It's R&D, stupid!

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Lorentzen, Jochen

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Jo Lorentzen

Department of International Economics and Management
Copenhagen Business School

School of Development Studies
University of KwaZulu-Natal, Durban

lorentzenj@nu.ac.za

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1 Introduction

Innovative firms in developing countries have the odds stacked against them in more than one way. They must contend with the objective difficulties of all sorts of capital shortages and deficient infrastructures. Highly-trained scientists, well-endowed labs, seed funding, and institutions that test and certify prototypes and protect the resulting intellectual property are few and far between in the South. They must also come to terms with global value chains in which for different reasons both multinational corporations and smaller, knowledge-intensive firms typically keep R&D close to home. And finally, they are up against the broad brush of academic thought on industrial development which essentially holds that because of the technology gap between developed and developing countries, innovation proper can only really happen in the North. Thus if innovative firms appear on the radar screen at all, they are likely to register but an errant blip, the exception to the rule, that do not warrant systematic analysis.

This paper analyses the absorptive capacities of automotive component suppliers in South Africa. It shows that some firms design and manufacture innovative products, while others upgrade their technological capability or merely strive to attain execution competence. It suggests that the reason for the differential performance lies in the strategic use of advanced technical skills and the kind of learning about frontier technology engendered by R&D. It further discusses the ways in which foreign-owned technology is internalised more or less easily depending on whether or not it is controlled by multinational firms or by passive investors. Section 2 reviews the literature on absorptive capacities in developing countries. Section 3 discusses innovation and the technology frontier in the automotive industry, and Section 4 briefly outlines why this is relevant to firms in South Africa. Section 5 presents data and methodology. Section 6 discusses the findings. Section 7 concludes with suggestions for further research.

2 Absorptive capacities in advanced developing countries

Whatever the outcome of the technological activities of firms, it is uncontroversial that their endeavours are based on learning. Learning, in turn, implies the ability to identify relevant knowledge from the environment, to get on top of its codifications or unwritten secrets, and to make use of its commercial potential. Relevant knowledge may exist as process or product innovations or in pre-commercial form, for example when basic research serves as a basis for applied R&D. The key tenet of this kind of learning, which has entered the vocabulary as absorptive capacity, is that it reflects a purposeful search – doing things differently, or generating and managing technical change – as opposed to mere learning-by-doing aimed exclusively at doing things right, or execution competence to produce industrial goods at given levels of efficiency and input combinations. Learning relies on prior knowledge which depending on industry characteristics may be very costly to accumulate. R&D promotes learning in that its very practice contributes to making informed, strategic choices about which external knowledge to select, how to evaluate and assimilate it, and in what ways to exploit it. Hence R&D is only partially about generating new information (Cohen and Levinthal 1989).

Absorptive capacity is also a byproduct of manufacturing operations insofar as they help firms recognize and make use of new information relevant to a product market, and it feeds off the skills created through advanced technical training (ATS). Strategically, firms with highly developed absorptive capacities are more likely to appreciate emerging technological opportunities, while underdeveloped absorptive capacities risk landing a firm in situations of lockout (Cohen and Levinthal 1990).

Since firms draw on individually specific resources and competences, they also differ in the way they acquire, assimilate, transform, and exploit knowledge. For instance, some firms may benefit from long and deep experience that allows them judiciously to pick the most relevant knowledge. Others may be particularly proficient in comprehending idiosyncratic methodologies of an external technology, while engineers in yet others may have a knack for adapting and internalizing that same technology and aligning it with the strategic orientation of their organization. Finally, a last group of firms may be relatively slow in the first three aspects but very disciplined and ultimately fastest in bringing the resulting product to market. For each individual firm it is important to achieve a balance between its potential absorptive capacity derived from knowledge acquisition and assimilation on the one hand, and its realized capacity resulting from knowledge transformation and exploitation on the other. Of course, a firm could be very “smart” in terms of figuring out exceedingly complex problems and at the same time relatively inept at translating those insights into feasible product strategies (Zahra and George 2002).

The absorptive capacities of individual firms exist in the context of an institutional milieu that influences how easy and attractive it is for them to acquire and internalize knowledge. Since firms interact with one another and with their institutional environment it is then possible to conceive of learning as a higher-level – regional or national – activity as well. Much like individual firms, countries follow more or less successful technological trajectories partly because the collective learning abilities they represent allow them to confront new information, digest technical change, and develop new knowledge. However, the rich literature on firm-level absorptive capacities is not yet reflected in equally consolidated analyses of national absorptive capacity. Authors use different terms when referring to similar ideas about the aggregation of firm-level capacities to the national level within some form of systematic knowledge infrastructure. Examples include accumulated technological competence (Bell and Pavitt 1993), technological capability (Lall 1993, Pack and Saggi 1997), local capability (Blomström and Kokko 1998), knowledge systems (Bell and Albu 1999), technology systems (Lall and Pietrobelli 2002), and so forth. For a systematic appraisal and critique of the literature, see Narula (2003).

In the absence of a generally agreed notion of national absorptive capacity aggregated upwards from firm-level competences, many analyses of the direction, depth, and success of technological activity make use of the concept of national innovation system (NIS; Edquist 1997, Freeman 1995, Nelson 1993; see also Rodrik, Subramanian, and Trebbi 2002)). NIS works roughly the other way round. It first specifies the institutional characteristics of country-level technological efforts, and then explains firm activities within them. As the name suggests, its heuristic focus is on innovation understood as a genuinely new commercialized product or process. Embedded in historical accounts with an appreciation for the role of social capital, analyses in this tradition consequently pay much attention to science and technology (S&T) institutions, resources committed to R&D, and patentable outputs. This makes it problematic to apply this framework to developing countries where technical change certainly takes place but where technological activity is not principally about pushing out the technology frontier, and where conventional S&T and R&D indicators are hard to come by and for a variety of reasons may not mean that much in any event (cf. Freeman 1994).

Yet to reconceptualise NIS as a national system of technical change (NSTC; Viotti 2002) merely swaps around two problems. Because of its preoccupation with cutting-edge, state-of-the-art endeavours, NIS does not really understand anything but frontier activities. And because of a presupposition that innovation proper can never happen in developing countries, NSTC is unable to account for the graduation of successful catch-up countries – or firms or sectors within them – to advanced levels of industrialization. For example, in the late 1990s the IMF reclassified Israel, Singapore, and Taiwan as developed countries. But this is merely a statistical convention. In reality, the graduation from developing-country status is obviously not a discrete event but a long and complicated process, articulated in a multitude of ways and, incidentally, subject to reversals. In other words, while NIS misses the wood for the tree, NSTC doesn't see the trees for the wood. Although the last word is clearly not yet said in this regard, emerging solutions to this problem may lie in attempts to link the absorptive capacities of firms with national performance in stage-based models of development that range from the pre-catching up to the frontier-sharing phase and are thus agnostic with respect to how far developing countries can catch up (Criscuolo and Narula 2002, Narula and Dunning 2000). The concept of national absorptive capacity has the advantage that it is *a priori* non-committal about who, and in what part of the world, innovates while offering however tentative conjectures about how a country moves from a lower to a higher level of technological activity.

By definition, the advanced knowledge that developing-country firms acquire is often foreign. Trade, FDI, and arm's-length projects such as license contracts are all important channels of technology. A couple of observations are in order. First, external knowledge and domestic absorptive capacity must match to generate long-run benefits. It takes two to tango; more advanced knowledge is wasted in the absence of an increased rate of human capital formation (e.g. Keller 1996; see Liu and White (1997) for an analysis of how Chinese firms gained leverage by investing in both technology imports and R&D personnel). Second, although MNCs and host-country firms have in some ways a diametrically opposed interest – namely to internalize the full value of productivity or efficiency benefits resulting from superior technology on the one hand, and realizing spillover benefits from the entry or presence of MNCs on the other – the imitation of FDI by local firms need not be adversarial. More precisely, if for cost reasons MNCs want to use advanced technologies in developing countries, then it is in their interest that domestic R&D activities expand the local technology frontier, providing a more fertile ground for their competitive assets (Glass and Saggi 1998).

Third, equity ownership does not in all instances equal control over technology. Of course, with internalized transfer modes control over the technology ultimately rests with the foreign firm. But (passive) foreign investors other than MNCs may take an equity stake without interfering with local management. Along with the more or less tacit character of the technology in question, this is likely to have implications for how much leeway local firms have to invest in their absorptive capacities. And fourth, globalization entails that developing-country firms that produce for global supply chains aimed at world markets increasingly turn out products to the same quality specifications as their competitors in advanced economies. Although this does not automatically imply a total homologation of processes, it clearly exerts pressure to adopt more and more advanced technologies, regardless of the comparative advantage of the production site in question. This underlines the importance of international best practices and the limits to national idiosyncrasies in process technology.

3 New knowledge in automotive component manufacturing

This section does four things. It first refers to the different incentives firms have across sectors with respect to what knowledge they internalize and how they exploit it. Then it describes ongoing technical change in car manufacturing, including innovations at the technology frontier. It further discusses the management of innovation in global supply chains. Finally, it draws out the implications of sector characteristics for absorptive capacities of automotive component manufacturers in developing countries.

The nature of technical change differs from sector to sector. Firms in production and scale intensive sectors such as vehicle assembly tend to concentrate on process innovation. Automotive production is extremely complex and the whole value chain is only as reliable as its weakest link. Operating conditions therefore put a premium on production engineering and process engineering in order to minimize bottlenecks and to squeeze productivity increases out of improved equipment. By contrast, in science-based sectors such as electronic engineering, firms devote most of their innovative resources to product innovation (Pavitt 1984). This means that firms involved in electronic automotive components are likely to search for different kinds of new knowledge compared to manufacturers of steel panels. It does not mean that they are more innovative, only that the nature of innovation in their sector is different. Differences across sectors are relevant to learning as well. The sector-specific characteristics of technological and scientific knowledge determine the ease with which firms learn. The larger the quantity and the higher degree of difficulty of knowledge to assimilate, the more incentives exist to learn and, thus, to invest in R&D (Cohen and Levinthal 1989).

Car manufacturers are caught between a rock and a hard place. Pressure comes from the market and from regulators. Consumers demand more features and performance options while also insisting on higher fuel efficiency and longer service intervals. Regulators insist on more stringent environmental rules. In Europe, the latter include the End of Life Vehicle Directive with its mandatory recycling of old vehicles by the manufacturer, and Euro-IV legislation that requires car makers to halve emissions of hydrocarbons, carbon dioxide, nitrogen oxide and particulates by 2005. Since many car makers are not very profitable and competition is intense, producing more variety with greater content at lower cost and environmental impact presents difficult challenges. In the short to medium term, projects include hybrids – cars that combine a conventional engine with an electric motor; 42V electrical systems to support the energy demand of extra applications; complex spark-ignition engines with electronically controlled valves, a variable compression ratio, cylinder deactivation, and an integral starter-generator; electronically shifted manual gearboxes and one-speed continuously variable transmissions; and the replacement of steel through aluminium, magnesium, and plastics for body and structure (Feast 2002, Jodoin 2001, Truett 2002, Vasilash 2003).

Much more radical change is in the pipeline for the medium term. Concept cars such as GM's "AUTOnomy" or Bertone/SKF's "Fib" combine fuel cell propulsion and drive-by-wire systems, thus doing away with internal combustion engines, drive train, transmission, and mechanical or hydraulic linkages or axles (Chiappero and Bak 2002, Teresko 2003). A less radical vision sees hydrogen fuel cells merely replace the internal combustion engine in what will otherwise remain a conventional car. Whichever vision prevails, some incarnation of fuel cell cars is expected to be commercially available as early as 2008 and no later than 2015 (Cato 2003), demanding both exploratory and radical learning – and hence more R&D effort – through the automotive supply chain.

Car makers responded to the cost pressures associated with making better automobiles at essentially constant prices by outsourcing part of the innovation behind improved vehicle designs. Like firms in many other sectors they also had to come to terms with an increase in the number of highly mobile knowledge workers and with private venture capital willing to bet on risky ideas. All of this made it more difficult to retain control of proprietary knowledge. Car makers began to adopt the open innovation model whereby they commercialized external as well as internal ideas (Chesbrough 2003). This does not mean that they discontinued or reduced internal R&D. On the contrary, as discussed in Section 2, internal R&D is a precondition for recognizing and selecting external knowledge (Howell and Hsu 2002; see Söderquist, Chanaron, and Birchall (2001) for an analysis of the learning challenges engendered by the transfer of design activities to OEM suppliers). Indeed in electronics, with 80-90% the most important area of automotive innovation by value, suppliers easily spend twice as much on R&D as the automotive industry average of about four per cent of turnover (Brown 2003).

World car designs – meaning the worldwide availability of locally adapted versions of essentially the same vehicle – and the partial devolution of design responsibilities to .5- and 1st-tier suppliers based on the principles of follow-source (the same manufacturer supplies parts in different locations) and follow-design (several countries share the same component design) provoked much speculation regarding the desirability of car industry investments in developing countries. The alleged problem is that the automotive value chain logic will always prioritise R&D in home countries, thus debasing local engineering skills and technological depth in developing countries more generally. But while this may have been true for the initial phase of investments in developing countries and transition economies undertaken in the 1990s aimed at world markets, the argument that it will of necessity always do so is not convincing (see Lorentzen and Barnes (forthcoming) and Lorentzen, Møllgaard, and Rojec (2003) for a fuller statement and a rebuttal of the argument).

Anecdotal evidence to illustrate this is easy to come by. For example, while it is true that only very few Brazilian car component suppliers own technology independently of their overseas principals, this does not stop them – and may indeed be a major incentive – from spending a higher share of their income on R&D (6 per cent) than MNC subsidiaries in Brazil (5 per cent) and, more importantly, than the automotive sector on average worldwide (4 per cent) (Zilbovicius, Marx, and Salerno 2002). This may suggest that their R&D expenditure is inefficient or, worse, redundant. More plausibly, however, these firms are investing in their ability to keep up with technological advances pioneered elsewhere (see also Rachid 2001).

Insights from Spain, until not so long firmly on the periphery of the European car manufacturing system, indicate that what hinders the extension of design activities in 2nd- and 3rd-tier suppliers is not technological capability *per se* but rather issues of firm size, international presence, specialization, attitude, and reputation (González-Benito 2001). Based on this analysis local firms in developing countries must, loosely put, simply find a partner, think big, and make friends in order to muscle into more challenging positions in global supply chains.

Finally, the car assemblers do not control everything that happens in the car industry. For example, the impending revision of the regulations of new car distribution in the EU involve a novel – and much broader – definition of what constitutes original spare parts sold under a carmaker's brand name, namely all parts that match the carmaker's specification regardless of where in the world and by whom they are produced. This opens the aftermarket and eventually perhaps also direct OEM supply to capable, independent component suppliers (Craemer-Kühn, Junghans, and Krönig 2004). All these issues are relevant to the automotive supplier industry in South Africa.

4 South Africa's automotive industry

All major OEMs are present in South Africa where they manufacture 13 brands in seven plants. In 2003 the country produced some 401,000 light vehicles, representing a mere 0.7 per cent of global vehicle production. But the automotive industry is the third largest sector in the economy, after mining and financial services, and in 2002 contributed 29 per cent to manufacturing output and 6.3 per cent to GDP. Since 1995, when government embarked on a strategy aimed at turning the formerly highly protected sector into a competitive global supplier, exports of CBU (completely built up) vehicles and components grew at a compound annual rate of 38 per cent. The share of automotive in total exports roughly tripled to 12.8 per cent. Easy availability of key raw materials, low energy costs, and the traditional flexibility to produce short runs allow for the occupation of niche markets, such as the right-hand drive BMW 3-series and the Mercedes C class. At the same time South Africa is also the most important supplier of catalytic converters to the EU, and the second most important to the US, holding 12 per cent of the world market.

The industry's performance under a radically liberalized trade regime is generally considered a success. Yet with competition looming from China and India, no let-up in the squeeze on margins worldwide, and a reduction in local value added in newer, more sophisticated models – which is only partly due to the Rand appreciation – imply that South African component manufacturers will have to upgrade to defend their position in the global value chain. According to the Department of Trade and Industry, "[i]nvestments in new technology for the component manufacturers will be a key driver in achieving the global objectives of the South African automotive industry" (DTI 2003, 38). This ties in with the National Advanced Manufacturing Technology Strategy (AMTS), promoted by the government, whose objectives include the reduction of the country's dependence on imported technologies and the strengthening of local innovation (CSIR 2003, 33). The Automotive Industry Development Council (AIDC), a semi-public service provider, projects the future of the industry in world model industrialization and concept engineering and design (www.aidc.co.za). This is a long way from the CKD (completely knocked down) production of the early days, quite apart from being an ambitious answer to the strategic challenges facing the industry. In sum, new knowledge is key to maintain the export success of South Africa's automotive component industry.

5 Data and methodology

The analysis is based on 25 case studies of South African automotive component suppliers from two of the country's three major car production locations. Two assemblers corroborated the claims made by the component suppliers. The case firms represent four per cent of the entire industry in number and account for 6-7 per cent of its turnover. The firms span the entire range of possible ownership constellations. 15 are domestically owned (13 privately and 2 by a large holding company), 5 are formerly domestic companies owned by international investors (of which 4 are largely passive), and 5 are foreign-owned subsidiaries of European or North American MNCs none of which were greenfield investments. Sales include the aftermarket (10), assemblers (13), and 1st-

tier suppliers (15) on both the local and the global market. Their export-to-sales ratio in 2002 was 0-80 per cent. They are either 1st- or 2nd-tier suppliers, or both. In terms of size, the firms ranged from 30 to 1000 employees and ZAR5 to ZAR1, 500 million turnover. The product portfolio includes relatively simple parts such as chassis elements, components such as alarm devices or lighting as well as complete systems for fuel and exhaust management and air conditioning.

Senior managers in the firms – in most cases the managing director or the CEO – agreed to an in-depth discussion with the author. They received a questionnaire as a basis for a semi-structured interview (see Appendix 1) prior to the meeting, and subsequently a written protocol for review. All interviewees were given a chance to review and comment upon the paper. Due to the in part highly confidential nature of the data, firm identities could not be revealed. The interview explored questions derived from the theoretical discussion in Section 2 and thus focused on the conditions under which learning is promoted by management, what kind of consequences it has for technological activities, and whether it supports technological upgrading and innovation.

Only two firms spent close to (3-4 per cent of turnover) or just above (5 per cent) the international average (4 per cent) for the automotive industry on R&D. Many firms reported no R&D expenditure at all. However, this information was not always to be taken at face value. Some firms really did not commit any resources to design-related activities or R&D proper. But the investigation revealed that others, especially smaller firms, simply did not account for human capital committed to activities that in larger organisations would be billed to the R&D budget. In several cases the absence of a dedicated development department meant that staff primarily assigned to production engineering and only partially responsible for activities to do with upgrading or innovation did not register with the latter activities at all even if they led to potentially patentable process innovations. This confirmed doubts referred to above concerning the appropriateness of conventional R&D indicators for assessing technological activities in developing countries (Freeman 1994, Viotti 2002). Hence while the analysis made unconditional use of reported positive R&D figures – and thus differentiated between high and low spenders – it only made qualified use of reported zero expenditure.

By contrast, the qualitative information about advanced technical skills (ATS) and the nature of technical agreements (TA) with foreign technology partners was reliable and provided a rich picture of the circumstances under which learning did or did not take place. Hence it was easy to probe how, and what for, managers utilised ATS, and in what way TAs related to know-how, know-why or – as the case might be – know-anything. In addition, information about the sub-sector specific technology frontier (see Appendix Table 1) made it possible to gauge the technological gap between each of the case firms and the leading firms and industrial research laboratories in the world in a particular product or process. In the absence of a reliable indicator of R&D spending, absorptive capacity is taken to be a function of the proximity of individual firms to the technology frontier and the use of ATS.

The different articulations of absorptive capacity thus constructed are captured in Figure 1. Close proximity need not – though may well – indicate that a firm owns an innovation but merely that it understands it as a result of learning resulting partly from R&D activities. It further means that it can fully replicate it or design a competitive product not long after the technology leader. Firms at medium proximity to the technology frontier understand the lead technology enough to adapt it or reengineer it with a considerable lag. Their main challenge is to marshal the resources necessary for the upgrading of their technological capabilities, aligning their process competence with the production requirements of advanced technology. Firms distant to the frontier understand frontier technology at most minimally. They are unlikely to have the capacity to handle it though they may be able to assemble simplified black-box kits that embody frontier technology. Their main challenge is to ensure that their production capacity is at a level where it can efficiently handle given input combinations.

Figure 1. – Operationalisation of absorptive capacities

		ADVANCED TECHNICAL SKILLS		
		Decreasing	*Stable*	*Increasing*
PROXIMITY TO TECHNOLOGY FRONTIER	*Close*	Firms lose edge	Active understanding of technology at frontier: high AC ↔	Firms push frontier
	Medium	Firms lose technological capability	Passive understanding of technology at frontier: medium AC ↔	Firms upgrade technological capability
	Distant	Firms lose production capacity	No understanding of technology at frontier: low AC ↔	Firms upgrade production capacity

The technological complexity and the rate of technical change of a subsector obviously condition the relative ease with which firms can attain proximity to the technology frontier. Thus this framework allows comparisons of like with like – for example, between the technological depth of exhaust manufacturers – but not, say, of producers of tapes for seat seams as opposed to manufacturers of HVAC systems.

Changes in the quantity or quality of process or product engineering skills influence the development of absorptive capacities. At one extreme, firms in close proximity to the frontier that strengthen their R&D commitment may acquire the ability to push the frontier further. By contrast, firms with low absorptive capacity and outdated machinery, depreciating labour and management skills, or organisational systems unable to cope with the requirements of lean production, are likely to exit the supply chain. Firms that successfully upgrade their production capacity may acquire technological capability and perhaps even innovative competence. Their trajectory would move from the bottom right of Figure 1 through the centre upward. Likewise, firms with decreasing ATS may regress from the top left through the centre downward.

6 Findings

The case firms can be categorised into four groups, namely innovators, followers, mandate executers, and cliff hangers. Key differences between these categories lie in the use made of ATS, the nature of technical agreements, forms of ownership and, with the caveat noted above, R&D spending.

Six firms are innovators (see Table 1). By definition they have high absorptive capacities. These firms maintained or increased considerable stocks of ATS dedicated to some form of design work which is partially reflected in significant R&D spending. One of them holds multiple international product patents and licenses its technology to major OEMs. Another participated in a government-sponsored research consortium (but reported zero R&D spending) that led to a patented process innovation. Three firms have technical agreements (TA) but in only one of these is the South African firm the junior partner. In one case the TA's main purpose is to reassure an OEM customer of a link-up with a preferred supplier but is effectively devoid of content. In another case, the technological relationship between the local firm and its foreign owner is mutual in that the two sides share their respective competences of design and testing on the one hand and production engineering and machining on the other. No firm is a MNC subsidiary. The foreign-owned firms do not have less leeway than their domestic competitors in deciding whether and how to commit R&D and ATS strategically to design activities.

All innovator firms find themselves in close proximity to the technology frontier, at least with part of their operation. Thanks to a strong strategic commitment to ATS, this appears unlikely to change in the medium term. Note however that this is not a guarantee to live happily ever thereafter. For example, the manufacturer of automotive leathers might get caught unawares by a radical product substitution away from natural hides. Also, the die caster is unlikely to have the financial depth required for the introduction of advanced rapid prototyping and rapid tooling techniques that directly convert three-dimensional CAD data into physical prototype and manufacturing. These techniques promise to reduce lead time and the cost of industrial tooling. This merely underlines that the maintenance of high absorptive capacity at least in some areas requires, next to a high level of ATS, considerable capital resources.

Eight firms are followers with medium levels of absorptive capacities (see Table 2). They have in common with the innovators that they maintained or increased their stock of ATS. However, their technological efforts are broadly directed at optimising process solutions. This ranges from improving their own production technology to designing less capital-intensive processes more amenable to the resource constraints in developing countries or even superior processes for customers in advanced economies. One firm hopes to leverage production competence into incremental design mandates, and another already has a partial design remit for a niche market. Two formerly domestically-owned firms had to discontinue process design and product R&D activities subsequent to the acquisition by foreign investors. The main reasons included the availability of superior technology through the parent and the need to centralise R&D in the multinational group. The discontinuation of these activities had some de-skilling effects yet it would not be fair to characterise the technological trajectory of either firm as stagnant or decreasing. That is because they use their accumulated experience to manage and generate technical change which is the common element across these follower firms. With one exception and regardless of ownership, these firms have TAs. They include licenses and intra-MNC technology transfer. This represents of course part of the external knowledge that the local firms both acquire and internalise. Most firms reported some R&D spending which is individually both lower and higher than that of innovator firms. The latter, in turn, simply suggests that some followers may invest more in their learning than some innovators in their innovation competence. Innovators, in other words, battle with diminishing returns.

Seven firms are mandate executers (see Table 3). They dispose of minimal stocks of ATS which they use to maintain or attain a quality of production capacity acceptable to OEM customers in the automotive value chain. Compared to innovators and followers, a larger share of the mandate executers' output is destined for local OEM supply and the aftermarket. Vehicles assembled exclusively for the domestic market belong to a different technological generation than those sold on the world market. Hence, the demands on parts and components are less exacting, too. The same applies to aftermarket accessories such as bull bars that are clearly easier to engineer than, say, replacement HVAC systems. Most of these firms are domestically owned and do not have technical agreements. Reported R&D spending is at best negligible which in the context of the interviews appears to reflect reality accurately. In the presence of tight resource constraints and all the other negative factors that bedevil the attempts at technological upgrading by developing-country firms, much appears to hinge on sheer entrepreneurial drive. The seat frame manufacturer, for example, successfully bid on an OEM contract without ever having manufactured a single such item and, more importantly, without disappointing its client upon winning the bid. Overall, the combination of a relatively low level of ATS or none at all, and no or little investment in learning suggests that these firms have difficulty in acquiring and internalising external information, especially if it is not available on the market. Hence, their absorptive capacities are low. These firms are likely to become marginal players unless they grow ATS or exploit TAs so as to prevent lock-in and ensure that, at a minimum, their distance to the technology frontier does not increase.

Four firms are cliff hangers. Note that the term does not imply that they produce low-quality components. In fact, the manufacturer of interior parts belongs to a MNC that produces technology at the forefront of automotive interior design. But becoming part of a multinational group is clearly no guarantee against a reduction in the level of absorptive capacity. In this particular case, were the parent ever to walk away from the subsidiary, technologically it would pretty much leave an empty shell. Cliff hangers, thus, are firms that do not necessarily understand the technology they are working with, let alone that at the frontier. None of these firms have increased their ATS; indeed many do not use them for anything to do with learning. Instead, the human capital that embodies these skills supervises production or runs the commercial aspects of the business. In the context of diminishing ATS, the TAs held by two firms are not a case of know-why and at most partly an aid to know-how. It thus makes sense that these firms report no or negligible R&D spending. Their absorptive capacities are quite clearly rather low.

Table 1. – Absorptive capacities of case firms: innovators

Product/ ownership	Firm mandate	Most advanced technical skills/ type of learning	Technical agreements	Knowledge characteristics at technology frontier	R&D spending/ turnover	Proximity to technology frontier
Automotive leathers/ Foreign (formerly domestically owned)	2nd tier. Follow-design supplier to world market with occasional design input	7 engineers/ purposeful search for new qualities and process savings in dedicated R&D facility	Co-development of new designs with input suppliers and downstream users	Seat filling innovations; leather material substitutes	2-3%	Close, increasing: design and process; Far, stable: leather substitution
Alarms, immobilizers/ Domestic	1st- and 2nd-tier. Mainly own design for aftermarket but also for domestic OEM supply	7 senior engineers, 1 draughtsman, 10 technicians/ purposeful search in dedicated design team	None	Interconnectivity of vehicle security systems with mobile phones and internet	5%	Close, stable: local mgmt put a premium on in-house design
Fuel tanks and systems/ Domestic	1st-tier. Primarily OEM supply for local market based on own process technology	3 engineers plus 2 engineering student interns/ purposeful search for new process and product to guarantee tank impermeability in dedicated design unit	Technical input from raw-material suppliers, alliances with and licenses from preferred OEM suppliers	Blow-formed complete vapour recovery tanks	1.2%	Close, stable: local mgmt research next-generation tank technology to comply with new 0-emission standards in view of gaining global niche mandates
Catalytic converters/ Foreign (formerly domestically owned)	Primarily global aftermarket for replacement and retrofitting	2 engineers, 1 technician/ purposeful search for optimal process lay-out for simplified state-of-the-art cats	JV with preferred OEM supplier, technology from parent and *to* OEM and 1st-tier supplier; international patent holder	Advanced simulation software, lighter and more complex (incl. air intake) exhaust system structure and design; lower emission product technology	3-4%	Close, stable: local mgmt exploits design and testing relationship with overseas parent
Tyres/ Domestic	Primarily aftermarket	8 engineers/ purposeful search for optimal properties of performance tyres	License from competitor	New tyre build processes and electronic "intelligent" tyre systems	1-2%	Close, stable: high-end performance tyres Medium, decreasing: intelligent tyres and new processes
Aluminium squeeze castings/ Domestic	1st- and 2nd-tier. Aftermarket and follow-design world market	3 engineers/ search for new materials and processes	Joint research with UKZN and CSIR on new process technology	Substitute materials and techniques with superior performance characteristics, rapid prototyping (RP) and tooling (RT) technology	0%	Close, stable: substitution of aluminium through magnesium; Medium, stable: everything else

Note: UKZN = University of KwaZulu-Natal; CSIR = Council for Scientific and Industrial Research. For information on technology frontier, see Appendix Table 1.
Source: Case firms

7 Conclusions

This analysis has produced three insights. First, firms in an advanced developing country sustaining an investment in their own learning travel on a different technological trajectory from those that do not. A higher level of absorptive capacity means that they partially or fully understand state-of-the-art technology, in some cases all the way to the technology frontier. Understanding technology is more important for catching-up than producing it. This is because producers of world-class parts or components that are not cognizant of the technology these products are based on are in principle substitutable through more cost-competitive plants elsewhere. By contrast, firms with the ability to search for and then internalise and transform technical solutions carry more weight in international supply chains. Firms with medium levels of absorptive capacity that want to upgrade their technological activity focus on process optimisation. This reflects their considerable accumulated knowledge that allows them to design process solutions even though they are part of a supply chain that often puts a premium not just on follow-design but also on follow-process. Hence, an improving technological capability not only reduces the distance to the technology frontier in terms of how to manage technical change, but also opens up opportunities for generating it.

Firms with depreciating or underutilised advanced technical skills that do not invest in their learning can hang on to their remits so long as technical change in their particular portfolio is slow and they are thus not much in need of learning. The occupation of downmarket niches – in the form of old-generation vehicles and the aftermarket demand they generate – is also a medium-term survival strategy. But downmarket niches are an exception to the trend of world cars and not suitable for anything but a defensive strategy. What is clear is that no amount of technology transfer will help firms stay competitive whose absorptive capacities are low because of decreasing ATS. Technology without learning is like a fish out of water and not a viable long-term proposition.

Second, the relationship between the absorptive capacity of developing-country firms and foreign technology is not straightforward. At issue is not product quality *per se* because anything other than high quality is not really viable in global automotive supply. Also, car assembly as such says little about the technological sophistication of a country and virtually nothing about its catch-up potential. The question is if the conditions of access to foreign technology allow for and enable further learning or not, and if the attendant opportunities are exploited. The case firms showed that multinational control over domestic firms – and, thus, repositories of existing national technological expertise – may help local firms upgrade or assign them dramatically regressive remits. See, for example, the difference between the two manufacturers of interior parts in Tables 2 and 4, respectively. This presents a stark alternative and goes to the heart of industrial development.

Liberal investment regimes preclude distinguishing between “good” and “bad” foreign investors, quite apart from the question of the technical feasibility of such an exercise. But the case firms also showed that all instances of “good” foreign ownership were characterised by a strong commitment to enhancing learning through ATS and investments in R&D on the part of local management. This is no guarantee for building sustainable local technological capabilities. But perhaps it is the next best thing (and also the reason for *It’s R&D, stupid!*). Therefore if the capacities created by the learning environment in an advanced developing country – or in this case more specifically the South African S&T and higher education infrastructure – lie below the requisites of using available foreign technology, then FDI holds much less promise for industrial upgrading. In other words, the potential benefits of foreign knowledge are largely wasted in a host country with mainly cliff-hanger firms. The graduation from mandate executers to followers is likely to rely on the availability of TAs, but the ultimate outcome of this catching up may well be to diminish the importance of FDI relative to other forms of external knowledge. In policy terms, this should put the knowledge infrastructure more prominently on the map.

Third, compared to the opportunities and pitfalls of FDI our understanding of national absorptive capacities in (advanced) developing countries is rather poor and warrants more attention. The significance and reliability of R&D indicators is a case in point. Without reliable indicators, learning at firm level is difficult to assess. And unless the micro determinants of absorptive capacities become clearer, empirical aggregation to higher-level units is fraught with problems. This asks for more case studies to qualify more representative but perhaps less solid survey or panel data (see Zahra and George (2002, 193-9) for a series of testable propositions). At the same time, the institutional characteristics of learning at national level should be addressed because they influence – through skill provision, basic and applied research and testing institutes, the intellectual property regime, and so forth – how firms go about their technological activities.

Table 2. – Absorptive capacities of case firms: followers

Product/ ownership	Firm mandate	Most advanced technical skills/ type of learning	Technical agreements	Knowledge characteristics at technology frontier	R&D spending/ turnover	Proximity to technology frontier
Interior parts and accessories/ Foreign (formerly domestically owned)	1st-tier. Strictly follow-design for world market and OEM supply for domestic market	1 engineer, 2 technical development managers/ purposeful search for best practices in production technology; own tooling discontinued	Knowledge transfer from licensors and JV partners in process and product	New materials, new moulding techniques, sophisticated systems architecture developed in advanced simulation programmes	2.3%	Medium, increasing: local mgmt interact with senior technology partners to bolster technological capability for independent contracting
HVAC/ MNC subsidiary (formerly domestically owned)	1st-tier. Mostly follow-design for world market; re-engineering for aftermarket; re-tooling for model changes	3 engineers + 3 technical support staff/ search for cost-effective solutions for aftermarket and in retooling; blue-sky R&D discontinued	Knowledge transfer from parent company	Energy, environmental, and lead time process innovations; differentiated A/C optimization for individual passengers	2.9%	Medium, stable: local mgmt have 6-8 years product cycle to understand frontier technology to re-engineer for aftermarket
Leather seat covers/ Foreign (formerly domestically owned)	2nd-tier. Mostly follow-design for world market, limited own design for select national market	1 leather technologist, 13 certified and 10 trainee technicians in dedicated design unit/ mix of learning-by-doing and search for process optimization	Cooperation upstream with tanneries and co-development downstream with seat manufacturer	Seat filling innovations; leather material substitutes	1.75%	Medium, stable: local mgmt understand sewing process innovation; Far, stable: product substitution
Door locks/ Domestic	2nd-tier. Primarily follow-design for world markets, OEM supply and some own design for domestic market	5 engineers + 2 technologists/ purposeful search for process (optimal toolings) and product upgrading (license improvement)	Licenses from preferred OEM suppliers	New low-cost bus communication subarchitectures; web-based telematics for door lock control	2.6%	Medium, increasing: local mgmt try to match execution competence with design reputation and look for European equity partner
Lighting systems/ Domestic (formerly MNC subsidiary)	1st-tier. Primarily OEM supply for domestic market, also aftermarket	6 engineers, 8 technicians/ purposeful search, esp. in reengineering and process improvements; also design of simpler products in dedicated development unit	Licenses with preferred OEM suppliers	Advanced simulation software to obviate prototype building, new light sources, adaptive lighting systems	2-3%	Medium, increasing: local mgmt do not have the volumes to justify capital investments to close the gap but are aggressive about process technology
Catalytic converters/ MNC subsidiary (formerly domestically owned)	1st-tier. Strictly follow-design for world markets but process autonomy	1 sr project engineer with 10 technical support staff and 10 engineering student interns/ purposeful search for cost-effective process technology	Knowledge transfer from parent	Advanced simulation software, lighter and more complex (incl. air intake) exhaust system structure and design; lower emission product technology	0%	Medium, increasing: local mgmt optimize processes for parent's technology
Fastening systems/ Domestic	Mostly follow-design for world markets, limited own design for domestic market	1 design engineer plus 4-5 technical support staff in dedicated R&D department/ purposeful search for customized fastening solutions and prototype tooling	Alliances with suppliers	Advanced simulation software, new material development	1.4%	Medium, increasing: local mgmt involved in numerous cooperative (non-automotive) R&D projects

Product/ ownership	Firm mandate	Most advanced technical skills/ type of learning	Technical agreements	Knowledge characteristics at technology frontier	R&D spending/ turnover	Proximity to technology frontier
Painted plastic parts/ MNC subsidiary	1st-tier. Mostly follow-design for world market and OEM supply for domestic market	5 engineers and 10 technical support staff in toolroom/ learning-by-doing and search for optimal tooling solutions	None	Dry paint and moulded-in-colour films with superior cost and environmental characteristics	0%	Medium, increasing: local management has upgrading agenda esp. for internal tooling competence

Note: For information on technology frontier, see Appendix Table 1.
Source: Case firms

Table 3. – Absorptive capacities of case firms: mandate executers

Product/ ownership	Firm mandate	Most advanced technical skills/ type of learning	Technical agreements	Knowledge characteristics at technology frontier	R&D spending/ turnover	Proximity to technology frontier
HVAC/ Domestic (formerly MNC subsidiary)	1st- and 2nd-tier. Primarily follow-design for world market plus aftermarket	61 engineers, 120 technicians, 15 technologists/ learning-by-doing plus identification of aftermarket niches; innovation activities and in-house tooling discontinued	Numerous licenses from preferred OEM suppliers; competition with licensors in overseas markets not allowed	Energy, environmental, and lead time process innovations; differentiated A/C optimization for individual passengers	0.5%	Far, decreasing: local mgmt execute licenses without fully understanding their technology; deskilling
Seat frames/ Domestic	2nd- and 1st-tier. Primarily follow-design for world market and OEM supply for local market	1 engineer/ learning-by-doing plus trial-and-error with technical change	None	Light-weight, active-grip seats with fold-away features	0%	Far, increasing: local mgmt accept risk of steep learning curves
Narrow-woven tapes for seat seams/ Domestic	2nd-tier. Strictly follow-design for world market and OEM supply for domestic market	1 narrow weaver, 2 engineers/ learning-by-doing	None	Embodied in advanced production technology with more quality and control features	0%	Medium, stable: local mgmt handle a mature product with little technical change
Valve guides and seats/ Domestic	1st-tier. Primarily aftermarket, some follow-design for world market	1 engineer/ learning-by-doing: competence through experience	JV with preferred OEM input supplier	New composite materials with superior wear resistance, emissions, and weight characteristics	0%	Medium, stable: local mgmt aim at increasing volumes supplied to OEMs
Specialized steel/ MNC subsidiary	Service centre: (minor) customization of steel sourced from parent for toolmaker customers	1 toolmaker/ learning-by-doing	Training through parent company	New steel qualities to build tools that accommodate lighter materials (e.g. plastics) in cars	0%	Far, increasing: local mgmt succeeded in upgrading the site from warehouse to service centre
Press tool parts, chassis brackets/ Domestic	1st-tier. Mostly OEM supply for domestic market and own design for aftermarket accessories	1 engineer/ some purposeful search for component design and prototyping	Co-development of fuel tank with customer	Laser technology instead of conventional press tooling	0%	Medium, stable: local mgmt tries to push design competence in context of mature product with slow technical change
Electroplating/ Domestic	2nd tier, primarily follow-design for world markets	2 electroplaters/ learning-by-doing and scanning of technical advances in field	Joint purchase of fully automated plant with biggest competitor	Vapour deposition coatings, “green” electrolyte technology, kinetic energy metallization	0%	Medium, stable: local mgmt keeps up with slow rate of change in industry

Note: For information on technology frontier, see Appendix Table 1.
Source: Case firms

Table 4. – Absorptive capacities of case firms: non-followers

Product/ ownership	**Firm mandate**	**Most advanced technical skills/ type of learning**	**Technical agreements**	**Knowledge characteristics at technology frontier**	**R&D spending/ turnover**	**Proximity to technology frontier**
Interior parts and accessories/ MNC subsidiary (formerly domestically owned)	1st-tier. Strictly follow-design for world market and OEM supply for domestic market	3 engineers/ only learning-by-doing: own toolshop discontinued	Tools from parent company, but no intra-group technology transfer	New materials, new moulding techniques, sophisticated systems architecture developed in advanced simulation programmes	0%	Far, decreasing: local mgmt do not comprehensively understand technology behind their product portfolio, deskilling
Lead-acid batteries/ Domestic	Exclusively aftermarket	1 engineer/ learning-by-doing: competence through flexible service	None	More powerful (42V), longer-lasting and fault-secure, intelligent power-management systems	0%	Far, decreasing: local mgmt have no remit to graduate to intermediate-generation battery technology
Parts from industrial rubbers/ Foreign	1st- and 2nd-tier. Follow-design for world market, and OEM supply for domestic market, aftermarket	1 engineer/ only learning-by-doing: no systematic knowledge mgmt	License for tyre retreads	New rubber compounds with superior heat, vulcanizate, and aging properties	0%	Far, decreasing: local mgmt do not understand technology inside their products
Metal stamping/ Domestic	2nd- and 1st-tier. Primarily follow-design for world market and OEM supply for domestic market	2 engineers/ learning-by-doing	None	New forming techniques, new composite materials, new hybrid technologies	0%	Medium, decreasing: local mgmt has only follower agenda in context of depreciating equipment

Note: For information on technology frontier, see Appendix Table 1.
Source: Case firms

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8 Appendix

Notes for a semi-structured interview with select car component manufacturers in South Africa, 2003

Premise

The purpose of these exploratory conversations is to probe the conditions for innovation activity in the automotive supply sector in South Africa. More specifically, the inquiry focuses on the relative dearth of product innovation since the opening of the sector to global competition and the arrival of foreign OEMs. Conceptually, we look at three different levels of analysis, namely the

- individual firm and its (dynamic) capabilities (including intra- and inter-firm relations)
- structure of global automotive supply chains
- national innovation system.

Section 1: The firm level

1.1 Do you aim at product innovation? (If “no”, why not?)

1.2 If “yes”, what do you target?

1.3 What type of resources do you commit to your innovation activity in terms of … ?
   a) capital investment/equipment: (specific R&D outlays)
   b) skills (operating and managerial know-how): (Is learning a by-product from doing or a purposeful search?)
   c) product and input specifications (How do you generate and manage technical change?)
   d) organisational systems (How do you combine activities of R&D labs, design offices, production engineering etc.?)

1.4 Do you believe that your involvement in quality control and production organisation has allowed (or will allow) you to generate activities in R&D, design, and production engineering (i.e. is there a progression from process to product innovation)?

Section 2: The supply chain level

2.1 In general, do you feel that local design and development activity is increasing or decreasing?

2.2 In general, what is the more important impediment to acquiring global supply mandates…?
   a) your technological capability *per se*
   b) the financial, managerial and organisational resources required to develop global operations
   c) control by OEMs and/or parent company and/or JV partner and/or licensor and/or technical aid partner

Section 3: The national innovation system

3.1 Do technological opportunities on the domestic market differ from the demands of the global market?

3.2 Are technical and graduate engineering skills readily available to you? (If “no”, what are the key weaknesses?)

3.3 Do you feel that your scientists and/or engineers possess the problem-solving skills and the familiarity with research methodologies and instrumentation (and are they perhaps members in international networks of professional peers) to put your skill profile/technological capability at par with your global competitors? (If “no”, probe for reasons.)

Table 1. – The Global Technology Frontier in Product Portfolio of Case Firms

Product/ component/ part	**Technology frontier**	**Principal customers/ competitors (examples)**
Interior systems	*Process innovation*	
	(i) "**Intertronics**": integration of electronics and interiors in common architecture of interchangeable ("pluggable") modular components to save costs, shorten lead times, and broaden consumer choice	(i) Lear (US)
	(ii) **acoustical testing systems** and laboratories to improve acoustic performance while reducing weight, lowering cost, and improving recyclability	(ii) Collins&Aikman (US), Johnson Controls (US), Lear (US), Magna Corp. (US) and others
	(iii) "**Ultra Light Technology**": non high-tech, sound-absorbing multi-layer material	(iii) Rieter (D)
	(iv) combination of acetal copolymer and thermoplastic elastomer (TPE) to allow **overmoulding** of soft surfaces onto acetal	(iv) Ticona (CAN), Kraiburg TPE (CAN)
	(v) **MuCell technology**: evenly distributed and uniformly sized microscopic cells with lower weight, higher dimensional stability, cheaper inputs, and reduced cycle time	(v) Johnson Controls (US), Magna (CAN), INOAC (J), Takagi Seiko (J), MIG Plastics (US) (license from Trexel US))
a. Instrument panel and console	*Process innovation*	
	(i) **combining blow and injection moulding** in single part manufacturing; use of cast-composite ceramic-like production tooling to reduce tool development time and costs	(i) Lear (US)
	(ii) **nylon 6** interspersed with layers of **montmorillonite** (nanocomposite): to reduce weight and improve mechanical properties	(ii) Toyota (J) + Ube Industries (J)
	Product innovation	
	(iii) **voice activation**: temperature control, radio, on-board computer, wipers etc.	(iii) Delphi Harrison Thermal Systems (US)
b. HVAC	*Process innovation*	
	(i) **parallel flow technology** to enhance efficiency of heat exchanger	(i) Modine Manufacturing (US)
	(ii) **use of CO2** to replace traditional greenhouse gas refrigerants	(ii) Denso (J), Modine (US)
	(iii) **brazed aluminium coil technology** to enhance thermal efficiency	(iii) Thermal Components (US)
	(iv) **no-frost evaporator** to reduce energy consumption	(iv) Bundy (UK)
	(v) use of **computational fluid dynamics software** to reduce system design lead time and improve system performance	(v) Visteon (US)
	(vi) Energy Efficient Thermal System (**EETS**): reduces amount of power required for climate management	(vi) Visteon (US)
	Product innovation	
	(vii) "**Intellek**" air quality sensor to block foul air from entering passenger compartment	(vii) Delphi (US)

Product/ component/ part	Technology frontier	Principal customers/ competitors (examples)
	(viii) **ACX-10** Air Conditioning Life Extender protecting A/C components against premature failure by monitoring refrigerant pressure and voltage	(viii) Index Sensors and Controls (US)
	(ix) **S8369** wide-angle photo sensor measuring IR-induced sun load as part of climate control and HVAC system	(ix) Hamamatsu (J)
	(x) **thermal imaging technology**: cooling system with differential temperatures along the passenger's body	(x) Delphi Harrison Thermal Systems (US)
c. Seating	*Process innovation*	
	(i) **Lightweight seat** from ultra-high-strength steel and aluminium components	(i) Magna International (CAN)
	(ii) DuPont's high-strength, **flexible fabrics stretched over a tubular metal frame** to achieve an ergonomically correct but comfortable seat while saving on foam and springs	(ii) Quantum Group (US)
	Product innovation	
	(iii) seats with posture improvement properties and **active seats** that grip passenger body in hard cornering	(iii) various tier-1 suppliers
	(iv) "**Open Seating**": high comfort, completely fold-away seat optimising cargo room	(iv) Johnson Controls (US)
c.1 Leather seat covers	*Process innovation*	
	(i) "**mold-in-place**": eliminates need for seat trim cover sewing by pouring seat foam directly into fabric;	(i) Magna International (CAN)
	(ii) cover substitution: elastomeric layer over moulded foam ("**upholstery skin**") in single-step technology	(ii) Dow Chemicals (US)
	Product innovation	
	(iii) **leather-like polymer** product with better feel and superior water absorption characteristics	(iii) Canadian General Tower (CAN) (licence from Idemitsu Technofine (J))
	(iv) **microfibre suede** materials to emulate grain leather or suede	(iv) Clarino Division of Kuraray (US)
c.2 Tapes for seat seams	*Process innovation*	
	(i) **advanced production technology** to allow e.g. for much wider patterning possibilities, photo-optical inspection etc.	(i) Jakob Müller (CH)
d. Door panels and trim	*Process innovation*	
	(i) **larger blow-moulded pieces** to consolidate functionality for doors; expanding **low-pressure injection moulding** to extend feasible types of fabrics	(i) Lear (US)
	(ii) "CrafTec partial mold-behind (**PMB**) and partial foam-in-place (**PRP**)": reduces multiple fabricating and assembly steps to a single operation by integrating cover materials with panels themselves	(ii) Johnson Controls (US)
	(iii) **polyolefin-based trim covers** instead of PVC to obtain higher durability, better low-temperature performance etc	(iii) Haartz Corp. (US), PolyOne (US)

Product/ component/ part	Technology frontier	Principal customers/ competitors (examples)
	(iv) **new yarns**, new finishing capabilities and new weaving and knitting technologies ➔ fabrics to contribute more to comfort (heating and cooling), be more durable and resistant to moisture, stains and odour retention.	(iv) major automotive textile companies
	Product innovation	
	(v) "phase change materials (**PCM**)": using changes of physical states of PCMs integrated in textiles and storing and releasing heat as programmed to aid in air conditioning	(v) Technical Testing & Innovation (??)
e. Door locks	*Process innovation*	
	(i) "Local Interconnect Network (**LIN**)": low-speed and low-cost bus communication subarchitecture controlling door locks, windows, and mirrors	(i) Philips Semiconductors (US) and many others
	Product innovation	
	(ii) "**CAReader**": telematic, web-based system aimed at remote fleet management and control, including unlock doors etc.	(ii) Networkcar (US)
f. Alarm systems	*Product innovation*	
	(i) **air-pressure sensing steering-wheel lock with wireless signal-transmission capability**	(i) Super Sun Precision Industry (Taiwan)
	(ii) **internet-based tracking and immobilization system** accessible through WAP mobile phone	(ii) miTrek (AUS)
	(iii) "**Datadot**" system: 10,000 microdots containing vehicle identification number sprayed on cars	(iii) Microdata Technology (AUS)
Lighting	*Process innovation*	
	(i) "**Fast Forward**" simulation software to validate optical performance of designs with 98% accuracy obviating the need for early prototypes	(i) Guide Corp. (US)
	(ii) bullet-type LED with a double reflector to double output from same amount of power using **microlens array technology**	(ii) Omron (US)
	(iii) interior lighting: **lightpipes** and **fibre optics** in optics; **halogen**, **electroluminescence** and cold-cathode fluorescent (**CCFT**) for niche applications	(iii) various
	Product innovation	
	(iv) "**adaptive front lighting systems**" based on high-intensity discharge lighting (HID) and free-form cylinders, using shutters and lamp combinations to optimise light direction and volume	(iv) Hella (D)
	(v) **soft front ends** to reduce impact in accidents	(v) Hella (D)
Engine parts, components, peripherals		
a. Valve guides and seats	*Process innovation*	
	(i) low-cost technology to produce **silicon nitride ceramics** with superior wear resistance properties compared to metal	(i) Eaton Corp. (US)

Product/ component/ part	Technology frontier	Principal customers/ competitors (examples)
	(ii) **Vespel SP 262**: polymide to replace metals in valve guides requiring less lubrification, with reduced oil loss and lowered diesel engine emissions	(ii) DuPont (CH)
	(iii) **thermoplastic composite valve cover**: achieves 65% weight reduction compared to metal at lower cost and environmental impact	(iii) Bruss Sealing Systems (D)
c. Batteries	*Process innovation*	
	(i) gas recombination: higher volumetric energy densities with enhanced cycle life	(i) various
	Product innovation	
	(ii) **Select Orbital**: sealed, modular, high-voltage battery system that can be located anywhere and in any orientation in the vehicle	(ii) Exide (US)
	(iii) "**Intelligent Power Management Systems**", including charge system failure and battery disconnect alarms, based on MOSFET semiconductors	(iii) Intra Technologies (US)
	(iv) more powerful and reliable **batteries for hybrid electric vehicles** (HEVs): valve-regulated lead acid, nickel metal hydride, and lithium ion batteries plus ultra-(i.e. double-layer electrochemical) capacitator	(iv) various
Fuel tanks	*Process innovation*	
	(i) "**blow forming**": processing technology allowing to insert components inside the tank	(i) ABC Group (US)
	(ii) **integrated plastic air intake and fuel system** with a fuel rail moulded into the air intake manifold, to reduce cost and weight and increase quality	(ii) various thermoplastic operators
	Product innovation	
	(iii) **Coex CVR** (complete vapour recovery) cover for plastic fuel tanks, meeting CARB (California Air Resources Board) emission requirements	(iii) Krupp Kautex Maschinenbau (D)
	(iv) "**Ship in a Bottle**" (SIB): components are moved inside the tank to reduce the number of shell openings	(iv) TI Group (US) + AMTECC (CAN) + Atofina (F)
Catalytic converters, exhaust systems	*Process innovation*	
	(i) "**Lightweight Exhaust System**": components independently attached to vehicle structure rather than being hung in one heavy piece, using stainless steel tubing anchored to floorpan; combination of acoustic and thermal insulation	(i) Bosal (US), (ArvinMeritor (US), Tenneco Automotive (US), Faurecia (F), Eberspacher (D))
	(ii) "**artificial muscles**": films of electroactive silicone or acrylic polymers that flatten or stretch with an electric current at fraction of weight of conventional dampeners	(ii) SRI (US)
	(iii) "**digital simulation of exhaust systems**": allows for calculation of dynamics of systems in use	(iii) Exa Corp.'s PowerFLOW software (US)

Product/ component/ part	Technology frontier	Principal customers/ competitors (examples)
	Product innovation	
	(iv) "**exhaust oxygen sensor**": determines stoichiometric air-to-fuel ratio point to optimise air and fuel management and minimise tailpipe emissions	(iv) Delphi (US)
	(v) "**zeolite-Y-based catalyst material for plasma-catalysis exhaust treatment**": allows for removal of 90% of NO without requiring major design changes to vehicles or fueling infrastructure	(v) Pacific Northwest National Laboratory (US), with Delphi (US) and Ford (US)
	(vi) new catalytic converter substrate (**Aluchrome 7A1 YHf**) to speed up reaching of ideal operating temperature and thus reduce pollution emission	(vi) Krupp VDM (D) + Fraunhofer Institute for Applied Materials Research (D) + University of Wuppertal (D) + Emitec (D)
	(vii) "**DPNR**": catalytic converter for diesel engines that simultaneously reduces oxides of nitrogen and particulates through a multi-function catalyst overlaying a porous ceramic filter	(vii) Toyota (J)
	(viii) **plasma-based regenerative filters**: reduce particulates of diesel emissions by 94-9%	(viii) Faurecia (F), NoxTech (US), DaimlerChrysler (D), GM (US, Ford (US, Delphi (US) + Peugeot Citroën (F)
	(ix) "**air-to-air package**": integration of fresh-air induction, emission control, and exhaust systems	(ix) ArvinMeritor (US) + Zeuna Starker (D)
Tyres	*Process innovation*	
	(i) "**C3M**": process technology that allows to build tread layer from several strips of compound with different, individually optimised properties	(i) Michelin (F)
	(ii) custom-designed f**ixed-mount sensors** to fit on rim directly and reduce manufacturing costs	(ii) SmarTire
	Product innovation	
	(iii) "**intelligent tyres**": application of silicon sensors, RF transmitters, and other sensing techniques to allow tyres to monitor pressure, track temperatures, know loading conditions, command onboard pumps to add air	(iii) BERU (D), Bosch (D), Cycloid (US), Goodyear (US), Infineon (D), Lear (US), Michelin (F), Motorola (US), Schrader Electronics (UK), SensoNor (N), SFK (S), TRW (US), Wabco Vehicle Control Systems (US)
	(iv) "**TIPM**" (Tire Intelligent Pressure Management): 380W air compressor mounted in trunk or engine bay to repressurise tyre by 25l air/minute	(iv) Michelin (F), Wabco (US)
	(v) "**SWT**" (Sidewall Torsion Sensor): magnetised sensors on tyre sidewall feed road, braking, and speed data to sensor mounted on axle assembly allowing faster reaction than current ESP technology	(v) Continental (D)
	(vi) **runflat tyres**: elimination of spare wheel	(vi) Bridgestone (J), Goodyear (US), Michelin (F)

Product/ component/ part	Technology frontier	Principal customers/ competitors (examples)
Industrial rubbers	*Product innovation*	
	(i) **Therban ®**: new formulation with higher heat resistance over time to accommodate increased under-the-hood operating temperatures	(i) Bayer (D)
	(ii) **Vulcuren ®**anti-reversion agent: bifunctional crosslinker improving thermal stability of crosslinks, aging behaviour, and static and dynamic vulcanizate properties	(ii) Bayer (D)
Body structure and parts a. Specialised steel	*Product innovation*	
	(i) "**Stavax Supreme**": premium grade stainless tool steel with greater corrosion resistance, to accommodate more ambitious use of plastics in cars	(i) Böhler Uddeholm (A)
b. Die castings	*Process innovation*	
	(i) "**MIM**": magnesium-injection moulding process offering strong, lightweight components with superior properties than die-cast magnesium	(i) Phillips Plastics Corp. (US)
	(ii) Charge-Air-Cooler high temperature **nylon end tanks**: lower weight and cost and better performance than die cast aluminium	(ii) Ford (US) + Valeo (F) + Carlisle Engineered Products (US)
	(iii) rapid prototyping (**RP**) and rapid tooling (**RT**): direct conversion of 3D CAD data into physical prototype and manufacturing, reducing lead time and cost of industrial tooling	(iii) various
	(iv) **High-Q-casting**: vacuum die casting technique producing thin-walled castings with high ductility (e.g. used for B-Pillar in all-alu Audi A2 chassis	(iv) Alcan (US)
	(v) **Ryobi New Casting** process: using finite-element analysis to boost strength-to-weight-ratio of castings; imcreases injection pressure, heats die halves, and introduces vaccum pumps to remove air bubbles for an improved quality	(v) Ryobi (J)
c. Metal stamping	*Process innovation*	
	(i) "Electromagnetically assisted stamping (**EMAS**)": applying electromagnetism to avoid for aluminium edges to tear or wrinkle during forming operations	(i) Ohio State University (US)
	(ii) process optimization – instead of sheet material improvement – to manufacture **stronger and lighter automotive panels in more complex shapes**	(ii) PNGV (Partnership for a New Generation of Vehicles) (US)
	(iii) **carbon-fiber composites** (instead of metal) in auto chassis structures using a production-capable process (compression-moulded SMC): reduces parts weight	(iii) Meridian Automotive Systems (US) for DaimlerChrysler (D)
	(iv) **plastic/metal hybrid technologies** where plastic joins steel in a true structural member and in the injection moulding pocess	(iv) Audi (D) + Faurecia (F)
d. Press tool parts	*Process innovation*	
	(i) "**parts without machining**": replacement of cutting tools or presses for manufacture of metal parts in favour of laser technology that allows going straight from a CAD model to a full-blown 3D part (➔ free-form fabrication through Laser Engineered Net Shaping)	(i) Sandia National Laboratories (US)

Product/ component/ part	Technology frontier	Principal customers/ competitors (examples)
	(ii) "**fineblanking**": material to be formed reliably held in place in the tooling to achieve much closer clearance between the elements than with conventional press tooling	(ii) both suppliers and OEMs with the requisite craftsmanship
e. Electro-plating	*Process innovation*	
	(i) **vapour deposition coatings**: allows deposition of metals and refractory compounds difficult to apply by other means, leading to functional and aesthetic finishes for interior parts, without environmental limitations or hydrogen embrittlement associated with platings	(i) Vapor Technologies (US)
	(ii) research into **"green" electrolyte technology** using far less toxic ionic Chromium III salts instead of conventional Chromium IV	(ii) Poeton Industries, Smiths Aerospace, Whyte Chemicals, University of Leicester (all UK), funded by UK government
	(iii) **kinetic energy metallization**: metal powders are high-velocity sprayed on substrate surface to establish an interfacial bond leading to a flat and well-adhered coating while eliminating caustic or poisonous chemicals often involved in electroplating	(iii) Inovati (US)
f. Fastening systems	*Process innovation*	
	(i) **linear-motor drive** with higher precision than electromagnetic devices to weld nohole systems	(i) Emhart Fastening Teknologies (US)
	(ii) **dynamic simulation of loading and strain rates** reflecting actual operating conditions of structures or components	(ii) Instron Corp. (US)
	(iii) use of **self-piercing rivets** with higher dynamic strengths than obtained in conventional spot welding	(iii) Textron Fastening Systems (US)
	Product innovation	
	(iv) **adhesives capable of bonding to less adhesive-friendly surfaces**; lower weight, and recyclable	(iv) 3M (US)
Painted plastic parts	*Process innovation*	
	(i) "**SLX** film": eliminates the need for double painting with colour-contrast vehicles	(i) GE Plastics (US)
	(ii) **dry paint film laminate**: allows for high- or low-gloss finishes at lower cost than spray painting and eliminates related environmental volatile organic compounds disposal issues	(ii) Avery Dennison (US)
	(iii) formable "**dry-paint films**": plastic films coated with stretchable paint layers that retain integrity when films are thermoformed; cost reduction, better resistance and recyclability	(iii) Soliant HHC (US)
	(iv) "**moulded-in-colour**" film: even cheaper than dry-paint films	(iv) Mayco Plastics (US) + DaimlerChrysler (D)
	(v) **nanocomposite thermoplastic olefin**: uses microscopic clay particle reinforcement to increase stiffness and improve ductility	(v) GM (US) + Basell Polyolefins (US)

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