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Increasing Global Competition and Labor Productivity: Lessons from the US Automotive Industry

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1. Introduction

Increasing global competition is changing the environment facing most companies today. As trade barriers fall and transaction costs decline, new global competitors are entering previously more isolated domestic markets. In response to this intensified competitive pressure, local companies are pushed to enhance performance by innovating and adopting process and product improvements. This domestic sector dynamic leads to higher productivity, which, in turn, can create sustainable competitive advantages for companies, as well as being the most important driver of job creation and per-capita income growth for the economy. This link has been established in McKinsey Global Institute's extensive country productivity research.

Our new study goes further than previous research by focusing on *how* increasing global competition leads to productivity growth, using the US automotive manufacturing sector as a case example. More specifically, we have focused on the production of new vehicles in the US, including parts assembly. We have chosen this example because of the globally competitive nature of the automotive market and the size of the US in this market over our period of analysis. As we shall see, some of the non-US original equipment manufacturers (OEMs) had clear productivity advantages which enabled them to create significant competitive pressure in the US market.

In this report, we look at how the Big Three US OEMs responded to the changed competitive environment, how they overcame barriers to compete, or failed to do so, and how their introduction of process and product innovations drove productivity growth (Exhibit 1).[1] We find that nearly half of the productivity increase over the period from 1987 to 2002 was driven by the adoption of improved process technology by the Big Three. About one quarter came from the shift to new products with higher value-added per hour worked. The remainder of the industry productivity increase came from increased features and quality in existing products, a shift within the industry to more efficient producers (including an increased share of production by high-efficiency transplants), and the process efficiency improvements that have arisen from changes in product mix.

[1] Productivity is measured by real value-added per hour worked. The Big Three OEMs are General Motors (GM), Ford and Chrysler.

The Japan-based OEMs (primarily Toyota, Honda, and Nissan), with their superior "lean production" process, were able to produce higher quality vehicles at lower cost. This competitive challenge was the most crucial driver of higher productivity as the Big Three were forced to respond by introducing their own versions of lean production. At the same time, the Korea-based OEMs competed on low cost, intensifying price pressure in the small car segment, and the German- (and Japan-) based OEMs provided a strong challenge in the luxury and performance segments. This three-pronged competitive threat took market share from the Big Three and put pressure on their profitability.

The automotive industry in the US is also strongly affected by regulation. Concerns about safety, fuel economy, and emissions have resulted in a complex and changing regulatory environment. The study examines the ways in which regulation has directly impacted on measured productivity and how it has influenced the competitive dynamics. It finds that the most important feature of the US regulatory environment is, in fact, that the market was open to global competition. Vehicles and parts imported into the US market on average face a very low tariff, while foreign direct investment is allowed, and even encouraged. Domestic producers were forced to compete against best-practice companies from around the world and this competition drove productivity growth.

By taking this detailed look at how different companies interpret, and respond to, increasing competitive intensity, and how their collective behavior changes sector productivity, we have been able to gain insight into the pressing questions on the minds of policy makers and corporate leaders alike: How does global competition change domestic sector dynamics and productivity growth? How quickly do these changes occur? What factors determine the speed of adjustment? What will be the impact on the stakeholders? What are the implications for policy makers and corporate leaders?

In the following section, we provide a synthesis of our findings, including the primary implications for policy makers and corporate leaders. The final section includes a short data appendix.

2. Synthesis: How Competition Drives Innovation and Productivity Growth

Over the period from 1987 to 2002, labor productivity in the US production of new vehicles (including parts and assembly) increased 3.3 percent annually. The hours required to produce the parts and assemble a vehicle fell, even while the average value-added per vehicle increased (Exhibit 2). Hours worked fell because of process innovations, shifts in market share to more productive players, and changes in product mix. Average value-added per vehicle rose because consumers purchased new, higher value-added models, and models with improved features and quality (Exhibit 3).[2]

In particular, we found that for the production of new vehicles,

- Innovations that improved process efficiency accounted for 45 percent of the total increase in labor productivity between 1987 and 2002.
- The introduction of new higher value-added models was the next largest contributor, accounting for 25 percent of the increase.
- Shifts in market share to more efficient producers, improvement in existing models (including higher quality and more features), and changes in product mix, accounted equally for the remaining 30 percent.

Our focus on new vehicle production differs from most common approaches. We include the assembly of new vehicles as well as the production of parts for new vehicles within our sector definition because we are interested in how innovation impacted the entire value chain of new vehicle production. This differs from most industry based analyses which tend to focus on assembly and parts production separately. It also differs from most economic analyses which typically focus on a

[2] We have chosen the 1987 and 2002 period for two reasons: it is the longest time frame for which there is consistent data, and after 1987, non-US OEM production facilities set up in the US played an increasingly important role in the competitive environment (see Exhibit 25). In our productivity calculations, real output is calculated from nominal value-added deflated by the gross output deflator. See the technical appendix for a discussion of why we use this approach to productivity measurement. The focus of this study has been the way global competition drives productivity within the US auto industry. The extent and nature of offshore outsourcing has not been a primary focus (see the MGI study on GIR, add citation).

broader definition of the sector.[3] In what follows, all references to the US automotive sector refer to new vehicle production.

The productivity performance of US new vehicle production was strong – substantially faster than the 2.1 percent growth rate achieved by the non-farm business sector over the same period. It also compared very favorably with productivity growth in the rest of the manufacturing sector. (BLS estimates total manufacturing output per hour grew at 3.5 percent a year between 1987 and 2002. Based on output-per-employee, we estimate that productivity increased at 2.4 percent a year in manufacturing, excluding the high-tech and auto sectors). Since new vehicle production is a relatively mature sector, it might have been expected to have grown sluggishly over this period but it didn't; its strong performance is therefore consistent with the view that global competition provided a spur to productivity improvement. Moreover, the largest boost to productivity growth came from process innovation brought into the US market by global competition—the lean production system developed in Japan.

Product innovations – that can also be linked to the arrival of global competitors – also contributed substantially to industry productivity growth. With their share of the car market rapidly eroded by foreign competitors, the Big Three looked for new products that would play to their strengths. They developed Sports Utility Vehicles (SUVs) and minivans that appealed to customer demand for larger vehicles which their global competitors were not offering and would not have the capability to offer for some years. Lower fuel economy standards on light trucks also made this segment attractive to the Big Three.

Although global competition provided the incentive for change, productivity growth in the US industry was primarily the result of actions and decisions made by the Big Three. In general, companies can respond to increasing global competitive pressure in various ways: they can seek trade and regulatory protection; they can build capabilities that will help them compete; or they can exit the segment, market, or industry (Exhibit 4). Between 1987 and 2002, there were no significant barriers protecting the US automotive sector from foreign competition, and none of the Big Three were driven to exit by competition (although Chrysler merged with Daimler Benz).[4] In fact, the Big Three reacted positively, building capabilities and improving their performance.

[3] Typically, the sector is defined according to the GDP-by-industry accounts, which also includes production of parts for the aftermarket, heavy duty trucks, truck trailers and recreational vehicles. See the technical appendix for a complete discussion of our sector definition.

[4] Two exceptions are worth noting. First, the voluntary restraint agreements we discuss below which limited automotive exports from Japan between 1981-1994. Second, the 25 percent tariff on imported pick-up trucks imposed in 1962

In the remainder of this section, we will describe the nature of the competitive challenge facing the US industry; the way the US industry responded; the impact on key stakeholders; and the implications for companies and policy makers. The impact of some auto-specific regulatory provisions is described in a box on page 7.

THE BIG THREE FACED A TRIPLE THREAT

The success of the global automotive players based in Japan, Germany and Korea created significant competitive pressures in the US auto market between 1987 and 2002. With the number of light vehicles sold in the US growing at only 0.8 percent annually over this period, competition for market share and profit margins was intense. A shift in consumer preferences from cars to light trucks played an important role in the competitive outcome over this period (Exhibit 5); so did environmental and safety regulations (see box on regulation).

Competition depressed Big Three market shares

The Big Three lost more than 10 percentage points of their light vehicle market share during the period of our study; losses in the car market were a particularly dramatic 21 percentage points (Exhibits 6, 7). If market shares had been maintained and other trends remained the same, Big Three sales would have been nearly 20 percent higher – increases in overall market demand, although modest, would have increased sales 13 percent and the shift in consumer preferences from cars to light trucks would have added nearly 4 percent (Exhibit 8).

Competitive pressures arising from differences in quality, pricing and product portfolios were driving these losses in car market share (Exhibit 9). The Japan-based OEMs primarily Toyota, Honda, and Nissan (then Datsun), scored their first successes in the US market during the 1970s, as demand for their fuel-efficient inexpensive cars increased in response to the two oil crises. After that, they refined their production processes, transformed their brands, and established a market-leading reputation for efficiency, quality, and good value from entry level models to luxury offerings. The Germany-based OEMs, primarily Daimler and BMW, were

during a trade dispute with Europe. This tariff pushed non-US producers to locate in North America (Canada has always been exempt, and Mexico has been exempt since the signing of NAFTA). But, production location decisions were also strongly influenced by the US centric nature of the world-wide pick-up market. Thus, the tariff influenced competitive dynamics and hence productivity to the extent that it independently drove location decisions, and raised pick-up prices. These independent impacts were likely small during our period of study because many production facilities were already located in North America by 1987, and new plants were for pick-ups destined almost exclusively for the US market.

established leaders in design and performance, especially in the luxury and performance segments and their product portfolios continued to put pressure on the Big Three in these areas. Later on in the period, the Korea-based OEMs, such as Hyundai, were establishing themselves as low cost producers and successfully attacking that end of the market. In addition, by 1987 most major players were producing vehicles in the US (Toyota started a joint venture with GM in 1984 and its own US production in 1988). This brought another dimension to the competitive dynamic.

The Big Three continued to dominate the light truck market between 1987 and 2002, facing very little competition most of that time. Their established strength in this segment, combined with the rapid increase in consumer demand for light trucks, enabled the Big Three to mitigate the impact of their loss of car market share. By the late 1990s, however, global competitors had developed their own successful minivans and SUVs, and began capturing market share here too.

Financial performance suffered

Competition also put pressure on the Big Three's financial performance. Between 1987 and 2002, returns to their shareholders underperformed the broader market the majority of the time (Exhibit 10). In the case of GM, monthly total returns were below the S&P 500 for 81 percent of the time over the period; in the case of Chrysler it was 71 percent, for Ford, it was 61 percent.

This poor performance was partly because the Big Three competed by cutting prices – because they lagged the competition in vehicle quality and durability, they were forced to offer significant and increasing discounts to sell their cars (Exhibit 11). The Big Three also suffered some disadvantages on the cost side. At the beginning of our period, they were far less efficient than the Japan-based transplants measured in hours-per-vehicle (Exhibit 12), a major driver of their labor productivity disadvantage (as we shall examine in detail later). In addition to lower levels of efficiency, labor contracts negotiated by GM management and the UAW paid Big Three workers relatively generous wage packages. Average wages of production workers were 50 percent above those of the transplants; benefits were 44 percent higher (Exhibit 13).

Just as increasing demand for light trucks helped stabilize overall Big Three market share, it also bolstered Big Three earnings. When the industry emerged from the Gulf War recession in the 1990s, they made significant profits from light truck sales. These strong profits attracted entrants, and, by the late 1990s, margins began to fall. By 2000, despite their strength in this segment, the Big Three were making only $350 per vehicle on average, compared with $1,940 for the Japan-based OEMs (Exhibit 14). In the car market, their margins had been reduced to essentially zero.[5]

Finally, non-operational factors also had a big impact on the Big Three's financial market performance. For the Big Three, a significant driver of financial market performance was outstanding health care and pension liabilities. In 2001, GM faced $60 billion in unfunded liabilities (Exhibit 15). This amounted to nearly $8,000 per light vehicle it produced. Workforces of the non-Big Three U.S. based plants are still too young for future health care liabilities to be material. We estimate that without these liabilities GM's return on invested capital (ROIC) would have been more than three times higher between 1992-2002, and roughly in line with broad industry trends (Exhibit 16). Such performance would have substantially boosted financial market returns to GM shareholders.

The Big Three were unable sustain strong financial performance despite the significant gains in productivity between 1987 and 2002 which we will now document. (See box on productivity and business performance for an explanation on the relationship between productivity and profits.)

BOX: PRODUCTIVITY AND BUSINESS PERFORMANCE

Companies that increase labor productivity will initially improve profitability, but the relationship between productivity and profits is more complicated over the long term. In our case study of the US automotive sector between 1987 and 2002, productivity gains by the Big Three translated into temporary improvements in financial performance, particularly during the mid 1990's, but not a sustained increase in profit growth. This outcome is a consequence of the dynamic relationship between productivity and profitability, as well as non-operational firm specific factors, such as pension and health care liabilities as documented in the text.

The dynamic relationship between productivity and profitability can be explained using a simple example. Imagine a situation where two companies compete in the same regional market with access to the same factor inputs. Both have similar levels of productivity and profitability. If one company is able to increase its productivity, it will be able to produce the same quantity of goods and services at the same quality level with less labor, or materials, and/or hours. In this case, higher

[5] One reason that the Big Three continued to produce these cars even though they were unprofitable was that the CAFÉ regulations require an average MPG for the fleet of cars produced by OEMs which cannot be achieved by simply producing light trucks.

productivity will create a cost advantage, and the company can use the resulting profits for new investments, or it can distribute these profits to shareholders. The company may also choose to offer lower prices in order to gain market share or pay higher wages in order to attract higher-skilled labor.

A one-time increase in productivity, however, will usually not lead to a sustainable advantage in profitability. In order to stay competitive, the other company will have to follow suit and improve its productivity. Once the two companies reach the same level of productivity, they will compete primarily on price until any advantages in profitability have disappeared.

As documented in the main text, this dynamic generally played out within the US Automotive sector. The shift in demand to light trucks in the late 1990s increased productivity by raising value added per vehicle. The Big Three’s experience with light trucks gave them an early competitive advantage, allowing them to dominate the market segment. Combined with their gains in manufacturing efficiency, this enabled the Big Three to reap substantial profits in the second half of the 1990s. By the year 2000, the Japan and Germany-based OEMs began to successfully challenge the Big Three in the light truck market. This trend was accelerated by the shift in demand from SUVs based on truck platforms, to SUVs based on cars, where the Japan and Germany-based OEMs have significant advantages and manufacturing know-how. The increased competition in light truck market materially eroded profit margins for the Big Three.

BOX: THE IMPACT OF REGULATION ON PRODUCTIVITY GROWTH

Specific features of government regulation of the auto industry impacted productivity growth both directly through mandates and indirectly through their effect on the nature of new product introductions.

Safety features and productivity growth

Regulation accelerated the diffusion of features and technologies. In the 1970s, cars were redesigned to protect the passenger compartment during accidents and were successful in reducing the impact damage to the occupants of vehicles. During the 1987-2002 period, passive restraint systems were mandated which rapidly pushed air bag penetration to 100 percent. OEMs added other safety features, such as anti-lock braking systems (ABS) without any government mandate. It is notable that safety were less stringent for SUVs and other light trucks.

Regulation generally increased the cost of production, and hence prices – pushing them some $2,500 to $4,000 higher than they would have been otherwise, according to one study. Vehicle prices may or may not show increases at the precise time new regulatory features are added because other cost changes and market conditions are in play. Regardless of whether new regulatory features can be seen to have impacted on prices, the measurement methodology used by BLS in the US counts them as additions to real value-added in the industry (based on the estimated producer cost of adding the features). The benefits to consumers of regulated changes are hard to assess, and may be higher or lower than their production cost.

In our calculations, regulatory changes that drove the addition of safety features did increase value-added per vehicle. Whether or not they also boosted productivity depends on their impact on assembly hours and our interviews with industry experts suggest that these changed very little because of these added features. Additional hours were added in the parts sector to produce air bags, ABS, and other regulated components, but we found that cost-per-unit declined sharply as volume and penetration expanded. On balance, we judge that regulated safety features have had a small positive impact on measured industry productivity.

CAFE and emissions regulation and new products

Fuel economy standards were first introduced in the 1970s (when gas prices were very high); they favored imported vehicles because these were smaller, more fuel-efficient, and could meet emissions standards more easily. Over time, the Big Three responded to the pressures of regulation by developing smaller cars and using fuel injection and computer-controlled engines to preserve power and drivability while meeting regulatory requirements.

In the late 1980s, the Big Three recognized that consumer demand for large and powerful vehicles could be met by modifying commercial vehicles for widespread consumer use – minivans, SUVs and pick-ups. These vehicles did not have to meet the fuel efficiency requirements established for cars, and when gas prices declined sharply in the late 1980s, the market expanded rapidly. Over time, consumer demand and further regulation caused OEMs to add additional safety features to these vehicles but the CAFE standards remain less demanding in this segment.

When SUVs and minivans were introduced, they commanded price premiums that, measured by the BLS, were counted as additions to real industry value-added. Since hours-per-vehicle were not higher for this segment in general – and were actually lower for many SUVs and pick-ups – this change in vehicle mix contributed substantially to productivity growth.

THE BIG THREE INNOVATE

We have found that 45 percent of the productivity increase seen between 1987 and 2002 was driven by process innovation – primarily the adoption of lean production techniques by the Big Three. About 25 percent of this increase came from the shift to new higher value-added products; the remaining gain came from added features and quality in existing products, a shift within the industry to more efficient producers, and a changed product mix.

Innovating to improve process

The leading Japan-based OEMs were clear efficiency leaders between 1987 and 2002. Their lean production techniques minimized the hours required for assembly and they improved quality by, for instance, nearly eliminating end-of-line re-work and establishing close privileged relationships with suppliers that raised quality and efficiency throughout the value chain. The Big Three lagged substantially behind on hours per vehicle and their catch-up to best practice was the largest driver of productivity growth over the period. Adopting lean production techniques was the key (Exhibit 17), but catching the Japan-based OEMs proved difficult – it took nearly two decades for the Big Three to learn, adopt, and implement these techniques.

The Big Three began responding in the early 1980s. All of them made efforts to learn lean production system, taking look-and-learn tours to Japan, and forging strategic alliances with the Japan-based OEMs. Although their responses seemed similar, in fact they took away different lessons and produced quite different results. In 1987, the beginning of our period of analysis, Ford was the only one of the three that had already reached best practice assembly hours-per-vehicle. It took Chrysler until 1992 and GM until 1997 to bring down hours-per-vehicle to a similar level (Exhibit 18).

These differences in rates of catch-up was due to the fact that competitive pressure hit their company performance at different times; they had different views of the nature of the initial competitive threat; and their organizations responded in their own ways to the barriers they had to overcome to make the required changes.

Timing of the competitive pressure – Ford was suffering through its worst financial performance after the 1981-1982 recession, and was continuing to lose market share to the Japan-based OEMs. This combination precipitated the company's focus on early adoption of lean production techniques. Although Chrysler required a financial bailout to survive in 1979, it was not until the late 1980s and early 1990s when its performance faltered again and it was forced to home in on the necessary process improvements. GM continued to lose market share to the Japan-based OEMs throughout the mid- and late 1980s; however, it wasn't until 1992, when GM's performance was undermined by the Gulf War recession, that it recognized the need for process transformation.

Initial diagnoses of the competitive threat – Ford's equity relationship with Mazda helped managers to recognize early that the advantages of lean production system extended beyond assembly operations to encompass the entire value chain including just-in-time inventory control, design for manufacturing, total quality management, and developing close partnerships with their suppliers. Their tradition of using external benchmarks to judge themselves made it easier for Ford to get wise early. In contrast, when Chrysler and GM first started working with the Japan-based OEMs in the early 1980s, they focused almost exclusively on assembly operations as the source of the efficiency advantage. They missed the broader nature of Japan-based OEMs' new production system.[6]

Chrysler's initial learning from Mitsubishi Motors focused on factory practices. They were more focused on new product development as a response to the increased competitive pressure. GM's initial position of strength in the industry made it less ready to acknowledge the large performance gap it faced. Their early efforts in process efficiency improvement strongly emphasized automation, exemplified by their acquisitions of Hughes Aerospace (for technology), Fanuc (for robotics) and EDS (for computer systems). GM failed to reap substantial gains from these acquisitions, and all these subsidiaries were eventually sold.

Organizational responses – Ford's early success was based upon implementing process improvements as part of a company-wide transformation program, and on the good relationship between the UAW union and management. Ford's management was able to capitalize on a shared sense of crisis with the UAW and the UAW leadership helped the process of transforming the design of people's tasks as well as putting in place quality-related initiatives. Ford also involved its suppliers early on in quality improvements initiatives – the company sent its parts supplier groups to Japan in the early 1980s to learn what Mazda suppliers did in quality management It took four years for Ford to go from a pilot program to widespread adoption of lean production.

[6] See Chapter 3 for a complete discussion of lean production.

Once Chrysler's CEO Lee Iacocca focused on the need to improve process efficiency, he exerted effective top-down leadership to force change. Iacocca reached out to Mitsubishi Motors to ask for full collaboration in transferring production know-how, and sent Chrysler engineers to Honda to learn how vehicles were designed efficiently and how the R&D teams and the production engineers collaborated. Iacocca, like Ford, was successful in creating common cause with the UAW, inviting key representatives to board meetings. Chrysler also made significant efforts to partner more closely with their suppliers in the early 1990s and improved the cost, quality and time required for design changes. After initiating these changes six years after the original partnership with Mitsubishi, it took an additional six years for Chrysler to register significant improvements.

GM did not see any pressing need for a large-scale change program. Furthermore, its decentralized organizational structure impeded its ability to carry out process transformation once it realized the need. As late as 1999, GM still had a brand-focused structure in which division leaders managed all the major functions for their particular brand, including engineering groups, plant production, and sales channels. There simply weren't sufficient incentives for these division leaders to focus on cross-brand, within-company learning. Although some of GM's plants, including NUMMI, were successfully implementing lean production and were classified as best plants in the industry, this experience of internal best practice was not fully transferred to the company's weak performing plants; the gap between the best and worst plants at GM was therefore much wider than that of Ford or Chrysler.

GM initially faced UAW resistance and was only able to gain the union's cooperation after management had put the work in to create a shared understanding of the extent of the transformation required To overcome the organizational challenges, they launched initiatives to help diffuse new process innovations across the company. This included transfers of experienced executives and mid-level managers and common platform projects (e.g., GMT 800). The Saturn pilot began in 1990, fully eight years after the NUMMI project was started and it took an additional seven years to reap the full benefits of the change program. However, although it took GM the longest to complete the transformation, its improvement was the most significant and GM is now the efficiency leader of the Big Three.

Parts manufacturers also improved their efficiency. The hours required to manufacture parts for new vehicles declined by 33 percent on a per-vehicle basis between 1987 and 2002.[7] This accounted for 24 percent of the overall sector

[7] Recall that our industry definition includes parts manufactured for the production of new vehicles, and excludes the aftermarket.

increase in productivity over the period. Although the fragmented nature of the parts industry makes it especially difficult to analyze sources of productivity improvement, we were able to identify the main drivers in engine and transmission manufacturing. For these two sub-sectors, (which accounted for approximately 25 percent of employment at that time), nearly all the productivity improvement came from changes in internal processes, including the introduction of easier-to-produce models using design for manufacturing techniques. The entrance of more efficient global competitors also had an impact.[8]

BOX: THE IMPACT OF CAPITAL ACCUMULATION ON LABOR PRODUCTIVITY GROWTH

Our decomposition of the sources of productivity growth is based on attributing increases in value added per worker to specific actions taken by the OEMs that either raised value added per vehicle or lowered hours per vehicle. We believe this approach has allowed us to understand the fundamental drivers of productivity growth by identifying the specific decisions and resulting activities undertaken by the Big Three. In some cases, the accumulation of additional fixed capital was the outcome of these decisions. A more traditional "growth accounting" approach is to decompose increases in value added per hour into contributions from capital deepening – increases in the ratio of capital services to labor hours – and total factor productivity (TFP).

There was essentially no capital deepening in the broadly defined US automotive sector (including production of parts for the aftermarket, heavy duty trucks, truck trailers and recreational vehicles) for the first ten years of our period of analysis (Exhibit 19).[9] In the later half of the 1990s, the capital labor ratio rose with increased investment and a decline in overall hours. Because the capital labor ratio was essentially flat for this initial period, TFP growth drove changes in labor productivity between 1987 and 1996. Between 1997 and 2002, capital services rose while labor hours remained flat or declined, so that capital deepening had a significant contribution during this period (Exhibit 20).

[8] For the purposes of disaggregating the sources of contributions for the parts producers, we assumed that the remainder of the parts industry outside of engines and transmissions improved their productivity for the same reasons. Some of the improvements in hours for the parts industry could have come about because of shifting jobs out of the US, primarily to Mexico (see the technical appendix for further discussion). It has not been possible to obtain quantitative estimates of this activity, although the qualitative evidence suggests that a large portion of parts imports are destined for the aftermarket.

[9] Capital stock data is not available in a form which allows us to compute the growth accounting exercise using our more narrow sector definition of new vehicle production.

Capital deepening is often attributed to firms substituting capital for labor because of differences in factor prices. Although GM and Chrysler did push for increased automation in the early 1990s, this did not result in any significant capital deepening. The capital deepening that occurred in the later half of the 1990s was accompanied by significant organizational and institutional change, and labor cost arbitrage was only one factor driving these changes. Other factors include changes in physical plant required to implement lean production, the upgrading of plants to produce new model SUVs, the construction of new plants by non-US OEMs, and investments by the parts sector driven in part by OEM outsourcing.

Beyond recognizing that a reduction in hours per vehicle would increase capital deepening (all else equal), there is no direct one-to-one direct mapping between these two approaches, although both of them capture the impact of capital deepening and TFP growth. As we have decomposed the factors driving changes in value added and hours per vehicle, increased investment in capital equipment will increase efficiency, driving down hours per vehicle. It will also increase value added, to the extent that new equipment improves the ability of OEMs and parts manufacturers to increase quality and produce new functional features. Similarly, to the extent that increases in TFP captures such things as the efficiency impact of improved organizational structures it will reduce hours per vehicle. TFP will also capture the additional value that the OEMs were able to extract through selling higher value added vehicles including many of the new SUVs.

Innovating new light trucks

Light trucks' share of total light vehicle sales rose from 32 percent in 1987 to 52 percent in 2002; the Big Three's share of the segment, while falling from 81 percent in 1987 to 77 percent over the same period, was still dominant. The shift to light trucks increased productivity because it increased average value-added per vehicle by nearly 15 percent (Exhibit 21), accounting for 25 percent of the total change in productivity during these years.

The Big Three were well positioned to capitalize on the shift in demand, particularly to SUVs – the biggest growth area of light trucks) – because of their experience in building pick-up trucks. The SUVs used identical underlying technology as the pick-ups, making it easy for the Big Three to penetrate this market. This technology was not only well known; it was cheaper than that being used in most cars, and far easier for the Big Three to assemble. Furthermore, less stringent CAFE regulations for light trucks meant that they could produce these vehicles without including expensive fuel-saving technologies. The strong profits they earned helped raise their overall, average value-added per vehicle.

While the Japan-based OEMs were able to sustain a competitive advantage because of their superior production processes, Ford was not able to sustain much of an advantage after the introduction of the Ford Explorer – the first "modern" SUV – in 1991. Although it took Japan- and Germany-based OEMs longer to respond because of their limited experience in US-style light trucks, Chrysler and GM followed Ford quickly with their own models.

The number of modern SUV models jumped from zero in 1987 to 54 in 2002 (Exhibit 22). This was important for sector productivity growth because of the widespread market penetration and the high value-added of these vehicles. On the downside, the fact that the Big Three responded to global competition through new model introductions reduced the sense of urgency that process improvement was needed, and is likely to have slowed productivity growth.

Improvements in features and quality

OEMs add new functional features to try and extract more value from their existing customers, to differentiate their products, and to try and maintain market share – and the Big Three increased the feature content of their vehicles significantly between 1987 and 2002. This was a natural response to the slow overall growth and competitive pressure in the market. We estimate that the addition of functional features alone would have produced a 7 percent increase in value-added per vehicle over the period (Exhibit 23). This is the equivalent of around a 9 percentage point contribution to the overall increase in productivity.

To understand how innovations embodied in functional features impact productivity growth, we studied the introduction, adoption, and market penetration of airbags and anti-lock brake systems (ABS). Airbags and ABS suffered from the kind of "infancy problems" encountered by many new technologies: technical difficulties, high costs, and limited consumer demand when first introduced. These problems, along with very little interest by consumers, caused the original innovators (GM for airbags, Ford for ABS) to withdraw these items from the market. Both of these technologies, with modifications, were later successfully introduced by Mercedes Benz, and adopted quickly by other luxury and performance brands.

Despite their successful introduction in high-end models, airbags did not achieve wide penetration in the US market until regulations were passed in 1991 requiring all new passenger vehicles to have passive-restraint systems installed. ABS did not achieve widespread penetration until their cost fell enough for them to be included in lower end vehicles (Exhibit 24). It was widespread penetration that drove their contributions to productivity growth.

As well as adding new functional features, the Big Three made progress in closing the quality gap between them and the best-practice, Japan-based OEMs. The Big Three improved their initial quality, measured as the number of defects reported in the first 90 days, from about 55 percent of the best practice level in 1990 to around 74 percent in 2002 (Exhibit 25). It took the Big Three roughly 12 years to cut the gap in half, partly because Toyota kept pushing the standard upward at an astonishing rate of 5.8 percent per annum. The Big Three also improved vehicle durability, measured as the number of problems per vehicle in the first three years, to reach 70 percent of best practice levels by 2002. We estimate that increases in industry vehicle dependability alone would have increased value-added per vehicle by 5 percent over the period (Exhibit 26). This translates to an approximate 6 percentage point contribution to the overall increase in productivity.

As noted above, part of the increase in quality is from the adoption of lean production techniques, which tend to reduce overall assembly errors, although our estimate of the magnitude of this positive spillover from process improvements is small. The majority of the quality improvements have come from the increased quality, reliability, and overall performance of components.

Shifting production to foreign transplants and changing the model mix

The Big Three's sales and financial positions were being battered by the 30 percent slump in demand during the early 1981-1982 recession which coincided with stiff competition from Japan- and Germany-based OEMs that were taking share in the car market. This combination led to calls for protection, and the US administration negotiated voluntary restraint agreements (VRAs) with the Japanese government in 1981, that restricted the number of cars that the Japan-based OEMs could export to the US. The VRAs were in place until 1994.[10] (Interestingly, GM resisted the plea by Ford, Chrysler and the UAW for trade protection during this period).

The VRAs accelerated a nascent trend: by 1987, all major foreign competitors had responded to the market opportunities, and changing economic and political environment, by setting up production facilities in North America. (Toyota had

[10] Estimates vary on how binding the VRAs were over this period. For a discussion and additional perspectives on the impact of the VRAs, see Berry, Steven, James Levinsohn and Ariel Pakes, "Voluntary Export Restraints on Automobiles: Evaluating a trade policy," *American Economic Review*, vol. 89, no. 3 (1999), and references therein

begun a joint venture with GM in 1984, and established its own US production in 1988.) The growth of the transplants meant that competition from global players was increasingly coming from facilities located in North America (Exhibit 27).

The increasing market share of domestic production facilities operated by non-US based OEMs was an important contributor to higher productivity. Together with concomitant improvements in the efficiency of parts manufacturing which also partially migrated to more efficient Japanese producers, this shift accounted for 10 percent of productivity growth over the period. In addition to this direct impact on productivity growth, the VRA's focus on numerical import targets rather than on the value of imports, created an incentive for the Japan-based OEMs to focus on creating higher value added models for export, and shifting the production of their entry and mid level cars in the US. The introduction of higher quality models and new brands (e.g., Lexus was launched in 1989) by the Japan-based OEMs was an important factor driving competitive pressure in the US market for years to come.

The move to light trucks also played an unintended role in improving process efficiency, since trucks are on average easier to assemble than cars. The externality produced by this shift in model mix shift accounted for 5 percent of productivity growth over our period of analysis. We have counted it separately from process innovation because it was not the result of deliberate actions taken by OEMs to improve manufacturing efficiency.[11]

GLOBAL COMPETITION AND PRODUCTIVITY DYNAMICS

This case study has allowed us to shed some light on the three key questions. How does global competition change domestic sector dynamics and productivity growth? How quickly do these changes occur and what factors determine the speed of adjustment? What will be the impact on the stakeholders?

How does global competition change domestic sector dynamics and boost productivity?

Global leaders with superior production processes and better quality products increase the competitive pressure on domestic players. This then kicks off a

[11] In 2002, trucks assembly on average required more hours than cars assembly. This was not because of the truck body complexity but because of the greater number of added-on features on truck. The lack of consistent company level data about the fragmented parts sector prevented us from quantifying the potential net impact of product innovation externalities on this part of the industry.

dynamic which leads to changes in company conduct, performance, and sector productivity growth. In particular, this pressure encourages companies to build the capabilities they need to compete, introducing process and product innovations and adopting the innovations of others.

Using our automotive case, it is helpful to illustrate this dynamic as a four-step process (Exhibit 28):

- **Market outcomes.** Competition drives changes in market share and profit margins. Market shares are a reflection of price/value combinations that are being offered to consumers; profit margins are a reflection of price/cost relations within OEMs.
- **Build capabilities.** OEMs respond to market share challenges and the erosion of profit margins by building new capabilities. They do so by introducing process and product innovations and adopting the innovations of others. OEMs can also try and build distinctiveness in supplier and labor relations.
- **Product offerings and costs.** The capabilities developed by OEMs are combined to produce a portfolio of vehicles, with a targeted group of features, at a particular cost. Process innovations and enhanced supplier and labor relations improve efficiency and lower costs. Product innovations provide capabilities to build new and improved models. Both types of innovations influence vehicle quality.
- **Pricing and competitive positioning.** The OEMs set prices based on vehicle demand, value propositions, cost structure, and the pricing and availability of competitive brands. Prices are adjusted and incentives offered to improve the positioning of vehicles, the success of which determines the price/value and price/cost relationships which govern market outcomes. As outcomes change, the reinforcing process begins anew.

As this process repeats, labor productivity improves either through a reduction in hours per vehicle or through an increase in average value-added per vehicle

How quickly do these changes occur and what factors determine the speed of adjustment?

Within the US automotive sector, we found that the speed with which competitive pressure translates into productivity growth depends crucially on the nature of the competitive challenge. It is typically easier for competitors to respond to the introduction of new products than to advantage based on process superiority.

Beyond the specific competitive threat, companies face factors at each link in the dynamic process that can impede, or accelerate, the rate at which competition produces productivity growth. The reinforcing dynamic which drives this process does not flow uninhibited (Exhibit 29).

- ¶ **Diagnosing market outcomes and building capabilities to compete.** The nature of the competitive threat is important in this phase as new products are typically easier to gather intelligence about and emulate than new processes that are not very transparent from the outside. Alliances can help accelerate the gaining of insight into the competitive threat. Organizational flexibility and readiness to accept change are critical to building new capabilities.
- ¶ **Turning capabilities into new or improved products.** Once new capabilities are developed, new or improved vehicles must be created. To do this effectively, OEMs must be good at evaluating the uncertainties of whether a new vehicle or feature will be a success, as well as the complexity of production. Strong working relationships with suppliers and labor have proven to be a big plus in making this transition.
- ¶ **Creating a strong competitive position through pricing.** OEMs must often contend with additional, non-production-related costs that can limit their pricing options (e.g., health care and pension-related obligations for the Big Three). Aside from factors that impact costs, brand strength and reputation for quality are important sources of pricing power. The Big Three make have to make aggressive use of price incentives to compensate for their perceived quality gap.
- ¶ **Turning competitive positioning into positive market outcomes.** Market outcomes are ultimately determined by the perceived value proposition of a particular vehicle, relative to price. Reputation is a significant driver of sales in the US automotive industry with consumers often willing to pay more for a product they perceive as superior. Customer loyalty is also very important for OEMs who actively strive to build long-term relationships with their customers. Once a customer shifts brands for whatever reason, they are difficult to win back.

What is the impact on consumers, shareholders and workers?

Consumers have been the largest beneficiaries of increased global competition. As discussed above, consumers have been facing falling inflation-adjusted prices for light vehicles, partly as a result of increasingly large incentives (see Exhibit 11). At the same time, the shift in vehicle mix has raised average value per vehicle and more and more features are being included (see Exhibits 21, 23). Moreover, there has been a dramatic improvement in the overall quality and durability of vehicles over our period of analysis (see Exhibits 25, 26).

As we discuss in more detail above, the Big Three's shareholders have not fared as well; their returns have remained stubbornly below market averages as the Japan-based OEMs maintained a significant competitive advantage (see Exhibit 10,14). They continue to suffer from a perceived quality/reliability shortfall for a range of Big Three products which equates to a $1,000 to $2,000 price discount to comparable products from Japan-based nameplates. The high mark-ups that had been available in the light truck segment have diminished sharply as industry supply has expanded and high fuel prices have made the segment less attractive to consumers. And, although this is not a focus of this study, the Big Three also face pension and health care costs that are substantially higher than their competitors (see Exhibits 15, 16). Partly as a result of these factors, the productivity increases in the domestic industry have not yet translated into sustained profitability.

Workers, however, have benefited from relatively stable levels of employment and purchasing power. Employment in the US automotive sector was essentially flat between 1987 and 2002 at some 1.1 million workers despite the cyclical fluctuations caused by two recessions, substantial increases in productivity, the signing of the North American Free Trade Agreement, and general trends in globalization (Exhibit 30).[12] But employment has shifted between companies. Big Three employment in assembly operations declined by about 190,000, while the transplants nearly doubled their employment from 15,000 to 29,000 workers. In addition, GM and Ford spun off their parts divisions into Delphi (GM in 1999) and Visteon (Ford in 2000). In 2002, these two parts suppliers had 270,000 workers. It is difficult to get company employment data for the parts industry, which is so fragmented, but there was a wave of closures, mergers, and takeovers among suppliers as the industry consolidated into larger entities. Overall, the share of employment in assembly operations fell while the share of parts employment rose.

Although employment declined in the Big Three, workers with jobs at the beginning of the period were given considerable employment protection. GM and Ford workers won a moratorium on plant closings in 1987, while Chrysler workers won job security as well as a moratorium in 1988. In 1996, the Big Three increased their job and income security funds and the union secured wage, pension and

[12] Unlike many industries that faced increased global competition, part of the reason that employment was so stable is that none of the Big Three exited the industry when faced with the competitive threat. As we note above, Chrysler needed a government bailout to survive in the late 1970s and then eventually merged with Daimler.

benefit increases – and further wage increases in 1999. As the workforce has aged, the companies have used retirements as a way to reduce employment. These successes by the union have helped automotive workers maintain average wages above those of production and manufacturing workers as a whole, and keep pace with inflation (Exhibit 31). Although an average of only 38 percent of workers belonged to the UAW between 1987 and 2002, non-union transplants have paid competitive wages too (Toyota matched UAW wages in 2004). Only non-union parts suppliers pay substantially lower wages (Exhibit 32).

IMPLICATIONS FOR COMPANIES AND POLICY MAKERS

What can policy makers and companies elsewhere learn from the U.S. auto sector experience? The policy case for economic openness is that prosperity depends upon the level of productivity in an economy and, as domestic companies and industries face increased global competition, they increase their productivity. But there are transition costs as the domestic industry adjusts to a more competitive environment. In this case study, we have identified ways in which policy makers and companies can help increase the benefits, and reduce the costs, of transition to more globalized sectors. To be effective, they must first understand how innovation ultimately drives productivity growth.

How innovation drives productivity growth

We have found three distinct phases in the evolution of a specific innovation, each of which has a different impact on productivity (Exhibit 33).

- **Initial innovation.** This phase covers the initial development and introduction of the innovation, including a new technology or product class, or a superior process. While critical, this phase generally has a low impact on industry productivity because the innovation has not achieved significant market penetration or been widely implemented throughout a particular company.
- **Adoption and learning.** Either competitors within an industry adopt innovations, or a company rolls them out more widely within its own organization. The ability to adopt the innovations of others depends importantly on their nature. It is often easier to imitate product advancements than it is to reengineer process innovations. Depending on the adoption rate, this second phase can have a moderate impact on industry productivity.

¶ **Penetration.** The final step of diffusion occurs as innovations become widely adopted within companies, and across an industry. Widespread penetration is what drives significant changes in market outcomes and raises industry productivity.[13]

How policy makers and companies can better capture benefits and reduce costs of global competition

Policy makers and companies must understand the impact of different phases of innovation on productivity and take on board that it is the penetration of innovations within companies and across markets that has the biggest effect. This diffusion often involves significant changes in market shares among companies and an associated migration of jobs. Policy makers often support policies that promote innovation such as aid for companies' R&D. But they should also make sure that policies do not create barriers to the industry shifts required for diffusion. There is also a case for policies to help workers that are adversely affected by the resulting adjustments. As for companies, they must focus not only on developing the next innovation, but on learning how to recognize the significant innovations of other companies. They must build capabilities to ensure that best practice process advancements are adopted and diffused across their organizations, and that product innovations achieve significant market penetration.

Policy makers can promote productivity growth – Policy makers must promote a level playing field and a competitive environment; be prepared to help ameliorate the impact of restructuring that sometimes results from global competition; and target polices that encourage the diffusion of innovations.

Promote competition from global players

Our US automobile sector case supports one of MGI's core findings from past productivity studies – that exposing domestic companies to competition from global best practice players is an effective way to generate strong pressure on performance and increase productivity growth.

Given the potential costs to incumbent companies and employees, it may be tempting for policy makers to draw back and impose or retain barriers to global competition but such a reaction would be a mistake. As we have seen, global competition has increased the overall productivity in the US auto industry and productivity is the ultimate driver of improvements in living standards.

[13] For a review of economic literature on drivers of the rate of diffusion of innovations, see Hall (2004): Innovation and diffusion. NBER Working Paper 10212.

Avoiding, rather than facing, global competition means giving up future productivity and income benefits. In any case, economies that shrink from global competition cannot ultimately hold back the forces of change – eventually the adjustment to best practice has to take place but it will be more difficult and costly because it has been delayed. The chances of ending up with a fully competitive industry are reduced, not enhanced, by the prolonged retention of barriers to competition.

Help compensate for restructuring costs

Global competition can lead to restructuring that does not benefit all stakeholders. In the case of the automobile industry, consumers have fared relatively well over the period we studied; employment overall has remained stable, but individual workers have been dislocated. Policy makers must try to separate policies that promote economic transformation, and those that help alleviate the impact of worker dislocation. Arguably, the company and labor market transitions in the US automotive industry would have been smoother if effective policies to promote worker reallocation were in place.

Several public policies could ease the transition – for instance, job-retraining credits to employers provide them with the incentive to hire displaced workers. Continuing education grants give workers a chance to build skills in demand, particularly from growing areas of the economy, such as healthcare, education, and social services.[14] Generous severance packages can help; and portable medical insurance plans and pension benefits are essential to a workforce changing jobs more frequently.

Target policies that encourage diffusion

We found no evidence in the auto sector that direct government policies to support innovation had a significant effect on productivity growth. As we have seen, the largest boost to productivity growth came from the diffusion of lean manufacturing adopted from Toyota and others. In the broadest sense, the education system is important; support for basic science and the availability of strong engineering and design talent are positive for productivity. But our findings are that it is the diffusion process itself – including learning, adoption, and penetration – that is the key to productivity growth. So the priority for policy makers is to do everything possible to remove barriers to, and promote, diffusion. Promoting diffusion is mainly done to companies (by, for example, creating flexible organizational

[14] Frank Levy and Richard Munrane, "How Computers are Creating the Next Job Market." Princeton University Press, Princeton, NJ, 2004.

structures), but governments can potentially play a role if diffusion is explicitly considered in research funding and regulatory processes.

Regulations can impede the diffusion of best practices and innovations (e.g., domestic content restrictions), but they can also promote it. In the auto case, we found that environmental and safety standards led to more rapid adoption and penetration of vehicle features than would have occurred without regulation; in this case, therefore, regulation actually contributed modestly to measured industry productivity growth.

There is also a role to play in actively promoting information-sharing. In the auto sector, government research grants facilitated the learning process when U.S. OEMs were identifying the root causes of the erosion of their competitiveness relative to Toyota and Honda. Such research helped establish the broad realization that the higher productivity of lean production was the main source of the competitive advantage, rather than lower labor and capital costs.

The introduction of OEM and car model quality rankings is a good example of how more widely available information can make a difference. Once consumers were able to compare the quality performance of different OEMs through information resources such as JD Powers and Consumer Reports, they were able to make better choices, changing the competitive dynamics of the industry. For instance, best performing models were now able to price at a premium to less reliable ones.

Companies must understand competitive threats and build new capabilities – Companies must carefully diagnose the nature of the competitive threat, and understand their comparative advantages relative to global players. Developing new and improved products is important, but will be ineffective in the long-term if they are still suffering from gaps in their underlying process-driven performance or if such new product innovations are not refreshed at a high frequency. In the end, the primary source of long-term sustainable competitive advantage lies in achieving higher productivity than the competition.

Understanding core drivers of relative strengths

Interpreting what is driving market outcomes and correctly diagnosing the nature of the competitive threat can be difficult, particularly if the challenger derives its advantage from less transparent internal characteristics such as production techniques or different costs structures. Traditional financial benchmarks may not reveal the source of a productivity gap; so companies should use a productivity-based diagnostic tool that can separate those factors driving differential market performance (such as reported profitability) and those that reflect fundamental differences in company operations and capabilities.

In our US automotive case, we found that companies had to go well beyond tracking the visible differences in market performance to understand fully the sources of their competitive advantage or disadvantage. They used productivity-based benchmarking as a management tool, and actively sought ways to learn from their competitors. Some companies took these steps earlier than others and used the results to make substantial changes in their operations. Some companies formed alliances but largely ignored the learning opportunity for some years.

Productivity advantage is key to sustainable performance

Our study has shown how the Big Three were able to develop highly successful new products (SUVs and minivans), creating a segment in which global competition was less of a threat and higher mark-ups were available. These new products provided substantial benefits, helping the Big Three sustain their light vehicle market share and profitability. The downside was that the “breathing room” this gave them made it easier to ignore the urgent need to change. The Big Three did continue to improve their operations, but rather slowly, and they continued to suffer from a quality/reliability gap.

Since product innovations are relatively easy to copy, they cannot be a permanent response to a new competitive challenge. It is a different matter with process innovation – Toyota, for one, has been able to sustain a strong performance through the process efficiency and quality control emanating from lean production. And Toyota has been able to maintain a lead against the Big Three because of the time and complexity they have faced in implementing changes in their production or business processes throughout their organizations. Companies that want to differentiate themselves through product innovations need to excel in the process of product development – an organizational skill that is harder for competitors to emulate than copying a specific product.

Organizational flexibility and readiness to change critical to new capabilities

Responding to the new global competition will often involve a radical reworking of product development, process technology, supply chain management and marketing and distribution. Yet companies face different initial conditions that impact on their capacity to implement these changes. Those that start with a very strong initial position in their domestic market can find it particularly difficult to recognize the seriousness of the competitive threat and that substantial operational changes are necessary, changes that will require diffusing productivity-improving innovations throughout the company.

Strict rules-based relationships with employees and suppliers can be a significant barrier to implementing changes. Buy-in from all stakeholders is required to reap the advantages of rapid diffusion. A strong top-down management structure can help facilitate faster transformation throughout the organization, and existing alliances can provide insight into ways to close performance gaps. The incentive structure thus needs to recognize and reward adoption and diffusion of best practices, both from within the organization, and externally.

* * *

The US auto industry has transformed since 1987. Productivity is much higher and consumers have been the primary recipient of the benefits. Global competitors have established efficient operations in the US and earn much of their worldwide profit in the US market. Faced with more intense competition, the Big Three companies, one of which is now part of Daimler-Chrysler, raised labor productivity between 1987 and 2002 by introducing and adopting process and product innovations, and improving overall vehicle quality. Although significant progress has been made, the Big Three have continued to face significant challenges turning these gains into ongoing profitability.

3. Data Appendix

The objective of this data appendix is to provide an overview of our data sources and the way in which we constructed our aggregate data set. We have not attempted to be exhaustive, but rather to highlight the critical inputs and assumptions. This appendix has two sections:

- ¶ **Aggregate data and adjustments** where we discuss how we estimated our measure of sector productivity growth
- ¶ **Aggregate productivity decomposition** where explain how we decomposed productivity growth into changes in value added per vehicle and changes in vehicle per hour

AGGREGATE DATA AND ADJUSTMENTS

Data sources

Gross output and value added. Base data was obtained for "Motor vehicles and equipment" In the GDP-by-industry accounts (NAICS codes 3361, 3362, 3363). It includes light vehicle assembly, and automotive parts production. It also includes heavy duty trucks, truck trailers and recreational vehicles. For nominal gross output and value added, we use the NAICS based series the BEA reports back to 1987.

Deflator for real gross output and value added. We used the gross output deflator for both gross output and value added. The primary reason for this choice is that the value added deflator is derived as an implicit deflator: nominal value added (computed as gross output less intermediate inputs) is divided by real value added (computed as real gross output less real intermediate inputs). As such, the value added deflator captures all the deficiencies in both the gross output and intermediate input estimates. Because intermediate inputs account for approximately 75 percent of gross output in this sector between 1987-2002, small changes in the measurement of intermediate inputs, sales and their prices can have large impacts on the computation of value added, and hence the value added implicit deflator. Not only is the value added deflator far more volatile, the growth rate of the value added deflator is significantly larger than both the gross output and intermediate input versions (Exhibit 34).

Using the gross output deflator does increase the compound growth rate of productivity from 3.0 percent to 3.3 percent annually, and raise the total change from 55 to 63 percent (Exhibit 35). However, decomposing the sources of productivity growth, we find that declines in hours per vehicle account for approximately 60 percent of the total 1987-2002 productivity change regardless of which deflator is used. Increases in value added per vehicle account for the remaining 40 percent (Exhibit 36). Using the value added deflator reduces the growth rate of value added, giving more emphasis to the change in hours, but as we are rounding our decomposition estimates to the nearest 5 percentage points, these small differences do not impact our interpretation of the sources of growth.

Employment. The employment series from the BEA is available on a NAICS basis only back to 1998. To estimate an employment series back to 1987, we use NAICS-based employment growth rates from the BLS.[15]

Average Hours per employee. These are taken from BLS. The total hours worked then result by multiplying the average hours from BLS with the employment series from BEA.

U.S. vehicle production and sales. Production data is taken from the Ward's automotive yearbook. Aggregate unit sales data is from the BEA.

Adjustment for elements not related to new cars and trucks

The "Motor vehicles and equipment industry," published in the GDP by industry accounts includes vehicle assembly and parts production. Assembly includes light vehicles, truck trailers and recreational vehicles; parts production includes parts for new vehicles and the aftermarket. We are focusing on the production of new light vehicles including assembly and the manufacturing of parts. Therefore, we need to adjust our value added and hours data to create time series that reflects just these elements of production. For each sub-sector defined in the GDP-by-industry accounts, we identified the share of output that flows into the sub-sectors "passenger car assembly" and "truck assembly." All other elements are excluded (Exhibit 37).

These adjustment change the labor shares of parts and assembly which drives the impact on productivity growth (Exhibit 38). The adjustments increase the level of

[15] http://www.bls.gov/lpc/iprdata1.htm

productivity by reducing the labor share of the less productive parts sector (Exhibit 39). They increase the growth rate of productivity because the labor share of parts is reduced by an increasing amount over time because the share of parts sales to other sectors and final demand is growing (Exhibit 40). Thus, new vehicle production has better productivity performance Overall, new vehicle production is more productive than the complete motor vehicle and parts sector (Exhibit 41).

Deducting imports from industries' commodity use. Our adjustments rely heavily on the "use table" contained in BEA's input-output tables in census years and sub-sector gross output and employment data from the ASM.[16] The use-table specifies the total amount of a commodity used by industry but does not specify how much comes from domestic production or imports. For imports, we know how much of a commodity comes into the country, but we do not know whether it is destined for new vehicle production or the aftermarket. To create an estimate of imports destined for new vehicle production, we assume that the import share for each commodity is equal across all industries and final consumption.

Determining the share of production flowing into new vehicles. For the sub-sectors engaged in the assembly of new light vehicles, nearly 100 percent of their total output flows to final consumption. For parts production, we estimate the proportion of sub-sector output that flows into new vehicle production by the ratio of commodity used by assemblers to total output of that commodity as specified in the use table. For gross output, we use total commodity output from the use-table; for value added, we exclude intra-industry purchases. With this approach, we construct gross output and value added adjustment ratios for each sub-sector. The total adjustment ratio for the industry is as a sub-sector weighted average.

For 1987, 1992, and 1997, data for gross output and value added are available on an SIC rather than a NAICS basis. A NAICS-consistent adjustment ratio must be estimated for these census years. We have used the published 1997 NAICS-SIC bridge to calculate a 1997 SIC based aggregate adjustment ratio that is comparable to 1992 and 1987. By splicing the pre-1997 growth rate to the 1997 NAICS ratio, we estimate a NAICS based time series of adjustment ratios.

Forecasting sub-sector use-table for census year 2002. The year 2002 sub-sector use-table will not be available until 2008, so we needed to construct estimates of this data. The use-table is available on a more aggregated level for 2002, so our estimates of sub-sector detail were constrained to the published aggregates. For 2002, import adjustments described above were only done at the more aggregated level.

16 The "use table" shows how much of a commodity is used by each industry, final consumers and for exports.

Estimating adjustment ratios between census years. Once we have estimated adjustment ratios for the census years, we estimate the values for the intervening years. This was done by interpolating the sub-sector adjustment ratios, and then using the sub-sector shares of employment and gross output from the ASM to create an aggregate adjustment ratio.

To adjust total hours worked in each sub-sector we use the same adjustment ratio as for value added. This assumes that sub-sector labor productivity is the same regardless of what the output is ultimately used for.[17]

Determining the split between OEMs and parts for gross output, value added and hours worked

To determine the relative contribution of OEMs and parts manufacturers to productivity growth, we estimated their relative shares of gross output, value added and total hours. All estimates are based on our adjusted numbers. There are three key steps involved in this calculation:

¶ First, we compute the relative sub-sector values of gross output, value added and total hours worked from the ASM.

¶ Second, using the sub-sector adjustment ratios, we determine the adjusted values for each sub-sector.

¶ Third, we link the NAICS and SIC based numbers together, based on the SIC growth rates.[18] The result is a complete time-series for the NAICS codes 3361, 3362 and 3363 and their relative shares in gross output, value added and total hours. 3361 is taken as the value for OEMs, the sum of 3362 and 3363 is taken as the value for parts.

Determining the split between production and non-production workers in total hours worked

To link to our company-level analysis with the aggregate data, we estimated total hours worked for production and non-production workers for both OEMs and parts.

[17] This does not mean that the adjustment ratio for the total sector is equal for value added and hours. Our assumption is applied at the sub-sector level. As a sector usually has different share in value added than it has in total hours worked (because productivity across sub-sectors varies), the impact of the adjustment ratio on industry hours worked is different than it is on industry value added.

[18] The sub-sectors that remain after our adjustments in SIC and NAICS fit relatively well. NAICS 3361 corresponds to SIC 3711, NAICS 336211 corresponds to 3713 and NAICS 3363 roughly corresponds to SIC 3714.

The share of production workers for each NAICS sub-sector is based on the BLS productivity study, which reaches back to 1987. The shares can therefore directly be applied to our time series of sub-sector NAICS hours we derived for the OEM and parts split in the last section. The NAICS sub-sectors are then aggregated.

AGGREGATE PRODUCTIVITY DECOMPOSITION

Calculation the required metrics

This section explains how the raw data and adjustments described so far are used to calculate various metrics we use to describe the evolution of the auto sector between 1987 and 2002. The metrics are always based on the adjusted data (i.e. the data excluding elements not related to new vehicles).

¶ Value added per hour

¶ Value added per vehicle

¶ Hours per vehicle

¶ Gross output per vehicle

¶ Intermediate inputs per vehicle

¶ Value added margin

Deriving the contribution to productivity growth

Relative contribution of OEMs and parts to productivity growth. Since we use the same gross output deflator for OEM and parts value added (see discussion above), real sector value added is the sum of OEM and parts real value added. The contribution of OEMs to value added growth is then

$$con_{OEM,t}^{VA} = \frac{VA_{OEM,t} - VA_{OEM,t-1}}{(VA_{OEM,t-1} + VA_{Parts,t-1})}$$

The same holds true, for total hours worked. OEM's contribution to total hours growth is

$$con_{OEM,t}^{H} = \frac{H_{OEM,t} - H_{OEM,t-1}}{(H_{OEM,t-1} + H_{Parts,t-1})}$$

The contribution of parts sector is computed similarly. Letting Z represent aggregate labor productivity, productivity growth equals

$$\frac{Z_t}{Z_{t-1}} = \frac{VA_t / H_t}{VA_{t-1} / H_{t-1}} = \frac{VA_t}{VA_{t-1}} \times \frac{H_{t-1}}{H_t}$$

Subtracting one from both sides, rearranging and denoting the growth rate of a variable between t-1 and t as g(t), this can be rewritten as:

$$g_t^Z = \frac{1}{\left(1+g_t^H\right)} \times \left(g_t^{VA} - g_t^H\right)$$

As we already know the contributions to value added growth and total hours growth, the contribution to productivity growth for each sector *i* at time *t* equals

$$con_{i,t}^Z = \frac{1}{1+g_{i,t}^H}\left(con_{i,t}^{VA} - con_{i,t}^H\right)$$

Using these formulas, total productivity growth is just the sum of the contributions, i.e.

$$g_t^Z = \sum con_{i,t}^Z$$

Relative contributions of value added per vehicle and vehicles per hour. Value added per hour can be expressed as

$$\frac{VA}{H} = \frac{VA}{V} \times \frac{V}{H}$$

The contributions are calculated using the additive properties of logarithmic growth rates

$$\Delta \ln \frac{VA}{H} = \Delta \ln \frac{VA}{V} + \Delta \ln \frac{V}{H}$$

Other relative contributions (e.g., production worker and non-production worker hours) are computed similarly. Based these calculations, we computed the following contributions to growth:

Contribution by / to	**VA/H**	**VA/V**	**H/V**
VA/H	100%	-	-
VA/V	42%	-	-
H/V	58%	-	-

OEMs	68%	74%	63%
Parts	32%	26%	37%
OEM PW H/V	-	-	70%
OEM NPW H/V	-	-	-7%
Parts PW H/V	-	-	33%
OEM NPW H/V	-	-	4%