	(3)	(4)	(5)
Trust index	**-0.034****	**-0.043*****			
	(0.015)	(0.016)			
Trust index (low-tech)			**-0.050*****		
			(0.018)		
Trust index (high-tech)			-0.028		
			(0.033)		
Trust index (low dev. costs)				**-0.012****	
				(0.006)	
Trust index (high dev. costs)				-0.003	
				(0.006)	
Trust index (below median patents)					**-0.016****
					(0.008)
Trust index (above median patents)					**-0.018****
					(0.007)
product type					
system (D)			reference category		
module (D)	-0.028	-0.032	0.083	-0.021	-0.028
	(0.083)	(0.084)	(0.210)	(0.051)	(0.051)
component (D)	**-0.165****	**-0.175****	**-0.145*****	**-0.155*****	**-0.146*****
	(0.0768)	(0.0763)	(0.0550)	(0.0529)	(0.0514)
commodity (D)	**-0.177****	**-0.183****	-0.0531	**-0.170*****	**-0.178*****
	(0.0734)	(0.0754)	(0.207)	(0.0508)	(0.0514)
supplier_revenues (bln)	-0.00123	-0.00135	-0.00124	-0.00173	-0.00143
	(0.00153)	(0.00134)	(0.00141)	(0.00151)	(0.00146)
N	0.00104	0.00105	0.00106	0.00152	0.00149
	(0.00106)	(0.00106)	(0.00107)	(0.00104)	(0.00112)
Buyer-FE (11)	**no**	**yes**	**yes**	**yes**	**yes**
# observations	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 level of buyer-seller pairs. * sign. at 10%; ** sign. at 5%; *** sign. at 1%.

Table 6: Trust and quality issues (proxy for investment): Fractional Probit results

For larger parts (systems and modules), the type dummies show that quality problems arise with significantly and substantially higher frequency. Including buyer dummies strengthens the relationship in focus. In the absence of buyer fixed effects, the strength of the trust/quality (or the suppliers' investment) relationship is underestimated. This indicates that a trusting buyer invests more in quality.

According to the estimates, the incidence of quality issues per standard deviation of the trust index (0.79, Table 4) 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 would therefore be associated with a reduction in the incidence of quality issues of between 19.6% and 28,0% relative to the average rate.

Columns 3 to 5 of Table 6 provide more detail. Is, as one might expect, the strength of the relationship relevant primarily for the high-tech rather than the low-tech parts? In column 3, we interact the trust index with the relevant indicator variable. It shows, perhaps surprisingly, that the relationship between trust and quality continues to matter significantly *only* for low-tech parts. For high-tech parts, the coefficient is half the size and not even close to significant.

Does the pattern still hold when we account for the substantial differences in embedded research and development between low- and high-tech parts? Recall that low-tech and high-tech parts differ especially w.r.t. R&D-efforts, but less so w.r.t. patenting intensity. Now, patented research (R) differs from development (D) effort embedding the part into a specific car model. IPR embedded in patents can be enforced in court, while relationship-specific development efforts embedded in the proprietary blueprint cannot.[25] Furthermore, patents contain public information that is transferable at low cost, while the experience in development effort is not.

We thus define variables indicating whether a part is associated with a higher or lower number of patents than the median, and with a development cost share of total costs above or below the observed median. In column 4 we interact trust with the development cost, and in column 5 with the patent indicator. As the coefficients in the latter are almost identical, the difference in patent protection cannot be responsible for the difference in results by part groups. The trust/quality association is significant only when the development cost share is relatively low. With our theoretical model, we will provide explanations for this perhaps puzzling finding.

4.2 Trust and quality: causality and robustness

What about causality in the observed association between trust and quality? Quality problems, typically caused by under-investment, could impose a burden on mutual trust especially on the buyer-side. This could be further exacerbated by some form of legal confrontation. However, quality issues are not related to empirical observations of legal conflict between suppliers and buyers. In 99.5% of our part-specific relationships the respondents report relationship histories without any legal conflict.

[25]However, 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.

Further details on the relationship history may contribute to a better understanding. We observe the past frequency of the perhaps most controversial Lopez-style behavior, leaks of supplier IPR by the buyer to competing suppliers without the owner's consent. There are two ways to use this information to study causality. As an explanatory variable replacing the trust index in the previous regression (i.e., as a reduced form instrument), or as an instrument for the trust index in an IV regression.[26]

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%.

Table 7: Trust and quality issues (proxy for investment): Reduced form instrument and IV results

Table 7 contains the results for both approaches. In columns 1 and 2 the 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. Columns 3 and 4 show that employing IPR pass-on as an instrumental variable is feasible (first stage F-statistics are above 10 for each specification) despite the limited number of observations;

[26]The exclusion restriction requires that passing on IPR in the past does not directly affect quality issues arising in later phases of production, except through the trust channel.

the association between trust (instrumented) and quality becomes slightly stronger and remains significant. Therefore, the empirical evidence is in favor of an interpretation in which mutual trust impacts part quality.[27]

In the online appendix, we carry out further robustness checks of this central result. In particular, we show that the result also holds for the alternative normalized trust index, when we introduce seller fixed effects, as well as for a further alternative trust measure that captures "directional" trust of the supplier in the buyer, and therefore neutralizes the possible channel of reverse causality described above.

4.3 Trust and competition

There are two ways to think about competition between suppliers in our setting. First, N potential suppliers are able to produce a given part, which we take from the WSW database. Second, n suppliers selected by the buyer compete to develop the part, and for production.

According to Figure 2 the average number of suppliers employed by the buyer differs along the part life-cycle. The nature of competition differs as well, from open competition regarding the quality of the blueprint in pre-development and development, to competition more latent in parallel series production. While all suppliers selected by the buyer for product-specific development are remunerated on average about 1/3 of development costs as a lump sum, only the winning supplier(s) can collect the remainder of their cost through markups on parts produced. To assess how competition induced by the buyer varies with trust, we consider the number of suppliers involved in a part-specific relationship during pre-development, final development, and at the start of series production.

The dependent variable in our Poisson regressions is the count variable n_{ijs}, the number of parallel suppliers involved in producing part i for buyer j from the perspective of supplier s in each of the three phases pre-development, development, and production. The independent variables are as before. Sometimes we include the "role of price" variable introduced previously: We hypothesize that price plays a larger role in the selection process if the buyer has the incentive to induce more intense competition among suppliers.

Table 8 contains the results. In the pre-development phase (columns 1 through 3), we observe no association between trust and the number of competitors. The same holds for the role of price (column 3). Despite the smaller number of observations, this is not a result of larger standard errors –especially in the specification with buyer dummies, the coefficient of trust is close to zero.

By contrast, in development and series production, both involving substantial relationship-specific investment, the association between trust and supplier competition is significant and large. In the development phase, during which suppliers are competing with their

[27]Note that the reduced-form approach is not limited only to IPR pass-on by the OEM, but can be applied to different types of IPR conflict, as reflected by Table 15 in the online appendix. This finding strengthens the assumption underlying the exclusion restriction, as these past patterns of buyer behavior are clearly not directly related to (or even caused by) current quality issues.

Variables	Number of suppliers at different phases								
	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

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%.

Table 8: Trust and Competition: Poisson-regressions

blueprints to obtain production contracts, (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 when compared to the average of 1.55 suppliers involved in this phase. Furthermore, the role of price is significantly and positively associated with the number of suppliers selected by the buyer (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 role of price and number of suppliers is, while positive, no longer significant.

Two aspects provide further insights into the buyer's motivation to employ more than one supplier in the development phase. First, larger suppliers (measured by revenues) tend to face significantly more competition, which may be result from an effort by the buyers to countermand larger players' better relative bargaining position. Second, more external market competition by a larger set of potential suppliers for a given part is associated with significantly fewer suppliers selected in both the development and production phases. This suggests that competition induced among the chosen suppliers within a given part-procurement and in the wider market are substitutes.

In Table 9, we again interact the trust index with a high tech-dummy in the regressions of each of the development phases. As in the trust/quality regressions, the association between trust and competition is significant only for low-tech parts, i.e., commodities and modules, and only in the phases development and series production. Joint F-tests reveal that for high-tech parts, the effect is insignificant (dev.: p-value 0.36; ser. prod.: p-value 0.95).

4.4 The effects of competition on quality and compensation

We have shown how trust between part suppliers and buyers is related to the quality of parts and the degree of competition in development competition and production induced by buyers. Perhaps most surprisingly, trust is associated with a larger number of suppliers involved in both development and series production. In the next step we study how competition is related to part quality and supplier compensation.

Focusing first on competition and quality, we claim that increasing trust implies increases in both. There is an immediate possible alternative explanation for the connection between the three variables: Tougher competition between suppliers forces them to exert more effort, or allows the buyer to select higher quality suppliers. Either of these effects would cause lower failure rates. Trust would then be the result of lower failure rates rather than their cause.

If this were the explanation for the observed pattern, then we should see significantly lower failure rates in relationships involving tougher competition in possibly pre-development, development and series production. We directly test this alternative hypothesis using the familiar empirical specification. the dependent variable is the rate of part, buyer and supplier specific quality problems, and the main explanatory variable is the number of suppliers at the different phases; added are the familiar vector of the controls, a constant, and a buyer-fixed effect. If the actual relationships that matter

Variables	Number of Suppliers		
	Pre-Dev.	Dev.	Ser. Prod.
	(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%.

Table 9: Trust and competition for low- vs. high-tech parts: Poisson-regressions

are between trust and quality/competition, respectively, then omitting the trust variable should lead to an (indirect) positive correlation between competition and quality. Therefore we include trust as an additional control in columns 2, 4 and 6 of Table 10 below.

There is no significant negative effect of the number of competing suppliers on failure rates. Higher levels of competition are not related to lower levels of part failures. If, by the alternative explanation, the correlation with trust really were only a by-product, then we should see stronger correlation between competition and failure frequencies than between the two and trust. Yet we observe the opposite. For the phases involving relationship-specific investment, there is no significant effect, and for pre-development we even get the opposite of the expected sign (i.e., more supplier competition is related to higher levels of part failures).

Variables	Frequency of Quality Problems					
	Pre-Dev.		**Dev.**		**Ser. Prod.**	
	(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%

Table 10: Quality, competition and trust: Fractional Probit-regressions

Furthermore, in the specifications including the trust measure, the relationship between competition and quality problems remains unchanged, while the coefficient of trust remains highly significant. This further indicates that the driver of the observed pattern is trust. In addition, the fact that we do not observe a significant positive correlation between competition and quality issues could indicate that at the margin buyers in fact use additional slack from higher trust to *either* induce additional competition *or* to enforce higher investment by suppliers.

Therefore, it is particularly important to better understand the role that competition plays for our central outcomes. For this, we now return to the compensation measures introduced in Subsection 3.1. We analyze how competition (and trust) are related to the share of suppliers' costs that is reimbursed via lump-sum payments, markups on parts produced, and overall. We run regressions using the familiar specifications, with the share of costs compensated by part, buyer and supplier separately estimated for the shares compensated via lump-sum, markups and overall. In Table 11, columns 1 to 3 the main control of interest is the number of suppliers in the development phase, and in columns 4 to 6 at start of production.

Variables	Shares of development cost compensated by the OEM					
	Total♠	**Mark-Up♣**	**Lump-sum♡**	**Total♠**	**Mark-Up♣**	**Lump-sum♡**
	(1)	(2)	(3)	(4)	(5)	(6)
trust index	.072	**.066***	.006	.062	.061	.001
	(.050)	(.038)	(.036)	(.051)	(.039)	(.036)
# suppliers devt.	**-.102****	**.050***	-.053			
	(.051)	(.030)	(.039)			
# suppliers prod.				**-.166*****	**-.098****	-.068
				(.039)	(.043)	(.043)
# suppliers overall	.000	.000	.000	.000	.000	.000
	(.003)	(.003)	(.001)	(.003)	(.003)	(.002)
supplier revenues	.000	.001	-.001	-.001	.004	-.001
	(.003)	(.003)	(.001)	(.003)	(.003)	(.001)
product type						
system (D)	reference category					
module (D)	**.216***	.150	.065	.155	0.127	0.028
	(.124)	(.121)	(.112)	(.130)	(.124)	(.108)
component (D)	-.074	.024	-.098	-.118	.008	-.125
	(.101)	(.110)	(.090)	(.103)	(.112)	(.085)
commodity (D)	-.181	-.093	-.088	-.141	-.052	-.089
	(.131)	(.118)	(.113)	(.132)	(.124)	(.103)
const	.679	.359	.320	.756	.404	.352
	(.266)	(.209)	(.173)	(.267)	(.210)	(.174)
Buyer-FE (11)	**yes**	**yes**	**yes**	**yes**	**yes**	**yes**
# observations	113	113	113	110	110	110
R^2	.290	.307	.252	.306	.323	.250

Dependent variables: ♠ total share of development costs compensated ♣ share of development costs compensated via mark-ups ♡ share of development costs compensated via lump-sum payments – 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%.

Table 11: Compensation of suppliers for development costs and competition: OLS regressions

The results clearly indicate that more suppliers involved in development and competition are related to significantly lower compensation shares for the (winning) suppliers. The statistically stronger, i.e., more significant, effect concerns the mark-ups, instead of the lump-sum payments. An additional competitor in development is associated with a reduction of the overall compensation share by more than 10 percentage points. Differentiating between channels shows that half of this is caused by lower compensation via mark-up, while the effect on lump sum compensation is of similar size, but statistically less significant. An additional supplier in the production phase is associated with a reduction of overall compensation by 16.6 percentage points. Compensation via markups is reduced by 9.8 percentage points, which results from a possible combination of reduced margins and lower production volumes.

5 A Model of Buyer-Supplier Relations

In our model we focus on key elements of the relational contracts that prevail in the German automotive industry. These elements are common to long-term buyer-supplier contracting relationships involving complex, buyer-specific parts with high development costs that are not easily adapted by suppliers not involved in the model-buyer-supplier specific development process.

The variables in our relational contract are determined alternatively by the typical buyer (when she has the bargaining power), or by the leading supplier (when he has the bargaining power). We identify the equilibrium of the repeated game that is best from the buyer's point of view vs. the supplier's point of view .

We then endogenize the party who has the bargaining power. For differing costs of switching to a non-developing supplier arising to the buyer, we identify the value of the repeated relationship to the buyer vs. the supplier. When, as for the supply of low-tech parts, that cost is low, the value of the relationship to the buyer is higher than that to the supplier; when, as for the supply of high-tech parts, that cost is high, the opposite is true. Any competitive allocation mechanism would then imply that the bargaining power rests with the buyer for low tech parts and the supplier for high tech parts. This results in drastic differences in the comparative statics with respect to the discount factor, our proxy for the trust measure employed in the empirical analysis. These differences correspond to those we observe in the data.

5.1 The model

In each period t of an infinite sequence of periods a buyer needs to procure an innovative intermediate product. 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. We assume that the investment I is neither observable nor contractible. The investment cost is sunk and normalized to I for I units of investment.

There are $N > 1$ firms capable of developing and supplying the intermediate product, by having invested in the pre-development phase (less connected to the buyer and not analyzed here). To simplify our analysis we assume that from the buyer's view, the N firms are identical at the outset.[28] In each period t the buyer selects a strict subset $n_t(< N)$ of the N firms for the development and the production of the part.[29] In case several suppliers are chosen by the buyer, the suppliers invest independently and

[28] In Subsection 5.3 we modify this assumption to allow for the buyer's selection of a favorite supplier.

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

competitively. As investment is buyer-specific, it has no value for buyers other than the one for whom the intermediate product is developed.

The value to the buyer of the final product with embedded investment I_t is $v(I_t)$, where $v(\cdot)$ is increasing, strictly concave and satisfying Inada conditions.[30] We denote with v_0 the value of procurement to the buyer if she stays in the relationship but the supplier's buyer-specific investment is nil; and with v_S the value to the buyer in case she leaves an established procurement relationship and starts procuring anew. The suppliers' outside option is normalized to zero. The investment fully depreciates at the end of the period.

After the development phase, a single supplier is chosen by the buyer from possibly the N suppliers to produce the part.[31] Supplier i's cost of production in period t is θ_{it}, assumed to be i.i.d. across suppliers and across periods, and drawn from a time-invariant 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 and without loss of generality, it becomes known to the other n suppliers.

Within the current period t, the buyer may ask supplier i to produce the intermediate product using the blueprint developed by another supplier j within the same period. Yet, for suppliers that did not participate in the development phase, this necessitates an adjustment cost k discussed below.

This procurement process is repeated over an infinite horizon. The stage game involving the typical period t (we henceforth delete subscript t to ease notation) involves the following timing:

t_1 *(Selection for development)*: When the buyer has the bargaining power, she selects n potential suppliers to participate in the development of a blueprint for the intermediate product. The buyer can then specify a minimal level of investment $\underline{I}$ she expects the selected suppliers to undertake. Furthermore, the buyer formally commits to pay a transfer w to each participant at the end of the development phase t_2.

When the leading supplier has the bargaining power, he commits to invest a specific level I towards the development of the part. Furthermore, he determines the transfer payment w he requires from the buyer towards his development investment.

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

t_3 *(Selection for production)*: The buyer invites $\tilde{n}$ suppliers to compete in an auction that allocates the production contract to a unique supplier h, and sets the price p payable on delivery of the intermediate product. When selecting a non-developing supplier to produce with the blueprint from a developing supplier the buyer needs to account for an

[30]As mentioned above we assume I to be neither observable not contractible, however 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 is in line with the relational contracting framework: a party's action is not observable by the counterpart, yet its outcome is.

[31]See the Theoretical Appendix for the case of more than one supplier selected by the buyer, that is multiple sourcing.

ex-ante uncertain adjustment cost $k \geq 0$ that is realised at this stage and that is private to and incurred by her.[32] The number and identity of the $\tilde{n}$ firms invited at the auction is public information. The production cost θ_i for each of these suppliers is realized right before the auction takes place.

t_4 *(Production)*: The selected supplier h produces at cost θ_h and receives p from the buyer. At the end of the stage game, the buyer observes the investment of the n suppliers invited to the development phase of the procurement process.[33]

In what follows we focus on stationary strategies of the infinitely repeated interaction. In t_1, let the buyer have the bargaining power. She will choose the performance requirement specified by the investment $\underline{I}$, and commit to the transfer w. In t_3 she commits to invite to the auction only the $\tilde{n}$ suppliers that were selected at t_1 for the development stage. The buyer would then exclude from further procurement any supplier who in the last stage game has not complied with the performance requirements $I \geq \underline{I}$. Conversely, the suppliers would collectively refuse to fulfil their strategy requirements in future stage games if in the previous stage game confronted with the buyer's decision to procure from (any of) the $N - n$ non-investing suppliers.

If in t_1 the leading supplier has the bargaining power, he will choose the level of investment I and formally commit to the transfer w. In stage t_3 the buyer will then commit to allocate the production contract to the leading supplier that managed the development stage: $\tilde{n} = 1$. The suppliers will then collectively refuse to fulfil their strategy requirements in future stage games if confronted with the buyer's decision, in the previous stage game, to procure from the $N - 1$ non-investing suppliers.

The assumption that the suppliers are identical ex ante is made for simplicity. As standard in the relational contracting literature and consistent with evidence from our survey, the transfer w is assumed contractible and, as such, enforceable by the courts. Both the level I_i invested by the typical supplier i at t_2 and the number $\tilde{n}$ of suppliers admitted to compete for production at t_3 are not contractible and determined in equilibrium. If $\tilde{n} > 1$ the buyer (optimally) allocates the production contract with a second price auction.

Both the level of I and whether suppliers for production are selected from the set of developing suppliers, $\tilde{n} \in n$, are not contractible in real life as well.[34] Although

[32]This cost is related to the training of such a non-developing supplier. It naturally reflects the idea that the production of complex parts not developed in-house requires the costly adaptation of skills and tools. Indeed, the deviation corresponds to Lopez' strategy (discussed in the Introduction) of sending teams of engineers for weeks on site to non-developing outsiders, to train them to reliably produce the part on the basis of a competing supplier's blueprint.

[33]Alternatively, investments in blueprints not used in production could be non-observable. At the cost of an additional incentive compatibility constraint, we could have modelled this possibility. This constraint would be needed to prevent that a firm i set $I_i = 0$, planning to avoid winning the auction and instead systematically cashing in w (if positive). This constraint would have no effect on our results.

[34]As to I, the steering committee in charge of the survey (used in the previous sections) decided to abstain from including questions on it in the questionnaire, as even the experts directly involved in the development and the production of the parts were unable to disentangle the general from the idiosyncratic components of investment in the development of a part. As for not including non-developing suppliers in $\tilde{n}$, the only way in which this could be included in a contract would have to be contingent

I and $\tilde{n}$ are not contractible, as clear from the strategies specified above, 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 from equilibrium levels of I and $\tilde{n}$. The observability of all investments directly before is clearly a strong assumption. However, similar results could be obtained assuming that the buyer only observes imperfect but informative signals of the investments.

As we have seen in the previous sections, there is significant duplication of investment in the development phase. We interpret this observation as an indication that the expected adjustment cost $E(k)$ is large enough so that the buyer prefers to avoid the unbundling of the blueprints development and production altogether, e.g., by having just one firm investing for a blueprint and all firms competing for production.[35] We also assume that the buyer cannot make contingent payments such as discretionary bonuses.[36]

The discount factor is unity across all phases of the same stage game, and $\delta \leq 1$ across different stage games. In line with the literature on trust and relational contracts discussed in Section 2 we interpret δ, common to both the buyer and the suppliers, as an indicator of the mutual trust the participants in the game associate with future co-operation. The common δ directly reflects the relevant question in the questionnaire survey, that mutual trust is the commonly understood level of trust between the buyer and her suppliers.

The game as described has a continuum of equilibria. In Subsection 5.2 below we focus on the equilibrium most profitable for the buyer, and in Subsection 5.3 on the one most profitable for the suppliers that participate in the development stage and obtain the production contract, respectively. In Subsection 5.4 we identify which equilibria we expect to see depending on whether we are considering the supply of low-tech, or high-tech parts.

5.2 Buyer's bargaining power

In this section we identify and analyze the equilibrium procurement relational contract that is most profitable for the buyer.

We consider symmetric stationary relational contracts where both the n suppliers each develop the required blueprint by undertaking investment $I \geq \underline{I}$, and the buyer abstains from inviting more than the announced n suppliers to compete for the production contract.[37]

on the value of k. But this is private information of the buyer and only identified after the blueprint has been selected. Hence the buyer could easily claim a low k, and with it expand $\tilde{n}$ to include non-developing suppliers.

[35]See the Theoretical Appendix for the optimality of bundling when $E(k)$ is large enough. Notice that even Lopez (discussed in the Introduction) did not factually procure the production from non-developing suppliers. He rather incurred the cost k to train non-developing suppliers, and used their price quotation to depress the winning developer's price.

[36]Empirically, we are not aware of any public or private procurement practice in which ex post monetary bonuses are regularly used, and the German car industry is no exception.

[37]Stationarity is without loss of generality with a single agent-supplier (Levin, 2003). Board (2011)

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 their bids. The winning supplier then sells his intermediate product at the price $p = \theta_{(2)}(n)$. If instead $n = 1$, then obviously $\beta(1) = 1$, 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.

A non-deviating supplier will optimally just satisfy the buyer's requirement by investing $I = \underline{I}$. His 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 he will be excluded from all future procurement by this buyer. Accordingly, 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

$$w + \beta(n)\pi(n) \geq \frac{\underline{I}}{\delta} \tag{2}$$

is satisfied. Hence 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 contemporaneous cost of the required investment $\underline{I}/\delta$. This cost is high if δ is small. Indeed, in such a case the typical supplier would face a stronger temptation to cheat in the investment phase, and to cash in the information rent in the production phase.

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 n firms compete for production.

When the n suppliers choose the required investment $\underline{I}$ in the development stage,

has shown that a principal-buyer may want to follow a non-stationary initial phase that leads to a stable group of preferred agents-suppliers. The equilibria that we consider here can be seen as the long-run steady state of this type of transition.

the buyer's infinite horizon payoff at t_3 is

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

Alternatively, at t_3 the buyer could deviate and invite $\tilde{n} > n$ suppliers to compete. In this case it would be optimal for the buyer to choose $\tilde{n} = N$, that is, to invite all available suppliers within the current stage game in order to take advantage of selecting the supplier with the lowest production cost from the largest set possible, thus paying a price $p^e(N)$ smaller than $p^e(n)$. Consequently, following a deviation, the buyer would expect that no supplier would ever invest in the future, and thus set the transfers w' so as to extract all the sellers' informational rents. The buyer's expected discounted payoff from deviating would then be

$$\{v(\underline{I}) - p^e(N) - k[1 - n\beta(N)]\} + [v_0 - Nw' - p^e(N)] \frac{\delta}{1-\delta}, \tag{3}$$

where the terms in the first bracket reflect her return in the current period, accounting for the cost of adapting the technology in case the producer ends up being a non-developer; and those in the second bracket her returns in the future stage games (where the buyer would have to rely on zero investment, maximal competition and transfer w').[38]

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

$$\delta\left[v(\underline{I}) - nw - (v_0 - Nw')\right] + (1-\delta)k\frac{N-n}{N} \geq p^e(n) - p^e(N) \tag{4}$$

is satisfied. The right hand side is the expected savings in the buyer's payment for the production of the intermediate good from having all N rather than n firms compete. The left hand side is instead the loss in the value of procurement she will face in the future, net of the difference between the equilibrium transfers nw and the ones associated to a deviation Nw' and the cost of adaptation. All else given, when δ is small the buyer also has a stronger temptation to deviate, benefiting from the (expected) reduction in the cost of production.

The optimal procurement program $\mathcal{P}_B$ of the buyer is then

$$\begin{aligned} \max_{\underline{I},w,n} \quad & [v(\underline{I}) - wn - p^e(n)] \frac{1}{1-\delta} \\ s.t. \quad & w + \beta(n)\pi(n) \geq \underline{I}/\delta && (IC_s) \\ & \delta\left[v(\underline{I}) - nw - (v_0 - \pi(N))\right] + (1-\delta)k\tfrac{N-n}{N} \geq p^e(n) - p^e(N). && (IC_b) \end{aligned} \tag{5}$$

If the buyer wants to induce high investment, she has to account for the typical

[38] The expected cost of adaptation (third expression in the first bracket in equation (3)) reflects the idea that all N firms are treated equally at the auctions. Although the expression of this cost would be different if the buyer treated differently those in n and the others, the idea and the consequences of the adaptation costs would remain the same.

supplier's incentive not to deviate, represented by (IC_s). Increasing the number n of competing suppliers has several effects. First, it reduces the expected price $p^e(n)$ the buyer has to pay, as production costs are drawn from a larger set of suppliers. Second, it reduces the buyer's temptation to deviate, since the difference in the production cost she has to bear between inviting n firms vs. all N firms to compete, $p^e(n) - p^e(N)$ in (IC_b), decreases in n.[39] Finally, it adversely affects the typical supplier's incentive to provide the required investment, because the expected rent $\beta(n)\pi(n)$ to the supplier also decreases in n.

It is immediate to see that in the optimum the buyer always reduces the (positive or negative) transfer w to a minimum, so that the incentive constraint (IC_s) is binding:

$$w + \beta(n)\pi(n) = \underline{I}/\delta, \tag{6}$$

which both increases the value of her objective function and relaxes her incentive constraint (IC_b). This leads to a simple yet interesting set of observations on the two main procurement choice variables: the level of competition n and of investment $\underline{I}$.

Proposition 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 $\underline{I}$.

Hence, when δ increases, the buyer can afford to invite a higher number n of competing suppliers (at given w and $\underline{I}$), which implies a lower expected production cost. An analogous reasoning applies to result (i). The intuition is that a higher discount factor δ grants the buyer some "slackness" in dealing with suppliers' incentives, which in turn translates into better procurement terms: more competition—that is lower cost of production—and/or higher investment—that is higher value for the final product.

The *overall* effects of a change of δ on the actual terms of procurement that solve $\mathcal{P}_B$ are more involved than the comparative statics of Proposition 1. Imagine, for example, that an increase of δ induces a higher level of investment. The overall effect of this increase in δ on n must then account not only for the *direct effect* described in point (ii) of Proposition 1, but also for the *indirect effect* due to the increased investment. If the latter is large enough, then a higher δ may actually call for a reduction in the number of firms, because the buyer should grant larger informational rents to create incentives for the selected suppliers to invest even more. In order to account for the indirect effects we need to solve the buyer's procurement program $\mathcal{P}_B$ and verify the effect of δ on optimal procurement $(\underline{I}^*_B, n^*_B)$.

Rather than providing a full solution to program $\mathcal{P}_B$, here we exploit some of its properties to verify conditions under which the general idea stated above—the "slackness" associated with an increase in the discount factor—induces the buyer to procure with both higher investment *and* more suppliers.

[39] In the (IC_b) we also account for the fact that when $n = N$ the buyer optimally sets $w' = \beta(n)\pi(n)$).

Since w is implicitly defined by (6), we can rewrite the buyer's per-period objective function as a function of the two main decision variables $\underline{I}$ and n,

$$H(\underline{I}, n) \equiv v(\underline{I}) - n\frac{\underline{I}}{\delta} - \theta^e_{(1)}(n), \tag{7}$$

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

$$v'(\underline{I}^n) = \frac{n}{\delta}. \tag{8}$$

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

Proposition 2 *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.*

In the Theoretical Appendix below we prove the sufficient condition on the value of investment $v(\cdot)$. Proposition 2 confirms that the general idea of the "slackness" induced by a higher discount factor δ also pertains to the two *optimal* control variables for the buyer, n^*_B and $\underline{I}^*_B$.[40]

While these comparative static results contrast with the intuition that trust requires an intimate relationship that is diminished by competition, they are clearly compatible with our empirical findings that involve low-tech parts. In this case there are many potential developers and the buyer has the bargaining power, hence the investment and competition requested by the buyer in the procurement process both increase with trust.

In the Theoretical Appendix we show that our results qualitatively hold as long as the buyer does not systematically open competition for production to all potential suppliers (i.e. allowing for $n \leq \tilde{n} < N$).[41] We also show that the results of Proposition 2 carry over the case of multiple sourcing (Proposition 5) and that, consistently with our

[40]The optimal transfer w^*_B is actually a residual variable determined by the binding constraint (6), which shows that increases of both n^*_B and $\underline{I}^*_B$ tend to actually increase the transfer that the buyer has to pay, if not sufficiently counterbalanced by the higher δ. Thus one cannot expect a clear relationship between δ and w^*_B.

[41]The case study evidence collected in 2005/06 for our industry shows that the blueprint submitted by the typical supplier is very much conditioned by the technology available to him, technologies vary across suppliers, and the winning supplier typically employs his technology. In this environment the costs of adaptation can be very large, explaining why the relational contract that we expect to prevail is the one studied in this section. Nevertheless, the production-adaptation expected cost $E(k)$ significantly differ between products, with more complex ones, like our "systems", displaying considerably higher costs than standardized ones, like our "commodities". This seems to be indeed the case in our data as we observe that the number of producers is larger than that of developers in 6.9% of the observations regarding commodities, 3.7% for modules, and it is never the case for complex systems.

findings (see Subsection 4.3), a larger δ induces the buyer to move from single-sourcing to multiple sourcing.

5.3 Supplier's bargaining power

We now identify the equilibrium procurement relational contract that is most profitable for the leading supplier. 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 twist our assumption that all N suppliers are *ex ante* symmetric. Especially when it comes to systems and components as parts categories, the buyer typically has one favorite supplier that is usually selected for the development of the part.[42] We then discuss the case $n > 1$.

The optimal procurement contract is now such that $n_S^* = 1$, and the procurement program $\mathcal{P}_S$ is

$$\begin{aligned} \max_{I,w} \quad & [w + p^e(1) - \theta^e(1) - I]\frac{1}{1-\delta} \\ s.t. \quad & \delta\,[v(I) - w - (v_0 - N\beta(N)\pi(N))] + (1-\delta)k\tfrac{N-1}{N} \geq p^e(1) - p^e(N) \quad (IC_b) \\ & w + p^e(1) - \theta^e(1) \geq I/\delta. \quad (IC_s) \end{aligned} \tag{9}$$

Here the supplier specifies an investment level that generates an output revealed to be valuable enough to the buyer, and towards that requires a transfer payment w from the buyer. Notice that the (IC_b) and (IC_s) coincide with the ones in problem (5) above when $n = 1$.

Here 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 program $\mathcal{P}_S$ becomes

$$\begin{aligned} \max_{I} \quad & [v(I) - I - K]\frac{1}{1-\delta} \\ s.t. \quad & v(I) - K \geq I/\delta. \qquad (IC_s) \end{aligned} \tag{10}$$

where

$$K \equiv v_0 - N\beta(N)\pi(N) + \frac{1}{\delta}\left[p^e(1) - p^e(N) - (1-\delta)k\frac{N-1}{N}\right] \tag{11}$$

depends on N and δ but not on I.

We can now identify two alternative characterizations of the equilibrium relational contract that is most profitable for the supplier. Denote by I^* the first-best investment defined by

$$v'(I^*) = 1. \tag{12}$$

If the (IC_s) constraint is satisfied at that investment level, then the relational contract

[42] A typical example 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.

is such that $I_S^* = I^*$. If instead the (IC_s) constraint would be violated at the investment level I^*, then the optimal investment I_S^* is such that (IC_s) binds:

$$v(I_S^*) - K = I_S^*/\delta, \tag{13}$$

and underinvestment occurs in equilibrium: $I_S^* < I^*$. Hence

Proposition 3 *In the equilibrium optimal for the leading supplier, $n_S^* = 1$, the optimal investment is*

(i) $I_S^* = I^*$ and an increase of the discount factor δ is not associated with any change in the optimal level of investment I_S^*;

(ii) $I_S^* < I^*$ and an increase of the discount factor δ necessarily induce an increase in the equilibrium level of investment I_S^*:

(iii) A large enough increase in k induces a switch from regime (ii) to regime (i).

When the supplier's incentive constraint is binding, the investment level varies with the discount factor. The reason is the buyer's incentive constraint that may be binding for low k. However, since K decreases in k, the incentive constraint is not necessarily binding when k is large.

Hence this proposition provides us with an explanation of our empirical finding that investment and competition do not increase with trust when high-tech parts are traded.

Although we have considered here the case with a single supplier, $n = 1$, and that supplier's optimal relational contract, the logic is the same when $n > 1$ suppliers have, collectively, 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 3 applies.

5.4 Switching-costs and bargaining power

With a careful description of the procurement process of parts by German car manufacturers, the two previous subsections allows us to draw the following inference: Whenever we observe that the level of trust between suppliers and the buyer is positively correlated with both the investment level in the development stage and the number of suppliers that are involved in that stage, as with low-tech products, we conclude that the bargaining power is in the hands of the buyer. If we instead observe that the level of trust between suppliers and the buyer is related to neither the level of investment in the development stage nor the number of suppliers involved in it, as with high-tech products, then the bargaining power rests on the supply side.

The question then is why one should expect this different allocation of bargaining power depending on high and low-tech products. This section provides a theoretical argument in support of this observation and allocation of bargaining power for the two product categories.

The idea is that the the cost of switching to other suppliers for production, k in our model, ultimately determines the party that has the bargaining power and becomes the principal who designs the relational contract for the other party.

Suppose that prior to setting the relational contract for each individual part the buyer and suppliers engage is a bidding game where the winner, that has the highest payoff from becoming the principal, obtains the bargaining power. Formally, denote V_B and V_S, respectively, the buyer's and suppliers' payoffs, associated with the solution to problems $\mathcal{P}_B$ and $\mathcal{P}_S$ when that respective party has the bargaining power. We do not explicitly model the bidding game but simply compare the parties' optimal payoffs for the different types of parts. In particular, we realistically assume that k, the cost to the buyer of switching production to a non-developing supplier is low when associated with low-tech, and high when associated with high-tech parts.

We thus compare $V_B(k)$ and $V_S(k)$ for different values of k.

Proposition 4 *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, it exists a threshold value $\bar{k} > 0$ such that for $k \leq (\geq)\bar{k}$ then $V_B(k) \geq (\leq) V_S(k)$.

The proposition shows that a high cost of switching to other suppliers, as with high-tech parts, increases the payoff of the supplier and instead depresses that of the buyer. (The opposite occurs when the switching cost k is low, as with low-tech parts.)

The intuition is that high k makes a buyer's deviation (i.e. increasing the number of producing suppliers) less profitable, so that a supplier with bargaining power needs to promise a smaller compensation to the buyer, thus appropriating more surplus. When instead the buyer has the bargaining power, a high k either has no effect, when the incentive compatibility constraint of the buyer does not bind, or, if it instead binds, then the buyer's equilibrium payoff is exactly equal to her deviation payoff which is obviously decreasing in k.

The second part of the proposition instead shows that the supports of the two functions $V_B(k)$ and $)V_S(k)$ overlap whenever procurement is valuable, so that for low values of k (respectively, high values) the buyer's payoff is higher (lower) than that of the supplier.

With this result we can conclude that when the switching cost to more supplier is low, as with low-tech parts, the buyer has the bargaining power and in that case an increase in δ is associated with an increase in both $\underline{I}_B^*$ and n_B^*, consistently with our empirical finding when considering low-tech parts. Conversely, for high values of k the seller has the bargaining power and in that case an increase in δ does not have a positive effect on both $\underline{I}_S^*$ and n_S^*, once again consistently with our empirical findings when considering high-tech parts.

By relating our equilibrium characterization to our empirical findings, we identified a compelling explanation for a puzzling and rich empirical evidence. Not only relational contracts are key in this important industry, we also show them adapting to the parties' bargaining power, via the switching costs in production.

6 Concluding Remarks

We analyse survey data providing unique evidence of the role of mixed formal and relational contract arrangements in a high-tech industry in a developed country. We observe substantial variation in trust across buyer-supplier relationships, caused by a shock to the established procurement practices due to aggressive behavior of a major industry participant.

We show that even within a stable functioning legal system, supply relationships benefit from higher levels of trust with regard to investment and quality of parts. This reflects the expectations from existing theory. Surprisingly, however, this association is significant only for low-tech parts; we do not observe it for more complex high-tech parts. Further, higher levels of trust are associated with buyers inducing more intense competition between suppliers. Again, this relationship is significant only for low-tech, but not for high-tech parts. Based on the evidence we provide, these results are driven by the different levels of trust observed across the part-relationships in our data.

We rationalize our empirical findings within a theoretical model that contains elements of formal and relational contracts. We show that, as long as the buyer has the bargaining power and can push suppliers to their incentive constraint, an increase in trust allows her to induce higher relationship-specific investment, and to increase competition among suppliers in both the development and the production stage. The bargaining power is tilted towards the leading supplier, however, when the provided parts are complex and the cost of switching to a non-developing outside supplier is high. Then the buyer can no longer leverage higher trust into increases of supplier investment, or impose tougher competition among suppliers.

Based on our evidence, short-term oriented, opportunistic behavior diminishes trust in relationships – with serious long-term consequences. By contrast, higher bilateral trust significantly enhances the value that innovative suppliers provide to buyers in a high-tech industry. Buyer-supplier relationships of this type are neither restricted to the sector nor the country discussed here. And their importance is likely to further increase with the upsurge of mechatronic devices and software solutions, as the products and production facilities of classical industries become increasingly digital. Given that this often involves cooperation with external innovative firms, our insights are highly relevant in this context.

We show in particular that relationships between pairs of firms may differ substantially at the level of individual parts procured. This indicates the importance and autonomy of individual procurement departments within corporations. Future research could be devoted to better understand how part specific development, production, and market conditions within multi-product firms interact with firms' reputations and shocks that affect it.

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Theoretical Appendix

Proof of Proposition 1

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

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

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

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

together with

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

and

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

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

$$w = \frac{I}{\delta} - \pi(1) \tag{14}$$

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

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

and

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

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:

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

which can be written as:

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

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

Q.E.D.

Proof of Proposition 2

Notice first that equation (8) 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 (8) above it could be

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

that is constraint (IC_b) can never be satisfied even considering different values of I. Clearly, in the steps of 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 (8). 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 (8) 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 (8) 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 (8) is smaller when n^*_B increases than when it remains constant.

Q.E.D.

Proof of Proposition 3

The supplier's problem (10) in Subsection 5.3 above can be rewritten as

$$\begin{array}{ll} \max\limits_{I} & [v(I) - I - K]\frac{1}{1-\delta} \\ s.t. & [v(I) - I - K]\frac{1}{1-\delta} \geq I/\delta \quad (IC_s) \end{array}$$

or

$$\begin{array}{ll} \max\limits_{I} & [v(I) - I - K]\frac{1}{1-\delta} \\ s.t. & [v(I) - \frac{I}{\delta} - K]\frac{1}{1-\delta} \geq 0. \end{array} \tag{15}$$

Given the definition of I^* in (12) above we can distinguish two possible cases. The first case is such that

$$[v(I^*) - \frac{I^*}{\delta} - K] \geq 0, \tag{16}$$

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

$$[v(I^*) - \frac{I^*}{\delta} - K] < 0. \tag{17}$$

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

$$[v(I_S) - \frac{I_S}{\delta} - K] = 0. \tag{18}$$

From (18) given (25) above we have that

$$\frac{dI_S}{d\delta} = -\frac{I_S + \left[p^e(1) - p^e(N) - k\frac{N-1}{N}\right]}{\delta^2\left(v'(I_S) - \frac{1}{\delta}\right)}. \tag{19}$$

Consider first the numerator of (19). Clearly 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 (19). 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 (18) 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

$$I_{S,2} < I^*. \tag{20}$$

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 (18) holds then

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

and from (17) above

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

that is

$$[v(I_{S,2}) - v(I^*)] > \left[\frac{I_{S,2}}{\delta} - \frac{I^*}{\delta}\right] \tag{21}$$

while from the definition of I^* we have that

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

or

$$[v(I_{S,2}) - v(I^*)] < [I_{S,2} - I^*].. \tag{22}$$

Inequalities (21) and (22) 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

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

This concludes the proof of Proposition 3.

Q.E.D.

Proof of Proposition 4

Consider first the situation where the bargaining power rests with the buyer. Using the binding (IC_s) constraint, as in (6), and (7) above we have that:

$$\begin{aligned} V_B(k) = \ & \max_{\underline{I},n} \quad H(\underline{I}, n)\tfrac{1}{1-\delta} \\ & s.t. \quad H(\underline{I}, n)\tfrac{1}{1-\delta} \geq H(0, N)\tfrac{1}{1-\delta} + \tfrac{1}{\delta}\{p^e(n) - p^e(N) - k[1 - n\beta(N)]\} \end{aligned} \tag{23}$$

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 (23). 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 $V_B(k)$ is weakly decreasing 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 $n_S^* = 1$.

Using (10) we have that

$$\begin{aligned} V_S(k) = \quad & \max_{\underline{I}} \quad [v(\underline{I}) - \underline{I} - K(k)]\frac{1}{1-\delta} \\ & s.t. \quad v(\underline{I}) - K(k) \geq \underline{I}/\delta. \end{aligned} \tag{24}$$

where

$$K(k) \equiv v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N) - (1-\delta)k\frac{N-1}{N}\right] \tag{25}$$

As we have seen above 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) constraint (13), in the objective function we have

$$V_S(k) = v(\underline{I}_S^*(k)) - K(k) \tag{26}$$

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

Finally, notice from problem (24) and (23) 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 the two functions $V_B(k), V_S(k)$ have overlapping supports. When $k = 0$ the (IC_s) constraint is:

$$v(I) - \frac{I}{\delta} \geq v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N)\right] \tag{27}$$

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

$$v(I^*(0)) - \frac{I^*(0)}{\delta} = v_0 - Nw' + \frac{1}{\delta}\left[p^e(1) - p^e(N)\right] \quad (28)$$

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 $v_0 \geq \hat{v}_0^s$

$$V_S(0) = v(I^*(0)) - v_0 + Nw' - \frac{1}{\delta}\left[p^e(1) - p^e(N)\right] \quad (29)$$

Consider now the case in which the buyer has the bargaining power, problem (23) 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:

$$v(I) - n\frac{I}{\delta} - \theta^e_{(1)}(n) \geq v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right] \quad (30)$$

Denote now $\hat{I}_b$ to be the investment level that maximizes with respect to I the objective function in problem (23) above:

$$v'(\hat{I}_b) = \frac{n}{\delta}. \quad (31)$$

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

$$v(I) - n\frac{I}{\delta} - \theta^e_{(1)}(n) = v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right] \quad (32)$$

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 $v_0 \geq \hat{v}_0^b$,

$$V_B(0) = v_0 - Nw' - p^e(N) + \frac{1-\delta}{\delta}\left[p^e(n) - p^e(N)\right] \tag{33}$$

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

$$v(I^*(0)) < 2\left[v_0 - Nw' - \frac{p^e(N)}{\delta}\right] + \frac{1}{\delta}p^e(1) + \frac{1-\delta}{\delta}p^e(n) \tag{34}$$

Consider now the values of $V_S(k)$ and $V_B(k)$ for k sufficiently large. Notice first that in 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

$$V_S(k) > V_B(k). \tag{35}$$

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.

Online Appendix

Suppliers' Market Power ($n > 1$)

Consider the case where a group of $n > 1$ suppliers approach the buyer for procurement and propose a level of investment I in exchange of an ex-ante payments w. When it comes to production the buyer has the possibility to exploit the best blueprint procured by the n suppliers and 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

$$w = \frac{1}{n}\left[v(I) - (v_0 - Nw')\right] + \frac{1}{\delta n}(1-\delta)k\frac{N-n}{N} - \frac{1}{\delta n}(p^e(n) - p^e(N)). \tag{36}$$

We focus here on the case in which the (IC_s) constraint does not bind. Substituting (36) in the suppliers' expected-discounted profit, the optimal level of investment I^* must satisfy the following condition

$$v'(I^*) = n. \tag{37}$$

This clearly shows that if, when δ changes, the number of suppliers n does not change, as we observe in the data for high-tech products, then the I^* does not change either. This is clearly different from the case where the buyer has the bargaining power because, see Proposition 2 above, there we see that if n does not change, then necessarily an increase of δ must induce an increase in I^*. It is also immediate to see from (37) above that n and I^* are negatively related being $v(\cdot)$ a 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.[43] 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 it can be 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 less 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,

$$E(k)(1 - n'\beta(N)) + \left[\theta^e_{(1)}(n) - \theta^e_{(1)}(N)\right] \geq \left[v(\underline{I}) - \frac{n\underline{I}}{\delta}\right] - \left[v(\underline{I'}) - \frac{n'\underline{I'}}{\delta}\right]. \tag{38}$$

The left hand side indicates the production-adjustment cost of unbundling. The two terms in 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 (38) 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 may be very small compared to the adjustment cost of producing it. 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 include as well 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 by the fact that, realistically, only the buyer has a clear idea of the effective 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 a number of

[43] 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.

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 be different from the one studied here, the main results would qualitatively hold in this case too, as long as $\tilde{n} < N$. In this case 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 is further discussed in the next appendix on multiple sourcing.

More 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.[44] 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 take place with probability α, in which case the unique supplier would be able to 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. The second-source contract, under which the complementary fraction γ is supplied, will be executed in this case.

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 in the case the adverse event is realized. The higher price paid by the buyer 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 $\pi_1(n)$

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

and $\pi_2(n)$.[45] 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 5 *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 (2), 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:

$$H_d(\underline{I}_d^*, n_d^*) = v(\underline{I}_d^*) - n_d^* \frac{\underline{I}_d^*}{\delta} - (1-\alpha\gamma)\theta_{(1)}^e(n_d^*) - \alpha\gamma\theta_{(2)}^e(n_d^*).$$

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

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

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

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

or equivalently

$$v_0 < \theta_{(2)}^e(N);$$

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

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

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

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:

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

[45] 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 $\pi_1(n) = \theta_{(3)}^e(n) - \theta_{(1)}^e(n) \geq \pi_2(n) = \theta_{(3)}^e(n) - \theta_{(2)}^e(n) \geq 0$.

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 on 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 2, 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:

$$\frac{\partial H_d}{\partial \delta} = \frac{(n^*_d \underline{I}^*_d)}{\delta^2}, \qquad \frac{\partial H}{\partial \delta} = \frac{(n^*_B \underline{I}^*_B)}{\delta^2} \tag{39}$$

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 is the level of δ. This concludes the proof.

Q.E.D.

Although the thresholds for concavity of Proposition 5 and of Proposition 2 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 at all, 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 to increase the buyer's expected value, which the main supplier can then extract. At the same time, the difficulty is that, in addition to his own incentives, the main 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.

Supplementary Tables

Variables	Frequency of Quality Problems (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

The table reports regression results for the following dependent variable: Frequency of quality problems arising (in percent) – average marginal effects and (p-values) reported; standard errors are clustered at the level of buyer-seller pairs; $trust_P D$ measures the supplier's trust in the buyer in the context of initiating pre-development * significant at 10%; ** significant at 5%; *** significant at 1%

Table 12: Robustness: Directed trust and quality issues (proxy for investment): Fractional probit results

Variables	Trust Index (normalized)					
	(1)	(2)	(3)	(4)	(5)	(6)
IPR Conflicts PD	**-0.420****					
	(0.170)					
IPR pass-on PD		**-0.378*****				
		(0.081)				
Risk sharing			**0.264*****			
			(0.0974)			
IPR Conflicts DEV				**-0.292*****		
				(0.0869)		
IPR pass-on DEV					**-0.132****	
					(0.0541)	
Lump-sum rebates						**-0.165*****
						(0.0520)
supplier revenues (bln)	-0.003	0.002	0.008	0.004	0.008	**0.008***
	(0.008)	(0.005)	(0.006)	(0.006)	(0.005)	(0.004)
# suppliers overall	-0.006	-0.010	-0.006	-0.007	0.003	-0.005
	(0.010)	(0.006)	(0.006)	(0.006)	(0.004)	(0.005)
product type						
system (D)	reference category					
module (D)	-0.050	0.142	0.145	0.082	-0.011	0.171
	(0.434)	(0.213)	(0.237)	(0.319)	(0.284)	(0.210)
component (D)	0.353	0.323*	**0.402****	0.253	0.131	0.170
	(0.306)	(0.192)	(0.201)	(0.268)	(0.237)	(0.189)
commodity (D)	0.078	0.061	0.294	-0.049	-0.017	0.154
	(0.310)	(0.224)	(0.242)	(0.282)	(0.253)	(0.201)
const	0.072	0.208	-1.366	0.122	4.973	5.059
	(0.344)	(0.288)	(0.278)	(0.316)	(0.261)	(0.218)
Observations	121	240	220	179	159	193
R-squared	0.091	0.134	0.066	0.069	0.068	0.093

Dependent variable: Normalized 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%.

Table 13: Determinants of the Normalized Trust Index: OLS regressions

Variables	Frequency of Quality Problems (1)	(2)	(3)	(4)	(5)
trust index (n)	-.014	**-.024****	**-.267****	**-.037****	-.010
	(.250)	(.038)	(.041)	(0.014)	(0.715)
supplier revenues (bln)	-.001	-.002	omitted	omitted	omitted
	(.352)	(.253)			
# suppliers overall	.001	.001	-.002	-.002	-.002
	(.390)	(.418)	(0.321)	(.135)	(0.235)
product type					
system (D)	reference category				
module (D)	-.032	-.042	-.087	.018	-0.007
	(.683)	(.593)	(.205)	(.823)	(0.944)
component (D)	**-.165****	**-.175****	-.076	.053	.027
	(.020)	(.013)	(.212)	(.626)	(0.757)
commodity (D)	**-.181*****	**-.189*****	-.084	-.005	-.020
	(.007)	(.006)	(.123)	(.819)	(0.780)
Buyer-FE (11)	**no**	**yes**	**yes**	**yes**	**yes**
Supplier-FE (13)	**no**	**no**	**yes**	**yes**	**yes**
Buyer-Part-FE	**no**	**no**	**no**	**yes**	**no**
Buyer-Supplier-FE	**no**	**no**	**no**	**no**	**yes**
# observations	127	127	127	127	127

The table reports fractional probit regression results for the following dependent variable: Frequency of quality problems arising (in percent). Avg. marginal effects and (p-values) reported. Trust index (n) is the alternative normalized trust index using the differences in importance between trust and price. Robust standard errors are clustered at the level of buyer-seller pairs. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 14: Robustness: Normalized trust index and investment proxied by quality issues (Fractional probit results)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Freq. of quality issues	1,00						
(p-level)							
(2) IPR conflicts PD	0.478	1,000					
(p-level)	(0.000)						
(3) IPR pass-on PD	0.196	0.178	1,000				
(p-level)	(0.023)	(0.053)					
(4) Risk sharing	0.129	0.083	0.048	1,000			
(p-level)	(0.143)	(0.448)	(0.490)				
(5) IPR conflicts DEV	0.320	0.495	0.445	0.216	1,000		
(p-level)	(0.000)	(0.000)	(0.000)	(0.013)			
(6) IPR pass-on DEV	0.205	0.269	0.526	0.073	0.507	1,000	
(p-level)	(0.034)	(0.007)	(0.000)	(0.437)	(0.000)		
(7) Lump-sum rebates	-0.034	-0.033	0.144	0.002	0.142	0.268	1,000
(p-level)	(0.714)	(0.774)	(0.056)	(0.974)	(0.120)	(0.005)	

Pairwise correlations (and p-values) between frequency of quality issues and different determinants of trust. "Reduced form" relationship between determinants and frequency of quality issues holds for each of the IPR-related behaviors.

Table 15: Correlation quality issues and trust determinants (p-values in parentheses).

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)	.004	.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

The table reports Poisson regression results for the following dependent variables: ♠ Number of suppliers employed during pre-development – coefficients and (p- values) reported – ♣ number of suppliers during the final stage of development – coefficients and (p-values) reported – ♡ number of suppliers at the start of series production – coefficients and (p-values) reported; robust standard errors are clustered at the level of buyer-seller pairs. Trust index (n) is the alternative normalized trust index using the differences in importance between trust and price. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 16: Robustness: Normalized trust index and competition: Poisson-regression results