Learning by Supplying

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Draft: October 2011
Please do not cite – preliminary and incomplete

Abstract

How do firms build capabilities and resources to generate and sustain competitive advantage in rapidly evolving industries? This question lies at the very heart of strategic management and has long pre-occupied scholars and practitioners alike. A common thread running through much of the research to date is a focus on learning: learning by doing, learning from exporting, learning from competitors, learning from users or learning from alliance partners. In this paper we focus our attention on a locus of learning that has garnered significant interest among practitioners in recent years, particularly with the rise of offshore outsourcing, but that has received less attention from academics: learning by *supplying*. By compiling an unusually detailed multi-year panel dataset on supply relationships in the mobile telecommunications handset industry, we are able to address the following questions: What factors contribute to a firm's ability to 'learn by supplying' and advance in terms of technological and market capabilities? Does it matter *to whom* the firm supplies? Is it more beneficial to supply to market leaders or to team up with market laggards? Must the supplier be actively involved in product design to effectively learn from its customers, or is manufacturing the key locus of learning? How does a supplier's own initial resource endowment and capabilities play into the dynamic? Our preliminary empirical analysis yields several interesting findings that have potentially important implications for theory and practice, and that suggest interesting directions for further study.

Learning by Supplying

How do firms build capabilities and resources to generate and sustain competitive advantage in rapidly evolving industries? This question lies at the very heart of strategic management and has long pre-occupied scholars and practitioners alike. While no simple prescriptions have emerged from the decades of study on the topic, scholars have nonetheless identified some key industry dynamics and firm-level processes that appear to underlie capability development in different contexts. One common thread running through many of these investigations is a focus on learning: learning by doing (Lieberman, 1984; Irwin and Klenow, 1996); learning from co-located competitors (Baum & Ingram, 1998); learning from users (Von Hippel, 1986, 1988); learning by exporting (MacGarvie, 2006; Salomon & Shaver, 2005); and learning through joint ventures and alliances (e.g., Mowery, Oxley & Silverman, 1996; 2002).

In this paper we focus our attention on a locus of learning that has garnered significant interest in the practitioner-oriented literature of late, but that has received much less attention from academics: learning by *supplying*. Interest in this dynamic is driven in part by the rise in offshore outsourcing of manufacturing and related activities, particularly to China and other emerging economies; interest is also fueled by the observation that some firms in these countries have successfully parlayed their experience as "OEMs" (Original Equipment Manufacturers) supplying to the major branded producers into positions as viable world-class players in their industry, perhaps at the expense of previous market leaders. Take for example this observation by Khanna and Palepu in their 2006 *Harvard Business Review* article subtitled "Building World-Class Companies in Developing Countries":

> Taiwan-based Inventec…is among the world's largest manufacturers of notebook computers, PCs, and servers, many of which it makes in China and sells to Hewlett-Packard and Toshiba… Inventec has mastered the challenges associated with sourcing components from around the world, assembling them into quality products at a low cost, and shipping them to multinational companies in a reliable fashion. Recently Inventec started selling computers in Taiwan and China under its own brand name. The computers have a Chinese operating system and software, so Inventec doesn't compete directly with its customers – yet. (Khanna and Palepu, 2006: 66-67)

This last possibility – that Inventec may eventually emerge as a direct competitor to its erstwhile customers – taps into a concern that has worried policy makers and commentators in the US and other developed countries for decades: i.e., that offshore outsourcing may lead to a migration of capabilities to foreign suppliers (Cohen & Zysman, 1987; Pisano & Shih, 2009; Teece & Chesbrough, 1996). However, prominent examples of firms 'breaking out' of their role of suppliers to major branded producers to become viable world-class competitors are few and far between. Indeed, many suppliers apparently feel trapped in a subordinate role, unable to support the investments in technology and marketing resources necessary for independent success.[1] Meanwhile, U.S. multinationals and other leading companies are bombarded with advice on how to *prevent* or *minimize* the migration of capabilities to their suppliers. Arrunada and Vazquez, (2006: 136), for example, prescribe the following for managing relationships with contract manufacturers: "modesty about revealing one's secrets; caution about whom one consorts with; and a judicious degree of intimacy, loyalty, and generosity towards one's partners..."

This situation raises intriguing strategic questions for the managers of firms seeking to 'break out' of their existing role as OEM suppliers: What factors contribute to a firm's ability to 'learn by supplying' and advance in terms of technological and market success? Does it matter *to whom* the firm supplies? Is it more beneficial to supply to market leaders or to team up with market laggards? Must the supplier be actively involved in product design to effectively learn from its customers, or is manufacturing the key locus of learning? How does a supplier's own initial resource endowment and capabilities play into the dynamic? To date, researchers and managers contemplating these questions have operated in a virtual empirical vacuum, as there have been, to our knowledge, no systematic large-scale studies of the phenomenon of learning by supplying. Our aim in this paper is to address this gap, providing empirical evidence of

[1] Acer is one possible example of this – for a while it looked like they were emerging as a fierce independent contender in the notebook computer industry, but have since faltered, and still get most of their earnings from OEM relationships. Careful study by economists on the impact of offshore outsourcing on wages and employment has also yielded little conclusive evidence to back up doomsday scenarios related to the 'hollowing out' of US technological capability (see Trefler, 2005, for a recent review).

learning by supplying in one industry context - the mobile telecommunications handset industry. We hope that our findings can inform future theory development and management practice in this important area.

The mobile telecommunications handset industry has many attractive features for an empirical study of learning by supplying: it is a relatively new industry which has experienced exponential growth over the last 15 years; outsourcing did not emerge as a common practice in the industry until the early 2000s, following the bursting of the 'telecom bubble;' since then, the supply base has developed rapidly, with many new and increasingly sophisticated OEM suppliers emerging, particularly in Asia. A few of these suppliers, such as Taiwan's HTC Corporation, have successfully matured into fully-fledged global players in the mobile telecom industry, but this is the exception rather than the norm. Within this context, we have collected data on all significant supply relationships for the design and manufacture of complete handsets for the major branded producers and telecom operators since the beginning of the 'outsourcing era' in the mobile telecommunications industry. By marrying this data with information on the patenting activities of customer and supplier firms, and data on the timing of all mobile handset introductions over the period 1995-2007 we are able to construct an unusually complete picture of outsourcing in this industry, assess the extent of technical and market learning achieved by supplier firms, and begin to disentangle possible sources of heterogeneity in the extent of learning.

Our preliminary empirical analysis yields several interesting findings. First, we find significant and robust evidence of 'learning by supplying' – both patenting and own-brand introduction increases after firms become actively engaged in handset supply relationships, and this effect amplifies when a supplier serves multiple customers, as well as over time, as the supplier accumulates experience in handset manufacturing and/or design. Our findings also suggest that it matters to whom you supply, although not necessarily in ways that one might expect: relative to branded producers, operators do not appear to be a robust source of technological learning-by-supplying. Firms supplying to operators generate fewer telecom-related patents, even though operators are more likely to delegate design activities to their suppliers; conversely, supplying to the most technically sophisticated customers increases technological learning, but seemingly only for those suppliers who have prior patenting experience (and thus adequate absorptive capacity). At the same time, supplying to market and technological leaders appears to inhibit *market* learning and own brand introduction amongst these capable suppliers. This is consistent with observations in the industry that market leaders tend to write more restrictive outsourcing agreements, particularly when they perceive that transfer of capabilities to their suppliers could pose a competitive threat. We believe that these findings have interesting potential implications for theory and practice, and raise several issues deserving of further study, which we discuss in the concluding section of our paper.

The rest of the paper proceeds as follows. In Section 1 we situate our study in the prior literature and discuss possible implications of prior research findings for the proposed empirical analysis of learning by supplying. We describe the empirical context of our study in Section 2, and the data and empirical approach are detailed in Sections 3 and 4. Section 5 presents the empirical observations and provides some preliminary interpretations, and Section 6 concludes.

1. Theoretical Background and Related Studies

Our objectives in this study are primarily empirical: to document and analyze the extent to which contract manufacturing firms producing handsets for major branded firms (producers and/or operators) in the mobile telecommunications handset industry have been able to learn and develop, to move out of their 'subordinate' role in the industry value chain and become active innovators, producing patentable technologies and introducing their own branded products into the marketplace. There has, until now, been a dearth of systematic empirical evidence that bears directly on this issue. There are nonetheless several streams of relevant prior research that shape our expectations about the determinants of learning by supplying and that can guide our empirical analysis. In this section we briefly summarize this prior literature and outline several empirical implications, which we then 'take to the data' in subsequent sections of the paper.

The importance of learning from direct production experience, or learning-by-doing, has been well documented in the economics literature, dating back to early theoretical work by Arrow (1962). The first empirical studies focused on the shape of individual firms' 'learning curves' in different manufacturing industries, and generated robust evidence that costs tend to decline (albeit at a declining rate) as a firm's cumulative production volumes increase (e.g., Alghion,1963; Rapping, 1965). Later extensions also found evidence of industry-level learning curves (e.g., Lieberman, 1984; Irwin and Klenow, 1996), suggesting the existence of learning-by-doing spillovers, although these studies reinforce the notion that it is a firm's own direct experience which has the greatest effect on learning.[2] These conclusions have found further support in research in the strategy and organizations field, which also relates the steepness of the learning curve to choices related to organizational design, product positioning and geographic location (e.g., Baum and Ingram, 1998; Darr, Argote and Epple, 1995; Ingram and Baum, 1997).

While the conventional learning-by-doing literature has focused primarily on the impact of cumulative experience on production costs, recent extensions of the basic concept have examined the impact of learning-by-doing on other measures of firm performance (e.g., survival, innovation) and have also begun to explore other types of experience-based learning. For example, a recent literature rooted in models of trade and endogenous growth (Romer, 1990; Grossman and Helpman, 1993) examines the link between international trade and innovation.[3] Starting from the premise that trade exposes firms to sources of knowledge that would otherwise be unavailable to them, scholars have looked for – and found – convincing evidence of "learning by exporting," (e.g., Salomon and Shaver, 2005) as well as "learning by

[2] Irwin and Klenow (1996), for example, show that firms learn three times more from an additional unit of their own cumulative production than from an additional unit of another firm's cumulative production.

[3] In addition to the firm-level studies discussed below, there is a very large body of literature examining the effect of international trade and foreign direct investment (FDI) on technological and economic convergence or 'catch-up' at the country level. This research, primarily undertaken by international economists and international business researchers, suggests that significant technological catch-up has indeed taken place over the latter half of the twentieth century. Understanding of the mechanisms underlying this general trend nonetheless remains quite incomplete – see Athreye and Cantwell (2007) for a useful discussion.

importing" (MacGarvie, 2006).[4] In an empirical model that allows for positive feedback between innovation and exporting, for example, Soloman and Shaver (2005) find that exporting leads to significant increases in both technical innovation (as indicated by an increase in patent applications) and product innovation (i.e., new product introductions) at the firm level.

Explanations of learning by exporting resonate particularly well with the concept of 'learning by supplying,' introduced here. In contrast to simple learning-by-doing arguments, which link performance to the focal firm's accumulated volume of production, learning by exporting posits that the identity or characteristics of the firm's customers (or intended customers) may also matter for the extent of learning: "For instance, exporters might benefit from the technological expertise of their buyers (Clerides *et al,* 1998). Moreover, exporters might receive valuable information about consumer product preferences and competing products….As the information collected from these sources filters back to the parent firm, it should incorporate the knowledge into its production function" (Salomon and Shaver, 2005: 434)

Thus, Salomon and Shaver (2005) relate the extent of learning to one particular buyer characteristic - location - suggesting that buyers encountered in export markets are more advanced and/or have different requirements than domestic buyers. Similarly, in the context of the current study, we conjecture that the extent of learning (i.e. accumulation of technical and marketing expertise) by firms supplying handsets to branded manufacturers or operators in the mobile telecommunications industry will depend not only on the supplying firms' cumulative handset production, but also on characteristics of the buyers for whom the handsets are produced. Relevant characteristics in this case may include the buyer's level of technical / marketing expertise *and* its willingness to share that expertise with the supplier.

[4] As discussed in these papers and elsewhere, evidence on the effect of trade on firm-level *productivity* is more equivocal: although there are significant differences in the average productivity of exporting and non-exporting firms, this is almost entirely attributable to selection effects rather than learning (see, e.g., Clerides *et al*, 1998). We discuss the empirical challenges associated with identification of causal relationships in this area of research on page XX, below.

Prior research on learning in inter-organizational alliances reinforces the notion that firms can gain access to valuable technical and market knowledge through vertical (as well as horizontal) linkages, and also generates more nuanced findings that may be particularly relevant in the context of learning by supplying. One stream of research, for example, has developed the idea that learning from alliance or exchange partners is conditioned on the focal firm's initial 'stock' of knowledge, both in absolute terms and in reference to the knowledge stock of the partner firm: firms with a higher initial stock of knowledge have greater 'absorptive capacity' (Cohen and Levinthal, 1990) and thus are able to acquire new knowledge from customers or alliance partners more readily; and, to the extent that absorptive capacity is "partner-specific" (Mowery *et al*, 2002), learning will also be enhanced when there is substantial overlap in the technical (or knowledge) domains of the firms involved in the exchange. Empirical analysis of changes in the patents granted to firms involved in technology alliances and licensing agreements has generated evidence consistent with these claims (Mowery et al, 1996, 2002; Lane & Lubatkin, 1998; Oxley & Wada, 2007).

As suggested above, the extent of learning by supplying may also be affected by the organizational and management decisions of the firm seeking to outsource production. If the outsourcing firm is concerned about the competitive consequences of a transfer of capabilities to the supplier firm, they may act to narrow the scope of activities carried out by the supplier and, in particular, may retain relatively tight control over the most technically sophisticated elements of production and/or design. In this case, the extent of learning by supplying will be reduced, *all else equal*. Prior research on the scope of technology alliances again provides some evidence that supports this line of reasoning. Oxley and Sampson (2004), for example, show that when alliances bring together firms that are direct product market competitors, the scope of alliance activities tends to be reduced such that the alliance is significantly less likely to encompass manufacturing and/or marketing activities along with R&D. This tendency is less common when alliance partners are industry laggards, suggesting that, "when laggards team up in an R&D alliance they are more willing to expose competitively significant know-how to their partners, perhaps in the hope of leapfrogging industry leaders" (Oxley & Sampson, 2004: 737-

738). Although the consequences of this observed variation in alliance scope for partner learning have yet to be fully explored, the prior research does suggest that learning by supplying is likely to differ depending on the scope of activities transferred to the supplier. In the context of our study, one might expect that mobile handset supply relationships involving design activities in addition to manufacturing (i.e. ODM versus OEM relationships) will offer more opportunities for supplier learning. Similarly, learning by supplying may vary depending on whether the buyer is a technological and/or market leader in the mobile handset industry, since this may impact the buyer's willingness to share information and collaborate intensively with suppliers.

The final stream of research that informs our empirical analysis is the emerging research on the link between outsourcing and firm capabilities. There is as yet very little large-scale empirical evidence to support (or refute) the importance of 'learning by supplying' for technological or product innovation. However, case studies on the rise of multinationals from emerging economies consistently point to the role of OEM relationships in the accumulation of capabilities (e.g., Khanna and Palepu, 2006; Duysters, Jacob, Lemmens and Jintian, 2009; Pisano and Shih, 2009). Some of these case studies also suggest that the accumulation of *technical* capabilities by supplying firms tends to occur more readily – and faster – than the accumulation of the marketing capabilities and resources necessary to sustain an independent brand. In their discussion of the rise of Haier in the domestic appliance industry, for example, Duysters *et al* (2009) note that Haier sold its products into the US under OEM arrangements with major branded producers for many years, and built up significant technical capabilities, prior to the eventual introduction of its own brand.

In sum, although there has been little systematic study of the magnitude and significance of learning by supplying in industries where substantial offshore outsourcing is occurring, prior research in related areas suggests that such learning may indeed be a significant phenomenon, and may result in increased technical and product innovation, and/or introduction of own-brand products into the marketplace. The prior literature also points us to several factors that may influence the extent of learning and therefore will be important to explore in our empirical analysis. These factors include characteristics of the supplying firm (e.g., technical capabilities), characteristics of the buying firm(s) (e.g., technical and market leadership, overlap in technical capabilities with those of supplier), and characteristics of the relationship or contract linking the two (e.g., OEM versus ODM agreements.) We incorporate each of these and other variables into our empirical analysis, below, but first we provide some additional background information on the empirical context of our study.

2. Empirical context

The empirical setting for our study is the mobile telecommunications handset industry. This setting is particularly well-suited to our purpose – the mobile telecommunications industry is a relatively new industry and we are able to observe the evolution of outsourcing over its entire history, allowing us to more-effectively disentangle the impact of initial conditions and endowments from learning by supplying *per se*. We focus our analysis on the outsourcing of complete handset production, where there is significant heterogeneity on both the producer and supplier sides in terms of both outsourcing activity and the extent and sophistication of technology development and own-brand distribution.

The first commercial mobile telecom handsets emerged circa 1985, but demand did not take off until the early 1990s (see Figure 1); since then, production has increased exponentially. From the beginning of the industry, the market has been dominated by a handful of powerful branded manufacturers –Nokia, Motorola, Sony and Ericsson[5] in the early days, later joined by Samsung and LG. Industry concentration remains high, and indeed has increased slightly during the last decade – today the five leading firms account for over 80% of global handset sales (see Figure 2). Demand growth was particularly strong during the 'telecom boom' of the late 1990s, when demand outstripped available supply. However, in contrast to other industries in the electronics sector, outsourcing of manufacturing among the leading branded producers was

[5] Sony and Ericsson merged their handset businesses in 2001, forming Sony-Ericsson.

quite rare throughout this period, as branded producers invested heavily in their own manufacturing plants in response to the supply shortfall.[6]

It was only in the post-boom crash of 2000-2001, with significant excess global production capacity emerging in the industry, that major branded manufacturers turned to outsourcing as a way to rationalize operations: many firms sold manufacturing plants to existing electronics manufacturing services firms (most notably Flextronics, Foxconn and Solectron), so opening the door to significant outsourcing of production in the industry. This door has since been flung wide open as many more suppliers came on line, with production at first centered primarily in Europe and North America, but rapidly shifting to E. and S.E. Asia.

Today, the industry continues to be dominated by a core group of branded handset manufacturers, but there is a vibrant and growing set of peripheral providers – operators and former OEM producers – some of whom are finding success with their own branded handsets, mainly in their home markets (e.g. Bird in China) but also occasionally in global markets (e.g., HTC, ZTE). OEM suppliers have also made significant leaps forward in terms of technological innovation: while as a group these firms held almost no telecommunications-related patents in the early 1990s, many are now active innovators and regularly patent their innovations in the US and elsewhere.

Our goal in the empirical analysis is to systematically document these advances in technological and market success of different OEM suppliers, and to explore the preconditions and strategic implications of 'learning by supplying' in this industry.

3. Data

Data for our empirical study comes from a variety of sources. Our goal for this project was to assemble a comprehensive dataset covering handset design and manufacturing relationships for all of the major branded handset producers and telecom operators active in

[6] Operators such as Italy's Telital and S. Korea's SK Telecom got into the game during this period. In addition to distributing handsets from branded producers, they also began procuring handsets from OEM suppliers and selling them under their own brand name to satisfy the exploding demand from new subscribers.

the mobile telecom handset industry from the beginning of the 'outsourcing era' to the present day. Extensive search revealed that (as we suspected), no single source existed that could accomplish this goal. We were, however, able to obtain handset supply data for the top eleven mobile handset producers[7] for the period 2000-2007 from an industry research company, THT Business Research.[8] Together these eleven manufacturers account for over 80% of total mobile handsets sold globally throughout this period and the THT data encompasses all major outsourcing relationships for the design and manufacture of complete handsets for these eleven producers. To extend the THT data to other branded producers and operators and additional years, and to collect detailed data on product features and introduction dates, we drew on a variety of web-based resources, crawling and compiling relevant information from current and archived pages of electronic product comparison websites as well as industry association and government sites. Appendix 1 provides information on the websites accessed for this purpose, and the scope of data coverage for each site.

Identification of valid outsourcing 'dyads' is complicated by the frequent occurrence of mergers and acquisitions in the mobile telecommunications and electronic manufacturing service industries during the period of study, and the complex and shifting ownership pattern that resulted from this process. To ensure that outsourcing relationships identified in our sample are in fact arrangements between independent firms, we documented the ownership history for each firm in the sample using Mergent Online and archived editions of the IT news website, Digitimes (http://www.digitimes.com); outsourcing relationships where the customer and supplier were joined by common ownership in the relevant years were omitted from the sample.

[7] These companies, listed in order of 2001 market share, are: Nokia, Motorola, Sony-Ericsson (following from the merger of the mobile handset businesses of Sony and Ericsson in 2000), Samsung, Alcatel, NEC, Panasonic, LG, Mitsubishi, Toshiba, and Hitachi. Rank ordering of market shares remained relatively stable over the 2000-2007 period, the most notable change being the rise of LG which by 2007 was almost tied with Sony-Ericsson as the 4th leading producer, after Nokia, Motorola, and Samsung.

[8] See http://www.thtresearch.com/. THT compiles this data from a wide variety of sources, including press releases and news items, company contacts (branded manufacturers and suppliers), and shipping organizations.

In order to construct our indicators of supplier learning, as well as the firm and relationship characteristics that we anticipated would condition the extent of 'learning by supplying,' we married our outsourcing data with patent data from Derwent, and financial data from Compustat's Worldscope Global and CapitalIQ. The Directory of Corporate Affiliations (DCA) was used to facilitate this process. In particular, in order to compile complete telecom-related patent portfolios for sample firms (suppliers and customers), we matched sample firms with all of their relevant subsidiaries (including sister subsidiaries) listed in DCA, and matched these with patent assignees in the Derwent database, to ensure that we captured all relevant patent applications for each firm.

After accounting for missing data, our sample comprises a total of 461 annual observations on 55 unique supplier firms engaged in the design and manufacture of complete handsets sold by branded producers and operators over the period 1995-2007. While we cannot claim that our data are exhaustive and capture *every* significant handset supply contract, we are confident that we have assembled the most comprehensive database of outsourcing relationships to date in this industry, and that there are few major omissions. This view is bolstered by our conversations with industry experts, who were unable to identify any significant handset supply relationships that we had missed. Details of the empirical variables constructed using these data are provided below, following an introduction to our overall approach to the empirical analysis.

4. Empirical Approach and Methods

The focus of our empirical analysis is on learning by supplier firms in outsourcing relationships in the mobile telecom handset industry. We are primarily interested in two types of learning in this context: technological learning, as evidenced by independent innovation by a supplier (proxied by telecommunications-related US patenting); and market learning, as evidenced by a supplier's independent introduction of one or more own-brand mobile handsets into the market place. Consistent with this focus, the unit of observation in our empirical analysis is $supplier_i$ - $year_t$ dyad, and we aggregate supply transactions identified in our outsourcing data to the firm level for each supplier in each year of the sample period. Since we are interested in estimating within-firm effects of supply activity on innovation and own-brand introduction, we employ fixed-effects panel regressions in most of our analysis.[9]

A major concern with any empirical analysis of the co-evolution of resources and organization is of course endogenous matching and unobserved heterogeneity (Hamilton and Nickerson, 2003). The primary concern in the context of our study is that branded producers will actively select the "most capable" candidate firms as suppliers and that these firms are also most likely to innovate (i.e., to patent or to introduce an own-brand mobile handset); in this case we may spuriously associate a disproportionate increase in innovation with learning by supplying when it is in fact simply a natural consequence of the firm's greater (partially unobservable) general managerial and technical capabilities. In the absence of any significant policy shocks that changed the likelihood that a given firm would be chosen as a supplier by particular suppliers we are unable to tackle this endogeneity issue head-on. We nonetheless can and do address the issue indirectly in a number of ways: First, we include supplier and year fixed effects in our regressions so that we are examining *within-firm* variation in our measures of learning, not cross-sectional differences. In this way we rule out the possibility that observed differences in the extent of learning are simply a reflection of different starting points (firm intercepts). This is only a partial 'fix,' however, since it does not exclude the possibility that the learning curves of more capable firms have steeper slopes. Second, we compare technical capabilities in yearly cross sections of active suppliers and 'inactive suppliers' (i.e. firms that are supply handsets at some point in our sample, but not in the year in question) to assess whether active suppliers are, on average, more capable than inactive suppliers at a given point in time. Third, we examine major producers' outsourcing decisions at the beginning of the 'outsourcing era' to more directly assess the extent to which technical resources or other observable producer and supplier characteristics have a significant influence on producer-supplier

[9] For our analysis of suppliers' own brand introductions we also estimate random effects logit models to account for the dichotomous nature of the dependent variable. In future work we also plan to implement Cox proportional hazard models to examine the relationship between OEM/ODM activity and the timing of own-brand introductions. We discuss this and other extensions in the concluding section of the paper.

matching. Results of this analysis are reported immediately following presentation of our main empirical results.

Dependent Variables.

We construct two firm-level dependent variables to measure the extent of learning by supplying. Our proxy for suppliers' technological learning is based on a count of US patent applications in telecom-related technology classes. More specifically, the variable $PATENTS_{it}$ is a log transformation of an annual count of the number of 'patent families' in (ultimately successful) US patent applications filed by $supplier_{i,}$ averaged over a three year window beginning in year t.[10] A three-year window is used to smooth the patent application series, which is typically quite lumpy, especially for firms with relatively small numbers of applications overall, as is the case for many of the suppliers in our sample; the log transformation is implemented to correct for the high degree of skewness in patent count data, reducing the impact of extreme values.

Our firm-level proxy for *market* learning is based on the introduction of one or more own-brand mobile handsets into the market by supplier *i*. This dummy variable, OWN $BRAND_{it}$ takes a value of 0 in every year up to the year in which supplier *i* introduces its own brand handset; OWN $BRAND_i$=1 for the year of introduction and every year thereafter.[11]

Independent Variables

For each supplier in the sample we construct a series of firm-level variables that we anticipate may influence the firm's technological and market learning. First, we construct two

[10] We use patent families rather than individual patents for our analysis in order to account for potential differences in scope of claims across technology classes (Alcacer & Gittelman, 2006).

[11] Information on the year of first introduction of own-brand products is drawn from the WCHT and PDAdb.net databases (see Appendix 1), with extensive checking against information on the supplying firm's own website as well as other archived webpages advertising and comparing mobile telecom handsets. In future work, we plan to also include variables indicating the level of sophistication of the own-brand models introduced and/or the extent of geographic markets covered.

variables that capture the incidence and longevity of a focal firm's supply activity in the mobile telecom handset industry. ACTIVE $SUPPLIER_{it,}$ is an indicator variable that takes a value of 1 in each year that supplier *i* has one or more active supply relationships with branded producers or telecom operators; 0 otherwise.[12] SUPPLY $TIME_{it,}$ measures the number of years since the focal firm first began supplying mobile telecom handsets, i.e. the number of years since its first active supply relationship observed in our data.

Next, we construct several variables characterizing active supply relationships that supplier *i* has in year *t*. First we differentiate between supply relationships involving handset manufacturing only (OEM relationships) and those that are for handset design *and* manufacturing (ODM relationships). We create two variables for each supplier-year observation: OEM_{it}=1 if supplier *i* is engaged only in handset manufacture for its customers in year t; if supplier *i* has one or more ODM agreements in year t (i.e. it is engaged in manufacturing *and* design), we set ODM_{it} = 1.[13] Next we examine the *identity* of supplier *i*'s customers in year *t:* if any of these customers is one of the top 5 firms in terms of market share in the mobile telecom handset market in that year, we set SUPPLYING MARKET $LEADER_{it}$ = 1. Similarly, if any of supplier *i*'s customers in year *t* is a telecom operator, then SUPPLYING $OPERATOR_{it}$ = 1. We also include a count variable, # CUSTOMERS equal to the total number of customers served by firm *i* in year *t.*

Learning may also be influenced by the technical sophistication of the supplier, through its impact on absorptive capacity, as well as the technical sophistication of the buyer which, as discussed earlier, may affect both their ability and their willingness to share relevant knowledge with suppliers. To capture suppliers' initial capabilities (absorptive capacity) we construct an

[12] The data from THT research includes annual shipments to a major branded producer from each supplier from 2000-2007. Data from other sources provides the identity of suppliers only in the year of introduction of a given handset model. According to industry experts, the typical life of a handset model is 2-3 years; we therefore make the assumption that supply relationships reported in these sources persist over a minimum of 2 years. Because the same supplier is frequently used for multiple model introductions, in many cases we observe supply relationships that persist over several years.

[13] None of the suppliers in our sample are engaged purely in design activities in any year.

indicator variable, HI TECH SUPPLIER and set this equal to 1 for all suppliers with at least one telecom-related patent in their first active supply year. We also interact this variable with ACTIVE $SUPPLIER_{it}$, and SUPPLY $TIME_{it}$.[14] Another indicator variable, HI TECH $CUSTOMERS_{it}$, is set to one if supplier *i*'s year *t* customers are in the top quartile in the sample in terms of average forward citations to patents applied for in a 3-year window ending in year *t*. In addition, to probe the possibility that there is active matching of buyers and suppliers, and that sophisticated suppliers learn more from sophisticated buyers, we interact HI-TECH $SUPPLIER_{it}$ and HI TECH $CUSTOMERS_{it}$ to create an additional variable HI-HI $MATCH_{it..}$ A second interaction, HI-LO MISMATCH indicates a high-tech supplier serving a low-tech customer; similarly, LO-HI MISMATCH indicates a low-tech supplier serving a high-tech customer; LO-LO MATCH is the omitted category.

To account for the possible effect of changes over time in firm size, revenues and R&D investments, we also include LOG $SALES_{it}$, LOG $ASSETS_{it}$, and LOG $R\&D_{it}$ in all model specifications. These are contemporaneous dollar-denominated logged values; log transformations are used to account for the significant skewness in these variables. And finally, for the own brand introduction regressions, since own brand introduction may be predicated on the attainment of an adequate level of technical capabilities, we also include $PRE\text{-}PATENTS_{it}$ the log transformation of an annual count of the number of 'patent families' in (ultimately successful) US patent applications filed by $supplier_{i,}$ averaged over a three year window ***ending*** in year t.[15] Descriptive statistics for this and other variables included in the analysis are shown in Table 1.

5. Empirical Results

Our first set of estimation results, displayed in Table 2, examines the relationship between supplying and technological learning as indicated by changes in the number of

[14] Note that the time-invariant indicator variable is not included in the regression specification since this is subsumed by the supplier fixed effects in the model.

[15] $PRE\text{-}PATENTS_{it}$ is thus equivalent to $PATENTS_{it}$ with a 3-year lag.

(successful) patent applications in telecommunications-related patent classes in the three years subsequent to the observation year. The dependent variable in these panel regressions is PATENTS[16] and all models include firm and year fixed effects as well as time-varying control variables related to firm size, revenues and R&D investments. These results (Models 1-4) indicate a robust positive relationship between the extent of supply activity and a firm's technological learning: ACTIVE SUPPLIER, SUPPLY TIME, and # CUSTOMERS are all positively related to subsequent patenting and are significant in all specifications. This indicates that patenting increases after the firm becomes actively engaged in handset supply relationships and that this effect amplifies when the supplier serves multiple customers, as well as over time, as the supplier accumulates experience in handset manufacturing and/or design.

When it comes to the type of supply relationship (Models 3-4) and the type of customer (Models 2-6) we see some unexpected results. One could expect that there would be more opportunities for suppliers to engage in learning-by-doing in ODM arrangements, leading to increased patenting in these cases. However, when we replace ACTIVE SUPPLIER with its constituent parts, ODM and OEM, (Model 3) we do not find any significant incremental effect for ODM agreements relative to OEM relationships.[17] In terms of the type of customer, it appears that supplying to a market leader does not increase learning relative to supplying to other customers. This result is in line with comments from industry experts, who suggest that leading branded producers such as Nokia and Motorola tend to keep particularly tight control over technology development of their products.

SUPPLYING OPERATORS carries a negative and significant coefficient in all of the model specifications (Models 2-6), suggesting that learning is lower for firms supplying to operators, all else equal. One of the major differences between operators and branded producers in the

[16] For convenience, firm and time subscripts are omitted from variable definitions hereafter.

[17] Note that there are no instances in our data where OEM=0 and ODM=1: all ODM suppliers have a mixture of OEM and ODM activities in any given year. Thus the coefficient on ODM is appropriately interpreted as an estimate of the incremental contribution of design activities to technological learning, over and above that gained from manufacturing.

mobile telecommunications industry is that operators tend to be marketing specialists and place little emphasis on in-house development of technical capabilities. Thus, operators may not represent an important source of technological learning for their suppliers because of a lack of relevant in-house capabilities.[18] That said, supplying to a technological leader in the industry does not appear to automatically lead to enhanced learning: when we add HI TECH CUSTOMERS to the specification (Model 4) we see no evidence of greater learning overall by suppliers whose customers are in the top quartile in terms of forward patent citations.

Models 5 and 6 further investigate the relationship between technical capabilities/endowments and supplier learning. Model 5 captures the potential impact of suppliers' absorptive capacity through the interaction of HI TECH SUPPLIER with ACTIVE SUPPLIER and SUPPLY TIME. Here we see some evidence of enhanced learning by suppliers with pre-existing capabilities (as indicated by telecom-related patenting prior to entering handset supply agreements) - HI TECH SUPPLIER x ACTIVE SUPPLIER is positive and significant, and the main effect on ACTIVE SUPPLIER becomes smaller.[19] We do not find any evidence that these suppliers learn *faster* however: HI TECH SUPPLIER x SUPPLY TIME is negative and marginally significant. Model 6 takes this analysis one step further, adding variables that capture the 'match' between customer and supplier technical capabilities. Intriguingly, it appears that most learning occurs when a 'high-tech' supplier is matched with high-tech customers – if a high-tech firm supplies to 'low-tech' customers, the extent of learning is no greater than that observed for low-tech suppliers (regardless of whether they are matched with low-tech or high-tech customers). This result should of course be treated with caution, hinting as it does at the possibility of endogenous matching of suppliers and customers (see below); it nonetheless does suggest that learning by supplying can be distinguished from simple learning-by-doing in that

[18] On the other hand, operators are much more likely to delegate handset design to their suppliers than are leading branded producers. Were it the case that suppliers experienced greater learning in ODM arrangements this could offset the negative impact on learning. However, as noted above, there is no evidence of greater technological learning in ODM arrangements compared with OEM arrangements.

[19] The result in Models 5 and 6 remain the same if ACTIVE SUPPLIER is replaced by OEM and ODM.

the identity (and capabilities) of the customer appears to 'matter' for the extent of learning in this case.

Turning to the relationship between supplying and *market* learning, Table 3 (a and b) presents the results of our analysis of the timing of suppliers' introduction of own-brand mobile handsets into the market. The models in Table 3a mirror the specifications in the previous table, and are implemented via fixed effects panel regressions. The dependent variable here is OWN BRAND, an indicator variable that takes on a value of 1 in the year of introduction of supplier *i*'s first own-brand mobile handset, and every year thereafter. In addition to firm and year fixed effects and financial controls, these models also include a backward-looking patent count (PRE-PATENTS). Table 3b presents similar specifications, here estimated using a random effects logit model. Results are generally quite consistent across these two sets of specifications.[20]

The results on own brand introduction reveal several patterns of learning that are similar to those found in the previous regressions, but also highlight some quite interesting differences. Once again, learning is significantly associated with positive values of ACTIVE SUPPLIER, SUPPLY TIME, and # CUSTOMERS. Greater technological capabilities (as captured by PRE-PATENTS) also increases the probability of own brand introduction, as one would expect. Interestingly in these models we see no consistently significant difference in the probability of a supplier's own brand introduction when they supply to market leaders *or* operators – if anything, supplying to operators tends to marginally increase the likelihood that a supplier will introduce its own brand, perhaps because operators (by necessity) involve their suppliers more deeply in design and other market-facing activities. This inference is also consistent with the positive association between ODM agreements and own brand introduction which we see in some model specifications. The lack of robustness in these effects prompts caution in interpretation, but they nonetheless hint at the idea that suppliers engaging in significant

[20] A fixed effects logit model would be most appropriate given the dichotomous nature of the dependent variable. However, as we are not able to implement the fixed effects logit model with our data we first report fixed effects GLS regressions to highlight the robustness of our results.

design activities with their customers (whether branded producers or operators) are able to capture valuable market-related knowledge that facilitates development of their own branded handset – an intuitively appealing result.

The estimated effects of the absorptive capacity-related variables in Models 11a and 11b have less immediately-intuitive interpretations. Here we see that HI TECH SUPPLIER x ACTIVE SUPPLIER is *negative* and significant while HI TECH SUPPLIER x SUPPLY TIME is insignificant (though also negative). This suggests that high-tech suppliers gain less market knowledge from their supply relationships – or at least that they are less likely to introduce their own brand. Models 12a and 12b point to a possible mechanism underlying this effect: when we add variables that capture the 'match' between customer and supplier technical capabilities we see that the combination yielding the lowest probability of own-brand introduction by the supplier is HI-HI MATCH. With the caveat again regarding possible endogenous matching, this result is consistent with the idea that high-tech customers are particularly wary of sharing market-based knowledge with their high-tech suppliers, since these suppliers are likely the ones that are, other things being equal, most capable of developing and supporting introduction of their own branded handsets.

As noted earlier, all of the regressions reported above (with the exception of those in Table 3b) are fixed effects regressions, with supplier (and year) fixed effects. This essentially rules out the possibility that our observed differences in the extent of learning are simply a reflection of different starting points (firm intercepts), but not that the learning curves of more capable firms have steeper slopes, such that their likelihood of patenting and own-brand introduction increases over time at a fast rate. This means that, if operators and major producers systematically choose more-capable firms as their suppliers we may spuriously associate these suppliers' increasing technological and marketing capabilities with learning-by-supplying. To further explore this issue, we first compared technical capabilities in yearly cross sections of active suppliers and 'inactive suppliers' (i.e. firms that are supply handsets at some point in the sample, but not in year *t*). The results of this analysis (not shown) indicate that in fact active suppliers are, on average, *no more capable* than inactive suppliers at a given point in time: in a total of 26 year-by-year OLS regressions (13 years, 2 dependent variables), ACTIVE SUPPLIER is a significant predictor of PATENTS or OWN BRAND in only 5 cases; in three of these cases the coefficient on ACTIVE SUPPLIER is negative, indicating that, in that year at least, active suppliers were on average less capable than inactive firms, all else equal.

Finally, for a more direct test of endogenous matching, we estimated supplier selection models (results not shown) for outsourcing decisions of major producers in 2000 – essentially the beginning of the outsourcing period. Not only is PRE-PATENTS not a significant predictor of selection as a supplier to one of the major branded producers at this time, we were unable to discover *any* significant predictor (including firm age, size, and HQ location). This is a puzzling result, and one that is worthy of additional study, a subject of discussion in the concluding section, below.

6. Discussion and Conclusion

The findings reported above provide robust evidence of both technological and marketing 'learning by supplying' in the mobile telecommunications handset industry. For the suppliers in our sample, patenting increases after the firm becomes actively engaged in handset supply relationships and they are also more likely to introduce their own branded telecom handset; this effect amplifies when the supplier serves multiple customers, as well as over time, as the supplier accumulates experience in handset manufacturing and/or design. Our findings also suggest that it matters to whom you supply, although not necessarily in ways that one might expect: relative to branded producers, operators do not appear to be a robust source of technological learning-by-supplying: firms supplying to operators do not increase their telecom-related patenting activity as much, even though operators are more likely to delegate design activities to their suppliers; conversely, supplying to the most technically sophisticated customers increases technological learning, but seemingly only for those suppliers who have prior patenting experience (and thus adequate absorptive capacity). At the same time, supplying to market and technological leaders appears to inhibit *market* learning and own brand introduction, amongst these capable suppliers. This is consistent with observations in the industry that market leaders tend to write more restrictive outsourcing agreements, particularly when they perceive that transfer of capabilities to their suppliers could pose a competitive threat.

Our analysis is, of course, subject to limitations, and these empirical results should be treated with caution. Although we find little evidence of the kind of selection issues that would most strongly challenge our ability to make valid inferences from the data, our exploration of these issues is still at a very preliminary stage. That we find few systematic predictors of supplier selection at the beginning of the 'take off phase' of outsourcing in this industry may not be as surprising as it first appears: the vendor landscape was relatively undeveloped at that time, and so major producers and operators may have had little basis for sophisticated analysis. Our results suggest that there is a significant amount of path-dependence in these decisions, as the supplier accumulates experience in handset manufacturing and/or design, increasing their technical and marketing capabilities as they 'learn by supplying.' Still, until we are able to better understand the focal factors in producers' and operators' supplier selection decisions we cannot rule out the possibility that unobserved pre-existing capabilities influence both the probability that a supplier is selected by a particular customer, and the rate at which it is able to 'learn by supplying.' Our data also impose limitations in this regard. Ideally we would like to have more detailed information on the content and volume of outsourcing relationships to further parse the connection between learning and supplying. We are still searching for and slowly compiling data on shipment volumes and handset technologies and features to further refine our measures but, given the sparseness and fragmentation of relevant data sources, these extensions are not immediately in prospect.

These important caveats notwithstanding, we believe that our empirical findings provide important new evidence on the extent of learning-by-supplying in the mobile handset industry. Contrary to some of the prominent commentary in the popular press, it appears that the progression from trusted supplier to threatening competitor among electronics manufacturing firms is far from inevitable, and that telecom operators and producers actively manage their relationships with their suppliers to support technological development while at the same time mitigating potential competitive threats. Our findings also resonate with the qualitative impressions that we have gleaned from conversations with experts in the mobile telecommunications handset industry regarding the interplay between major producers and their suppliers. Exploration of this interplay represents a fascinating avenue for further study, particularly as it relates to actions taken by *suppliers* to maximize the benefits of learning-by-supplying while also practicing sufficient restraint as to maintain good relationships with their customers.

In terms of immediate extensions to the research reported here, our next step is to supplement our analysis of the extent of learning by supplying with an exploration of the *direction* of learning. For technological learning this means examining the extent to which suppliers' patent portfolios converge with those of their customers over the course of a supply relationship: do the types of factors that appear to influence the overall rate at which suppliers learn from their customers also influence the extent of technological convergence? For market learning, to what extent are the handsets introduced by suppliers 'spin-offs' from the models produced for major customers? Are own-brand products introduced into the same markets as those of their customers, or do suppliers shy away from the major markets and instead target different niches, perhaps in emerging countries? There is much to do, and as yet more questions than answers, but we look forward to sharing future developments as they emerge…

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Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
PATENTS	461	1.924	1.871	0	5.832
OWN BRAND	461	0.525	0.500	0	1
ACTIVE SUPPLIER	461	0.562	0.497	0	1
OEM	461	0.562	0.497	0	1
ODM	461	0.334	0.472	0	1
SUPPLY TIME	461	3.659	3.556	0	12
# CUSTOMERS	461	2.275	4.585	0	43
SUPPLYING MARKET LEADER	461	0.152	0.359	0	1
SUPPLYING OPERATOR	461	0.317	0.466	0	1
HI TECH CUSTOMERS	461	0.334	0.472	0	1
HI TECH SUPPLIER	461	0.315	0.465	0	1
HI TECH * TIME	461	2.809	3.742	0	12
HI-HI MATCH	461	0.148	0.355	0	1
HI-LO MISMATCH	461	0.273	0.446	0	1
LO-HI MISMATCH	461	0.187	0.390	0	1
LOG ASSETS	461	7.743	2.107	-1.897	11.667
LOG SALES	461	7.856	2.199	-1.204	12.221
LOG RND	461	4.179	2.345	-3.912	8.446

Table 2: Technological Learning

Fixed Effect Regressions - Dependent Variable = PATENTS

N=461 (55)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
ACTIVE SUPPLIER	0.081 †	0.211 **			0.127 †	0.177 **
	(.047)	(.068)			(.075)	(.075)
OEM			0.226 **	0.172 *		
			(.065)	(.074)		
ODM			-0.039	-0.025		
			(.062)	(.063)		
SUPPLY TIME	0.071 ***	0.082 ***	0.081 ***	0.081 ***	0.105 ***	0.078 ***
	(.018)	(.018)	(.018)	(.018)	(.025)	(.018)
# CUSTOMERS	0.031 ***	0.033 ***	0.034 ***	0.032 ***	0.031 ***	0.032 ***
	(.006)	(.006)	(.007)	(.007)	(.006)	(.007)
SUPPLYING MARKET LEADER		0.042	0.048	-0.089	-0.035	0.001
		(.072)	(.073)	(.077)	(.072)	(.079)
SUPPLYING OPERATOR		-0.240 ***	-0.224 **	-0.215 **	-0.321 ***	-0.248 ***
		(.066)	(.070)	(.070)	(.072)	(.066)
HI TECH CUSTOMERS				0.099		
				(.063)		
HI TECH SUPPLIER					0.189 *	
					(.081)	
HI TECH * TIME					-0.032 †	
					(.018)	
HI-HI MATCH						0.230 **
						(.079)
HI-LO MISMATCH						0.003
						(.083)
LO-HI MISMATCH						-0.120
						(.089)
LOG ASSETS	0.174 **	0.167 **	0.167 **	0.164 *	0.151 **	0.171 **
	(.064)	(.063)	(.063)	(.063)	(.063)	(.062)
LOG SALES	-0.136 *	-0.119 *	-0.118 *	-0.116 *	-0.099 *	-0.120 *
	(.055)	(.055)	(.055)	(.055)	(.055)	(.054)
LOG RND	0.086 *	0.085 *	0.086 *	0.086 *	0.081 *	0.074 *
	(.038)	(.037)	(.037)	(.037)	(.037)	(.037)
F-STATISTIC	9.52 ***	9.50 ***	9.05 ***	8.78 ***	9.05 ***	9.29 ***
	(18,388)	(20,386)	(21,385)	(22, 384)	(22, 384)	(23, 383)

Firm and Year Fixed effects in all models

† = p<0.10; *=p<0.05; **=p<0.01 ***=p<0.001

Table 3: Market Learning

(a) Fixed Effect Regressions - Dependent Variable = OWN BRAND

N=461 (55)	Model 7a	Model 8a	Model 9a	Model 10a	Model 11a	Model 12a
PRE-PATENTS	0.053	0.061 †	0.059 †	0.063 †	0.079 *	0.098 **
	(.035)	(.035)	(.035)	(.035)	(.035)	(.035)
ACTIVE SUPPLIER	0.116 **	0.095 *			0.251 ***	0.173 **
	(.035)	(.046)			(.055)	(.056)
OEM			0.063	0.118 *		
			(.049)	(.056)		
ODM			0.084 †	0.070		
			(.047)	(.047)		
SUPPLY TIME	0.042 **	0.038 **	0.038 **	0.037 **	0.060 **	0.041 **
	(.014)	(.015)	(.014)	(.014)	(.019)	(.014)
# CUSTOMERS	0.011 *	0.012 *	0.011 *	0.012 *	0.010 *	0.013 *
	(.005)	(.005)	(.005)	(.005)	(.005)	(.005)
SUPPLYING MARKET LEADER		-0.058	-0.045	-0.003	-0.093 †	-0.084
		(.054)	(.055)	(.058)	(.054)	(.059)
SUPPLYING OPERATOR		0.061	0.027	0.019	0.136 *	0.080
		(.049)	(.053)	(.053)	(.054)	(.049)
HI TECH CUSTOMERS				-0.103 *		
				(.048)		
HI TECH SUPPLIER					-0.314 ***	
					(.068)	
HI TECH * TIME					-0.012	
					(.013)	
HI-HI MATCH						-0.182 **
						(.060)
HI-LO MISMATCH						0.096
						(.062)
LO-HI MISMATCH						0.049
						(.067)
LOG ASSETS	-0.065 *	-0.069	-0.067	-0.065	-0.057	-0.077
	(.048)	(.048)	(.048)	(.048)	(.048)	(.047)
LOG SALES	0.014	0.014	0.012	0.109	0.003	0.015
	(.041)	(.041)	(.041)	(.041)	(.041)	(.040)
LOG RND	0.043	0.043	0.041	0.041	0.048 †	0.052
	(.028)	(.028)	(.028)	(.028)	(.027)	(.027)
F-STATISTIC	9.26 ***	8.58 ***	8.38 ***	8.29 ***	9.24 ***	9.08 ***
	(19,387)	(21,385)	(22,384)	(23, 383)	(23, 383)	(24, 382)

Firm and Year Fixed effects in all models
† = p<0.10; *=p<0.05; **=p<0.01 ***=p<0.001

(b) Random Effects Logit - Dependent Variable = OWN BRAND

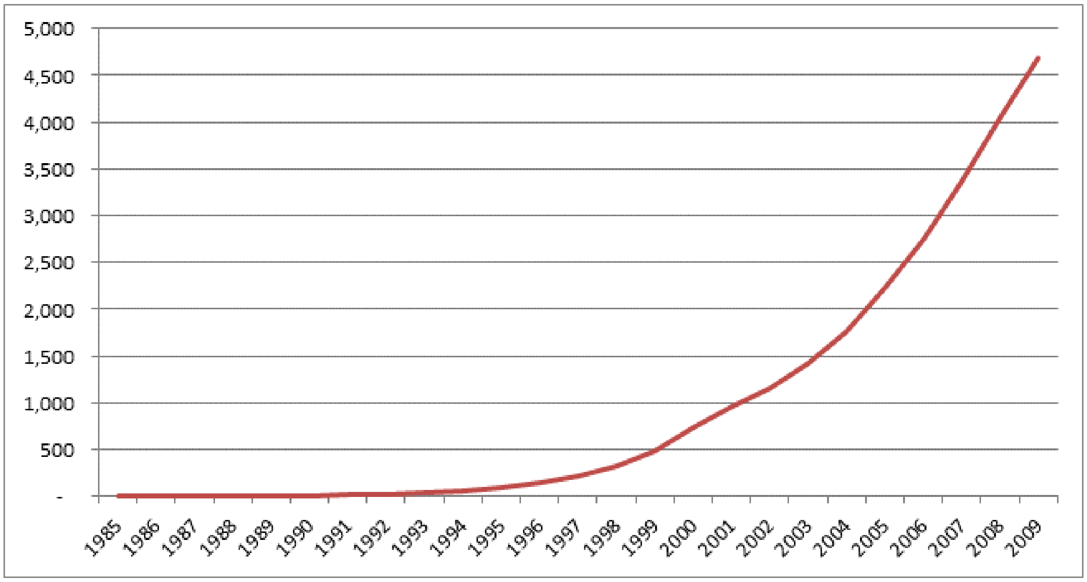
N=461 (55)	Model 7b	Model 8b	Model 9b	Model 10b	Model 11b	Model 12b
PRE-PATENTS	2.029 *	7.775 ***	1.513	2.542 **	3.127 ***	3.383 **
	(.992)	(1.52)	(.969)	(.932)	(.797)	(1.27)
ACTIVE SUPPLIER	8.367 ***	18.29 ***			12.73 ***	11.33 ***
	(1.97)	(4.40)			(2.79)	(3.16)
OEM			6.064 *	7.993 *		
			(2.80)	(3.53)		
ODM			6.109 *	6.009 *		
			(2.71)	(3.23)		
SUPPLY TIME	2.093 ***	6.126 ***	2.711 ***	1.953 **	3.385 ***	2.138 ***
	(.589)	(1.011)	(.690)	(.627)	(.696)	(.580)
# CUSTOMERS	0.011	0.325	0.015	0.031	0.128	-0.047
	(.258)	(.608)	(.212)	(.259)	(.316)	(.282)
SUPPLYING MARKET LEADER		-0.263	-0.946	-0.306	-1.815	-2.712
		(4.54)	(.252)	(.299)	(2.49)	(2.85)
SUPPLYING OPERATOR		2.804	-0.385	-0.380	3.196	2.661
		(4.28)	(2.53)	(3.05)	(2.82)	(3.08)
HI TECH CUSTOMERS				-2.12		
				(3.31)		
HI TECH SUPPLIER					-9.263 **	
					(3.16)	
HI TECH * TIME					-0.141	
					(.704)	
HI-HI MATCH						-7.791 *
						(3.73)
HI-LO MISMATCH						3.204
						(3.27)
LO-HI MISMATCH						2.297
						(4.33)
LOG ASSETS	0.201	1.735	0.400	-1.281	-0.835	-0.447
	(2.13)	(3.44)	(1.96)	(1.70)	(2.32)	(1.68)
LOG SALES	-1.289	-2.160	-0.722	-0.592	-1.448	-1.421
	(1.33)	(3.58)	(1.73)	(1.41)	(1.64)	(1.33)
LOG RND	1.655	4.178 **	1.196	1.879 †	2.419	1.292
	(.927)	1.513)	(1.06)	(1.04)	(.891)	(1.04)
Wald Chi-square	71.08 ***	665.56 ***	125.30 ***	194.45 ***	188.06 ***	122.75 ***
	(19)	(21)	(22)	(23)	(23)	(24)

Year Fixed effects in all models

† = p<0.10; *=p<0.05; **=p<0.01 ***=p<0.001

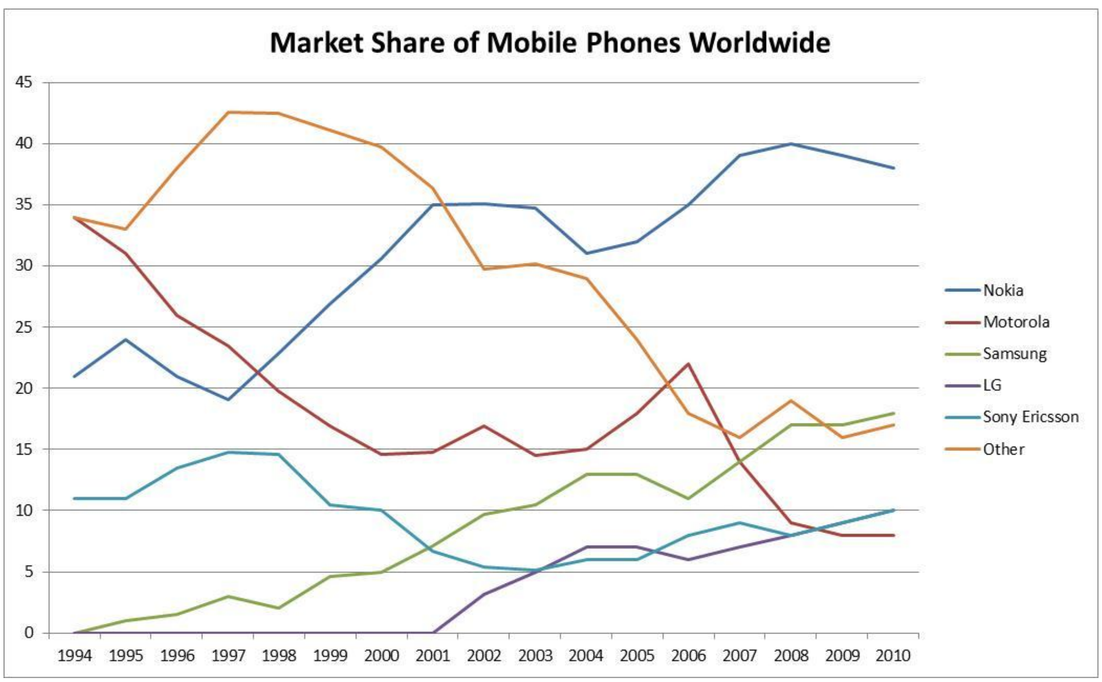
Standard errors in parentheses

Figure 1: Global output in the mobile telecom handset industry



Source: Dataquest

Figure 2: Global market share of leading producers



Source: Dataquest

Appendix 1: Data Sources for Supply Relationships

Data Source	Data Description and Scope
THT Business Research http://www.thtresearch.com/	Annual data on all significant handset outsourcing (OEM/ODM) relationships for 11 major branded producers, including aggregate shipment data; some data on phone type (e.g., operating system, low-, middle-, high-end phone). Years covered: 2000-2007. Proprietary.
World Cellular Information Service (WCIS) http://www.informatandm.com/about/wcis/	Comprehensive tracking of global handset introductions. Data includes model name/number, date of introduction, OEM manufacturer, and detailed product features. Years covered, 1990-2008. Proprietary.
World Cellular Handset Tracker (WCHT) - http://www.telecomsmarketresearch.com/research/TMAAAQIV-World-Cellular-Handset-Tracker--mobile-phone-industry-data.shtml	Detailed information on handset introductions by mobile telecom operators in 17 countries. Data includes model name/number, operator, manufacturer, date of introduction and detailed product features. Years covered, 1990-2009. Proprietary.
PDAdb.net - http://pdadb.net/	Product comparison data covering PDAs, smartphones, tablets, netbooks; includes introduction year, brand, manufacturer, designer, detailed product features. Years covered (for smartphones), 1999-2010. Non-proprietary.
Phone Scoop - http://www.phonescoop.com/	Detailed information on handset introductions into the US market. Data includes model name/number, brand, date of introduction and FCC approval ID and date (see below) and detailed product features. Years covered, 1998-2011. Non-proprietary.
Federal Communications Commission Equipment Authorization System-https://fjallfoss.fcc.gov/oetcf/eas/	Provides public information on FCC approvals for handsets (and other telecommunications devices) introduced into the US. Information includes model information, date of introduction and name of applicant (product manufacturer). Years covered, 1998-2011. Non-proprietary.