Dror Etzion and Aviad Pe’er

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Strategic Management Journal Volume 35, Issue 11, pages 1605–1625, November 2014

doi: 10.1002/smj.2178
http://onlinelibrary.wiley.com/doi/10.1002/smj.2178/abstract

Mixed signals: A dynamic analysis of warranty provision in the automotive industry, 1960- 2008

Dror Etzion
Desautels Faculty of Management
McGill University
1001 Sherbrooke Street West
Montreal, Quebec H3A 1G5
dror.etzion@mcgill.ca

Aviad Pe'er
Rutgers Business School
1 Washington Park
Newark, New Jersey 07102
apeer@business.rutgers.edu

Abstract

Often, signaling research in the strategy and economics literature postulates the existence of an ostensible signal and then empirically tests its veracity, utilizing cross-sectional data. We argue that this static approach does not allow researchers to fully incorporate the concept of equilibrium in their analysis, thereby potentially violating a key axiom of signaling theory. We propose that a dynamic analysis of signals can address this omission, and then conduct such an analysis. We use empirical data on warranty coverage offered by automobile manufacturers in the US market extending from the first warranty offered by the industry in 1960 through to 2008. Our findings support the notion that signaling behavior differs in periods of equilibrium and disequilibrium, in turn influencing signal accuracy.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/smj.2178

Keywords: Signals; Signal dynamics; Signal accuracy; Signal equilibrium

Information flows are central to markets. In deciding with whom to transact, which persons to employ, or what products to buy, the choices individuals and organizations make are ased on information they have gleaned about their potential transaction partners. In the absence of information, or if the information available is likely to be inaccurate, markets are prone to inefficiency, and can in fact fail entirely (Akerlof, 1970). Firms therefore invest significant resources into transmitting information in manifold ways, including advertising and other forms of marketing; certification which attests to the quality of the products they produce; publishing voluntary reports about their environmental impacts; discussing financial performance expectations with stock market analysts, among many others. Indeed, a branch of economics has developed over the past several decades to better understand the significance of information in markets (Stiglitz, 2000). Among the main insights developed within information economics has been the identification of signals (Spence, 1973) as mechanisms which allow credible information to flow within markets.

Signaling theory has compellingly demonstrated that certain actions pursued by firms can be construed as credible indicators of firm attributes, thereby reducing information asymmetries and allowing potential buyers to make informed purchasing decisions. Research has revealed that firms indeed make frequent use of signals, employing them in contexts as diverse as employment of prestigious directors (Deutsch and Ross, 2003), provision of warranty (Balachander, 2001), and certification to environmental standards (King, Lenox, and Terlaak, 2005). But, prior research has focused primarily on identifying and assessing the accuracy of signals at a given point in time. Often, results have been equivocal, even when research settings and designs are nearly identical, with some studies identifying viable signals, other studies demonstrating that the same ostensible signal provides no information, and some even demonstrating that signals convey accurate information, yet in a direction opposite to theoretical predictions (see Connelly *et al.*, 2011; Riley, 2001 for reviews). Upon closer examination, however, it becomes apparent that some of these contradictory findings are based on data from different time periods, thereby suggesting that a viable signal in one time period may not be a viable signal in a subsequent time period. More generally, inconsistent findings suggest that signals should be perceived not as universal and invariant, but rather as time dependent.

Recognizing that signaling activity is likely to be time dependent, in this study, we introduce and explore a dynamic, rather than static, conceptualization of signaling. Rather than assessing whether, within a specific empirical setting, certain behaviors are or are not signals, we explore the possibility that signaling behavior changes longitudinally. For example, firms may opt to expend significant resources on information provision in certain time frames, such as when raising capital or introducing new products, yet refrain from investing in costly signaling in other timeframes. In particular, we argue that over time signaling behavior may diverge from equilibrium during certain periods, as firms shift strategies, competitors respond, and market onditions evolve.

To study signal dynamics, we undertake a detailed examination of a particularly well-established and oft-studied signal from its emergence through to the present: product warranty. Specifically, we analyze the evolution of warranties in the US automotive industry from the first warranty provided in 1960 through to 2008. Warranties conform with a signaling logic, because consumers typically construe them as an indicator of product quality, with longer warranty periods implying higher quality (Murthy and Blischke, 2006; Spence, 1977). Yet, our analysis corroborates prior research and reveals surprisingly weak overall correlation between warranty coverage provided by manufacturers and the quality of vehicles they produce (Chu and Chintagunta, 2011; Cooper and Ross, 1985; Lutz, 1989). However, whereas prior research focused primarily on determining whether automotive warranties were or were not viable ignals, our dynamic analysis reveals that at times they do function as signaling theory predicts, nd at other times do not. In particular, our results demonstrate that warranties serve as more accurate signals of automobile quality in periods when the industry is profitable. These findings nderscore the importance of ascertaining equilibrium in signaling research, and highlight the theoretical and analytical benefits of explicitly integrating temporal data in empirical studies.

SIGNALING THEORY

In economic theory, “signals are things one does that are visible and that are in part designed to communicate” (Spence, 2002: 407). The key attributes of signals and the way in which they function were first elucidated in an influential study by Spence (1973). Spence onceptualized an economic signal as a mechanism for credible information flow between economic agents with a great deal of accurate information (sellers) and those with little accurate information (buyers). Accurate information, he showed, can be transmitted through signals when t is less costly for a provider of a high quality good to generate the signal than it is for a provider f a low quality good. Spence demonstrated this insight using the example of labor markets, wherein he conceptualized a diploma as a job market signal. In his model, “high quality” job-seekers are individuals for whom the cost of obtaining a diploma (the signal) is lesser than that of “low quality” job-seekers. Employers pay premiums to job-seekers with diplomas because these employees provide certain labor outputs more cost-effectively than job-seekers without diplomas. For “high quality” job seekers the difference between these premiums and the cost of signaling is positive, whereas for “low quality” job seekers it is negative, thereby providing an educational incentive for the former and a disincentive for the latter.

This stratification is known formally in signaling theory as separation (Riley, 2001; Spence, 2002). When the cost of attaining a signal is sufficiently high to deter low-quality actors from pursuing one, the resultant separation yields two clearly demarcated sub-populations: high quality actors that generate the signal, and low quality actors that do not. Often, however, the contingencies required for separation are absent, and an ostensible signal is attained by both high-quality and low quality actors, leading to pooling, and thereby precluding accurate distinction between actors of differing quality. Pooling can occur when high quality actors will not be able to recoup the greater costs they must invest to attain separation, and so, in essence, they allow low quality actors to free-ride on the signal (Chu and Chintagunta, 2011). Pooling can also ensue if all actors decide not to signal, because market conditions are such that no actors will recoup the cost of signaling via subsequent benefits (Spence, 2002). Whereas separation yields variance in signals within a population, pooling implies no variance.

An important component of Spence’s theorization is the concept of equilibrium. Equilibrium is attained when buyer beliefs about the relation between the signal and the seller’s underlying quality are consistent, meaning that, “they must not be disconfirmed by the incoming data and the subsequent experience”. In particular, in a separating equilibrium, buyers offer different payment schedules at various levels of signaling, with higher premiums offered to sellers providing better signals. Illustrating again with the job market exemplar, “… wage offers in turn determine the returns to individuals from investments in education, and finally, those returns determine the investment decisions that individuals make with respect to education, and hence the actual relationship between productivity and education that is observed by employers in the marketplace. This is a complete circle. Therefore … in equilibrium, the employers' beliefs are self-confirming." (Spence, 2002: 411).

Generalizing from this example, equilibrium implies that both buyers and sellers are cognizant of the signal, its costs and benefits, and comply with the economic rationale that underlies the existence of the signal. In contexts of disequilibrium, such assumptions do not hold, and observed signaling behavior may not conform to theoretical expectations. Yet, even though equilibrium is a theoretical precondition for assessing whether signals are indeed accurate, prior research generally assumes, rather than questions, whether an empirical setting being examined is indeed in equilibrium. But of course, over time, a signal may not consistently be in equilibrium, an important contingency which a dynamic view of signals can uncover.

Signal Dynamics

The idea of market signals is intuitively appealing and has attracted widespread interest and support in both economic and management research (Connelly *et al.*, 2011; Heil and Robertson, 1991; Riley, 2001). But, Spence's use of the job market as a paradigmatic exemplar includes two implicit assumptions not necessarily applicable to organizational settings. First, it is predicated upon a large pool of sellers, none of whom individually wields significant market power. As such, firm entry and exit, competitive dynamics, and discrepancies in size or market share are not, in Spence's theorization, expected to markedly affect signaling behavior. And second, education as a signal is an unalterable decision; once a diploma is attained, and the costs invested in its attainment sunk, it cannot be modified or returned, even if market conditions make it advantageous to do so.

Yet, these two preconditions cannot be assumed in all competitive contexts. Some markets are oligopolistic rather than perfect, and firms may decide to signal more or less accurately depending on their overarching competitive strategy. For example, firms may attempt to differentiate themselves or pursue short-term advantage by signaling "inaccurately" for a limited period of time. Further, depending on their competitive positioning, some firms may either forego signaling entirely, or choose to complement signaling with other modes of information provision more suited to their strategy, such as advertising, pricing and brand reputation (Erdem and Swait, 1998; Scitovszky, 1945; Wernerfelt, 1988). Second, signals are often flexible rather than fixed, meaning that they can be modified or even abandoned, in line with competitive strategy. Firms can change the directors they employ, their CEOs, and even their names, all of which have been understood as viable signals (Filatotchev and Bishop, 2002; Kassinis and Vafeas, 2002; Lee, 2001; Zhang and Wiersema, 2009). Similarly, a company that begins offering inferior products after altering its strategy from niche differentiation to low cost competition may retain, at least for the short term, signals consistent with its previous strategy. In short, a signal that is accurate in one timeframe may convey different or even contrary information when generated in a different timeframe. And yet, even though signaling behavior and signal accuracy are likely to vary over time, signal dynamics have been conspicuously absent from most signaling research. Indeed, as noted by Bacharach & Gambetta (2001: 168), signaling theory is essentially "an equilibrium theory with no dynamics", unable to capture temporal effects. Research has often presumed, rather than confirmed, equilibrium before evaluating whether an ostensible signal is accurate or not.

We depart from this assumption, and suggest that signaling may not always occur in a context of equilibrium. In particular, a signal may be in equilibrium in certain periods of time, yet diverge from equilibrium during other periods. For example, an aggressive entrant into a new market may initially choose to generate signals that imply a high quality product, even though the quality of its products is low, and thereby attain market share. In seeking to preserve their competitiveness and rebuff this entry strategy, incumbents may react by matching these signals, as a short-term response. Cumulatively, these choices can result in a period of signal instability and disequilibrium, before the cost burden of inaccurate signaling compels a return to equilibrium. Researchers investigating signaling behavior statically during this period of disequilibrium may obtain results substantively different from those that would be obtained through an analysis of the same market and the same firms in a later time period, when equilibrium has been reestablished.

Therefore, whereas prior research has implicitly assumed two possible signaling states – separating and pooling equilibrium – we introduce a third possibility, episodic equilibrium, describing a situation in which a market alternates between being in equilibrium (either separating or pooling) and disequilibrium. Below, we draw out the contrasting theoretical predictions for these distinct possibilities, buttressing our argument with rationales that are explicitly dynamic.

Hypotheses

A dynamic analysis of signals is centered upon understanding time-dependent changes in the informational value that they provide. We examine these changes at two distinct levels of analysis – the population and the individual firm. To analyze population level dynamics, we introduce the term *signal credibility.* This construct captures the extent to which an observer can correctly interpret a signal as a reliable indicator of quality in a population of firms. Importantly, a specific signal's credibility can change over time, depending on whether members of the population continue to invest resources in its provision, whether its costs of generation change, a new signal emerges to replace it, and so forth. We formally define signal credibility as the correlation between a signal and quality for an entire population of firms at a given point in time.

At the level of the individual firm, we use the term *signal accuracy* to denote the extent to which a specific organization emits a signal consistent with its underlying quality. In contrast to the concept of signal credibility, which is novel, analysis of signal accuracy is the primary focus of signaling research, albeit analysis is primarily static (Connelly *et al.*, 2011; Riley, 2001). Signal accuracy and signal credibility are of course not unrelated. In particular, when all individual firms signal accurately, then at the population level a signal is credible. However, as we derive below, the linkage between signal credibility and signal accuracy depends upon the form of equilibrium in which signaling occurs.

Our analytical approach entails developing distinct hypotheses for each of three possible states: separating, pooling and episodic equilibrium. Within each of these three states we theoretically derive how population level signaling credibility is expected to evolve over time, and, at the individual firm level, the extent to which signaling is accurate. In particular, our theoretical development and subsequent analysis explore how the type of equilibrium affects individual firm signaling choices. Importantly, our theoretical derivations are explicitly dynamic, rather than static.

Separating equilibrium

A separating equilibrium occurs when the cost of a signal is sufficiently high to prevent low-quality actors from attaining one, thereby yielding clearly demarcated sub-populations: high quality actors that generate the signal, and low quality actors that do not. A viable signal, of course, is one in which the observable behavior is consistently correlated with unobservable quality, for all organizations in the population, over time. Thus, in a separating equilibrium, signal credibility is expected to be time-invariant, or, formally:

Hypothesis 1a: In a separating equilibrium, signal credibility remains constant over time.

Moreover, in a separating equilibrium, the decision on whether to generate a signal or refrain from doing so is not directly linked to the decisions made by other signalers. Put differently, if signaling yields an economic benefit, a firm would decide to signal regardless of whether twenty, fifty or eighty percent of its competitors were signaling[1]. All variance in signaling choices would be explained by variance in underlying quality, and there would be no reason to expect any correlation between the variance of signals in the population and signal accuracy. Greater similarity in signals over time, or lower variance, if it occurred, would simply be a result of greater similarity (lower variance) in underlying quality. Lesser similarity, or higher signal variance, would be a consequence of, for example, proprietary technological enhancements developed by some firms, yielding greater differences in quality within an industry. Overall, in a separating equilibrium, we would expect:

Hypothesis 1b: In a separating equilibrium the variance of signals is unrelated to signal accuracy.

Pooling equilibrium

Often, the contingencies required for generating a separating equilibrium are absent, and an ostensible signal is attained by both high quality and low quality actors, thereby leading to a

[1] Of course, indirectly, as more organizations signal, the proportion of high quality sellers in the population increases, driving down the price premium that signalers can capture. But, if an economic justification for signaling exists, high quality firms would be expected to signal, irrespective of the extent of signaling in the population.

pooling equilibrium. Whereas a separating equilibrium helps reduce information asymmetry, a pooling equilibrium does not. Consider the canonical example of education as a job market signal. Census data reveals that in 1940, high school graduation rates in the US reached approximately 25% of the population. By the year 2000 however, high school graduation rates had surpassed 80%, and college graduation rates had reached the 25% level, comparable to the high school graduation rate sixty years prior. From a signaling perspective, high school diplomas constituted an effective separating signal in labor markets around the middle of the 20th century, but as graduation rates climbed, high school education effectively devolved into a pooling equilibrium because it could no longer effectively distinguish between employees. This evolution suggests that, when a pooling equilibrium is established, credibility is reduced. Formally:

Hypothesis 2a: In a pooling equilibrium, signal credibility declines over time.

Notably, this form of pooling equilibrium is sub-optimal – even though informational asymmetry is not being reduced, actors needlessly expend costs on generating a signal, which provides no benefit. Such a situation may continue indefinitely, unless one or more actors decides to stop signaling, and is followed by others, yielding a more stable pooling equilibrium, in which no actors are generating the signal. Regardless of whether the resultant pooling equilibrium is one in which all actors signal or all actors do not signal, variance is low and the informational value of the signal is low:

Hypothesis 2b: In a pooling equilibrium, lower signal variance is associated with lesser signal accuracy.

Episodic equilibrium

Whereas a separating equilibrium assumes that organizations always signal consistently and accurately, it is quite conceivable that competitive dynamics will influence signaling activity. For example, since signals are by definition observable, it is possible that changes in the signaling behavior of one organization will trigger changes in the signaling behavior of its competitors. In fact, since the observable behavior of competing organizations is a central driver of competitive strategy (Marcel, Barr, and Duhaime, 2010; Porac *et al.*, 1995), "signaling wars" may be the norm rather than the exception (Heil and Robertson, 1991). If one organization attempts to differentiate itself by generating a stronger signal, other competitors may be tempted to match or beat that attempt. Conversely, if one organization comes to the realization that it has overreached in its signal and is incurring losses as a result, it may decide to recalibrate its signal to a lower level. Its competitors, observing this strategy, may decide to mimic this recalibration, even though their signals were accurate at the costlier level, simply as a way of reducing costs and thereby improving profitability. These scenarios and others suggest that signals that were in a separating equilibrium will not necessarily remain in such a state indefinitely.

However, it is important to remember that because signals are costly, departures from equilibrium cannot be stable. If signalers are overambitious in the signals they generate, signaling costs eventually become too burdensome and a period of correction must ensue. Conversely, if competitive dynamics have led to adoption of signals that are easily attainable by all competitors – or, in other words, to pooling equilibrium – at some point it is likely that high quality producers would again attempt to establish their distinctiveness by generating a costlier signal more closely aligned with their underlying quality. These scenarios suggest that the extent to which a signal is correlated with an underlying quality is tenuous, and likely to fluctuate.

Hypothesis 3a: In episodic equilibrium, signal credibility fluctuates over time.

Moreover, if changes in signal credibility are episodic, then accuracy would depend upon whether the market was in equilibrium or disequilibrium at that point in time. Periods of high variance could be periods of disequilibrium in which competitors differentiate themselves by sending overly-attractive signals, whereas periods of lower variance could be periods of equilibrium in which competitors revert to generating a signal more closely aligned with their real quality. Formally, we would expect the following:

Hypothesis 3b: In episodic equilibrium, lower signal variance is associated with greater signal accuracy.

EMPIRICAL CONTEXT: THE AUTOMOTIVE INDUSTRY

Various types of activities can serve as signals. Prominent among these are third-party certifications, such as the seminal example of educational accreditation (Spence, 1973). Third party certification also occurs in organizational contexts, for example through certification to the ISO 9000 quality and ISO 14000 environmental standards (King *et al.*, 2005; Terlaak and King, 2006). Other signals are generated by organizations themselves. For example, Nelson argues that advertising is a signal (1974). Milgrom and Roberts (1986) formalize Nelson's insight, demonstrating that price can also be a signal, and discuss high rent locations and corporate philanthropy as essentially equivalent examples. Financial actions, such as dividend, investment and stock repurchase choices, can also be understood as signals (Riley, 2001; Williams, 1988).

Product warranties can also constitute signals. "The reasons why *m*, the liability or guarantee, may be a signal of the level of *s* [the probability of product failure], are first that guarantees are costly to the seller and second, the costs are systematically related to product liability” (Spence, 1977: 569). When providing a warranty, the seller in effect enters into a contract with the buyer, that the product or service sold will satisfactorily perform its intended function when properly used. Since warranties are contractual, it would appear likely that sellers of low quality goods would shy away from providing comprehensive coverage, because they have full information about the quality of their own goods, and therefor understand that they would be exposed to substantial losses through overly generous warranty provision. Sellers of high quality goods, in contrast, would be able to provide more comprehensive warranties for their products, creating separation from sellers of lower quality goods, yet at the same time limiting the extent of coverage so as to remain profitable, even when some items are returned. Warranties thus provide a particularly appropriate setting for examining signals, because the signaling logic is stark and clear-cut; high quality means less product failures means longer warranty horizons can be offered.

Whereas economic theory has predicted that warranties can serve as signals, marketing research has empirically confirmed that they truly are construed as such: “in general, consumer responses to warranties are consistent with the behavioral assumptions of signaling theory.” (Boulding and Kirmani, 1993: 111). Srivastava and Mitra (1998) corroborated these results while also controlling for reputation. More recently Miyazaki, Grewal and Goodstein (2005) examined the relationship between price and perceived quality in the presence of another cue. One such cue examined was warranty. Results indicated that two positive cues (price and warranty), when present together, led consumers to perceive high quality. A similar effect between multiple cues, one centered upon brand reputation and warranty, was uncovered by Price and Dawar (2002).

Warranties are fairly ubiquitous for many consumer products, but their signaling power is likely more effective for items that are particularly expensive, and which necessitate greater deliberation and evaluation prior to purchase. As such, automotive warranties are particularly compelling for empirical study, because they are among the most costly consumer items for which warranty is generally provided. Moreover, regulations require auto manufacturers to allocate sizable sums to backing warranty coverage. Indeed, automakers typically earmark 2-5% of annual revenue towards warranty accrual (Warranty Week, 2011), implying that decisions pertaining to the extent of warranty coverage have enormous implications for profitability and therefore cannot be made lightly. For example, in 2009, Ford spent $2.481B to cover costs associated with basic warranty coverage, and at year end maintained a $3.219B warranty reserve for future warranty expenses (Ford 10-K, 2010), a sum equivalent to roughly 3% of the company's automotive sector sales that year (nearly $106B). As such, the warranty reserve set aside that year was not only greater than the net income generated by Ford's automotive sector that year ($1.212B), but also greater than the net income generated by the Ford Motor Company in its entirety ($2.717B). Clearly, warranty provision in this industry is a cardinal concern.

Historically, the automobile industry became, in 1960, the first U.S. industry to systematically offer product warranties, primarily in response to recurrent complaints regarding quality. Federal law on warranty provision - the Magnuson-Moss Warranty Act of 1975 - stipulates language and terminology that enhances clarity and comparability of warranty terms and conditions, but does not in fact require manufacturers to provide any warranty at all (Schroeder, 1978). In parallel, most states have enacted "lemon laws" that lay out clearly defined remedial processes for repairing nonconforming vehicles. Yet, the terms set forth in these laws are either predicated upon the warranty terms provided by the manufacturers, or set at levels much lower than those generally available. In practice, the extent of new vehicle warranty coverage in the United States is discretionary, and not imposed by fiat.

Because warranty coverage above the minimum level set by law is discretionary, it appears logical that automotive warranties would fully conform to expectations derived from signaling theory. Yet prior research, which has examined signals statically, has not borne out this expectation (Cooper and Ross, 1985; Lutz, 1989). Various reasons have been proposed. One explanation is that profit maximizing firms might select greater warranty and lower quality if they hold a comparative advantage in the provision of warranty service (Douglas, Glennon, and Lane, 1993; Jiang and Zhang, 2011). Another explanation is that consumer moral hazard creates situations in which high quality goods will not be maintained appropriately by users, and therefore cannot be guaranteed with lengthy warranty periods (Cooper and Ross, 1985; Lutz, 1989). Balachander (2001) proposed that the mismatch between theoretical expectations and empirical findings can be attributed to new product entry and the response of incumbents. New products, about which information asymmetries are great, need to provide longer warranties than existing products. Incumbents, for which information asymmetries are smaller, need not react, leading to a situation where longer warranties may be offered by lower quality manufacturers. All told, however, empirical support or compelling theoretical explanations clearly establishing warranties as credible signals remains elusive (Chu and Chintagunta, 2011).

Figure 1 provides some indication as to the inconsistent linkage between warranty and quality over time. It depicts signal credibility, as defined above, by graphing, for each year, the correlation between warranty and product quality (as published by Consumer Reports) for all car models manufactured that year. In the late 1980's for example, for the industry as a whole, warranty length was *negatively* correlated to product quality, whereas a few years later this correlation was reversed and the linkage between quality and warranty became positive. These transitions from a state of credibility to non-credibility are consistent with the notion of episodic equilibrium, as set forth in hypothesis 3a. Although not discernible in Figure 1, new entrants differed in their signaling choices and, throughout the sample period, entrants elected to provide coverage that was either higher, lower or equivalent to that provided by incumbents.

FIGURE 1 HERE

Of course, warranties are but one mechanism through which potential buyers can infer quality. Prior reputation; analyses provided by Consumer Reports, J.D. Power and similar organizations; media coverage; advertising; and, the very price at which models are sold can also provide some indication as to automobile quality, each with its attendant advantages and disadvantages. Thus, like other signals, warranties are not the only mechanism available for reducing information asymmetry, and their influence is contingent upon other cues that shape buyer opinion. Their signaling credibility and accuracy are therefore likely to be influenced by these others sources of information.

Notwithstanding, warranty terms are often trumpeted by manufacturers. For example, in 1982, Chrysler claimed that it had substantially improved its car quality such that it could offer the best warranty in the industry. It launched a TV advertising campaign featuring its chairman Lee Iacocca using a punchy “best-built, best-backed” tag-line to describe Chrysler cars. Ford and GM moved quickly to match the warranty terms set by Chrysler, with Toyota extending its warranty only in 1989 (Guiles, 1989). In contrast, in 2002, when Chrysler was once again a first mover in extending warranty coverage, GM and other competitors declined to follow suit (Saranow, 2005), leading Chrysler to eventually backtrack to more modest warranties in 2006. Unsurprisingly, changes in warranty coverage appear to have a sizable impact on market share. In 1999, for example, Hyundai boldly extended their powertrain warranty from 5 years/60,000 miles to 10 years/100,000 miles. Imitating this strategy in 2001, and matching the powertrain warranty advertised by Hyundai, Kia saw its market share increase 65% from 1.09 to 1.80. Similarly, consumers seem to react unfavorably when firms shorten their warranty. Attempting to reduce costs, Volkswagen reduced their powertrain warranty in 2002 from 10 years/100,000 miles to 5 years/60,000 miles. This change was associated with a 30% drop in sales over the subsequent three years. As these vignettes demonstrate, warranty provision appears to be closely intertwined with competitive strategy.

DATA

Our primary goal in the analysis is to identify how signal credibility (at the population level) and accuracy (at the individual firm level) have changed throughout the period in which automobile manufacturers have been offering warranties, from the very first warranties in 1960 through to the present. To do so, we collected data at three nested levels. The most granular level was the level of the individual model, e.g. the Corolla manufactured by Toyota. The second, intermediate level was the brand or make, such as Toyota and Chevrolet. Finally, at the broadest level was the manufacturer, which often encompasses more than one brand. For example, Toyota Motor Corporation is the manufacturer of several brands including Toyota and Lexus. Warranty terms do not generally differ across models under the same brand, but they do differ across brands offered by the same manufacturer. Lincoln (owned by the Ford Motor Company) offers longer warranties than the Ford brand; Lexus offers longer warranties than the Toyota brand; and Cadillac offers longer warranties than other GM brands. More generous warranty coverage for luxury brands is consistent with the assumption that warranty is less costly for higher quality vehicles.

Dependent Variable

Auto manufacturers offer two different types of warranties: "basic" ("bumper to bumper") warranties have been provided since 1960, whereas "powertrain" warranties have been provided since 1962. Basic warranties cover any part of an automobile; powertrain warranties cover the key components - namely the engine, transmission and driveshaft. Both provide coverage limited by the number of miles and duration. For example, in a 5 year/50,000 mile powertrain warranty, a powertrain is covered for up to 5 years or 50,000 miles, whichever comes first. Typically, powertrain warranty coverage is more generous than that provided by the basic warranty. We use the powertrain warranty in our analyses as it is often emphasized more prominently by auto manufacturers, has greater variance across brands, and is modified more frequently by manufacturers. Our primary dependent variable is thus the number of miles stipulated in the powertrain warranty. From a signaling perspective, a longer warranty implies higher vehicle quality.

To our knowledge, no comprehensive data set cataloging automotive warranty from 1960 has ever been assembled. We harnessed several sources to create such a data set: the trade journal "Automotive News"; "Dealer Insight", a warranty consulting and training firm; Randy Shepard & Associates, Inc. a consulting and administrative service provider in automotive warranty claims; "Warranty Direct", an internet based company selling extended warranties; reports by the Automotive Analysis Group at the Center for Automotive Research (CAR); White (1971); and, "Warranty Week", an online newsletter for warranty management professionals. In instances where data was not available we assumed that no changes in warranty occurred between the observed years.

Independent variables

To measure product quality we used the annual Consumer Reports Buyer's Guide which consistently contains a through and detailed section on automobiles. Importantly, Consumer Reports has published product quality reports since 1936 and is well-established as a preeminent purveyor of information from which consumers can learn about product quality. Its automobile reviews focus strictly and solely on reliability as an indicator of quality, with no adjustment to account for a car model's price, size, power, mileage or any other extraneous attributes. The information it provides is accessible to the general public, for a fee, and is considered unbiased, because the organization does not accept advertising. We collected the quality score for all 9,658 models surveyed by Consumer Reports since 1960. During these years, Consumer Reports twice changed the format of information regarding automobile quality in its Buyer's Guides. Using simple linear transformations, we normalized the scale used by in the reports over these periods in order to standardize our quality measure over time.

For each automobile model offered in the U.S. market we obtained the manufacturer's suggested retail price from Ward's Automotive, an industry research group. In order to ensure the greatest comparability between models, we used the price of the base-model, i.e. the model with no additional features. In cases where price information could not be obtained, we extrapolated data from the same model in the previous year. This was accomplished by averaging all the available prices for a given brand in year t and dividing by the average of all available prices for the same brand in year $t-1$, obtaining a brand-inflation factor. The extrapolated price for a given model was calculated as the price in year $t-1$, multiplied by the brand-inflation factor.

At the level of the brand, we obtained data about the volume of annual sales for each brand in the U.S. consumer market through Ward's Automotive. This data also captures information about year of brand entry and exit from the market. Since 1960, the number of brands increased from an average of 14.7 mostly domestic brands in the 60's, to an average of 27 brands (about 50% imports) in the 1970's and 1980's, reaching an average of 34 brands (about 60% imports) in the 1990's and 2000's. Finally, at the level of the manufacturer, we collected financial data from Compustat.

ANALYSIS

Signal credibility

Each of our three contrasting hypotheses makes distinct inferences about signal credibility, or the extent to which warranties offered by the population of automobile brands in a given year is correlated to product quality. Model specification should allow us to assess whether the effect of initial signal credibility is temporary (hypothesis 3a), invariant (hypothesis 1a) or whether it erodes over time (hypothesis 2a).

Our dependent variable to capture industry-level signal credibility in a given year, C_t, is defined as the correlation between quality and warranty coverage for all brands that operated in that year in the U.S. market. There are two sources of heterogeneity that may have an impact on (C_t): industry level covariates that exist in period *t-1* (I_{t-1}) such as average corporate profitability, capital expenditures, sales, or number of competing brands; and the effect of initial signal credibility C_{t0} during the year when product warranties were first introduced into the automobile market. To test our hypotheses, the model must assess whether the effect of initial signal credibility varies systematically over time. A simple way of achieving this is to express the coefficient of initial signal credibility as a constant plus a term that is linear in time $\eta + \delta t$ (Disney, Haskel, and Heden, 2003). Our model for specifying credibility at time *t* is therefore:

(1) $C_t = \alpha I_{t-1} + \eta C_{t0} + \delta t C_{t0} + u_t$

where C_t, is signal credibility in year *t;* u_t is assumed $\sim N(0, \upsilon^2)$ and captures the variability of all unsystematic and random influences on C_t; I_{t-1} is a vector of industry level covariates that exist in period *t-1,* C_{t0} represents initial signal credibility in the industry, and $\delta t C_{t0}$ is the interaction term between initial signal credibility and time. With this specification, if δ (the coefficient of the interaction term) turns out to be negative and $\eta \neq 0$, we would conclude that the effect of initial signal credibility declines over time, supporting hypothesis 2a. If, however, $\delta = 0$ and $\eta \neq 0$ we would conclude that the effect of initial signal credibility in this market is permanent (i.e., constant over time) thus supporting hypothesis 1a.

Table 1 reports descriptive statistics and correlations of key variables and Table 2 reports the results of analysis. Model 1 in Table 2 suggests that lagged industry level covariates have an impact on signal credibility. Specifically, higher levels of corporate profitability (*average net income*) and *capital expenditures* are positively related, and *number of brands* is negatively related to signal credibility. Our controls for the number of units sold (*sales), revenues* and the year of passage of the *Magnuson-Moss Act* (1975) are insignificant. To examine hypotheses 1a and 2a, Model 2 adds the covariates of initial signal credibility and its interaction with time. Insignificant coefficients on both covariates suggest that the effect of initial signal credibility does not impact subsequent signal credibility. Therefore we reject both hypotheses 1a and 2a. We now turn to hypothesis 3a.

TABLES 1 AND 2 HERE

Variance in signal generation

Figure 2a shows the evolution of warranty coverage provided by the five leading brands in the US market from 1962 to 2008 and Figure 2b depicts the variance in warranty coverage for all brands over the same period. Figure 2b suggests that in certain periods manufacturers provided differentiated warranty coverage, whereas in other periods manufacturers converged upon warranties more similar to those of their competitors. To examine whether this phenomenon yields a subdivision of the sample period into distinct periods, we employed a simple discriminant analysis procedure identical to the one used by Gort and Klepper (1982 - see Appendix for details). We utilized this procedure to distinguish between periods of high variance in warranty coverage and periods of low variance in warranty coverage. The analysis yielded five different periods over the 48 years of our sample. Periods of high variance were identified between 1962-1969, 1980-1990, and 2000-2008 and periods of low variance were identified between 1970-1979 and 1991-1999.

FIGURES 2A AND 2B HERE

Table 3 describes manufacturer characteristics in the two types of periods. In order to make comparison across periods meaningful, we normalize all financial values to inflation adjusted 1990 US dollars. Mean *revenues* and *R&D expenditures* are significantly higher in periods of low variance than during periods of high variance whereas mean *advertising expenditures* are significantly higher during periods of high variance. We examine whether periods of low and high variance are associated with differences in signal credibility in two ways. First, we use a one-dimensional Chi–Square test of independence to check the relationship between signal credibility and periods of high vs. low variance (Table 4). Absence of a significant relationship between the five periods and signal credibility would be consistent with the assertion that signal variance is unrelated to signal credibility, as put forth in hypothesis 1a. Yet the test results indicate that signal credibility is statistically different across periods. They also suggest that signal credibility is higher during periods of low variance than it is during periods of high variance, providing support for hypothesis 3a.

Second, in Model 3 of Table 2, we add the variable *high variance* to Equation (1) above, resulting in the specification:

(2) $C_t = \alpha I_{t-1} + \eta C_{t0} + \delta t C_{t0} + \beta HV_t + u_t$

where HV_t is a dummy variable coded as 1 during periods of high variance, and 0 during periods of low variance. Consistent with our Chi-square test, and again supporting hypothesis 3a, we find that the coefficient is negative and significant (β = -0.0426, p<0.01) suggesting lower signal credibility in periods of high variance than in periods of low variance[2].

TABLES 3 AND 4 HERE

To summarize our findings to this point, hypotheses 1a and 2a are not supported. Rather than becoming increasingly similar over time, warranties evince episodic shifts between periods of low and high variance, as put forth in hypothesis 3a. Further, periods of high variance are characterized by lower signal credibility than periods of low variance. In other words, periods in which manufacturers attempt to differentiate through provision of generous warranty coverage are periods in which credibility is low.

[2] We repeated this test using a continuous, rather than dichotomous, measure of variance, obtaining nearly identical results.

Signal accuracy

Whereas analysis to this point has examined the industry in its entirety, in order to test hypotheses 1b, 2b and 3b regarding the effect of periods of high and low variance on signal accuracy we shift the level of analysis to the brand-year, i.e. the warranty provided by each brand in each year in our sample. Model specification is:

$$(3)\ PT_{b,t} = \beta_1 quality_{b,t} + \beta_2 age_{b,t} + \beta_3 adv\_exp_{b,t} + \gamma_1 B_{b,t} + \gamma_2 M_{b,t} + \gamma_3 I_t + \varepsilon_{b,t}$$

where the dependent variable $PT_{b,t}$ is the level of powertrain warranty offered by brand *b* in year *t.* Our main independent variable, $quality_{b,t}$ is brand quality at time *t*, operationalized as an unweighted average of the quality of individual models sold by each brand in each year. We use two proxies to capture information asymmetry, or the extent to which information about brand quality is publicly available: *brand age*$_t$ and *advertising expenditure*$_t$. Our controls are at three levels. At the brand-year level, we control for the implicit association between quality and price (Scitovszky, 1945) by using the natural logarithm of the manufacturer's suggested retail price (MSRP), averaged over all models produced by the brand. We also control for the volume of cars sold by each brand to account for consumer familiarity with more prevalent cars. At the manufacturer-year level, we control for manufacturer age, to account for differences in information asymmetry between brands launched by an incumbent manufacturer as compared to those launched by a new entrant. We control for financial strength by using the natural logarithms of capital expenditure, net income and revenue. To control for technological superiority we use R&D expenditures. Finally, at the industry-year level, we control for competitive intensity by counting the number of brands in the industry, and employ a dummy variable to distinguish between the years before the Magnuson-Moss Act and those that follow. We also control for quality variance, to account for the possibility that variance in warranties simply mirrors the variance in quality of the cars manufactured. Since multiple brands are associated with the same manufacturer we cluster standard errors by manufacturer. Due to differences in vehicle quality or signaling strategy among manufacturers, the error terms might violate the assumption of normality. Q-Q plots, and the Jarque and Bera (1987) goodness-of-fit test, however, did not reject the null hypothesis of normality.

Table 5 reports descriptive statistics and correlations and Table 6 summarizes our results. Model 1 indicates that *quality* is negatively, rather than positively associated with powertrain warranty. Supporting the notion that more expensive cars provide greater warranty coverage, *price* is positively associated with warranty offered. Consistent with a key tenet of signaling theory, we find a negative and significant effect of *brand age* on the level of powertrain warranty offered. Higher *brand age* implies greater familiarity among consumers, meaning lower information asymmetry, which suggests less of a need to signal, as we find in our results. Model 2 adds *manufacturer age* as a control, to account for information spillovers when established manufacturers launch new brands. Addition of this variable causes the coefficient of *brand age* to lose significance, due to high correlation. We therefore remove *manufacturer age* from subsequent models. The specification in Model 3 adds several manufacturer level and industry level controls. While the added covariates increase the model's explanatory power, financial data are not available for many of our brand-year observations forcing us to use fewer observations. Results indicate that increased market competition as measured by the *number of brands* is associated with higher levels of warranty.

TABLES 5 AND 6 HERE

Model 4 changes the model specification by including year dummies to control for industry and macroeconomic variation that was not captured before with the simple *Magnuson-*

Moss Act dummy. The model also introduces the second key measure of information asymmetry – *advertising expenditures*. Results indicate that brands that reduce information asymmetry by spending more on advertising tend to offer lower levels of warranty. Surprisingly, manufacturers with higher *R&D expenditures*, implying higher quality, provide lower levels of warranty. While this specification substantially improved the predictive power of the model, data availability for advertising and R&D expenditures further reduced the sample size.

To directly test hypotheses 1b, 2b and 3b, the specification in Model 5 introduces the dummy variable *high variance*. Consistent with our analyses at the industry level, results indicate that brands offer greater warranty coverage during periods of high variance. Models 6 and 7 split the sample into periods of high and low variance, respectively. Different signs on the coefficient of quality in Models 6 and 7 allow us to reject hypothesis 1b by showing that signal accuracy is significantly different in periods of high and low variance. Moreover, these results indicate that warranty coverage during periods of high variance is inconsistent with a signaling logic – quality is significantly yet *negatively* correlated with warranty (β_1 = -1.2293, P<0.05). Periods of low variance, in contrast, do adhere to expectations from signaling theory, in which quality and warranty are significantly and *positively* correlated, although at a weaker level of significance (β_1 = 1.1723, P<0.1). Thus, we find support for hypothesis 3b, with periods of low variance implying equilibrium and periods of high variance implying disequilibrium.

Notably, the two types of periods differ substantially in terms of the factors that impact warranty coverage. In periods of high variance, *revenues* are negatively correlated with warranty coverage, implying that smaller firms employ warranties more aggressively than their competitors. The negative and significant coefficient of *quality variance* suggests that differentiation through warranty coverage in these periods is *not* based on differences in the technological quality of the cars being manufactured. Moreover, as evinced in Table 3, mean *advertising expenditures* are significantly higher during these periods, suggesting that warranty is likely being employed as part of a concerted marketing strategy in these periods, in an attempt to create greater willingness to buy. In contrast, in periods of low variance, *price* becomes a significant predictor of warranty, and – albeit at a lower level of statistical significance – so too does *net income*. *Sales* are negatively correlated with warranty coverage, implying that in periods of low variance - as in periods of high variance - smaller brands employ warranties more aggressively.

In sum, our findings reveal an episodic pattern of signal credibility, and suggest that market conditions influence signaling choices. Warranty signals in the automotive market function with some accuracy some of the time, but they are most accurate when they are least differentiated, i.e. in periods of low variance. Periods in which the industry converges upon similar warranty coverage appear to be periods in which the industry is, on aggregate, more profitable, and manufacturers do not perceive a need to provide overly-generous, “inaccurate”, warranties in order to be competitive. These conditions engender equilibrium, in which signals are more accurate, and signaling is credible. As expected in equilibrium, higher car prices and lengthier warranties are aligned, reinforcing each other as cues for higher quality. But when market conditions change and revenues decline, firms increase their advertising expenditures and extend their warranty coverage. As a result, the industry departs from equilibrium, with quality and warranty becoming negatively correlated. Since disequilibrium is untenable over the long term, however, signals eventually revert to more accurate levels, credibility increases, equilibrium is reestablished, and the cycle begins again.

Robustness Checks

We tested several additional models to ascertain the robustness of our results. First, we performed sensitivity tests to see if the results are robust to a change in the break-year classification between periods of high and low variance. Second, we calculated initial signal credibility in the market using the averages of brand level powertrain warranty and quality over the first three years powertrain warranty in the industry (1962-1964), rather than just one year (1962). Third, we used an inverse Herfindahl-Hirschman Index (HHI) as an alternative measure of competitive intensity. We calculated the measure based on annual brand level market share (units sold):$HHI_t = \sum_{i=1}^{N} s_{it}^2$ where s_{it} is the market share of brand *i* in year *t.* Fourth, we repeated all the analyses reported in Table 6 replacing *brand age* with *manufacturer age* to address the possibility that information asymmetry is a manufacturer, rather than brand level phenomenon. Fifth, to account for the fact that signaling decisions are made in a context that includes other concurrent strategic choices, we ran a seemingly unrelated regression to better control for unobservables that affect both warranty and pricing. And sixth, we ran the same tests with alternative operationalizations of our two dependent variables - signal credibility and signal accuracy - using powertrain warranty years, basic warranty miles and basic warranty years instead of powertrain miles (see Table 6, Model 8 for results with basic miles). In all these tests we obtained results substantively identical to the results we reported.

DISCUSSION

Research on signaling is predominantly oriented to static analyses that examine which forms of organizational activity constitute accurate predictors of quality. Moreover, most studies implicitly assume that the signal being examined is in a state of equilibrium. To examine whether these characteristics of prior research have limited our understating of signals in competitive contexts, in this study we theorized and employed a dynamic approach to assessing the credibility and accuracy of automobile warranties as signals of quality. Our findings corroborated prior research and demonstrated that the overall correlation between warranty coverage and the reliability of cars is generally weak. But, we have also shown that signaling behavior changes over time, alternating between periods of volatility (high variance) and periods of relative stability (low variance). In periods of volatility, signal accuracy is lesser than in periods of stability. Periods in which manufacturers provide warranties more similar to those of competitors, in contrast, appear to be periods in which signaling choices are more accurate, conforming with theoretical predictions.

Our interpretation of these findings is that warranties indeed do serve as signals in the automotive industry. We diverge from the prevailing view, however, by arguing that signaling behavior is not always in equilibrium. Manufacturers may decide to be “irrational” for a period of time, others may decide to follow suit, and the result of these dynamics may be a period in which warranties are less credible. However, warranty provision really does constitute a significant cost for manufacturers, and so it must, in the long run, be aligned with the quality of the vehicles they produce, meaning that departures from equilibrium cannot continue indefinitely.

Consequently, we contend that a more complete theory of signals must more comprehensively incorporate contextual conditions and temporal dynamics into its core tenets. Simply put, market conditions and industry characteristics matter. For example, signal dynamics are different in large populations, as epitomized by individuals considering a university education, and in small populations, as exemplified by a small number of competing automakers. Similarly, signaling behavior will likely be different when a signal can be modified - as in the case of a warranty - or not, as in the case of a university diploma. Perhaps most importantly, the existence of signaling equilibrium, according to which subjective beliefs in the market regarding quality are continuously reconfirmed (Spence, 1973) cannot be assumed to hold true, but rather requires empirical validation.

Time matters too (Etzion, Forthcoming). Our findings suggest that research that examines signals cross-sectionally is likely to be incomplete. As we have demonstrated, results are quite sensitive to the specific time-frame examined, suggesting that conclusions drawn from a static analysis may be spurious, inadvertently leading researchers to introduce and examine causal explanations extraneous to how signals truly function in competitive settings. Consequently, we believe that for future signaling research conducted statically, a necessary first step is ascertaining that the empirical setting is in equilibrium within the period being examined.

A key limitation of our study, of course, is the extent to which it is generalizable. We chose the automotive industry as our empirical context because warranties in this industry are indeed expensive, and because longitudinal data are available to control for many confounding factors. And yet, signals in the industry are aggregated because they are provided at the brand level, whereas quality can vary significantly among specific models within the brand. Additionally, automobile shortcomings often surface several years after the initial purchase, leading to significant lags until quality can be affirmed. As a result, companies that face a liability of newness (Stinchcombe, 1965) may be tempted to signal inaccurately in order to build awareness and gain initial market share. These characteristics of the automotive industry may not be broadly generalizable to other industries, and future studies should attempt to replicate our results in alternative empirical settings.

Notably, our theorization conforms to a key characterization of signaling theory, which sees signals as actions designed in part, but not necessarily exclusively, to communicate (Spence, 2002). Our analysis does not attempt, nor does it need to, disprove the notion that warranties, in addition to being signals, also provide consumers with legal recourse in case of product failure. Consequently we believe that our conclusions are applicable to additional signaling contexts, and not just product warranties. For example, research has shown that companies certifying to the ISO 9000 system are signaling high quality products but in parallel are also improving inventory management and generating other operational benefits (Terlaak and King, 2006). Similarly, entrepreneurial young firms recruiting respected board directors are signaling quality but also obtaining managerial expertise and a rich network provided by these investors (Deutsch and Ross, 2003). Signaling effects that improve operational performance are also obtained, for example, when entrepreneurial firms associate themselves with prominent underwriters, venture capitalists and alliance partners (Reuer, Tong, and Wu, 2012). We believe these contexts to be eminently suitable for future research that investigates signal dynamics.

Notwithstanding, the automotive industry is a particularly appealing empirical setting for further exploring the way in which firms dynamically employ signals in a competitive context. For example, research in emerging markets, where cars are only now being widely adopted, can examine how warranty coverage evolves from a baseline of higher quality than that provided by US manufacturers in the 1960's, over shorter time frames, and within different regulatory contexts. Even within the US market, the findings of this study may not be definitive. With warranty coverage reaching 10 years on some models, its provision may have become to some extent symbolic, given that average vehicle age in the US car fleet is 10.6 years (R. L. Polk & Co, 2010). If this is indeed the case, how will warranties continue to evolve? Will they still be used by manufacturers as signals? Will manufacturers identify alternative mechanisms through which to differentiate based on quality?

Finally, our findings draw attention to the limitations which must be considered when transposing theoretical ideas from one empirical context to another. A key aspect of signaling theory in the job market is that signals are tightly linked to individual quality, and that this quality is invariant. While this may indeed be true for individual employees, it is almost certainly untrue of large organizations. Rarely - perhaps never - are companies and products consistently great or consistently poor. Organizations change; they have no invariant attributes. A theory that aspires to accurately depict organizational signaling cannot ignore this fact, nor downplay it, but must rather grapple with it head on.

Acknowledgements

We are grateful for the encouragement and insight provided by Bruno Cassiman, Petra Christmann, Robert David, Andy King, Larry White, Zvi Singer and participants at research seminars at the Hebrew University of Jerusalem and at Tel Aviv University. This research was supported by the Social Sciences and Humanities Research Council of Canada [SSHRC Award 410-2009-1259].

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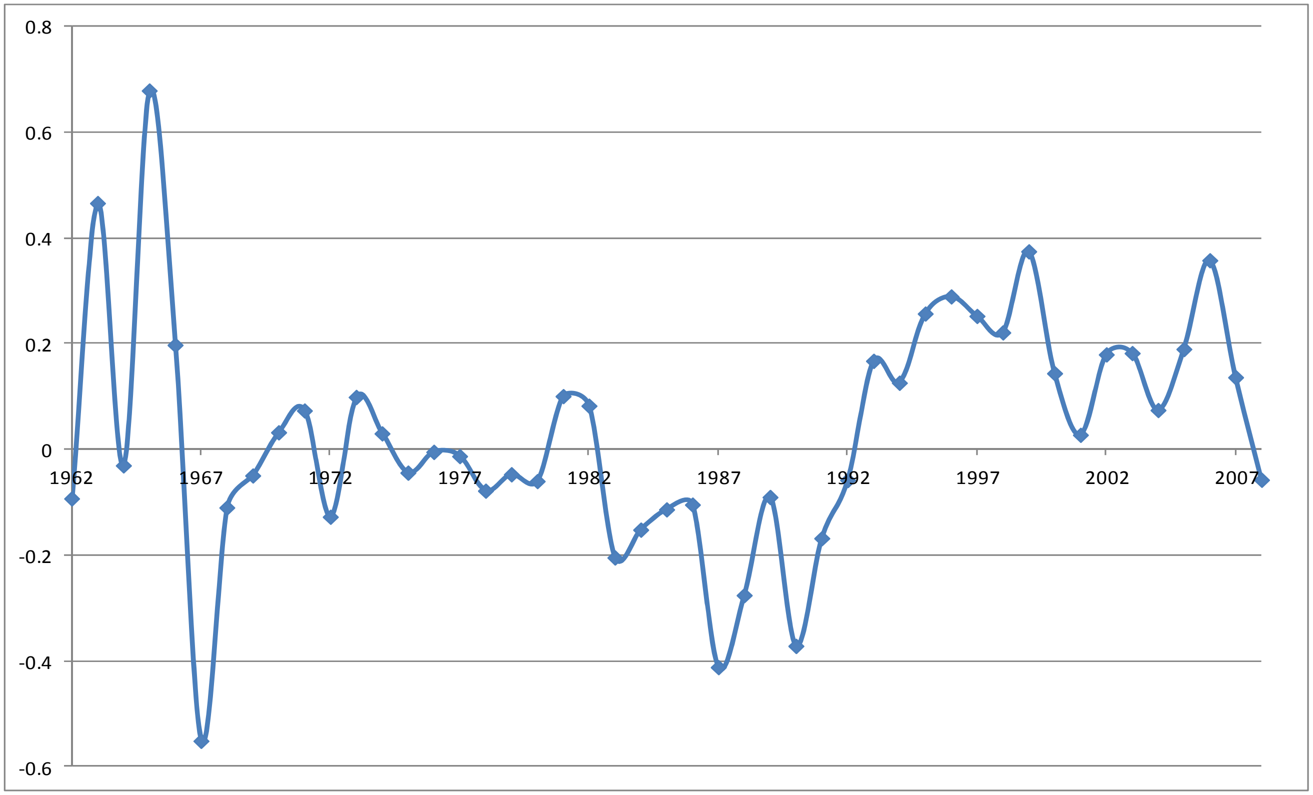
FIGURE 1

Signal credibility in the automobile industry 1962-2008



To generate this figure we calculated, for each brand and each year, the average quality of all the models produced by that brand and assessed by Consumer Reports. We then ascertained the powertrain warranty provided by each brand each year. Each data point in the figure represents the correlation coefficient (*r*) between quality and warranty for all brands in the US market in a given year. A positive (negative) value implies that the industry, on aggregate, provided longer (shorter) warranties for higher quality vehicles in that specific year.

FIGURE 2A

Powertrain warranty for the highest volume brand (units sold) for each of the top five manufacturers

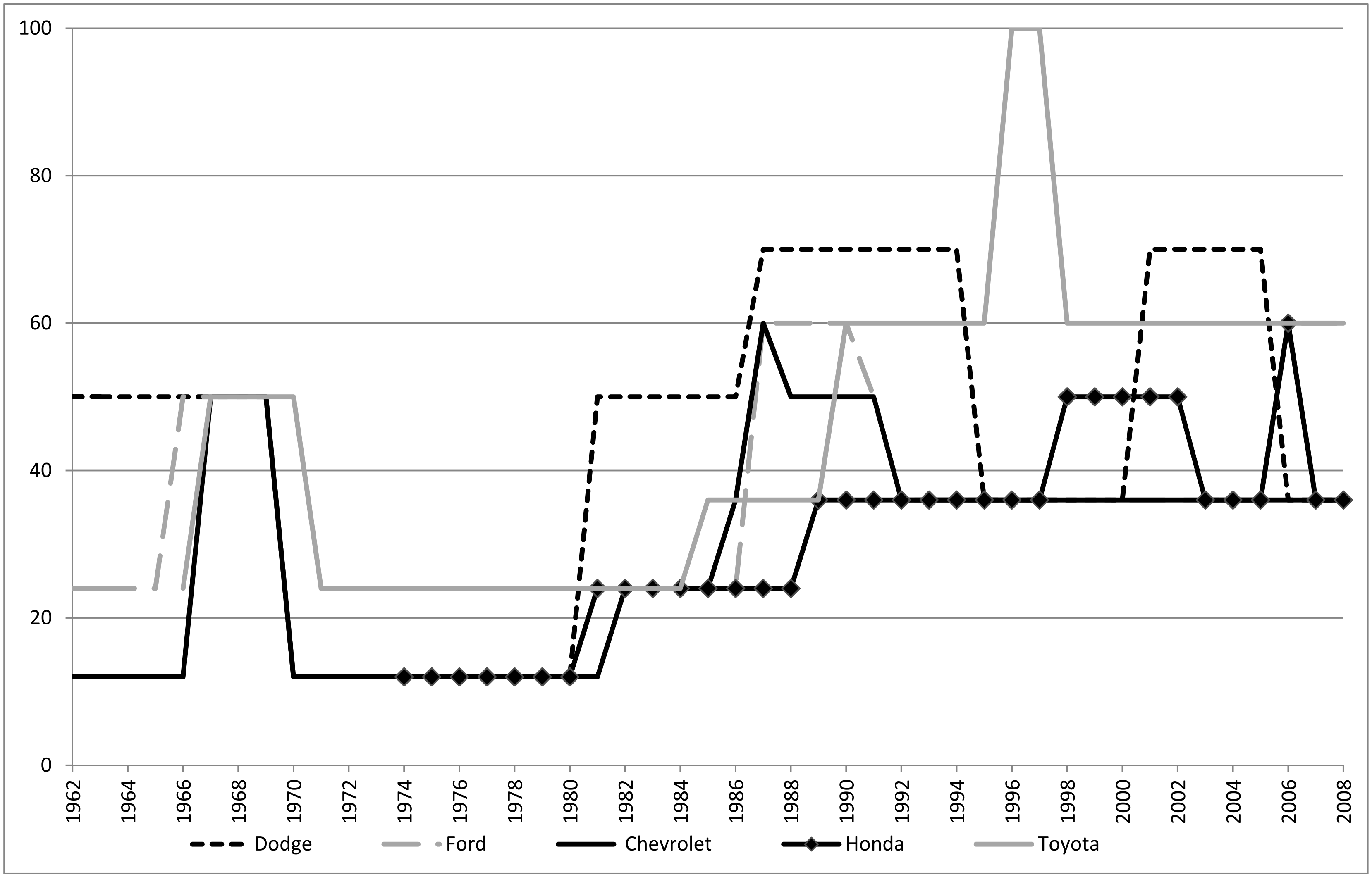


FIGURE 2B

Variance in powertrain warranty for all brands in the US market, by year

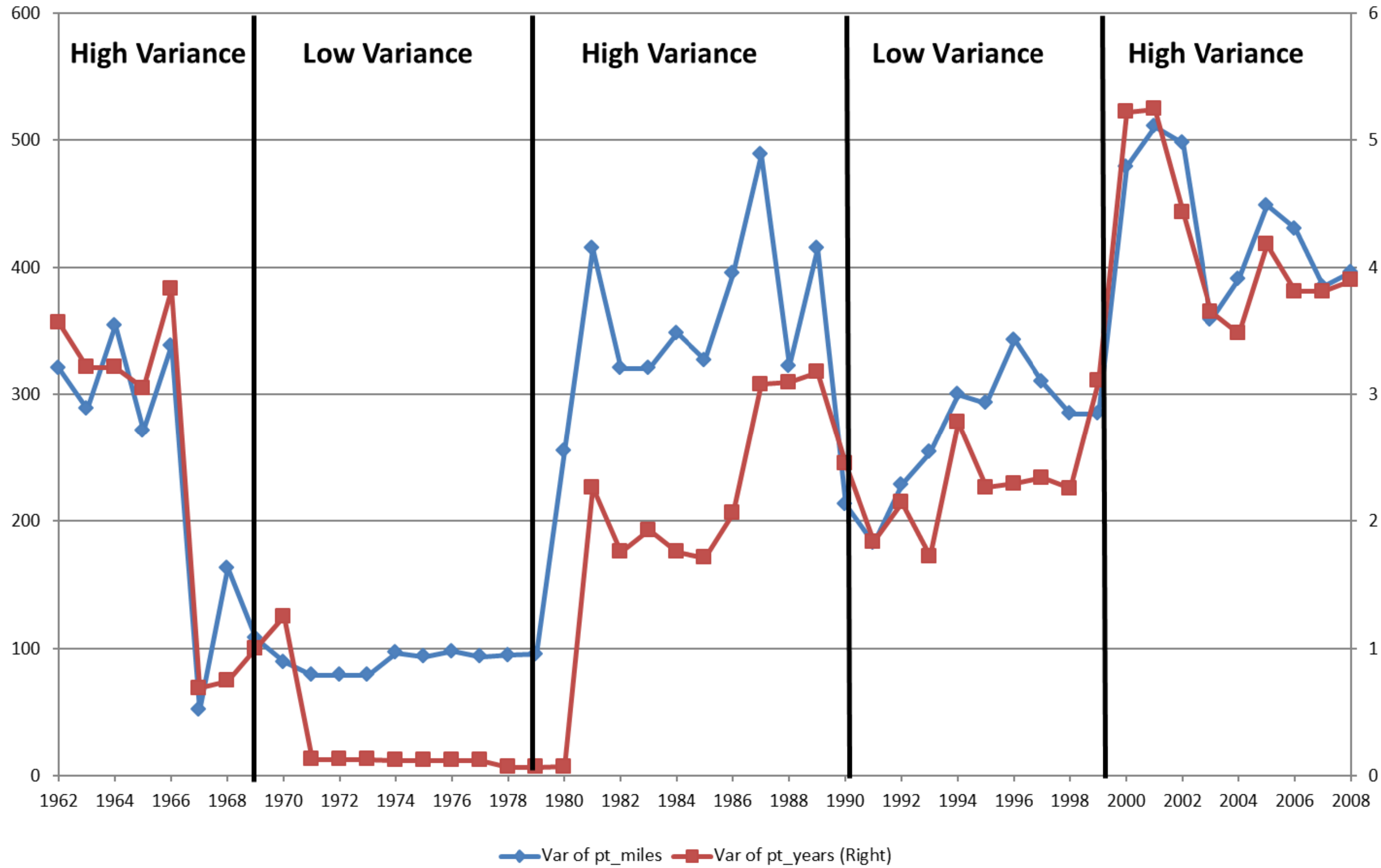


TABLE 1

Descriptive statistics and correlations at the industry level

		n	mean	std. dev	Min	Max	1	2	3	4	5	6	7	8
1	Signaling credibility $_t$	46	0.038	0.227	-0.551	0.679								
2	Signaling credibility $_{t-1}$	45	0.046	0.209	-0.514	0.679	0.57*							
3	High variance dummy	46	0.562	0.501	0.000	1.000	-0.27*	-0.11*						
4	Net income	46	1,235	4,672	-38,732	22,071	0.23*	0.17*	0.02					
5	Sales [units]	46	442,176	656,870	65	3,473,096	-0.050	-0.051	0.01	0.35*				
6	Capex	46	4,865	7,149	0	39,523	0.26*	0.27*	-0.09*	0.83*	0.14*			
7	Revenues	46	46,206	50,070	628	242,819	0.18*	0.16*	-0.12*	0.86*	0.17*	0.96*		
8	Number of brands	46	29.52	7.61	11	38	0.22*	0.16*	-0.08	0.42*	-0.23*	0.55*	0.48*	
9	Magnuson-Moss Act	46	0.81	0.39	0	1	0.03	0.003	0.00	0.36*	-0.12*	0.41*	0.37*	0.79*

*: Correlation coefficients significant at the 5% level.

Financial covariates are displayed in millions of inflation adjusted 1990 U.S. dollars

TABLE 2

Dynamic models of signal credibility

		1	2	3
H1a, H2a	Signal credibility t_0		0.0158	0.0167
			(1.36)	(1.34)
	t x Signal credibility t_0		0.0304	0.0306
			(1.61)	(1.58)
H3a	High variance dummy			-0.0426***
				(2.38)
	Controls			
	Average net income	0.0194**	0.0190**	0.0194***
		(2.16)	(2.20)	(2.28)
	Average sales [units]	-0.0374	-0.0373	-0.0320
		(1.01)	(1.03)	(0.91)
	Average Capex	0.1212***	0.1208***	0.1174***
		(3.47)	(3.43)	(2.83)
	Average revenues	0.0054	0.0055	0.0057
		(1.18)	(1.19)	(1.18)
	Number of brands	-0.0146**	-0.0146**	-0.0163**
		(2.20)	(2.16)	(2.19)
	Magnuson-Moss Act	-0.0698	-0.0686	-0.0559
		(1.65)	(1.64)	(1.60)
	Adjusted R-square	0.3403	0.3415	0.3504
	# of observations	46	46	46

t-statistics in parentheses

*: p<0.10, ** p<0.05, ***p<0.01

Natural logarithm is taken on all financial covariates (Values were top coded as 1 if negative)

TABLE 3

t-tests for differences in mean attributes between periods of high and low variance

	all observations	**only during periods of high variance**	**only during periods of low variance**	***t* -statistic**	***n* (manufacturer-year)**
Capex	4,865	4,755	4,911	1.41	923
Net income	1,235	1,104	1,351	2.04*	732
Revenues	46,206	43,052	48,832	3.12***	1,033
Advertising expenditures	1,635	1,958	1,586	2.14**	468
R&D expenditures	2,402	2,235	2,703	3.20***	772
Number of brands	29.52	32	28	1.07	1,387

Significance tests are based on the two-sided alternative hypothesis that the means differ, allowing for unequal variances. Since some of the covariates are not normally distributed, we also used the nonparametric Mann-Whitney test to compare the medians of the periods of high and low variance. P-values of the Mann-Whitney test for the medians were consistent with the t-test results reported for the means.

*: p<0.10, ** p<0.05, ***p<0.01

Financial covariates are displayed in millions of inflation adjusted 1990 U.S. dollars

TABLE 4

One-dimensional Chi–square test of independence of signal credibility and periods of high and low variance

	Mean signal credibility	Chi-square	P value
Low variance	0.05316	6.58	0.001
High variance	0.01503	5.57	

TABLE 5

Descriptive statistics and correlations at the brand-year level

		n	mean	std. dev	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Powertrain warranty	1,387	45.804	21.482	12	120																
2	Quality	1,387	2.95	1.23	1	5	-0.01															
3	Signaling credibility $_{t-1}$	1,387	0.046	0.209	-0.412	0.679	0.22*	0.01														
4	High variance dummy	1,387	0.44	0.50	0	1	0.17*	-0.14*	-0.27*													
5	Brand age	1,387	20.24	12.82	1	49	0.21*	-0.22*	0.23*	0.06												
6	Advertising	309	1,635	1,538	38	5,800	0.62*	0.00	0.23**	0.12	0.75*											
7	Price	843	18,949	13,919	1,279	108,648	0.40*	-0.03	0.39*	-0.03	0.59*	0.78*										
8	Sales [units]	843	442,176	656,870	65	3,473,096	-0.15*	0.14*	0.25*	0.02	0.11*	0.23*	-0.37*									
9	Manufacturer age	1,387	18.72	12.26	1	49	-0.01	-0.17*	-0.05	0.11*	0.55*	0.85*	0.22*	0.35*								
10	Capex	432	4,865	7,149	0	39,523	0.62*	0.09	0.12*	-0.09*	0.18*	0.93*	0.32*	0.14*	0.21*							
11	Net income	432	1,235	4,672	-38,732	22,071	0.33*	-0.01	0.23*	0.02	0.54*	0.81*	0.46*	0.35*	0.53*	0.83*						
12	Revenues	432	46,206	50,070	628	242,819	0.54*	0.21*	0.18*	-0.12*	0.03	0.96*	0.20*	0.17*	0.06	0.96*	0.85*					
13	R&D	309	2,402	2,431	30	8,974	0.54*	0.19*	0.27*	0.17*	0.19*	0.95*	0.38*	0.06	0.17*	0.95*	0.85*	0.98*				
14	Magnuson-Moss Act	1,387	0.81	0.39	0	1	0.32*	0.02	0.03	0.07	0.48*	0.31*	0.59*	-0.12*	0.24*	0.41*	0.36*	0.37*	0.29*			
15	Number of brands	1,387	29.52	7.61	11	38	0.48*	0.07	0.22*	-0.08	0.58*	0.84*	0.77*	-0.23*	0.28*	0.511*	0.42*	0.48*	0.61*	0.79*		
16	Quality variance	1,387	1.37	0.53	0	2	0.06	-0.03	-0.21*	0.09	0.26*	-0.04	0.31*	0.05	0.13*	0.211*	0.19*	0.17*	-0.01	0.56*	0.55*	
17	Basic warranty	1,387	30.751	16.452	3	60	0.57*	0.04	0.34*	0.01	0.39*	0.61*	0.71*	-0.41*	0.07	0.52*	0.37*	0.44*	0.45*	0.47*	0.68*	0.14*

*: Correlation coefficients significant at the 5% or 1% level

Financial covariates are displayed in millions of inflation adjusted 1990 U.S. dollars

TABLE 6

Dynamic models of signal accuracy

	1	2	3	4	5	6 only during periods of high variance	7 only during periods of low variance	8 Dependent variable = Basic Miles
Quality	-1.2967*	-1.0655	-1.2185*	-1.6531***	-1.2308*	-1.2293**	1.1723*	-1.3152**
	(2.08)	(1.72)	(2.04)	(2.35)	(1.98)	(2.23)	(2.13)	(2.17)
High variance dummy					16.9884***			14.6208***
					(3.01)			(3.15)
Brand age	-0.3913***	-0.2782	-0.3189***	-0.4599***	-0.4572***	-0.3517**	-0.3413***	-0.4366***
	(5.28)	(1.87)	(3.33)	(3.44)	(3.41)	(2.16)	(3.96)	(3.35)
Advertising expenditures				-18.7443***	-18.7370***			-18.0027***
				(3.81)	(3.75)			(3.52)
Controls								
Brand level								
Price	13.1597***	13.3563***	5.4482***	4.1554***	4.1104***	1.6875	3.0803***	4.2378**
	(11.19)	(11.47)	(3.54)	(2.78)	(2.83)	(0.82)	(2.54)	(2.17)
Sales [units]	-1.1123*	-0.5928	-0.9843	-1.6448**	-1.6255**	-0.7861	-1.6110***	-1.5706**
	(1.96)	0.98	(1.21)	(2.15)	(2.19)	(1.82)	(2.79)	(2.18)
Manufacturer level								
Manufacturer Age		0.2717***						
		(4.31)						
Capex			-3.2085*	-2.3411	-2.3413	-6.2381*	-2.3024	-3.0853*
			(1.94)	(1.11)	(1.11)	(2.05)	(1.26)	(2.08)
Net income			1.9829*	0.6045	0.9048	2.1168	2.3036*	0.9608*
			(2.02)	(0.54)	(1.93)	(1.49)	(1.98)	(2.03)
Revenues			1.3364	24.1666***	20.3508***	-12.4520***	0.6994	18.9055***
			(0.44)	(3.76)	(3.61)	(2.67)	(0.21)	(3.40)
R&D expenditures				-13.8468***	-11.3116***			-10.5861***
				(3.21)	(3.10)			(2.86)

TABLE 6 (continued)

	1	2	3	4	5	6	7	8
Industry Level								
Magnuson-Moss Act	8.0747***	9.2676***	-5.0452					
	(2.66)	(3.07)	(1.87)					
Number of Brands			2.0478***	5.9863***	7.5674***	1.1984***	1.5568***	7.5503***
			(6.10)	(4.90)	(5.89)	(4.44)	(3.59)	(5.03)
Quality Variance			7.2908***	11.2354*	19.4922***	-7.5445**	5.9024*	16.0027**
			(2.97)	(1.97)	(2.89)	(2.21)	(2.01)	(2.14)
Year dummies	NO	NO	NO	YES	YES	YES	YES	YES
# of observations	843	843	432	309	309	213	219	309
Adjusted R-Square	0.2433	0.2589	0.3444	0.6519	0.6572	0.4094	0.8045	0.6801

Standard errors are clustered by manufacturer; t-statistics in parentheses

*: p<0.10, ** p<0.05, ***p<0.01

Natural logarithm is taken on all financial covariates, price and volume (Values were top coded as 1 if negative)

All independent variables are lagged

APPENDIX A

To analytically determine periods of convergence and divergence, we analyze the series warranty variances offered over *T (T=1961, 1962….. 2008)* consecutive years labeled as $v_1, v_2, \dots, v_T$. The goal is to choose an optimal dividing year *j* such that observations $v_1, v_2, \dots, v_j$ are categorized as a convergence period and observations $v_{j+1}, v_{j+2}, \dots, v_{j+d}$ are categorized as divergence period; where *d* represents the duration of the divergence period. The phase that follows can, in general, change to a convergence period $v_{j+d+1}, v_{j+d+2}, \dots, v_T$, or continue as a divergence period, i.e., *j+d=T.*

To identify these periods empirically we used a procedure set forth by Gort & Klepper (1982):

1) For each *J=1,2,… T,* we computed

   $$\mathrm{X}_1(j) = \sum_{i=1}^{j} \frac{\mathrm{v_i}}{\mathrm{j}}$$

   $$\mathrm{X}_2(j) = \sum_{i=j+1}^{d} \frac{\mathrm{v_i}}{\mathrm{d-j}}$$

2) The choice of the year that divides between periods was limited to those values of *j* for which

   $$|X_1(j) - \mu_1| \leq |(\mu_1 - \mu_2)/2|$$

   $$|X_2(j) - \mu_2| \leq |(\mu_1 - \mu_2)/2|$$

   where μ_1 and μ_2 are the mean variance a given type of manufacturer warranty for the convergence or divergence periods. If there were no values of *j* satisfying Equation 2, then all observations were placed in the convergence period, if $|X_1(j+d) - \mu_1| < |X_1(j+d) - \mu_2|$, into the divergence period. The rationale behind this step was that the mean of the observations (i.e., for example, the mean of a time-series of variance of all powertrain warranties offered in the market by all brands during a divergence period) associated with each of the two periods is closer to the sample mean of the observations initially put into those periods than in the alternative period.

3) If multiple values of *j* satisfied Equation 2, we selected the value of *j* from the set that maximized $|X_1(j) - X_2(j)|$. This step ensured that among the classifications that would satisfy step 2), the classification that was chosen maximized the difference between the means of the observations placed into the two periods.