Breaking the Mirror

Modular Encapsulation and Japanese Dominance of the Professional Camera Sub-Market, 1955-1974.

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Modular encapsulation provides new features without altering the number of the core modules that make up a complex product, or their functionality. This innovation strategy has not been considered in the mirroring literature. Using a dataset of prices and product features for 1,816 professional cameras sold between 1955 and 1974, we apply data envelope analysis (DEA) to test the strategic significance of lens and body encapsulation by proprietary automated exposure (AE) systems. We find that the professional camera market was modular between 1955 and 1960, dominated by German specialist body and specialist lens manufacturers. Market structure changed due to the success of innovative Japanese start-ups, particularly integrated body and lens manufacturers who, from 1961, successfully developed proprietary AE systems that offered users novel features. The success of these Japanese integrated manufacturing firms broke the mirror between product architecture and industry architecture.

Keywords: encapsulation, mirror hypothesis, innovation, professional cameras.

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1. Introduction

This paper contributes to the theoretical and empirical literature on the mirroring hypothesis, empirically examining the impact of encapsulation strategies used by new market entrants from Japan in the high-end professional camera markets between 1955 and 1974. Module encapsulation is an innovation strategy that has not been considered in the mirroring literature.

In 1955 the camera industry was modular. There was a set of specialist firms manufacturing camera bodies, and a different set of set of specialist firms manufacturing lenses. The core technological knowledge was mechanical and optical engineering. In both modules, German firms were technological leaders, enjoying first-mover advantages they had established prior to WWII. German firms had developed the key camera types – twin lens reflex (TLR) designs and single lens reflex (SLR) designs – and the optical lens designs (leaf shutters and aperture only) used by professional photographers producing images for magazines and newspapers, wedding photography, and art photography.

The prediction of the mirroring hypothesis is that this symmetry would be maintained. If change were to occur, the expectation would be that module decomposition would take place to create new modules, and that new, specialist manufacturers of these modules would enter the industry, maintaining the symmetry between product modularity and industry specialisation within specific modules.

The opposite occurred. Within 20 years there was industry consolidation. Yet architecture and the number of core camera modules remained the same. Integrated firms from Japan such as Nikon, Canon, Pentax, Minolta, and Mamiya, with capabilities in lens and body manufacture, had overtaken the established European and U.S. firms to become the dominant players. Further, a great many of the established firms had gone bankrupt and exited the professional submarket.

How had the mirror between product and industry structure been broken? Our analysis highlights the strategic importance of encapsulation. Modular encapsulation is a strategic innovation choice not previously considered in the mirroring literature. Japanese firms applied new electronics knowledge for the development of proprietary automated exposure (AE) systems that offered users new features – aperture-priority and shutter priority settings - that automated the taking of pictures allowing the user to focus more on composition and less on the mechanical act of taking a picture.

AE systems require the lens and body to communicate in order to set the correct aperture and shutter combination. The need for a bayonet, to correctly align the communication pins between camera and body, opened the way for alternative (non-interoperable) configurations by rival Japanese firms, setting up a standards competition that drove out specialist firms unable to develop their own AE systems.

Following an overview of the mirroring hypothesis and its predictions regarding the development of product and industry architecture over the industry life cycle, we discuss modular encapsulation in section 2 of the paper. This lays out the principles of encapsulation, and how this strategy differs to module integration.

Moving from theory to practice, section 3 discusses the post-war development of the camera industry. This highlights the strengths of the German system of modular specialisation amongst firms and the use of flexible, small series methods for production using highly skilled workers ('kleinserien-produktion'). Firms in this system had developed novel, high-quality camera types in small numbers. The high costs involved in production (using artisan labour in small batch production) were sustained in the professional camera sub-market. As we show, the limitations of this system were exposed by new Japanese entrants that developed an alternative production model for quality mass manufacture. This was applied to both lens and body manufacture in Japan, enabling start-ups to rapidly catch-up with established European firms. From there, integrated producers engaged in product innovation, developing proprietary AE systems. We examine the way in which the German model of kleinserien-produktion hampered the ability of German firms to respond to the encapsulation strategy of integrated Japanese rivals.

The hypothesis that AE encapsulation drove competitiveness in the professional camera sub-market is empirically tested using a dataset of 1,816 cameras listed in the annual Buyers Guide of *Amateur Photographer* magazine between 1955 and 1974 (inclusive). These cameras are TLR, 35mm SLR, medium format SLR, and Hasselblad type cameras which were used by professional photographers in this period. Recognising the effect of quality mass manufacturing on the costs structures of Japanese firms, we apply data envelope analysis (DEA) to this data. We find that a high proportion of models with AE lie on the efficiency frontier and, as the number of Japanese cameras with AE increases, so an increasing number of Japanese cameras lie on the efficiency frontier. The results highlight the strategic importance of AE encapsulation in driving competition in the professional sub-market.

2. Modularity and the mirroring hypothesis

The mirroring hypothesis links industry structure - the division of labour and knowledge across firms within an industry - to the modular structure of a complex product (Parnas 1972, Colfer and Baldwin 2010). In a modular product design, a set of interrelated functional features are captured within a self-contained component, or 'module'. The key advantage of a modular architecture is that improvements can be made to one module without needing to make changes to other modules (Simon 1976, 1978; Henderson and Clark 1990; Ulrich 1995; Ulrich and Eppinger 2008), and reciprocal interdependencies between modules are minimised by common industry standards for interfaces (Parnas 1972; Langlois and Robertson 1992; Baldwin and Clark 2000). Langlois and Robertson (1992) propose that modular production networks are particularly advantageous in industries where there is rapid technological change, as modularity reduces the cost of explorative innovation.

Typically, a set of engineering product choices made early in the industry life cycle establish the ground rules for technical relations between firms. The mirroring hypothesis posits that these ground rules also determine the ground rules for economic interactions between firms, and consequently for the types of firms that can co-exist. Jacobides et al. (2006) call the structure of inter-firm interactions the 'industry architecture', which places constraints on incumbent firms with respect to both firm boundary choices and product design choices.

In particular, the industry architecture induced by modularity lowers entry costs for new firms. Modularity enables specialist firms, especially in the early phase of an industry life cycle, to develop new modules and/or modify existing modules to improve product quality (Baldwin and Clark 2000; Langlois 2002). Independent individuals, teams or firms can separately design and improve upon different modules while common industry standards for interfaces between modules ensure that they work together as a whole (Colfer and Baldwin 2010). In the longer term, limited economies of scope enable firms to continue to specialise in the production of modules that are 'informationally self-sufficient'.

Langlois (2003) predicts a trend in industry architecture that mirrors the tendency for modularity to rise over time in complex products. By further sub-dividing modules, with new supporting interface standards, firms are able to avoid coordination costs associated with vertically integrated production, and, through increased specialisation, gain economies of scale in production. Since different modules can, in principle, be produced at multiple geographical sites, this opens up new possibilities for outsourcing, extending supply chains locally and globally. As a consequence, vertical and horizontal disintegration occurs over time due to the evolution from integral to increasingly modular product architectures.

A number of longitudinal case studies provide supporting evidence for the mirroring hypotheses. In line with Langlois' prediction, IT hardware and software sectors (Schilling and Steensma 2001, Sturgeon 2002, MacCormack et al. 2008), stereo hi-fi (Langlois and Robertson 1992), certain banking products and services (Jacobides 2005, Consoli 2005), and automobiles (Ro et al. 2007) initially consisted of vertically integrated firms producing integrated products. The commercial success of new, modular products saw a rapid change in industry structure, with different firms specialising in specific product modules.[1]

Not all specialized firms are equal in stature. For example, Sturgeon's (2002) analysis of the U.S. IT sector identifies two types of firms: de-verticalised lead firms and turn-key suppliers. Lead firms control the design and the marketing of complex artefacts while turn-key contract manufacturers produce modules to the lead firms' specifications. Lead firms generate new product combinations while turn-key suppliers exploit economies of scale (in the manner discussed by Arora et al. 1998). Sturgeon argues that an important competitive advantage of this "New American Model" is the building up of external economies of scale (Sturgeon 2002, p. 489).[2]

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[1] In some cases, such as browser software (MacCormack et al., 2008), and numerical controls (Shibata et al. 2005), increasing modularization was temporarily reversed by a technological shock. A period of integration occurred as new competences were developed, before the process of modularization resumed. However, some shocks can have more persistent effects on industry structure. For example, the Pilkington float glass process, which changed the rules of the game in the glass industry, led to global consolidation as firms that were unable/unwilling to invest in Pilkington's patented process were driven out of the market (Quinn 1991).

[2] However, Abelshauser (2005) points out that flexible production methods ('kleinserien-

2.1 *Modular integration and encapsulation*

Modular industry architecture limits the scale and scope even of lead firms. This provides an incentive to undermine modularity. Christensen (2002) and Christensen et al. (2002) suggest that these incentives may be strongest in sub-markets where demanding consumers seek improved functionality that is difficult to attain in a modular structure. In such submarkets, successful innovators will attempt to develop products that are relatively integrated, as this enables engineers to maximise the degrees of freedom needed to "wring the best performance possible out of the available technology" (Christensen 2002, p.36).[3] Examples include customised college textbooks (Schilling 2000), click shifting gears on bicycles (Schilling 2000, Fixson and Park, 2008), disk drives and Microsoft Office suite (Christensen et al., 2002), building facilities (Cacciatori and Jacobides, 2005), 126 cameras in the amateur camera sub-market (Windrum 2005), and the substitution of laptops, all-in-ones, and tablets for the modular desktop and monitor.

Modular integration potentially yields value to lead firms in several ways. First, successful integration may increase the functionality of a previously modular product. In such cases, it not only provides a means by which a lead firm can enter the market for a module it did not previously produce, it also strengthens its competitive position with its original module. Second, even if lead firms continue to outsource part of the production, modular integration turns producers of final products into suppliers of unfinished components, with a consequent capture of value by the lead firm. Moreover, the conversion from producer of a standardised finished product to a component supplier may generate asset specificity that subjects suppliers to hold-up.

However, modular integration is not the only way in which lead firms can undermine the industry architecture. An alternative that has not yet received attention in the mirroring literature is to develop new functionality in products in such a way as to alter the interfaces between modules. Lead firms may then choose whether to limit the ability of other producers to adopt the new interfaces. We call this *modular encapsulation*, and suggest that it is a strategy distinct from

produktion') are neither new, nor particularly American. They have been a feature of German manufacturing since the late 19th century.

[3] By contrast, a modular architecture inhibits engineers' degrees of freedom, forcing them away from the technological frontier.

module integration: while module integration involves the development of a single product that encompasses the functionality of two or more existing modules, encapsulation leaves the number of components unchanged, but changes the way these modules are linked together.

Perhaps the most salient modern example is the Apple's development of a proprietary interface between itunes and ipods. However, the case that we study in the next section – the introduction by Japanese camera firms of electronic communication between lens and body modules that underpinned automatic exposure – had, we argue, a much more important impact on industry architecture. Our case study also suggests that modular encapsulation is a more challenging strategy than integration. While integration may be accomplished through little more than a design change without altering the way the modules actually interact, encapsulation involves a substantive change in underlying knowledge. However, when successful, as was the case in the camera industry, modular encapsulation can bring about a radical and enduring change in industry architecture.

3. Post-war development of the camera industry

In 1945, cameras were purely mechanical products, comprising two key modules: the camera body and the camera lens. European and U.S. camera body manufacturers used a common interface standard – the 'Universal' M42 screw mount system – for connecting lenses to camera bodies. This enabled customers to buy and use a range of lenses, of different focal lengths and quality. There was modular specialisation in the industry between, on the one hand, camera body manufacturers of medium-format and 35mm camera bodies and, on the other, lens manufacturers. The key technical challenge for camera body producers was the manufacture of accurate shutter lenses to control the amount of light exposing the film. The key challenge in lens production was the precision grounding of glass lenses.

German firms had dominated the camera industry before World War II and, despite the partition into West and East Germany, these leading firms had quickly re-established production and their pre-eminent position within the industry by 1950. These leading German specialists applied flexible, small series production methods - 'kleinserien-produktion' - that were developed in German manufacturing from the late 19th century onwards (Abelshauser 1998; 2005). The use of small series methods with a highly skilled craft workforce had been proven advantageous for the development of new product types prior to WWII – most notably, for high-end, professional users, the 35mm single lens reflex camera (SLR) and the twin lens reflex (TLR) medium format camera types. These offered new possibilities for commercial photographers in sports, wedding, fashion, and commercial (industry) photography (Hicks 1986; Langford 1993).

This industry structure is consistent with the mirroring hypothesis. If one were to make a prediction, then it would be that new specialists would enter the industry, engage in modular product development and that this would lead to further specialisation over the course of the industry life cycle. Yet the opposite pattern occurred. Post-war, integrated Japanese lens and body producers successfully entered and took over the professional camera sub-market. Their success lay in a combination of radical process innovation and product innovation. The former involved the development of quality mass manufacturing which enabled them to enter and establish themselves in the professional sub-market. They were able to produce high quality features in a short space of time by developing quality mass manufacturing processes. Once established, a set of Japanese firms captured the market by applying new electronics technology to cameras. The key was the development of automatic exposure (AE) which provided new features by encapsulating the lens and body, making one module communicate with the other. Importantly, encapsulation allowed the user to switch between new (automated) and old (manual) features, and did not require new skills or knowledge on the part of the camera user.

Dominant West German firms could not match the scale, efficiency or quality control of the Japanese quality mass manufacturing methods, and specialisation proved to be an Achilles heel as German lens and body specialists were unable to coordinate to develop a response to camera automation. By the mid-1960s, formerly dominant companies such as Rollei (which had invented the TLR) were losing money, despite increasing global sales in their product categories. By the mid-1970s, many had gone bankrupt (Schott and von Grebmer 1974).

In order to understand this train of events, we consider, in turn, the strengths and weaknesses of the German system of flexible, small series production methods ('kleinserien-produktion'); the advantages of the system of quality mass manufacturing developed by Japanese camera manufacturers; and the consequences of encapsulation for industry structure.

3.1 *Specialisation versus hierarchy in German camera manufacturing*

The strengths and weaknesses of artisan 'kleinserien-produktion' are evident in the immediate pre- and post-WWII development of the German camera industry. There was vertical specialisation between lens manufacturers and camera body manufacturers, with standardisation around the M42 'Universal' screw mount facilitating interoperability of lenses across different camera bodies. This enabled innovative German camera manufacturers, such as Rollei, Voigtländer, Leica and Contax to focus on the development of radically new medium film format and 35mm film camera types in the 1920s and 1930s, such as the single lens reflex (SLR) camera and the twin lens reflex (TLR) camera. At the same time, specialist lens producers such as Zeiss and Schneider made rapid developments in the manufacture of camera optics and came to dominate global lens sales. At the outbreak of WWII, German firms dominated world exports in both high quality cameras bodies and in high quality optics.

German body and lens specialists re-established themselves after WWII in much the same manner as before. There was vertical and horizontal specialisation, with Zeiss and Schneider dominating lens production, and – at least prior to 1955 when international trade restrictions in Europe and elsewhere to Japanese products were lifted - Rollei and Voigtländer re-establishing their positions in medium format cameras and Leica and Contax their positions in 35mm rangefinder and SLR cameras. The loss of manufacturing plants in the new East Germany was quickly addressed by the establishment of new West German plants in the late 1940s / early 1950s. Rather than introducing mass manufacturing processes, the new plants were run on established kleinserien-produktion lines.

The kleinserien-produktion system has distinct intra-firm and inter-firm features. Within the firm, flexible, small series production runs are combined with formal qualification and artisan craftsmanship, i.e. a highly skilled, knowledge-intensive artisan workforce. Between firms, there is a very pronounced division of labour, both vertically (with several levels of subcontracting) and horizontally (specialization). Whereas the standardisation of parts was an essential aspect of vertical integration within U.S. companies prior to WWII (Hounshell 1984; Scranton 2007), in Germany, standardisation was for products traded between companies and, hence, for a value chain which spread across many companies. As a result, the German production system was more 'modular' and more flexible across companies. The establishment of standardisation in components ensured consistency in the quality of components and other intermediate goods traded between firms along the supply chain. As a result, German supply chains became more 'modular' and there was greater flexibility across companies. This system enabled firms to reap scale economies by trading standardised technical products to many industrial users.[4]

Kleinserien-produktion was an alternative to the U.S.-style mass manufacturing model, forged by the resistance of both employers and workers to mass manufacturing methods on the shop floor, and by a lack of interest in cheap mass manufactured goods on the part of German consumers. At the heart of the kleinserien-produktion system is the view that "Klasse statt Masse" (quality beats quantity) (Radkau 1989, p.279). Radkau (1989) describes the role played by Loewe, the sewing machine manufacturer, in the early development of kleinserien-produktion. Loewe had initially wanted to copy U.S. producers in order to introduce cheaper, mass produced sewing machines to Germany in the 1870s. He quickly realised there was no domestic market for mass produced machines. As a result, Lowe focused on quality products, combining workshop production with line production to develop a flexible, small series production method.

Leading 19th century industrialists could be as vigorous as German artisans in their resistance to mass manufacturing principles. In his study of Siemens AG, Homburg (1991) discusses how its founder, Ernst Werner von Siemens, despised U.S. methods of mass production and, hence, continued with a workshop organisation of small, specialised series production using qualified labour. The head of AEG, Emil Rathenau, was by contrast favourable to mass production techniques but realised these needed to be changed considerably in order to overcome resistance from his artisan workforce which, as in German manufacturing in general, were effective in organising resistance to the introduction of mass production. As a consequence, Kleinserien-produktion retained highly-skilled labour for the flexible production of specialised (small) batches (Radkau 1989, p.282).

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[4] Integral to this German manufacturing system was a national system of product and component standardisation. The Standards Committee of German Industry (a precursor to DIN) was founded in 1917

The decision by West German camera firms not to develop mass manufacturing after WWII but to continue along the path of kleinserien-produktion was typical of the majority of West German industry, and subsequently in the re-united German state (Abelshauser 2005). Indeed, mass manufacturing was only ever adopted in a few sectors in West Germany; most notably in the automobile sector and in certain parts of the precision machine sector during the 1950s and 1960s. From the 1960s onwards, West Germany returned to the trend of "diversified quality production" (Abelshauser 2005, p. 30).

3.2 *Development of quality mass production by Japanese camera manufacturers*

Japanese camera firms were small to medium-sized businesses, independent of large industrial groups (keiretsu). The boom in demand for cameras, both domestic and foreign, in the early 1950s attracted two types of entrepreneurial start-ups. One type was the producer of high-quality cameras, mostly targeted at export markets. The other type sought to make a quick return by producing low-quality cameras for the domestic market (Lewis 1991). The most successful of the Japanese exporters were integrated firms with optical, lens and precision mechanical components manufacturing capabilities. A number, such as Mamiya, Minolta, and Pentax were originally optical and binocular manufacturers. Nikon had been a specialist lens and body manufacturer before WWII, and was the primary source of lenses for Japanese firms that did not have internal lens capabilities. The dangers of hold-up had been highlighted by Canon's experience in the late 1940s. It originally relied on Nikon for lenses for its 35mm rangefinder camera. A shortage of silica meant Nikon was temporarily unable to deliver lenses to Canon, which quickly moved to acquire its own capabilities (Lewis, 1991). Learning this lesson, post-war start-ups such as Yashica and Zenza Bronica moved to acquire high quality optical and lens production operations.

Japanese exporters were able to establish themselves in export markets in just a few years due to their development of quality mass manufacturing processes. This enabled Japanese firms to produce high quality cameras containing precision components that matched, and even surpassed, German and other European manufacturers in the quality of construction and tolerances, more efficiently and at lower cost using mass line manufacturing processes with unskilled labour. Mass production processes had hitherto been applied only to the manufacture of simple, inexpensive cameras, most notably by Kodak and other U.S. camera manufacturers.

Donzé (2011, 2013) highlights the importance of Swiss machine tools and the acquisition of watch making techniques for component manufacture by Japanese camera firms. Precision mechanical components manufacture is important for producing accurate focal plane shutters (the most complex part of the camera body), and leaf shutters. High quality components manufacture ensures accuracy, removing the need for finishing while ensuring higher tolerances and the interchangeability of component parts. This gave Japanese firms a great advantage over German body and lens manufacturers, in both quality control and in cost since German firms needed to employ expensive artisan labour for finishing activities.

Swiss machine tools were considered to be the best in the world for the manufacture of precision machinery. Some firms, such as Yashica, had originally been watch component manufacturers (Heiberg 1979). Other companies moved to acquire watchmaking knowledge in order to develop shutter expertise (Donzé 2011, 2013). An important policy measure in the early 1950s, devised by General Headquarters of the Allied Occupation of Japan, was to secure money from the US government in order to enable Canon, Minolta, Nikon, and Seiko (the watch and camera shutter maker) to import precision machine tools from Switzerland (Kusumoto 1989).

According to Lewis (1991) and Alexander (2002), the quality and reliability of Japanese body and lenses were matching, and even surpassing, the established high-end European and U.S. producers by the mid-1950s. Ricoh was the first Japanese camera company to develop and apply, in 1950, a full mass production process to manufacture the Ricohflex Model III TLR. The company reduced the number of parts, and more accurately machined tolerances increased the durability of each part.[5] Other Japanese camera companies followed Ricoh's lead. By the end of the 1950's, camera makers such as Mamiya, Minolta, Yashica, Fuji, Nikon, Canon, Olympus and Pentax had successfully introduced conveyor belts into the

[5] The Ricohflex Model III retailed at 6,800 yen in Japan, compared to an average camera price of 20,000 yen. It was a major commercial success. At its sales peak, the Model III accounted for over 50% of total camera production in Japan and the company was producing 20,000 units per month. In 1957, Ricoh was awarded the Okochi Prize in recognition of its achievement in establishing mass production in the industry.

assembly process, production engineers rethought factory organisation, purchased machines and hired new personnel. At first, they introduced the new methods in easy-to-manufacture parts and assembly. Later they transferred their experience to other, more complicated, phases of the production process (Donzé 2011, 2013; Nakaoka et al. 2001). This enabled Japanese camera firms to shift from manual to automatic lens machining, to employ specialised machines for the camera body that raised component tolerances, ensuring fully interchangeable parts, and to raise the quality of finished products through improved inspection methods. The result was higher quality, more reliable products, manufactured at lower unit costs.

The attitude towards mass manufacturing amongst Japanese camera firms was very different to their West German rivals. The Imperial Japanese Navy (IJN) had played a major role in the development of optics and camera production in pre-WWII Japan. Between 1923 and 1945, the IJN funded scientific research in optics, and set up leading edge glass production foundries in Japan.[6] The IJN had also built up a precision machinery sector, essential for the mass manufacture of high quality components, and to the development of the engineering skills base in optics. By 1945, wartime munitions firms and optical firms had a significant amount of mass-production experience in the organisation of assembly lines, automated systems, and the simplification of worker tasks via push-button machines (Wada and Shiba 2000). This experience was carried over and further developed by firms, such as Minolta and Nikon, who had produced precision optical munitions for the IJN (Kamera Rebyū 1998; Morris-Suzuki 1994; Alexander 2002; Long 2006).

3.3 *Modular encapsulation through automation*

Having established themselves in the professional sub-market, a number of Japanese firms engaged in radical product innovation. Integrated lens and body pro-

[6] The IJN required the large quantities of superior optics in order to outrange the enemy and deliver night attacks (O'Neil 2003). The success of the IJN in developing high quality Japanese optical technology was recognised by the U.S. Naval Technical Mission to Japan in 1945, which reported that Japanese optics matched U.S. and even German glass products (Grimes 1945).

ducers, in particular, drove forward modular encapsulation through the development of automatic exposure (AE) systems. This involved the strategic application of electronics to cameras. It was a new type of technological knowledge that European and U.S. high-end camera firms failed to acquire. Integrated Japanese firms were willing, and able, to invest in the coordinated body and lens R&D that was central to the successful incorporation of electronics into cameras. By contrast, German camera body specialists failed to develop electrical capabilities needed to match their Japanese rivals, and did not acquire glass and lens plants. This put them at a distinct disadvantage.

Accurate, built-in metering on camera bodies was the first key application of electronics to cameras by Japanese firms. Through-the-lens metering accurately estimates the amount of light falling on the object being photographed. An equally important development was electronically controlled shutters in camera bodies. This enables both greater accuracy of film exposure and faster shutter speeds. These developments facilitated, in turn, automatic exposure (AE) systems that calculate and adjust exposure settings. AE was first applied in the early 1960s, in fixed lens rangefinder cameras such as the Konica Auto S, sold to amateur photographers. From the mid-1960s onwards, Japanese firms applied AE feature encapsulation to each of the camera types used by professional photographers - the 35mm single lens reflex (SLR), the medium format film SLR, the medium format twin lens reflex (TLR), and the Hasselblad type.

Japanese firms tended to offer one of two types of AE. One is 'shutter-priority' automation, where the camera metering system selects the correct aperture automatically. The other is ‘aperture-priority' automation where the metering system selects the correct shutter speed (Codax 1984). The earliest AE developments were aperture-priority automation on leaf shutter lenses. From the mid-1960s onwards, Japanese firms started to develop shutter-priority automation systems. This was more challenging, as it required the automation of very accurate shutters in the camera body.

The control of both lens and body making activity by these integrated Japanese firms was an important consideration in their decision to develop proprietary bayonet mounts to connect the lens to the camera body. Bayonets were required in order to ensure the correct alignment of pins between body and lens - electrically controlled pins in the body mount closing the lens aperture to the correct setting and bar in the mount depressing the pin when the shutter is released. In principle, a common bayonet standard could have been introduced. However, integrated Japanese firms took the opportunity to develop their own, proprietary mounting configurations. Adapters were available to enable users to attach (manual) M42 lenses onto the bayonet mounts of new camera bodies, although of course these could only operate in manual mode given there are no electrical pins on these older lenses. Bayonet mount lenses of rival manufacturers could not be used.

The modular encapsulation represented by the proprietary bayonet mounts changed the nature of competition in an industry, driving out specialist firms. For the user, the camera could still be operated in the original way, i.e. a picture could still be exposed by manually setting the aperture on the lens and the shutter speed on the camera body. Indeed, professional photographers are, to this day, keen to have the flexibility to switch between manual and automated operation. Hence, there was no change in the practice of picture taking and no new learning required on the part of the user. Furthermore, encapsulation did not affect the ability of the professional photographer to use a range of interchangeable lenses, or to use older lenses without electronic features in manual mode.

However, the creation of rival, non-interoperable combinations created a discrete choice for users (Farrell and Saloner 1989). Amateur camera users needed to choose between the non-interoperable combinations of lenses and camera bodies, offered by rival Japanese manufacturers, in return for previously unavailable automated features. While many professional users were willing to supplement the Japanese system they purchased with specialist European lenses for manual use, the professional market was much smaller than the amateur market. As a consequence, the specialist lens manufacturers in Germany were unwilling to finance R&D for their own bayonet type. They were also unwilling to invest R&D to support a diverse set of proprietary Japanese bayonet standards. This hastened the loss of competitiveness amongst specialist European and U.S. firms. In Japan, non-integrated firms such as Kowa, Topcon and Konica, who were themselves early AE innovators, also failed to keep up with the technological developments of integrated Japanese firms, and were forced to exit the market.

4. Dataset and methods

4.1 *Data*

Our dataset is collected from information published in the UK consumer magazine *Amateur Photographer*. This is a well-known, reputable, and publicly available source for contemporary secondary data. Each year, *Amateur Photographer* produced an annual 'Buyers Guide' listing makes, models, recommended retail prices, and features. Data were taken from the guides published from 1955 to 1974 inclusive.

As a data source, *Amateur Photographer* offers a number of advantages. First, the data is consistent and complete. Second, the use of an independent, publicly available source enables other researchers to access the same information to replicate results. Third, the magazine reports price and the performance features which manufacturers use to convey to the consumer the quality of their product designs and which consumers use in their decision-making.

Our dataset contains 1,816 different listings for 635 distinct camera models. Each model tends to be present in more than one year. Also, manufacturers often offered consumers different lens options. Bundles with faster lenses were more expensive. Hence, we have 1,816 complete listings for *price* and seven characteristic variables *lens speed*, *shutter speed*, *IL*, *internal metering*, *electronic shutter*, *automatic exposure*, and *built-in motor*. These characteristics have been shown to be the most important quality indicators in previous studies by Alexander (2002), Windrum (2005), and Donzé 2013. The dataset also contains discrete variable information on country of origin, manufacturer's name, and camera type.

The variable *price* is the manufacturers recommended retail price and is reported in UK pounds sterling. All model prices are deflated using the official UK deflator, with 1974 as the base period. The variable *shutter speed* is the number of stops offered on the camera body. Each stop is a halving/doubling of light exposure onto the film. *lens speed* is a continuous variable containing information on the speed of the standard lens that is sold with the camera body. This is the f value of the lens at open aperture. The remaining five product characteristics are dichotomous variables. *IL* takes a value of 1 if the model allows for interchangeable lenses, and a value of 0 otherwise; *internal metering* indicates whether or not the camera body has in-built exposure metering; *built-in motor* indicates if the camera came with a motor for automatically winding on film between shots, and *electronic shutter* indicates whether the focal plane shutter in the camera body is electronically or mechanically controlled.

These variables are on observations across four camera types used by professional photographers: 35mm SLR cameras, medium format SLR cameras, medium format TLRs, and medium format Hasselblad-type cameras[7]. The four camera types differ in their degree of modularity. At one end of the spectrum is the TLR camera type originally invented by Rollei. These typically had non-interchangeable lenses. At the other end of the spectrum, the Hasselblad camera type is the most modular of designs ever invented, with interchangeable viewfinders, film magazines, and lenses. We note that Japanese firms applied AE to each of these camera types without altering their architecture, or the number of modular components. Yashica was the first Japanese company to produce a fully automated exposure TLR camera (the Yashica 'E') in 1964. The Mamiya 'RZ67', introduced in 1982, was the first Hasselblad type camera with AE, beating Hasselblad's first AE model (the '200') by nine years (Mamiya 1990). As noted above, many Japanese firms were offering AE systems on 35mm SLR cameras from the mid-1960s.

The first Japanese model with AE that is listed in our dataset is a 35mm SLR camera. We will therefore consider two sub-periods in our analysis: 1955 – 1960, and 1961 – 1974.

4.2 *DEA model*

We use data envelopment analysis (DEA) to identify the most efficient camera models over the sample period. The advantage of DEA is that one can include within the same analysis the effects of process innovations that affect productivity product innovations that improve the quality of product features. By contrast, Hedonic regressions methods require one to either adjust price information for quality changes in order to measure productivity change in a longitudinal frame, or else conduct a short-run analysis in which there is assumed to be no productivity change (i.e. there is a fixed set of production possibility curves) and estimate the contribution of a particular product characteristic to the average priced good (Griliches 1971; Pakes 2003).

[7] Other types of cameras that were not used by professional photographers are excluded from the sample. These include box camera, folding camera, 126 and 110 cartridge, and non-reflex 35mm and medium format, and half-frame cameras.

DEA is a non-parametric linear programming technique for analysing the efficiency of decision-making units (DMUs). The efficiency of the DMU is measured by its relative distance to the efficient frontier which is constructed from observations of comparable units. An efficient DMU will operate at a point on the frontier and receive an efficiency score of 1. A score below 1 indicates that the DMU is operating below the frontier and hence, is inefficient relative to comparable units. DEA is particularly useful in that it can accommodate multiple input-output situations whilst still yielding a single measure of relative performance. Moreover, this methodology does not require an a priori specification of the weights assigned to the inputs and outputs.

In the context of modelling cameras, the DMUs are the individual camera models; the input is the price of the camera and the outputs are the different characteristics of the camera model. This approach has also been adopted in previous studies to compare products which vary across several dimensions (see, for example, the studies of Doyle and Green (1991) on printers, Fernandez-Castro and Smith (2002) on diesel cars, and Swann (1981) on refrigerators).

We apply DEA to our dataset of 1,816 camera listings, containing complete information on *price* (deflated by 1974 prices), *lens*, *shutter speed*, *electronic shutter*, *automatic exposure*, and *built-in motor*. We estimate DEA on an annual basis for each camera type.

5. Hypotheses

We are interested in how product and process innovation by new Japanese entrants altered within the professional camera sub-market. For this reason we report, for each year, the camera models that are at the envelope of the DEA; i.e. which have a DMU equal to 1.

There are two pure innovation strategies, and one mixed strategy, which a firm can use to move towards the efficiency frontier. The first pure strategy is to produce a camera with higher quality product characteristics. Ceteris paribus, this will tend to cost more to manufacture, and so the firm will need to charge a high price to cover the additional costs. The second pure strategy is to develop a process innovation which increases the efficiency of manufacturing giving the firm a cost/price advantage. The mixed strategy is to engage in both product and process innovation simultaneously.

From our previous discussion of the historical development of the professional camera submarket (section 3), we expect to see a particular pattern in the DEA estimates in the two sub-periods 1955 – 1960, and 1961 – 1974, and for this pattern to be consistent in each of the 4 camera types included in the analysis.

At the outset of the 1955 – 1960 period, it is proposed that German and other European firms enjoy first mover advantages in the professional camera submarket; advantages that were established in the pre-WWII period. This provides our first hypothesis

> **H1**. *Camera models at DMU = 1, in each of the 4 camera types, are produced by German and other European firms in the early years of the 1955 – 1960 period.*

In the latter part of this period, the first mover advantages of German and other European firms are eroded due to process innovations by new Japanese entrants. By developing quality mass manufacturing methods, Japanese entrants are able to manufacture cameras with competitive price/quality characteristics equal to their European rivals. As a result, Japanese cameras will be at the DEA efficiency envelope by the end of this time period.

> **H2**. *Camera models produced by Japanese firms are present at DMU = 1, in each of the 4 camera types, in the latter years of the 1955 – 1960 period.*

During the 1961 – 1974 period, Japanese firms gain a competitive advantage through the development of novel automated features – specifically, automated exposure (AE) systems. This pushes forward the technological frontier. European firms are unable to engage in this radical product innovation and, hence, by the end of this period Japanese cameras are predominant at the DEA envelope.

> **H3.** *Camera models at DMU = 1 are predominantly Japanese, in each of the 4 camera types, in the 1961 – 1974 period.*

6. Results

6.1 *Descriptive statistics*

The summary statistics for the period averages of the variables used in the estimation are given in Table 1.

Table 1. *Summary Statistics*

	Mean	*Median*	*S.D.*	*No. observations*
price	188.61	160.37	137.36	1,816
lens speed	2.8	2.8	1.6	1,816
shutter speed	9.6	10	2.7	1,816
electronic shutter	0.02	0	0.15	1,816
automatic exposure	0.06	0	0.22	1,816
interchangeable lens	0.68	1	0.47	1,816
internal metering	0.44	0	0.49	1,816
built-in motor	0.08	0	0.27	1,816

Note: *price* is deflated by 1974 price index.

As noted, we have 635 different camera models over the entire sample period. These tend to be present in more than one year, with different lens bundles offered at different prices. Hence, we have a total of 1,816 observations on our set of *price* and the five characteristic variables *lens*, *shutter speed*, *electronic shutter*, *automatic exposure*, and *built-in motor*. Table 2 shows the number of camera models in each model type.

Table 2. *Number of Distinct Cameras in the Sample, By Camera Type*

Camera Type	**Number of Cameras**
SLR	14
Hasselblad	23
TLR	131
35mm SLR	467
Total	*635*

The 635 cameras originated from 15 different countries. Table 3 shows the total number of camera listings in our dataset (i.e. all body/lens bundles offered over multiple years) by country of origin. As can be seen, the largest number of camera models originated from West Germany and Japan.

Table 3. *Number of Camera listings in the Sample, By Country of Origin*

Country	Number of Cameras
Japan	344
West Germany	131
East Germany	72
UK	14
US	8
Sweden	6
Hong Kong	3
China	1
France	11
Italy	5
Poland	2
Czech	6
Soviet Union	12
Monaco	1
Switzerland	19
Total	**635**

The average period between a camera being launched onto the market and its being removed/replaced is approximately 2 years and 11 months. The median period is 2 years. For a camera featuring AE, the median period is 4 years. There is a significant amount of entry and exit of camera models over the period 1955 - 1974. In 1955, 52 cameras were being manufactured. In 1974, this number had increased to 117 cameras. The total number of new models introduced between 1955 and 1974 was 583, of which Japan accounted for 344 and West Germany 112 new models. Hence, the total number of models that exit the sample is 518. Of these total exists, 250 are Japanese models and 121 are West German models. This higher turn-over rate indicates that Japanese firms were engaged in higher rates of product innovation and/or there was a higher rate of firm entry and exit amongst Japanese firms than amongst West German firms.

Turning to the number of manufacturers, there are 70 different manufacturers in our dataset. Table 4 reports the number of manufacturers by country of origin. The largest source of camera models is Japan, followed by West Germany. On average, a firm manufactures 23 different cameras over the 20 year period. The median number of cameras is 20.

Table 4. *Number of Manufacturers in the Sample, By Country of Origin*

Country	**Number of Manufacturers**
Japan	32
West Germany	11
East Germany	4
UK	8
US	2
Sweden	1
Hong Kong	1
China	1
France	3
Italy	2
Poland	1
Czech	1
Soviet Union	1
Monaco	1
Switzerland	1
Total	*70*

Over the period 1955 – 1974, 61 new firms enter the market. Of this number, are Japanese. 46 firms exit the market over this period, of which 15 are Japanese.

Figure 1 presents the number of manufacturers by national origin in each year. It highlights the dramatic change in fortunes of West German and Japanese firms during this period. The number of West German firms rises up to 1960, reach a peak of 17 independent firms manufacturing cameras. Thereafter the number of West German firms collapses until, by 1974, there are just 4 remaining surviving firms. Japanese firms come to dominate this sub-market. There is a slight fall in the number of Japanese manufacturers between 1958 and 1968, from 19 to 12 firms, but the number of active Japanese firms rises thereafter. The distribution of the number of camera models by manufacturer is listed in Table 5.

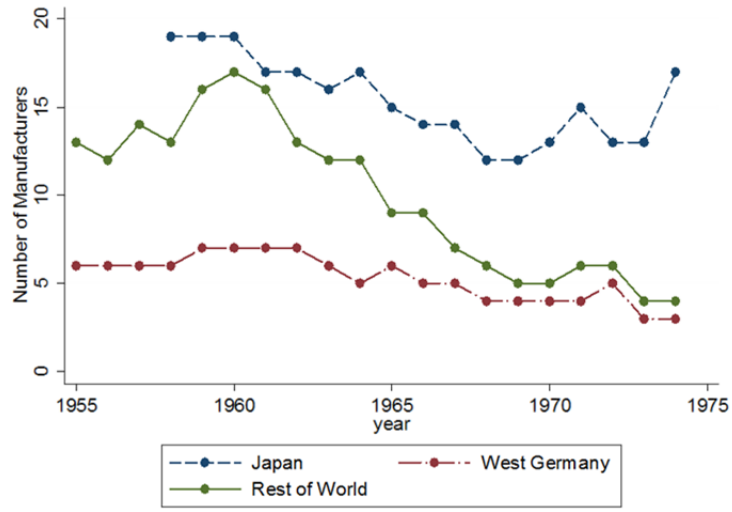

Figure 1. *Number of Manufacturers by Country of Origin, 1955 to 1974*

Table 5. *Distribution of Cameras by Manufacturer, 1955 to 1974*

No. of camera models	No. of manufacturers	%
1-5	39	56
6-10	12	17
11-20	10	14
21-30	2	3
31-40	5	7
Over 40	2	3
Total	**70**	**100**

Figure 2 shows the annual number of camera model listed from Japan, West Germany and all other countries. There is an upward trend in the number of Japanese models over time. The number of West Germany cameras per year is reasonably consistent up to 1965, and thereafter starts to fall year upon year. The elsewhere in the world begins a little earlier, in 1962. This increasing share of models produced in Japan is an important indicator of the success of these firms in outperforming rivals in the professional sub-market, and is corroborated by existing data on the increasing international market shares of Japanese firms (Nelson 1998; Windrum 2005).

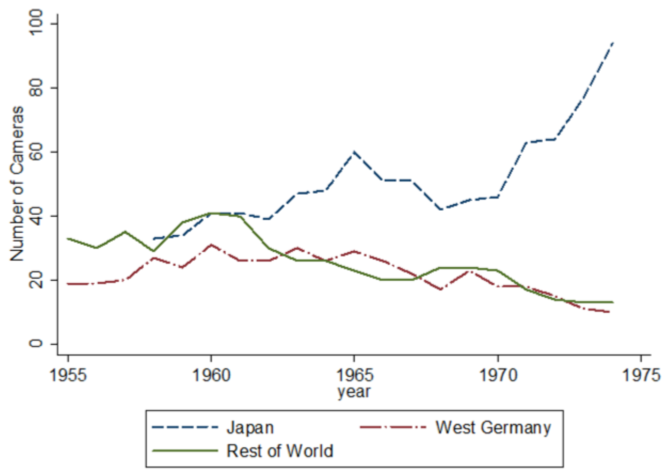

Figure 2. *Annual Number of Camera Listings from Japan, West Germany, and Rest of the World*

In order to analyse this general trend in greater detail, Figure 3 presents the annual number of camera models by country for each camera type. The numbers of medium format SLR and Hasselblad-type models offered each year are very small (between one and seven models per year). It is the growth in the number of 35mmm SLR models that is driving the overall trend. The number of SLR models offered by Japanese firms rose from zero in 1955 to over 80 in 1974. The number of SLR models offered by West German firms plateaued at around 20 between 1961 and 1965, after which the numbers fell year upon year.

Over the twenty year period, there is clearly a switch in focus from the production of medium format TLRs to 35mm SLR cameras. The numbers of models offered by West German, Japanese and all other countries fall notably over the entire period. The figures for Japanese manufactured TLRs are particularly notable. In 1958 there are 21 different models manufactured in Japan. This is far larger than any other camera type that year. In 1974, just four TLRs in our dataset were Japanese. This suggests that, in order to survive, Japanese firms that began by manufacturing and exporting TLRs switched to production of 35mm SLRs.

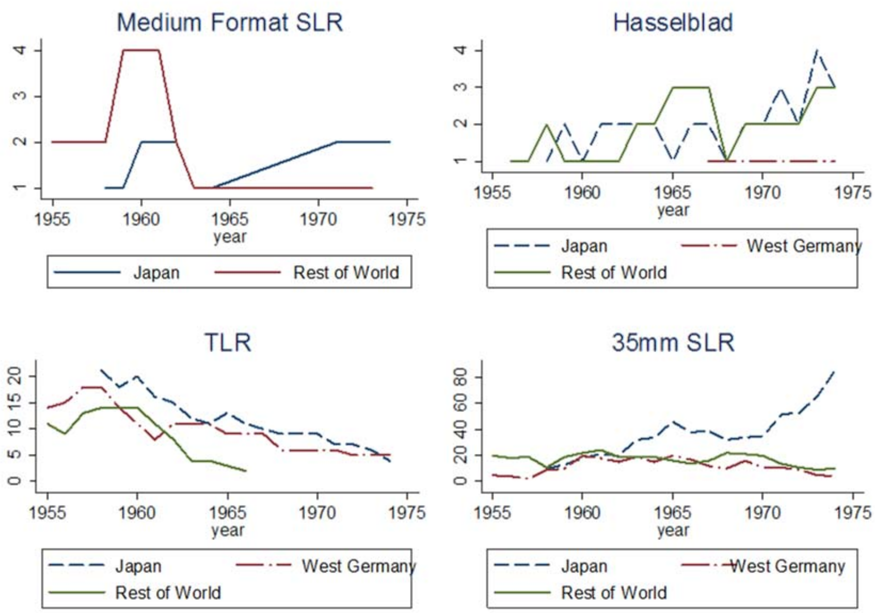

Figure 3. *Number of Camera Listings in Each Year from Japan, West Germany and Rest of the World, By Camera Type*

The pricing strategy of manufacturers is of particular interest in our study. The average price of a professional camera across all camera types is £188.61 (Table 1 above). The average for West German manufacturers is £218.66, while the average for Japanese manufacturers is £185.96. This lends support to the hypothesis Japanese manufacturers are enjoying that a significant cost/price advantage over West German firms.

In order to explore this issue further, we examine the average price of cameras of Japanese manufacturers, West German manufacturers, and the Rest of the World (i.e. all other manufacturers by country of origin).We consider each of the four camera types in our dataset – i.e. Medium format SLR, Hasselblad-type, medium format TLR, and 35mm SLR camera types.

As seen in Figure 4, Japanese cameras are on average cheaper than West German cameras. Japanese cameras are on average lower priced than cameras produced in the remaining countries of the world during the 1955 – 1960 period. While these data have no reference to product quality, they provide corroborating evidence for hypothesis H2 that Japanese firms are able to access key advantages in production that give them an international cost/price advantage.

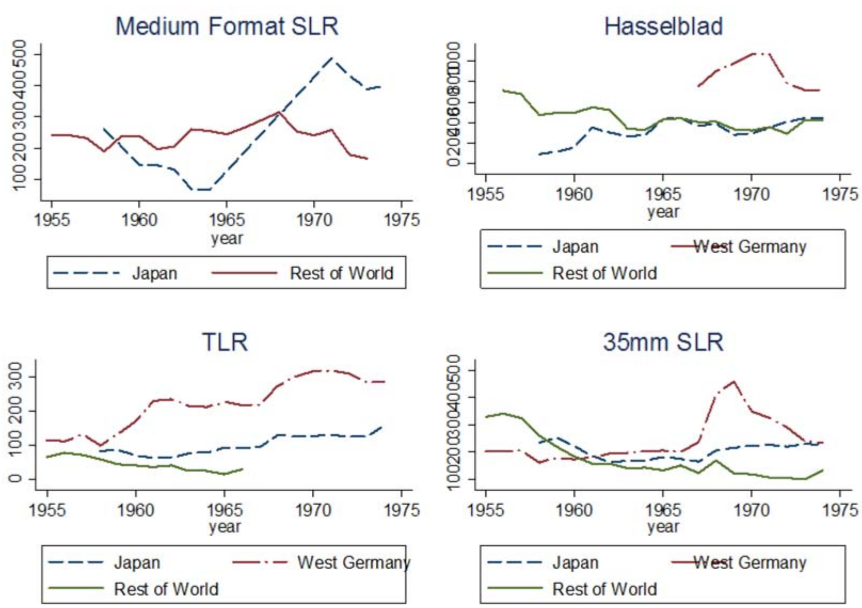

Figure 4. *Average Price of Cameras by Country of Origin, by Camera Type.*

Japanese camera manufacturers maintain an average cost/price advantage over West German manufacturers over the period 1961 – 1974. Interestingly, we see that Japanese camera prices are, on average, becoming higher than the average prices o f manufacturers from all the remaining countries ('Rest of World'). This is consistent with hypothesis H3 that Japanese firms were repositioning themselves as producers of leading-edge products innovators, and incurring higher costs as a consequence. Still, it should be noted, Japanese firms appear to retain a competitive advantage in efficiency over their West German rivals during this second period.

The above price patterns do not take into account quality differences between Japanese and non-Japanese cameras. We therefore examine the estimated residuals of two hedonic regressions, one for the period 1955 – 1960 and one for 1961 – 1974. An overpriced camera has a high residual price, indicating the manufacturer is inefficient relative to the average.

In addition to the set of explanatory characteristic variables *lens*, *shutter speed*, *electronic shutter*, *automatic exposure* and *built-in motor*, we follow the standard procedure of including year dummies, camera type, and manufacturer dummies. Year dummies correct for any upward shift in technology. Manufacturer dummies correct for brand effects and/or any firm-specific product features not included in the set of explanatory characteristic variables.

Kernel density plots of the estimated price residuals for Japanese and non-Japanese cameras are presented in Figure 5. In the first sample period, 1955 – 1960, the mean of the adjusted price distribution of Japanese cameras (conditional on the observed features) is £144.27, and the mean price of non-Japanese cameras is £149.03. The conventional t-test indicates the difference between these two means is not statistically significant at the 0.10 level, the critical t value being 0.34 (p=0.37).

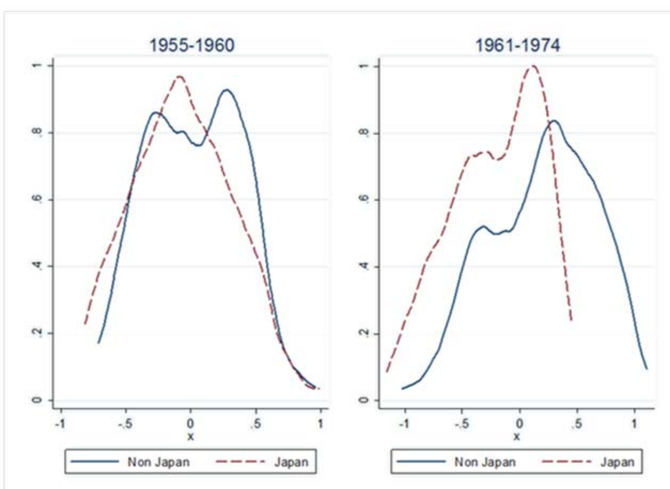

Figure 5. *Kernel density plots of residuals from hedonic regressions, 1955-1960 and 1961-1974.*

Put into context, this finding indicates that new Japanese start-ups were able to overcome the first mover scale and scope advantages of established firms by 1960, their cameras matching the quality-adjusted prices of European and U.S. firms. This supports hypothesis (H2) that the development of quality mass manufacturing methods by Japanese entrants enabled them to manufacture cameras that were competitive in quality and price products with their international rivals.

There is evidence that the non-Japanese distribution is bimodal, suggesting that one group of non-Japanese camera producers is more efficient than the other. The information presented in Figure 5 suggests that it is West German firms that tend to be the producers of high cost cameras (i.e. these are low efficiency firms). The average West German camera price in this period is £159.3. The difference between the Japanese and West German mean prices is not statistically significant at the 0.10 level. The critical t value is 0.96 (p=0.17).

In the second sample period, 1961 – 1974, the distribution of Japanese camera is notably different to non-Japanese price distribution. The average price of Japanese cameras in this second period is £155.23 compared to an average of non-Japanese cameras of £191.35. The difference between these two means is clearly significant at the 0.01 level with a critical t statistic of 4.62 (p=0.000). The non-Japanese firms that survived into the second period appear to be primarily those that produce unusually expensive (quality-adjusted) models. The difference between the average quality-adjusted prices of West German and Japanese cameras is particularly pronounced. The average price of West German cameras is £270.39, The critical t statistic for the difference between West German and Japanese cameras is 8.49 (p=0.000), indicating that that West German products were significantly more expensive for the quality of features offered than the Japanese alternatives.

Hypothesis 3 proposes that Japanese firms were more successful in developing automatic exposure (AE) systems than non-Japanese firms. Table 6 reports, for each year, the number of new cameras that feature AE. Information is provided on the country of origin and the type of camera. 61 new cameras featuring AE (9.6% of the total) were introduced between 1955 and 1974.[8] Of this total, 56

[8] 6% of all camera listings have *AE* (see Table 1). The difference between the two figures reflects the larger number of different lens-body combinations offered with non-AE cameras than with AE cameras.

were manufactured by a Japanese company. Just 3 models were manufactured by a West German company. This highlights the inability of West German firms to develop AE over time. The first West German camera with AE to enter our dataset is the Edixa Electronica, manufactured by Wirgin, in 1961. This model is listed for one more year (1962) and then disappears from the annual catalogue. It is not until 1969 that another West German camera is launched with AE, the Zeiss Ikon Contarex Electronica. This model ceases to be reported in the annual guides in 1973. The final new West German camera to be listed is the Wirgin Electronica 2 in 1971. This is not listed in 1972 guide. The only other West German model to appear in the dataset is a TLR, the Rollei Magic II, which is listed from 1963 to 1967. To put this into context, Japanese AE cameras are listed for a median of 4 years. As previously noted, the median period for all cameras is 2 years. No manufacturer from any other country was capable of developing AE in our sample period.

Table 6. *New Models with Automatic Exposure, 1955 - 1974.*

Year	Camera Type	Country	No. of Cameras
1961	35mm SLR	Japan	2
1962	35mm SLR	Japan	1
	35mm SLR	West Germany	2
1963	35mm SLR	Japan	2
	TLR	West Germany	1
1964	35mm SLR	Japan	1
	TLR	Japan	1
1965	35mm SLR	Japan	2
1966	35mm SLR	Japan	2
1967	35mm SLR	Japan	2
1969	35mm SLR	West Germany	2
1970	35mm SLR	Japan	2
1971	35mm SLR	Japan	4
1972	35mm SLR	Japan	4
1973	35mm SLR	Japan	10
1974	35mm SLR	Japan	23

This information clearly indicates the march that Japanese firms had over their rivals in this area. What is more, the number of new Japanese models being introduced with AE increases dramatically at the end of our data period, with 10 new models featuring AE introduced in 1973 and 23 introduced in 1974.

5.2 *DEA Results*

Table 7 provides data, for each year, the number of cameras by country of origin that lie at the efficiency frontier (DMU = 1) in each of the four camera types used by professionals. In parentheses we indicate the number of cameras that have the AE feature. For example, in the 35mm SLR listings, the result in 1961 is 'Japan 4 (2*)'. This indicates that 4 Japanese 35mm SLR cameras were at the efficiency frontier that year. 2 of these 4 cameras had AE.

The findings provide support for hypotheses H1 and H2. European and U.S. firms enjoyed first mover advantages in the early years of the 1955 – 1960 period. The remarkable ability of Japanese firms catch up with these established firms, thanks to their development of quality mass manufacturing, is clearly evidenced by the presence of Japanese TLR and Hasselblad-type cameras at their respective efficiency frontiers in 1958, and the first Japanese 35mm SLR camera at its frontier in 1959.

Next, let us turn to hypothesis H3 that cameras at the efficiency frontier in the 1961 – 1974 period will be Japanese models offering AE. It is striking how many 35mm SLR models with AE are located on the efficiency frontier (DMU = 1) from 1961 onwards. Of course, offering AE as a feature was not, in itself, sufficient for a camera to be at the frontier. It must be competitive in the quality of other key product characteristics and be manufactured at a competitive cost. However, it is evident that the ability to offer AE, at a competitive price, confers a significant competitive advantage.

A second striking result is the frequency with which a 35mm SLR camera, if it offers AE, will be on the efficiency frontier. This is also the case for medium format TLR cameras. There are only 3 TLRs with AE in our dataset. Two were manufactured by the Japanese firm Yashica, the other by the West German firm Rollei (see above). These models are estimated to be on the efficiency frontier in each year in which they are listed as being sold. Linking back to our discussion on the inability of West German firms to develop AE, these findings indicate that this had a significantly adverse impact on the competitiveness of West German cameras.

AE was not offered on medium format 35mm cameras or Hasselblad-type cameras in our sample period. Interestingly, Japanese cameras do not dominate in these camera types to the extent that they do in the 35mm SLR and TLR categories. As discussed earlier, there were relatively few models offered in the medium format 35mm cameras and Hasselblad-type camera categories, and sales of these types were notably lower than TLR and 35mm SLR cameras.

Table 7. *Number of Efficient Camera Models by Country, Year and Camera Type*

Year	**MF-SLR**		**TLR**		**Hasselblad-type**		**35mm-SLR**	
	Country	**No.**	**Country**	**No.**	**Country**	**No.**	**Country**	**No.**
1955	UK	1	W. Germany UK	2 1	-	-	E. Germany W. Germany	4 3
1956	UK	1	W. Germany USA	3 1	Sweden	1	E. Germany W. Germany Switzerland Italy	2 2 1 1
1957	UK	1	W. Germany USA	2 1	Sweden	1	E. Germany Italy	2 1
1958	UK	1	W. Germany USA Japan	1 1 2	Sweden Japan	1 1	E. Germany W. Germany Switzerland	2 2 1
1959	UK	1	France USA Japan	1 1 3	Japan	1	E. Germany W. Germany Japan	4 2 1
1960	UK Japan	1 1	USA Japan	1 3	Sweden Japan	1 1	E. Germany W. Germany Japan France	2 6 1 1
1961	UK Japan	2 1	France USA Japan	1 1 2	Japan	2	E. Germany W. Germany Japan France	3 3 4 (2*) 1
1962	UK Japan E. Germany	1 2 1	France Japan	1 2	Japan	2	E. Germany W. Germany Japan France	2 4 (1*) 3 (3*) 1

Table 7, continued

1963	Japan E. Germany	1 1	W. Germany Japan	1 (1*) 2	Japan	2	E. Germany W. Germany Japan	3 3 (1*) 7 (3*)
1964	Japan E. Germany	1 1	W. Germany Japan	1 (1*) 3 (1*)	Japan	2	E. Germany W. Germany Japan	2 2 7 (3*)
1965	E. Germany	1	W. Germany Japan	1 (1*) 4 (1*)	Japan Sweden	2 1	E. Germany W. Germany Japan	1 2 11(4*)
1966	E. Germany	1	W. Germany Japan	1 (1*) 3 (1*)	Japan Sweden	2 1	E. Germany W. Germany Japan	2 2 6 (3*)
1967	E. Germany	1	W. Germany Japan	1 (1*) 4 (1*)	Japan Sweden W. Germany	2 1 1	E. Germany W. Germany Japan	2 1 12 (4*)
1968	E. Germany	1	Japan	4	Japan W. Germany	1 1	E. Germany Japan	3 6 (4*)
1969	E. Germany	1	Japan	4	Japan W. Germany	2 1	E. Germany W. Germany Japan	3 1 4 (3*)
1970	E. Germany Japan	1 1	Japan	4	Japan W. Germany	1 1	E. Germany W. Germany Japan	2 1 6 (4*)
1971	E. Germany Japan	1 1	Japan	3 (1*)	Japan W. Germany Sweden	1 1 1	E. Germany W. Germany Japan	1 1(1*) 6 (4*)
1972	E. Germany Japan	1 1	Japan	3 (1*)	Japan W. Germany Sweden	1 1 1	E. Germany W. Germany Japan	3 1 (1*) 8 (4*)
1973	E. Germany Japan	1 1	Japan	3 (1*)	Japan W. Germany Sweden	2 1 1	E. Germany Japan	2 6 (5*)
1974	Japan	2	Japan	3	Japan Sweden	2 1	E. Germany W. Germany Japan	2 1 8 (6*)

Note: Figures in parentheses are models offering AE.

6. Conclusions

The goal of this paper is to highlight the importance of modular encapsulation as an innovation strategy. It is a strategy that has not been recognised by the mirroring literature and by the complex product literature. Yet, as the camera case study highlights, this can be a very powerful strategy for altering the terms of competition and, as a consequence, industry structure. What is particularly important about the encapsulation strategy is that neither the architecture nor the number of core modules changes. As we have seen, encapsulation *broke the mirror* between the number of key modules and industry structure. Within two decades, integrated Japanese start-ups had replaced the previously dominant European and U.S. specialist body and lens manufacturers within the professional camera sub-market.

Looking forward, more research is required to understand the modular encapsulation as an innovation strategy within complex products. It is quite unlike modular integration (a strategy that has been studied extensively). With modular integration, two or more modules are replaced with a single, integrated module with the same functionalities (Ulrich 1995; Ulrich and Eppinger 2008). Encapsulation provides new functionality by linking together a given number of existing modules, but these modules may still act independently. In the case of AE in cameras, the lens and the camera body remain two distinct modules, and can be used in manual mode by the photographer in exactly the same way as previously.

Encapsulation is also very different to architectural change (see Henderson and Clark 1990). Encapsulation by AE does not alter the relationship between lens and camera body. The technological knowledge underpinning optics and lens manufacture, or the mechanics of camera body and focal plane shutter manufacture did not alter. Further, the professional photographer uses the camera in the same way. Encapsulation, by adding electronics to the lens and camera body, enables the user a new set of automated options. Encapsulation has powerful potential commercial gains.

Positioning our findings within the mirroring hypothesis literature, this case study adds to our understanding of the strengths and limitations of this explanation of industry structure over time. Prior research has questioned the proposition that there is a tendency towards increasing modularity over time. There are cases where the development of new, integrated products has led to increased vertical concentration. Examples include customised college textbooks (Schilling 2000), click shifting gears on bicycles (Schilling 2000, Fixson and Park, 2008), disk drives and Microsoft Office suite (Christensen et al., 2002), building facilities (Cacciatori and Jacobides, 2005), and 126 cameras in the amateur camera submarket (Windrum 2005). We note that, while this pattern challenges the prediction of a general tendency towards increasing product and organisational modularity, it is not, per se, inconsistent with the argument that industrial structure mirrors the architecture of the dominant product type. As we have seen, the importance of modular encapsulation is that the symmetry is indeed broken.

Finally, our research is sympathetic to the criticism that modular product architectures, in themselves, do not provide the information needed by different actors to coordinate activity through the market mechanism (Brusoni et al. 2001; Brusoni 2005; Hobday et al. 2005; and Brusoni and Prencipe 2006). The camera industry highlights a lack of system integration amongst German specialists and their inability to coordinate an effective response to new integrated producers offering encapsulation features. As Brusoni and Prencipe (2006) have argued, decisions regarding product restructuring - partition, recombine, or (in our case study) to encapsulate – are strategic choices. It is the visible hand of organisations driving strategy, not the invisible logic of a product architecture.

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