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A New Global Auto Industry?

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Abstract

This paper brings together a number of robust trade models to shed some light on the likely evolution of the global automotive industry. Vertical product differentiation, intra-industry trade and fragmentation of production leading to international outsourcing are important features of the existing global automotive sector. The global automotive sector will most likely experience groundbreaking changes over the coming decades. The sector is confronted with a multidimensional technological revolution spurred by radical product innovation, shifts in customer demand and government incentives. A dominant driver will be growing public concern about climate change. China and India might well become leading players by 2050, if not earlier.

Key words: automotive industry, trade flows, product differentiation, new technology, outsourcing, China

JEL codes: F12, F13, F14

I. Introduction

The subject of this paper is the evolution of the automotive industry, seen from a global perspective. The automobile industry is a truly global industry: its contribution to the gross world product is approximately the same as the entire GDP of the UK, the sixth largest economy in the world. Almost 70 million cars are produced in the world annually, providing employment, directly or indirectly, to over 100 million people in approximately 100 countries. Most industrialized countries, and an increasing number of emerging economies, export either cars or automotive components. (Practically all countries are car importers.) The sector also invests over US$100bn per year in R&D.

When the bottom fell out of the national auto industries, policy-makers rushed to help,

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which was not surprising given that the predicament of the sector resulted in part from the macroeconomic and financial crises. The main purpose of these crises-inspired programs was saving jobs and "cash for clunkers" became a policy instrument of choice.

Policy-makers all over the world realize that they need to support the development of efficient, safe and environmentally clean automotive industries in their countries. The car manufacturers themselves recognize that the industry is in for big changes and are attempting to introduce low-carbon cars to the market. For many manufacturers, this has become a matter of survival. In addition, newcomers to the industry see opportunities to capture a large share of a rapidly changing market.

The present paper attempts to gauge how the auto industry might change in its international dimensions. Several existing trade models serve as a "walking stick." We identify two principal drivers of the change: income growth and the emergence of electric vehicles as an efficient and ecologically friendly means of transportation. China and India might well become centers of a new global auto industry.

II. Modeling the Global Auto Industry

Modeling the global auto industry is a difficult task, for several reasons. First of all, the industry does not produce a homogenous good but differentiated products, with a multitude of existing models, colors and options. Fortunately, numerous models of product differentiation have been developed.

The second obstacle to setting up a one-size-fits-all model of the global auto industry stems from the fact that the minimum number of countries that such a model should contain is greater than 2. In many cases, 2 countries can be used in the development of trade models. However, the appearance of new players in East Asia and Central Europe calls for a modification of the traditional 2-country set-up. The framework consisting of just 2 countries and only two homogenous goods will not do.

At least one more modification is needed. In the traditional 2-country model, production of a good is confined to a country in the sense that the entire production process would be executed, *in toto*, within national frontiers. However, in the contemporary global economy, production of a good does not have to be confined to national frontiers. Fragmentation of production and international outsourcing have become symbols of globalization. A US, French or Japanese car typically contains hundreds of parts and components coming from a multitude of countries, in addition to elements supplied by numerous domestic subcontractors. The national frontiers blur.

In sum, a sound and robust model of the global auto industry has to capture product differentiation, must be set up in a multi-country world and should take account of production fragmentation and outsourcing. Such a model does not exist yet and, in my view, is unlikely to turn up soon. However, there are well developed model "parts and components," which I intend to bring together in this paper.

Let me begin with modeling product differentiation in the auto industry. In general, a researcher has a choice of either horizontal or vertical differentiation. One could not deny that there is some horizontal product differentiation going on in the auto industry. After all, we see yellow Volkswagens and blue Volkswagens. However, the horizontal product differentiation takes a second seat to vertical product differentiation in this sector.

The Falvey–Kierzkowski (1987) model was specifically set up to deal with vertical differentiation. It works like this. Assume that there are: 4 countries, Germany, the USA, China and India; two commodities (sectors), food (*F*) and auto (*A*); and two homogeneous factors of production, capital (*K*) and labor (*L*). Assume further that sector *F* produces a homogeneous product and sector *A* produces a continuum of differentiated products called qualities, which are indexed by $s(0 < s < s_m)$. The homogeneous product sector uses a Ricardian production function with labor being the only input. In contrast, the differentiated product sector uses *L* as well as *K*. Constant returns to scale and perfect competition prevail in the two sectors, *F* and *A*.

The analysis can be greatly simplified if it is assumed that production of each level of quality demands a fixed capital–labor ratio. Production of all levels of quality requires one and only one unit of labor but higher levels of quality require more capital. More specifically, production of 1 unit of *A* of quality *s* calls for *s* units of capital, in addition to 1 unit of labor. Although there is no substitution between labor and capital for any particular level of quality, the capital–labor ratio for the sector as a whole varies in response to changes in the quality mix of the sectoral output. Finally, commodity *Y*'s price is set as 1. Given the above assumptions, two 0 profit conditions are obeyed in the two sectors:

$$bw = 1.0 \quad \text{and} \quad w + sr = p(s), \tag{1}$$

where *b* is labor required to produce 1 unit of food; *and w*, *r* and *p*(*s*) stand for the wage rate, the rental rate and the unit price of *A* of quality *s*, respectively. The model outlined above also satisfies two full employment conditions:

$$bY + X = L \quad \text{and} \quad \int sX(s)ds = K, \tag{2}$$

where X and Y stand for the total level of production of the two sectors, and $X(s)$ stands for output of quality s.

This completes the description of the supply side. Let us turn to the demand specification. Unlike in horizontal differentiation models, here individuals have no preferred models and their tastes are identical. Therefore, every individual maximizes the same utility function containing the quantities of the two goods and the quality of the differentiated product sector.

Although individuals share the same taste, their incomes are not equal. It follows that utility maximization will yield different results depending on the budget constraint of a person. Where does unequal distribution of income come from? Assume that everybody makes the equilibrium wage rate and, in addition, receives some income generated by capital employed in the differentiated product sector. There are a fixed and large number of shares based on K, which are initially distributed by a lottery. Some workers have income based on their wages and others enjoy additional income derived from share holdings. Although the distribution of the shares does not change, incomes of individuals are affected by changes in the equilibrium wage rate, return to capital, commodity prices and technological change.

Bringing together demand and supply conditions will determine the values of all the endogenous variables. This kind of exercise can be undertaken for a closed economy. However, it can be repeated in an open economy context. For the purpose of the present paper, I assume that the world consists of 4 countries: India, China, the USA and Germany. Assume further that in comparing the labor input coefficients in agriculture we establish that India has the Ricardian comparative advantage in agriculture and that it is also relatively well endowed with labor. Suppose that Germany has the greatest relative abundance of capital and that its agriculture is the least efficient of the 4 countries. China and the USA are somewhere in between India and Germany.

International trade will equalize commodity prices if commodity flows are not impeded by transportation costs, tariffs and other barriers. However, even under free trade and equalization of commodity prices, factor prices will not be equalized. The wage rate will be lowest in India, followed by the wage rates in China, the USA and Germany. This result is a consequence of the Ricardian flavor of the model. If wages are not the same across the world, then the rental rates will differ as well. Capital will be most expensive in India and least expensive in Germany.

India and possibly China will be food exporters, whereas Germany and possibly the USA will be food importers. However, who will have comparative advantage in cars? To answer this question let us draw four unit costs equations as a function of quality.

Figure 1 shows the unit output costs, $C(s)$, along the vertical axis and the quality measure, s, along the horizontal axis. Given Equation 1, the vertical intercept represents the wage rate in the 4 countries in terms of the numeraire good. From the same equation, the slope of the four cost lines gives the rental rate in India, China, the USA and Germany. In the production of cars, the inner envelope of the cost curves indicates the different qualities that countries will specialize in. Therefore, India will produce cars of low quality up to the model s_1, China will limit its production to models between s_1 and s_2, the USA will enjoy comparative advantage in the $s_2 - s_3$ range, and Germany will capture the high end of the market.

One of the conclusions of the Falvey–Kierzkowski model is that every country will be a car exporter. India, for instance, will export some of its car production to China. However, it will also export some cars to the USA and Germany because there is a market for lower quality vehicles in these countries. By the same token, India will import some high-quality models, such as Cadillac or Mercedes, because there is a market for higher-end cars in India. On the whole, however, India will be a net importer of cars. The average car quality in India will tend to be rather low given the average per capita income there. On balance, it will be a net importer of cars.

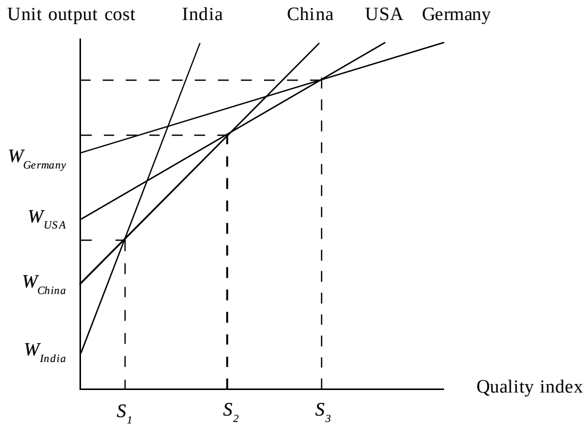
Moving to the other end of the quality spectrum, Germany will export and import cars to and from the USA, India and China, but, on balance, it will be a net exporter of cars. Its trade surplus generated by the auto industry will be exactly matched by food imports.

Consider now the case of China. It is worth noting that its direct competitors in production and exports are India and the USA. German producers operate in the range that is currently beyond the reach of the Chinese auto manufactures. Can China, or India for that matter, expand their production range? This will be a central component of the analysis in the latter part of the paper; however, to whet the reader's appetite I can say that the answer is "yes." In fact, there are several ways in which this outcome might be brought about. An increase in China's capital endowment, for instance, would lower the rental rate and the unit cost curve would become flatter. This effect would be primarily at the expense of US auto producers; it would also leave more room for Indian producers.

So far, the analysis has been limited to final goods. However, globalization has led to an expansion of outsourcing, international fragmentation of production and to the slicing up of the value chain. International trade increasingly involves exchanges of not only final goods but also intermediate products, parts and components, at different stages of production. This trend has been detected right across industries, with the automobile sector being no exception.

Let us now turn to the task of explaining this new dimension of many global industries. Ronald W. Jones and I proposed some time ago a theoretical framework explaining the phenomenon of fragmentation of production leading to outsourcing (Jones and Kierzkowski,

Figure 1. Unit Production Costs and Car Quality



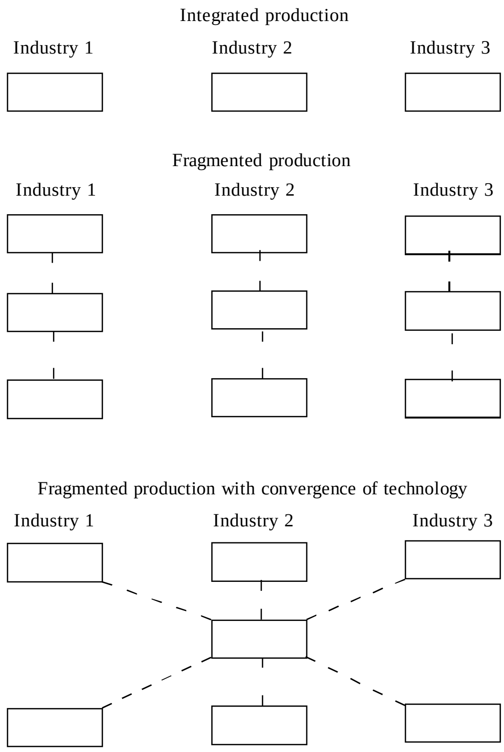
1990 and 2001a). Under fragmentation, instead of a single production block, the production process consists of a number of stages. The production blocks do not function independently but are connected through service links. A whole range of services might be required to coordinate car production in a fragmented process, including transportation, design, quality control, insurance, R&D and telecommunications. The degree of fragmentation measured by the number of stages or production blocks varies between industries and over time. As the degree and complexity of fragmentation increase, the importance of service links grows.

Fragmentation of production gives rise to domestic and international outsourcing. Different regions in the same country or different countries have different endowments, labor conditions and different levels of technological advancement. Competition forces producers to look for better organization of production in order to reduce costs and to increase profits. Several factors influence the extent of fragmentation, domestic and international. In the Jones–Kierzkowski framework, the size of the market determines when the switch from integrated to fragmented production becomes efficient. Furthermore, as the size of the market increases so does the optimal degree of fragmentation. Last but not least, costs of service links are bound to weigh heavily in deciding whether production should be integrated or fragmented.

So far, the process of fragmentation has been considered in the context of a single industry. What is good for one industry might well be good for other industries. Consider now car, laptop computer and mobile phone industries (called industries 1, 2 and 3) and imagine that they all apply integrated technology, as shown in the upper part of Figure 2. Over time, however, the three industries move to fragmented technology.[1]

[1] For a discussion of horizontal aspects of vertical fragmentation, see Jones and Kierzkowski (2001b).

Figure 2. Fragmentation and Technology Convergence

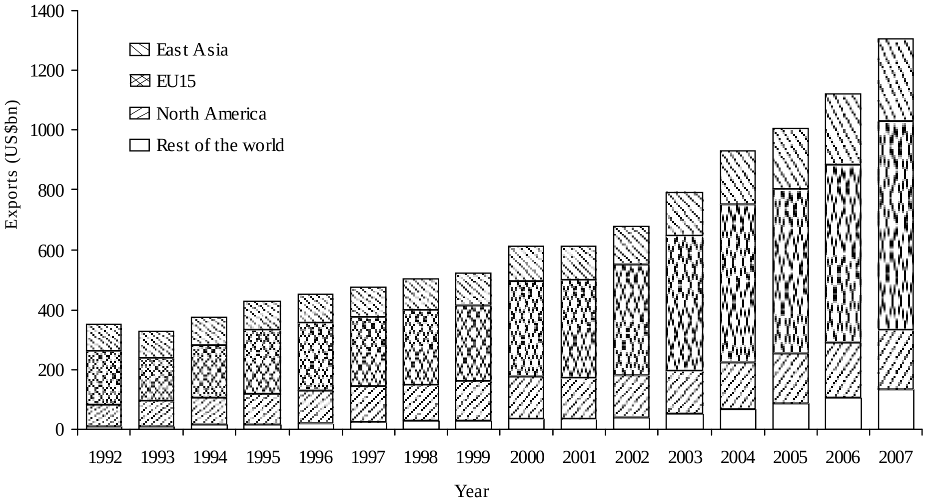


After a new equilibrium with three production blocks has been established in the economy, the producers of cars, laptop computers and mobile phones, always keen to reduce production costs, might discover that there is a part or component that they all use. It is not exactly the same but it performs similar tasks and is built based on the same principles. It becomes tempting to standardize the common element and to produce a one-size-fits-all component. This is what the bottom part of Figure 2 shows. Later on, I will argue that there is technology convergence involving some production blocks in the auto and other industries. The reader will no doubt notice that the possibility of horizontal convergence of common production blocks might well intensify and speed up R&D efforts. After all, a super-efficient and long-lasting battery for a personal computer could be used in digital cameras, mobile phones and even electric cars.

III. Empirical Trends

Figure 3 conveys a general picture regarding world exports of road vehicles between 1992

Figure 3. World Trade in Road Vehicles (Exports)



Source: UN COMTRADE database.

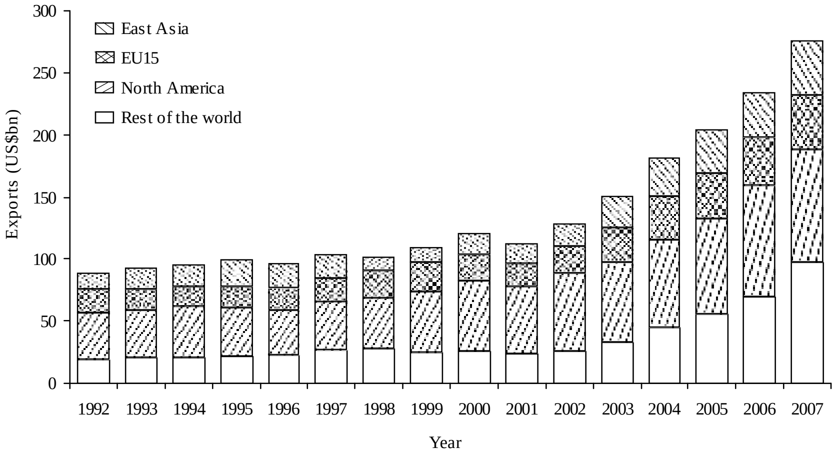
and 2007. World exports of road vehicles expanded by 373 percent during this period in nominal terms, with interesting shifts in the composition of total exports. The EU (EU-15) carved up 51.2 percent of the global market in the beginning of the period, with this value increasing slightly by the end of the period (53.5 percent in 2007). Perhaps surprisingly, East Asia and the North American Free Trade Area had their relative weights reduced somewhat. In the case of the former grouping, the decline was from 22.6 to 21.3 percent, whereas the latter trading block had an even bigger decline: from 19.6 to 15.2 percent. Who was the big winner hidden in the rest of the world category? It was the countries of Eastern Europe who later joined the EU and are now part of the EU-12.

As Figure 4 shows, East Asia saw its exports expand from US$89.1bn in value in 1992 to US$275.6bn in 2007. Almost half of East Asian car exports went to North America in the beginning of the period, and only one-third in 2007. The share of exports going to the EU-15 also declined, from 20.6 to 16.0 percent. It is the rest of the world that significantly increased its importance as a market for cars from East Asia.

Taking into account the recent experience of the EU-12 and East Asia, one of the main predictions of our earlier theorizing holds up rather well. Countries with relatively low capital endowments per capita can become exporters of cars. In addition, their exports need not be limited to countries with similar relative factor endowments.

Beginning with the pioneering work of Yeats (2001), refined and extended by Ng and Yeats (2001), Athukorala and Yamashita (2007) and Chen (2008), there is very solid evidence backing the claim of ever-growing trade in products and components. One of the main

Figure 4. Exports of Road Vehicles from East Asia



Source: UN COMTRADE database.

conclusions of the current empirical research is that: "there is clear evidence that fragmentation trade is expanding more rapidly than conventional final-goods trade. The degree of dependence on this new form of international specialization is proportionately larger in East Asia compared to North America and Europe" (Prema and Nobuaki, 2007, p. 97).

This conclusion is based on total manufactured trade but it holds well for trade in auto parts and components.[2] Figures 5 and 6 testify a rapid expansion of this type of trade with regard to East Asia. This rapid expansion is also shared by the EU-12, hidden again in the category of "the rest of the world." One can argue that the export of auto parts and components is a "back-door" way of accessing the markets of advanced countries. Reaching far away markets does not have to limit regional flows: quite to the contrary, it might boost them significantly.

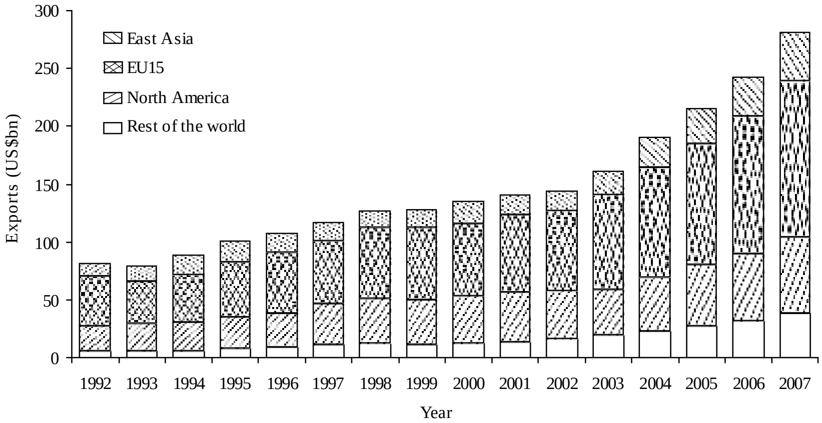
IV. A New Global Auto Industry?

The theoretical models discussed earlier suggested that market forces might lead to the creation of a global auto industry with a multitude of producers and a multitude of products. Such a system was created in the second half of the 20th century and is still in existence now. However, this system is very likely to change beyond recognition.

Economic growth and demand for cars affect the equilibrium of the industry globally

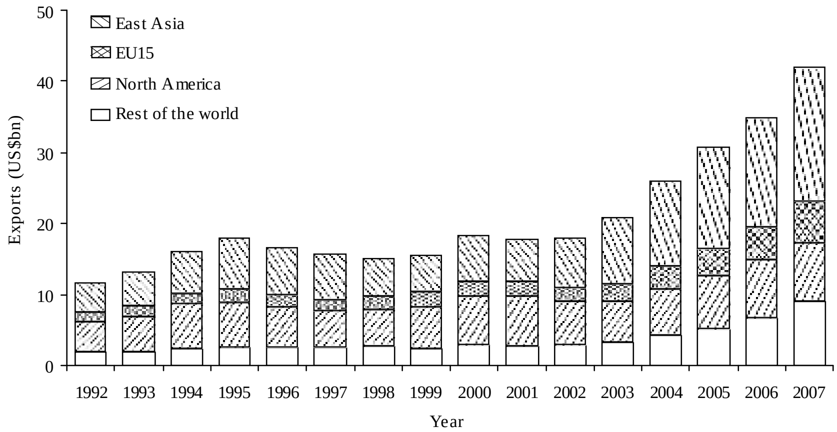
[2] The figures were provided by Lurong Chen and Nobuaki Yamashita. I wish to thank both of them.

Figure 5. World Trade of Motor Vehicle Parts and Components (Exports)



Source: UN COMTRADE database.

Figure 6. Exports of Motor Vehicle Parts and Components from East Asia



Source: UN COMTRADE database.

and in individual countries. Growth stems from different sources, such as capital accumulation, technological progress, increase in human capital and better functioning of the economy. The obvious manifestation is rising income and GDP per capita. These key variables affect the demand for cars and their quality, as stressed by the Falvey–Kierzkowski model discussed earlier.

There is increasing evidence suggesting that China and other countries of East Asia will continue to expand their economies rapidly in the decades ahead. It is not always going to be plain sailing: economic turbulence encountered along the way might slow them down somewhat but short-term macro reversals should not significantly diminish long-term performance. It is worth recalling that East Asia recovered rather quickly from the 1997 crisis and China was affected by it only to a modest degree. The current crisis shows again the great economic resilience of China, India and other emerging Asian economies.

A recent World Bank study analyzes the consequences of income growth on mass car ownership in the emerging market giants (Chamon *et al*., 2009). It is pointed out that many Chinese families already enjoy having modern home appliances, such as washing machines and refrigerators. Many families also have televisions and computers. However, having a car is still an unfulfilled wish of countless Chinese, and only 158 per 1000 people are car owners. An even lower ownership indicator is observed in India: 6.5 cars per 1000 people. In both countries, therefore, policy-makers have freedom in shaping the domestic automotive market. The auto makers' lobby is still relatively weak.

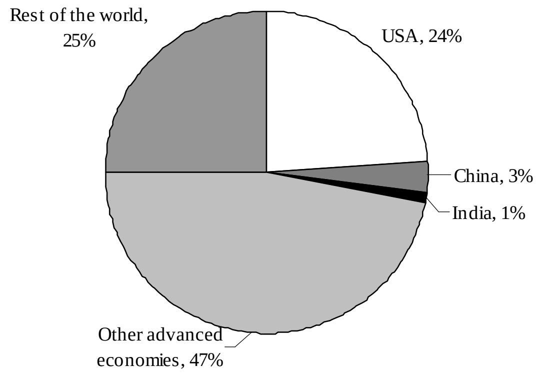
Based on in-depth household surveys, World Bank researchers Marcos Chamon, Paolo Mauro and Yohei Okawa (2009, p.1), demonstrate that there is: "a remarkably stable relationship between GDP per capita and car ownership, highlighting the importance of within-country income distribution factors: car ownership is low up to per capita incomes of about US$5,000 and then takes off very rapidly. Several emerging markets, including India and China, the most populous countries in the world, are currently at the stage of development when such takeoff is expected to take place."

The consequences of economic growth will be stupendous. The number of cars will increase in the world from the present 646 million to 2906 million by 2050. Most of the increase will occur in developing economies. In particular, China, with a car fleet of only 21 million in 2005 is projected by the World Bank to have 573 million cars by 2050, roughly the same number as the present stock of cars in the entire world. India is expected to have by mid-century a fleet of 367 million cars, approximately the size of today's US stock.

Figures 7 and 8 show details regarding car ownership in the world as a whole and in the major regions of the world. What is striking is an exact reversal of the 30–70 percent split of car ownership between developing and advanced economies. By 2050, a car will no longer be a symbol of economic success associated with the North; it will become proof of the South's accomplishments.

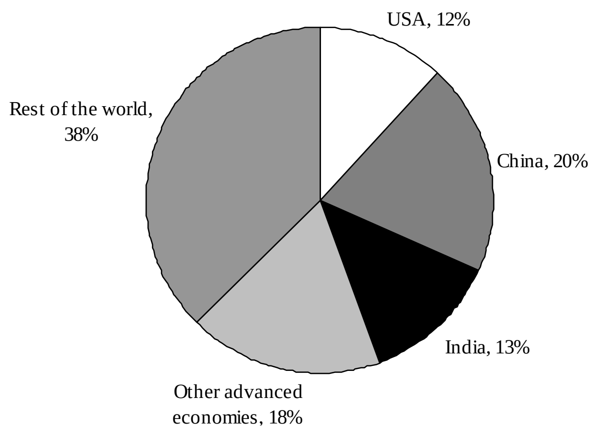
Our earlier analysis in this article suggests that for the world as a whole there might be some lowering of the average quality demanded compared with the situation of economic growth occurring mainly in the advanced countries. There will be scores of rich or affluent people in China, India and other emerging economies (there are already some) demanding luxury cars, but most car owners will have more modest demands than the majority of car owners at present in advanced economies. This means that cheaper cars will have to be designed if the auto makers want to capture new markets. They will also have to be more

Figure 7. World Car Fleet in 2005 (664 million)



Source: See Chamon *et al.* (2009).

Figure 8. Projected World Car Fleet 2050 (2.9 billion)



efficient to take into account the relative cost of running them in countries with modest incomes.

The impending demand changes alone will affect the global auto industry. However, there are also big shocks to be expected on the supply side. The car industry will likely go electric, thus completing a circle that began more than a century ago. The electric car industry started in Europe in the second half of the 19th century and gradually spread to North America at the beginning of the 20th century. With oil discoveries in the USA and the revolution in the organization of auto production introduced by Henry Ford, the development of the electric car was suspended for a century.

Why is the electric car expected to make a comeback? There seem to be two primary reasons: (i) there are growing concerns surrounding environmental issues; and (ii) greatly improved batteries have become available and a battery is the heart of an electric car.

New and highly efficient types of battery were introduced in the late 1980s and early 1990s in response to a new fad spreading through the world: mobile phones. Another rage, laptop computers, and later digital cameras, boosted the demand for rechargeable batteries. Initially, the nickel–cadmium battery was widely used in electronic devices, only to be replaced by the nickel–metal hydride battery. Batteries continued to find new applications, and, ultimately, found a use in hybrid cars, such as the Prius.

Today, there are between 50 and 100 electric cars in development. The precise number is difficult to pin down because some big car makers keep their plans close to their chest, whereas other producers are remarkably boastful, often in response to public expectations, political winds and possible inflow of public and private financing. In addition to the world-class auto makers, the field has been entered by a number of new small players. Although many of these innovators fall by the wayside, perhaps one or two, and that is all it takes, might change the history of the automobile industry.

All-electric cars are not what most of auto producers are thinking of today. They are much more inclined to bet their money on hybrid cars, at least in the near future. There are basically two types of hybrid electric cars: (i) a car that has both a petrol engine and an electric motor, and both are used to move the car along; and (ii) a car that is only powered by a battery, with an electric motor doing all the pushing (or pulling). However, a petrol engine is installed to generate additional electricity when required.

More and more people are becoming convinced that the future belongs to a pure-electric car. Basically, one does not need suspenders and a belt to keep one's pants up. The high price of these cars today will come down in the years ahead because the battery cost and weight will quite likely decline. The batteries and the cars will be produced not by the hundreds or thousands but by the millions. So, today's prices are not really of great relevance. Remember how much an IBM office computer cost and weighted in the 1960s or 1970s and compare this to the computer sitting on your desk now.

Even at this early stage of the paradigm shift, the superiority of the electric car over cars with internal-combustion engines appears rather clear. Consider first the running costs. Assume that it takes 8 L of petrol to drive 100 km in a traditional car and that a 12 kWh battery will do the same job in an all-electric car. A comparison of relative driving costs can be readily calculated for a number of countries. This is displayed in Table 1. In addition, I have calculated the cost arbitrage index, showing the relative costs and saving opportunities that the new technology offers.

The lowest arbitrage index is, not surprisingly, in the USA. In other countries, it is at least twice that high. For a price of one trip in a petrol car from Sydney to Melbourne you

Table 1. Petrol versus Electricity: Cost of Driving 100 km in 2008

Country	Petrol car (US$)	Electric car (US$)	Cost arbitrage index
USA	4.48	1.11	4.0
UK	11.52	1.34	8.6
Germany	12.5	1.58	7.9
France	12.16	1.02	11.9
Australia	5.92	0.85	7.0
China	6.37	0.79	8.1
India	8.72	0.65	13.4

Source: Data on electricity prices come from "Key World Energy Statistics 2008," International Energy Agency, Paris, www.iea.org; fuel prices are super gasoline and diesel retail prices as of mid-November 2008 reported on the GTZ web page, www.qtzde/fuelprices.

can make six trips in an electric car. In general, electric motors are superior to internal combustion engines because they convert electricity to traction in a very efficient manner. Generally, 90 percent of the electric power will be transformed into horse power. In the case of traditional cars, the conversion ratio does not exceed 35 percent, and most of the energy generated by the combustion engine dissipates as heat.

An electric car offers additional advantages: it generates no pollution, although electricity production is not pollution free; it is silent and its acceleration is astounding. There is no need for a gearbox and the engine block also disappears. As an electric motor can be placed inside the wheels, the geometry of the car will also change. One can think of designs that will provide greater protection to the driver and passengers. Car makers have their work cut out for them.

Of course, the cost of deployment of electric car infrastructure will be enormous and, therefore, battery costs must still be greatly reduced. Fortunately, battery technology is constantly improving. Although a new generation of lithium-ion batteries is the main contender to power the green car in the future, there are some alternative technological solutions under intensive development. The most promising appear to be ultra capacitors: energy storage devices that can be charged and discharged extremely fast without being worn out. Ultra capacitors contain no chemical substances to store energy, but their storage time is relatively short.

The application of the battery is much wider than the passenger car. Other candidates include bicycles, scooters, motorcycles, tractors, trailers, buses, garbage trucks, pickup trucks, electric trains and even locomotives. New applications are being investigated. *The Economist* reported on 26 October 2010 that a Canadian company had received an order for a 2.2 MWh battery, the size of a big truck, to be used in a Chinese coal-based power station as a back up.

Convergence of technology between sectors using similar production blocks can further expand battery use, increase R&D and speed up technological progress in this field. Some rough numbers will suffice to suggest possible scale or scope economies. Back-of-the envelope calculations suggest that in 2007 there were 54 million cars produced in the world, global sales of mobile phones reached 1.15 billion units, worldwide shipments of personal computers numbered 271 million units and 131 million of digital cameras were produced.

Can the process of transition to the electric car be accelerated and can certain policy measures be taken to assist in the process? What role can emerging East Asia giants play in this process?

V. Policy Issues and Proposals

There are a multitude of policy issues related to the expected paradigm shift in the auto industry. Most importantly, China has an opportunity to become a leader in the new global auto industry. However, being a leader means more than producing, exporting or importing a large number of cars. It also means setting the pace and direction in which the global auto industry develops.

With a projected car fleet of 573 million by 2050 in China (and 367 million cars in India) policy-makers need to throw their weight behind the "green" car. The time to act is now. The most urgent task is to speed up improvements in batteries, in terms of efficiency, safety, durability, weight and recharging time.

Given our discussion on convergence of common production blocks among industries, the promotion of new energy devices should be far and wide. This is how scale and scope economies can be captured. Battery standardization could accelerate the changeover. The basic battery unit should be clearly defined and designed to be relatively small and easily expandable to much bigger blocks usable in different industries.

Standardization should be achieved through an international agreement. Unfortunately, the Doha Development Round and the 2009 Climate Conference in Copenhagen demonstrate that multilateral international cooperation is extremely difficult. Therefore, a regional standardization agreement (within the EU or among East Asia countries) could be an alternative to a global arrangement. Even a single but a very big player, such as China, could have an international impact by imposing domestic standardization requirements for batteries because of the sheer size of the internal market waiting to be captured. (Foreign car producers would certainly pay attention if they wished to get a share of the pie.) It is also worth pointing out that setting a standard fast, but not faster than necessary, is important in creating a new technological trajectory. Once a standard is introduced it becomes difficult to replace. Although the role of the government should be very important in creating a general legal and institutional framework, the market should primarily be transformed through competition among innovators. However, the market does not always pick up the best technology, and uncertainty about outcomes slows down the process. A little intervention from the government and the right incentives can help.

China could declare its willingness to buy, preferably through future public auctions, huge numbers of standardized new batteries. Such a commitment could be executable in a few years, say in 2015, to give innovators time to increase their efforts. It can be expected that a lot of R&D efforts would indeed be stimulated across the world if a non-discriminatory treatment of the innovators could be assured. To increase further the effect of its initiative, the authorities would also make a commitment to repeated public auction, say in 2016, 2017, 2018, 2019 and 2020. Finally, the government could clearly state the quantities it was going to purchase in terms of a basic unit. (For instance, the basic unit could be a battery capable of driving a small car over *X* km using not more than *Y* in energy and costing less than *Z*. The battery design would have to permit installation in a number of products, such as cars, motorcycles and light delivery trucks.)

Make an arbitrary assumption that the auction would involve 10 million battery units per year. With the current battery cost of, say, US$5000–10 000, the government would be putting US$50–100bn into the pockets of battery producers for 5 successive years. This is not the end of the story; given the relative share of the battery in the unit car cost, the multiplier effect would be of the order of US$100–300bn per year. This kind of number would certainly catch the attention of battery and car producers alike. If this enabled the battery costs to decline, all the better. Further positive effects could be achieved if China and India acted jointly.

The 2 countries are in the same boat. If the government of India made a similar commitment for, say 5 million battery units annually during the 2015–2020 period, there would be little doubt about who were the leaders shaping the future of the global auto industry. Well-defined standards and flexible technology should allow the 2 countries to transform the forward purchases into their preferred national combinations of, for example, cars, motorcycles, city buses and tractors.

If China and India were to act in a strategic alliance in setting global battery standards, there would be an additional reason for added flexibility in defining the basic unit. India and China are already a major force in the market for motorcycles, in terms of production and in terms of domestic use. The world stock of motorcycles is over 300 million, 80 percent of which is in Asia and 50 percent of the total in India and China alone. They could strongly encourage the motorcycle industry to start moving to using batteries by 2015. Environmental effects in terms of pollution and noise would be soon noticeable. Other populous countries of the region, such as Indonesia, could follow the same path.

One can make a number of objections in connection with the above proposal. Even if the scheme were acceptable, should it start in 2015? If the policy-makers waited longer there would be even better technology. Perhaps better technology would come about without encouragement from policy-makers? There will always be better technologies available later. However, that does not prevent you or me from buying a new laptop even though we know there will be a better model next year. As Yogi Berra famously stated: "If there is a fork in the road, take it." Strong public support could put an industry on the right technological trajectory.

One wonders whether this kind of support should not: (i) be limited to domestic firms; (ii) cover only auto makers; and (iii) be provided upfront as an R&D subsidy. The answer to each of these three questions is negative. New innovations can come from anywhere: a great battery could be invented in China or India, but also in Finland or Argentina. Limiting domestic consumers to domestic technology, apart from fairness and legality under international rules and obligations, would not necessarily make Chinese or Indian consumers better off.

It is also important to prevent auto makers from dominating the auctions. This would occur if the government committed itself to buying green cars with batteries embodied in them, rather than batteries alone. This action would greatly reduce the real purchasing power of the scheme. More importantly, auto makers have no comparative advantage in inventing new batteries. Established big car producers, especially in the USA, have reasons to slow down the process. In fact, they are not a solution to the problem; they are a big part of the problem.

Compensating winners at the finish line rather than subsidizing possible innovators at the start of a technological race would save a great deal of money and prevent excessive lobbying at the cost of making real R&D efforts. I certainly would not favor a policy of "picking winners" by the government, which tends to result in well-connected losers being picked.

The program being outlined here advances an idea of fragmentation of sales. Earlier, I discussed the concept of fragmentation of production and benefits stemming from it. The corresponding concept of fragmentation of sales introduces flexibility and a potential for gains on the purchasing side. A consumer does not have to buy a car produced by X with a battery produced by X. He can buy a car from X and a battery from Y as long as basic compatibility and standards are guaranteed. Perhaps the consumer does not have to buy a battery at all! An explanation follows.

Once the government of China buys 10 million standardized batteries in 2015, and then again another 10 million a year later, and then again, and again, the question of what to do with these purchases can be legitimately asked. The government certainly should not become an auto maker. It does not have to. If the announcement of a future auction leads to the expected reaction, the principle purpose of the intervention would be achieved. In order to sell cars in China in the future you will have to go electric. At the right time, the government should sell what it has bought to whoever is willing to repurchase the batteries.[3] This might well include auto makers. However, new actors might well appear on the stage as new business models are put into operation. (For instance, countrywide networks of battery-rental stations could emerge.)

The balance in favor of the all-electric car could be further tipped by a commitment to impose appropriately high taxes on petrol cars bought in 2015 and afterwards. In this way, the relative price of electric cars would be reduced. Parking rights in city centers could be restricted to pure-electric cars. Taxing of combustion-engine cars entering high pollution zones could be implemented as well. The government could gradually make its car fleet go electric, and taxi networks could be required to switch to batteries over a period of time.

Admittedly, the scheme presented here is not modest. However, the auto industry is a big industry facing big problems. In addition, there is still a larger picture to consider, in particular the environmental impact of a new global auto industry. I shall touch on this only briefly.

The all-electric car creates no pollution, so positive effects will be felt in big cities already facing severe environmental problems. Electricity creation will be generating pollution somewhere else, hopefully in locations with low population density. Will there be any net gain at all, or will benefits in one site be exactly offset by losses in another place? Much depends on the technology used in electricity generation. It turns out, however, that even present coal-based electricity will have an overall positive effect. One of the greatest authorities on the subject, Professor David MacKay (2009, p.1), issues a clear verdict: "I conclude that switching to electric cars is already a good idea, even before we green our electricity supply."

The policy towards electric cars needs to be embedded in a much larger framework of national energy and environmental policies in countries such as China and India. National interests and concerns over citizens' health should be the main motivator. Of course, attention should be paid to international considerations as well. However, it serves no purpose to use international pressure and trade threats to bring about the "right" energy and environmental policies.[4]

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[3] Keeping in mind the principal purpose of the intervention, creation of a new technology, the government should not be tempted to corner the market and make money. There should be a zero-budget-implications policy.

[4] This is why I am puzzled by Paul Krugman's remark made in the *New York Times* on 14 May 2009: "As the United States and other advanced countries finally move to confront climate change, they will also be morally empowered to confront those nations that refuse to act. Sooner than most people think, countries that refuse to limit their greenhouse gas emissions will face sanctions, probably in the form of taxes on their exports. They will complain bitterly that this is protectionism, but so what? Globalization doesn't do much good if the globe itself becomes unbelievable. It's time to save the planet. And like it or not, China will do its part."

How serious is the environmental threat that China poses to the entire world? Again, I can do no better than turn to an author in the know and quote him at some length: "We conclude that China's urban air quality, although low by current international standards, seems quite typical of circumstances in fast-growing economies during peak periods of industrialization. China's urban air quality has improved substantially during the past quarter-century. This improving trend began at an earlier stage of the development process than in Japan or Korea. The cost of further improvements in air quality seems well within the reach of China's economy … China's recent ban on leaded gasoline and promulgation of auto emission standards beyond those currently in force in the USA indicate that the Beijing authorities are both aware of the problems posed by the spread of car ownership and are prepared to take remedial action. In China, as elsewhere, we cannot yet predict the environmental consequences of humanity's love affair with the automobile" (Thomas, 2006, p. 32).

There seems to be some exaggeration in the general assessment of China's environmental record. However, because we cannot fully predict the impact of people's love for the car, policy-makers would be wise to act decisively now to be prepared for the worst-case scenario.

Introducing the electric car on a massive scale according to a well-defined program integrated with energy policy could be China's and India's contribution to the global reduction of greenhouse gas emissions. In return, the advanced countries could contribute in terms of capital, technology and management skills to the greening of the coal mining industry in both countries. The initial production of electric cars will probably be targeted towards the domestic market in China and India. However, as the 2 countries develop comparative advantage in the new auto industry, they will expand their car exports, hopefully without any trade impediments.

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