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CENTRINO AND THE RESTRUCTURING OF WI-FI SUPPLY

Roberto Fontana
Shane Greenstein

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ABSTRACT

In this paper we examine Intel's launch of Centrino and interpret it as platform leader's attempt to restructure a supply chain. We provide a narrative of key actions and how they coordinated changes and offer a framework of the predictable consequences for complementary markets. We then collect data and test these predictions on outcomes in several related complementary markets. The overall findings are consistent with our framework. We show that the launch of Centrino increased the likelihood of exit from internal and external Wi-Fi cards markets, and we find that the magnitude of the effect was largest for internal cards. We also show that the launch of Centrino's stimulated product introduction in the markets for complements overall and find that the effect varied across type of routers. Finally, we show that experience with producing Wi-Fi cards shaped product introduction by router providers.

Roberto Fontana
University of Pavia
Via San Felice 5
27100, Pavia
Italy
and ICRIOS-Bocconi University
roberto.fontana@unipv.it

Shane Greenstein
Technology Operation and Management
Morgan Hall 439
Harvard Business School
Soldiers Field
Boston, MA 02163
and NBER
sgreenstein@hbs.edu

1. Introduction

Under the rubric of studying "platform leadership," an array of studies has deepened understanding of strategies that look beyond a narrow focus on only a product and its distribution. Studies of leading platforms identified and inferred principles for guiding future managerial actions. For example, studies have shown that managers at leading platforms can and do make strategic investments related to every important complementary market with which their product interfaces, and that platform leaders can and do develop principles for negotiating with complementors, investing in administrative support for them, and coordinating a range of activities with them. These studies conclude that these actions from platform leaders can and do improve their platform-based businesses (Gawer and Cusumano, 2002; Cusumano, Gawer, and Yoffie, 2019).

Should a platform leader take action to alter their supply chain so that it reorients the supply chain to serve a long-term interest for the platform leader? While prior studies of actions with complementors suggests that a well-managed platform leader could restructure a supply chain, no study had investigated such a wide-ranging strategy. Nor has any analyzed the managerial challenges platform leaders faced. This gap arises because the vast majority of empirical studies of platform leadership are situated within computing and digital gaming markets in which the platform leaders interact with applications. In these contexts, negotiations take place between an upstream platform leader and a downstream application provider, in which applications face uncertain demand. Rearranging a supply chain requires platform leaders to consider more than negotiating with application providers. A platform leader must consider the internal costs of migrating from an established platform to a potential new one, as well as the external costs of designing for complementors in a new platform, while managing the complex tradeoffs among numerous internal constituents, and across multiple parts suppliers, developers, assemblers, and distributors.

In this study we measure the consequences of the actions by a platform leader to rearrange its supply chain. These actions, taken during Intel's large, risky, and costly campaign to re-architect the supply chain for laptops and introduce a non-proprietary standard, IEEE 802.11, became identified with Intel's branding "Centrino." This is an important program to study, because Intel restructured the supply chain for laptops, and its actions contributed to growing laptops into a mass market. It is also interesting because of its complexity and drama. Intel took many actions – i.e., gave away new designs, enabled new complementary designs, reduced the cost of complements, induced entry of complements, and raised the quality of complements. This is a rich setting for empirical scholarship to infer costs and consequences.

Using a variety of sources, we describe management's actions, and the costs it chose to incur to alter internal priorities. While it is well known that laptop sales growth accelerated after Centrino's introduction (Burgelmann, 2007, Exhibit 8), the breadth of the scope of changes in complementor markets, and complexity of managing those changes, is generally overlooked, and has not been measured. While reviewing events, we identify a set of crucial actions, and we link these to measurement of the consequence. We focus particularly on changes in the mother board, external and internal WI-FI cards, and WI-FI router markets, and how Intel's actions altered behavior in these markets.

Our data show that the launch of Centrino increases the hazard of exit from both Wi-Fi cards markets, and, further, that the magnitude of the effect is higher in the case of internal cards. We also show that the launch of Centrino's stimulated product introduction in the markets for complements overall, particularly routers. The magnitude of the effect and its statistical significance vary across type of routers. Surprisingly, this difference in complementor performance correlates with a firms' prior experience in Wi-Fi cards, but not evenly in both low and high-end routers. Prior experience in Wi-Fi card is beneficial for product introduction in Small office Home office (SoHo) routers (low-end). It is not beneficial, or it is (perhaps) harmful for the introduction of Enterprise and Broadband routers (high-end).

All these findings lead to the conclusion that Intel's management coordinated a set of changes to the supply chain that made Intel's laptops more appealing, and most, but not all of it unfolded as planned. While it is not possible for any observer to view what might have happened had Intel's management not taken any action, our findings are consistent with the view that Intel acted before growth occurred and accelerated a potential change in the market. More to the point, its actions accelerated it in ways that aided Intel's own interests. As such, we offer novel evidence of a platform strategy that coordinated across a wide range of complementors in a supply chain, enabled large scale growth, and under conditions of considerable demand uncertainty. In addition, our study offers observations about the challenges to participating firms, either as a platform leader or as business partners. The study highlights the costs, risks, and complexity of changing the conditions for many complementors to a platform leader, and managerial dilemma of balancing between commitments to "stay the course" and adjusting to new information. Complementors must react to the "do-or-die" changes in their production costs and in the demand for new features.

1.1. Contribution to related literature

While many studies have studied aspects of platform leadership, no existing study examines a leader's restructuring of supply chains, as this study does. This section identifies the gap and foreshadows how this study fills it.

The closest analysis to this study is Gawer and Henderson (2007). They focus on Intel in an era just before our study, when desktops were the dominant user of Intel's microchips. They analyze which complementary markets Intel chose to enter and which to avoid, trading off strategic interests in complementary market with binding backward compatibility constraints. We overlap in our focus on a range of complementary relationships, but we examine a later and a wider array of complementors in the supply chain for laptops. We examine Intel's entry into motherboard design and some of these microchips, and, additionally, the consequences of Intel's actions on complementary markets where it does not have a presence, such as antennae, cards, and routers. We also provide extensive statistical support for the analysis, which the prior study could not do.

We also related to studies of platform leadership during the "Wintel era," which have focused on the rollout of Windows 95, the use and support of APIs (Cusumano and Selby, 1998), the management of complementors at Intel (Gawer and Cusumano, 2002; Gawer and Henderson, 2007), the management of platform competition (Cusumano and Yoffie, 1998), the management of conflicts over the scope of the old and new platforms (Bresnahan, Greenstein and Henderson, 2011), and the contrast between platform leadership and the use of open principles (Greenstein, 2015: chapter 7). We build on this rich literature of negotiation with complementors and use many of its core insights to analyze restructuring the supply chain after the millennium.

We draw our review of events around Centrino from three sources – i.e., one case study (Burgelmann, 2007), one book chapter (Greenstein, 2015: Chapter 14), and a retrospective celebration of Wi-Fi by its inventors (Lemstra, Hayes and Groewegen, 2011). In contrast, none have attached their analysis to measurable change in complementor markets.

The literature on "dominant design" does discuss structuring and restructuring supply chains, but this study does not build on that tradition. On the surface the Centrino program may seem to resemble platform leadership *before* the emergence of a "dominant design" that enables a "taking off" to a mass market. We regard this resemblance as superficial and not substantive, and to avoid confusion we draw out the differences now. We would not label laptops as a nascent or new market in 2001, nor would have contemporaries. The laptop market already did exist, and it had used a stable set of component designs for many years, just at a small scale. That stability and predictability makes this setting an awkward fit into standard theories of the emergence of a dominant design. Instead, we view the Centrino program as a re-architecting of the existing supply chain – that is, the introduction of a new set of arrangements with many complementor markets, as well as with OEMs. We label these as "coordinated actions" carried out within the boundary of the actual or potential complementary markets influenced by Intel's standards.

Another thread in the literature focuses on incentives at platform leaders to support and compete with complementors (Zhu and Liu, 2018). Technical standards are not central to their analysis, however, and they do not consider a coordinated set of actions across multiple complementors, as we do. Zhu (2019) provides a broad review and analysis of platform leader's entry into complementary spaces. Among the studies reviewed there, we most resemble Foerderer, Kude, Mithas and Heinzl (2018) and Li and Agrawal (2016), who analyze the consequences for photo applications from, respectively, Google and Facebook's actions. Google's actions shape traffic and clicks for photos, affecting demand for services by larger and more diversified providers, while Facebook alters its governance after its merger with Instagram, creating heterogeneous effects on photo applications, favoring large over small. In contrast, we do not find large firms necessarily benefit more than small from Intel's actions. And, more important, the Centrino episode necessarily leads us to examine and measure a broader range of actions and markets across the supply chain.

Like recent research in this vein we focus on a "trigger event(s)" (Agarwal, Moeen and Shah, 2017), which, in this case, are (a) Intel's actions to reshape laptops after both (b) Apple's introduction of the Apple Airport, and (c) Dell's development of wireless local access for PCs. Arguably, all three actions – (a), (b) and (c) – add up to one big trigger event, though we focus most of our attention on (a), which the platform leader undertook. Though Intel's management could make educated guesses about the consequences of their action, there was no way to know how mass market buyers would act until firms attempted to grow a mass market supply chain.[1] To this literature we add insights from measurement.

[1] We share the focus of studies on "economic experiments" by leading firms to learn about market features that otherwise cannot easily be discovered in a laboratory (Rosenberg, 1992; 1996). In this study we do not stress controlled experiments internal to the firm (Thomke, 2003a; 2003b). Rather, we stress experiments in nascent platforms prior to the emergence of large scale production (Moeen, Agarwal and Shah, 2019; Moeen and Agarwal, 2017), such as economic experiments external to the firm to learn demand, costs at mass market scales, or operational processes (Moeen, Agarwal and Shah, 2019; Greenstein, 2012; 2007; Rosenberg, 1996; Stern, 2006).

Our approach resembles many studies that examine the tradeoff between backward compatibility and new potential markets, as it plays out in application markets, such as gaming (Kretschmer and Claussen, 2016). In gaming, variance across genres and/or in the timing of customer adoption identifies consequences from the action of platform leaders, such as demand expansion from a leader's entry into one application area (Cennamo, Gu and Zhu, 2018; Rietveld and Eggers, 2018). In contrast, we examine a management team at a leading firm using coordinated economic experiments in several complementary markets to resolve uncertainty about a supply chain for a system, which had otherwise not previously experienced mass market demand.[2]

We also relate to extant research, which has focused on the role or prior experience as source of heterogeneity among entrants in an industry (Helfat and Lieberman, 2002; Klepper and Simons, 2000). It has also focused on the role of complementary assets (i.e. manufacturing, sales and distribution) both at the firm level (Teece, 1986; 2006) and at the industry level (Kapoor and Furr, 2015). Like this research, we consider how the redeployment of complementary resources and capabilities was driven by the possession of prior experience.

2. Background the early Wi-Fi market

We provide a brief review of the events that led to the efforts by Intel, which we give the label "the Centrino program." The discussion identifies the key elements of this program.[3] A visual timeline of the events before the launch of Centrino is presented in Figure 1a and a

[2] This study also considers how the development of Centrino introduced possible bottlenecks within the system (Rosenberg, 1963) as well as opened-up new opportunities (Adner, 2012). Bottlenecks could create frictions among the components and constrain the diffusion of the new technology. New opportunities could advance other elements of the systems (components and/or complements) which could sustain the competitiveness of the existing technology or even improve it (Henderson, 1985; Adner and Kapoor, 2016). In both cases transition from the old to the new technology can be delayed. In contrast to these studies, we highlight how Intel coordinated actions that aided the transition from the 'old' platform to the 'new' one, and how it occurred rather quickly.

[3] This account draws from, and synthesizes Burgelmann (2007), Lemstra et al. (2011), chapter 4, and Greenstein (2015), chapter 14.

simplified visual representation of the supply chain before Centrino is provided in Figure 1b. The detail behind Figure 1b requires lengthy explanation, which the Appendix provides.

[Insert Figures 1a and 1b about here]

The first trigger event: Apple pioneers market (these are depicted in the timeline under events 1-5).

Apple first pioneered the Wi-Fi router using 802.11b, the second design to come out of the IEEE 802.11 committee, which was an improvement on the first (and flawed) design released in 1997. The Apple Airport—the first mass-market Wi-Fi product—debuted in July 1999 at a MacWorld convention in New York. Famously, Jobs took out a hoop during the presentation to convince the audience that there were no wires.

The Airport did something no prior wireless product had done: it was aimed at the mass market. The expansion card for the laptop had been priced at $99, and it came in a branded product from Apple. The base station was sold separately. Apple distributed the entire system.

Apple got the components for the card and base station from Lucent. Lucent's employees knew about the 802.11 standard because some of their employees had participated in committee 802.11. Lucent's cards for Apple laptops and the Apple Airport system did not serve PCs from suppliers other than Apple. At the time that left a large part of the PC market uncovered because most PCs used a Windows operating system from Microsoft.

The second trigger event: Dell pioneers Microsoft-compatible systems (these are depicted in the timeline as events 6-10).

The IBM-compatible market became first addressed at Dell computer. Michael Dell was CEO of Dell Computer, one of the largest PC providers in the world by 1999. Dell learned about the announcement of the Apple Airport and contacted Lucent. According to the account from an employee, Cees Links, Dell was "furious" with Lucent because Dell was not first to experiment with a wireless product release.[4]

The two parties subsequently came to a deal. Making Wi-Fi compatible with Windows XP was the main challenge for the team at Lucent. Eventually Lucent would succeed. To do that Lucent and Microsoft cooperated in changing the design of Windows XP, and a new version was released in 2001. It supported IEEE 802.11b in a Windows based system. Just as with Apple, Lucent made a hardware card for an external slot in a PC.

Those first two projects established the potential for a larger market for laptop use, pioneering the technical issues affiliated with the challenges of the Apple and Windows operating systems. Both were investments in product designs embedding 802.11b, aimed at fostering sales as part of either Apple's or Dell's portfolio of products. By 2001 some insiders forecast that other laptop providers would include expansion slots in their systems and try to grow use of wireless laptops.

Around the same time as the publication of 802.11b, firms that had helped pioneering the standard—including 3Com, Aironet (now a division of Cisco), Harris Semiconductor (now Intersil), Lucent (now Agere), Nokia, and Symbol Technologies—formed the Wireless Ethernet Compatibility Alliance (WECA). WECA branded the new technology "Wi-Fi," which was a marketing ploy for the mass market. WECA's members believed that "802.11b" was a much less appealing label.[5]

WECA arranged to perform testing for conformance to the standard, such as certifying interoperability of antennae and receivers made by different firms. In brief, while the IEEE

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[4] Lemstra et al. (2011), Chapter 4, page 131. Links says Michael Dell "was furious about the fact that he had been beaten by Apple…" Lucent executives had to remind Michael Dell that he had an opportunity to be in on discussions as early as 1992. However, Dell had decided in 1993 to stop the discussions because he concluded (incorrectly, as it turned out) that there was no market for the technology.

[5] The choice of the label "Wi-Fi" resembled "Hi-Fi" or high-fidelity, a term commonly used to describe high quality and expensive musical components. The label was meant to signal high quality transmission. Yet, 802.11b actually has little to do with music or fidelity, and "Wi-Fi" is a made-up phrase.

committee designed the standard, a different body (drawn from similar participating firms) performed conformance testing.

Technical successes became publicized. Numerous businesses became early users of Wi-Fi and began directed experiments supporting what became known as *hot-spots,* which was an innovative business idea. A hot spot is a data transmission mediated, potentially by a third party, for local use in a public space or on a retail premises. A hot-spot in a public space could be free, it could be installed by a home-owner, or it could be maintained by a building association for all building residences. It could be supported by the café or by a restaurant or by a library trying to serve its local user base. Or, it could be subscription-based, with short term or long-term contracts between users and providers.

The third trigger event: Intel initiates Centrino (these are depicted in the timeline as events 8 and 11).

While demand for desktop and notebook computers had grown along with the Internet in the 1990s, Intel's own marketing department forecast an imminent slowdown in the share of desktop sales, as well as increasing engineering challenges supplying faster chips.[6] More worrisome, Intel had branded itself as a firm that always marketed better and faster microchips, though there were doubts raised about whether demand for bigger and faster would continue to grow across all segments of computing. Notebook users valued mobility, for example, which placed value on longer battery life, less energy-intensive chips, smaller storage, more compact designs, less weight, and less heat. The open question: would mass market mobile users give up improvements in bigger and faster microprocessors to get improvements on these other attributes?

In 2001 Intel's management thoroughly examined the supply chain for laptops, as depicted in Figure 1b, and decided to consider changing priorities from desktops to laptops. Labeling this a "left turn", the company considered how to support a Wi-Fi connection in all notebooks that used

[6] While the forecast about the slowdown in Moore's law continues to receive debate, the forecast about desktop and laptops did, in fact, come true, albeit this result is endogenous to Intel's contributions. In 2006 the sales of laptops exceeded sales of desktops, and that continued thereafter.

Intel microprocessors. Those in favor of the change hoped that its program would increase demand for wireless capabilities within notebooks by, among other things, reducing weight and size while offering users simplicity and technical assurances in a standardized function. The proponents of the change also anticipated that its branding would help sell notebooks using Intel chips and motherboard designs instead of using microchips from Advanced Micro Devices (AMD). Furthermore, they expected antenna and router equipment makers to welcome a standardized format for wireless notebooks, which might help raise demand for their goods.

The proponents at Intel also hoped the standardization of design on non-proprietary designs would invite many entrants, introduce scale economies into production of ancillary chips and circuits, and reduce differentiation between them. They also hoped it would reduce differentiation between OEMs, again, reducing margins. The hope was that the sum total of those changes would eventually reduce costs and margins, and lower laptop prices. The precise consequences further down the supply chain for related components, such as routers, was more difficult to forecast, but there was a hope that demand for such complementary components would rise.

Intel made desktop motherboard designs available to others at little or no cost. The firm had crept into motherboard design slowly over the prior decade as it initiated a variety of improvements to the designs of computers using its microprocessors. The wireless capabilities of a notebook had not been the focus on these earlier programs, so the announcement of the Centrino program represented a shift in strategic aims and direction for this activity.

These initiatives met with considerable internal resistance inside Intel. The choice *not only* involved redesigning the Intel microprocessor, Intel's core product, stressing lower power and lower processing speeds, but it also involved redesigning the motherboard, adding antennae and supporting chips. None of these actions could be taken quickly, and each redesign touched the business of scores of business partners. The initiative also redistributed resources from the division that supported desktop OEMs, which had a successful track record, and redirected resources to the laptop division, which was still small in 2001. Contemporaries regarded the program as risky because it undermined the ability of the desktop division to be at full strength.

Additional controversy arose from the scope of the Centrino program. Intel's management considered exploring activities far outside of its core business of manufacturing and distributing microprocessors. These actions were a reinterpretation of its philosophical approach to managing the demand for microprocessors, activities initiated under Andy Grove's leadership in the 1990s. Intel had previously made a distinction between managing its first job, making microprocessors, and managing anything that helped it sell more microprocessors, which was often given the label "Job 2"(Gawer and Henderson, 2007). To skeptics of Job2, the expansion to aid wireless laptops represented new actions outside of Intel's core strengths.

It is easy to have a retrospective bias and presume the success of this Centrino program, but to contemporaries success was not a foregone conclusion. We will not dwell on the internal fights for Centrino, but simply remind the reader about what is already known (Burgelmann, 2007). The internal fights became heated, bitter, and prolonged, and became so encompassing for the organization that the CEO had to risk his career to fully execute the Centrino program.

Conflicts with complementors in the supply chain (if the reader requires a guide, the Appendix provides details behind the main participants, as reported in this section).

Centrino was officially launched in March 2003. The redesign eliminated the need for an external card for the notebook, which was usually supplied by a firm other than Intel and installed by users or OEMs. Intel hoped for additional benefits for users, such as more reliability in wireless functionality, fewer set-up difficulties, longer-lived batteries due to less need for heat reduction, and thinner notebook designs due to smaller cooling units. Seeking to inform users about all those less visible changes, Intel adopted "Centrino" as a label, affiliated it with a trademarked symbol (a butterfly in commercials, and that OEMs placed on laptops). It initiated a program to market the design and certify compliance.

Intel's motherboard designs could increase the efficiencies of computers, but that benefit was not welcomed by every OEM who assembled PCs, or other market participants. For example, firms such as Texas Instruments and Intersil had lobbied earlier for different designs for upgrades, investing heavily in the efforts at committee 802.11. Neither of them had intended to help Intel's business, and neither of them wanted to see Intel increase its influence over the designs that were deployed to most users. As another example, Intel's designs eliminated some differences between OEMs and other component providers. Many of these firms resented both losing control over their designs and losing the ability to strategically differentiate their own designs. At the same time, other OEMs, especially smaller ones, liked aspects of the Intel design, since it allowed the firms to concentrate on other facets of their business. That competitive rivalry eventually generated cooperation from every small OEM, especially after Intel initiated marketing programs for Centrino.

Intel ran into several unanticipated crises, such as insufficient parts for the preferred design and resulting delays, as well as a trademark dispute over the use of its preferred symbol for the program. However, the biggest and most important resistance came from the largest distributor of PCs, Dell Computer, who was the earliest IBM-PC compatible firm to offer wireless features. Dell insisted on selling its own branded Wi-Fi products, buying internal cards from others that handled Wi-Fi, bypassing Intel altogether. Dell branded its solution and had grown a good side business from its pioneering efforts. Dell's reluctant cooperation emerged only a year later, and observers at the time believed Dell experienced a decline in sales of Dell-branded cards and routers.

Conflicts also arose with other complements. Even before the launch of Centrino hot-spots began to grow at business buildings, in homes, in public parks, and in a wide variety of settings. Intel's certification program grew to considerable size. Intel initially certified (fifteen thousand) hot-spots in hotels, airports, and other public places by the time Centrino launched.

The growing use of hot-spots raised numerous unexpected issues about interference, privacy, and appropriation of the signals of neighbors. Nevertheless, these issues did not slow Wi-

Fi's growing popularity.[7] Web sites sprouted up to give users, especially travelers, directions to the nearest hot-spot. As demand grew, suppliers met it. As in a classic network bandwagon, the growing number of hotspots would attract more users and suppliers.

2.1. Counterfactuals and predictions

Before undertaking the statistical measurement, we note one principal challenge for inference: we do not observe the alternative history. It is not possible to observe what might have happened had Intel not undertaken its Centrino program. Would demand for laptops have grown at the same rate if Intel had not acted? Would the same firms have succeeded that Intel had not restructured the supply chain? There is no way to know. We can only work with the historical events we observe and speculate about plausible alternatives.

One possible alternative is a world in which laptop sales grew, but, had Intel not acted, not in directions that necessarily benefited Intel. This alternative scenario would have been one in which OEMs had more negotiating discretion to choose non-Intel chips if they desired it, where this group includes both Apple, Dell, and other IBM-compatible OEMs. That could have happened had the growth in Wi-Fi occurred without any redesign of the lap-top, where users continued to get wireless functionality with an expansion card, and without an Intel endorsement.

We stress, therefore, what we can observe. If the Centrino program caused growth in the mass market, we could expect to see both the right timing (i.e., after 2003), and changes in a wide breadth of markets (i.e. many types of complementors). We also note that measuring these effects is quite challenging as researchers, but we have the benefit of hindsight. Intel's management had to monitor and measure events in real time and must have faced considerable difficulty managing events in the many markets touched by its actions.

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[7] In high-density settings it was possible for there to be interference among the channels, or interference with other users of the unlicensed spectrum reserved by the FCC, such as cordless telephones.

Our review of the Centrino program highlights several ways in which Intel reshaped markets for laptops. As noted above, some features are already well documented, such as the change in demand from desktop to laptops, linked especially to the rise in wireless capabilities embedded within laptops. We also expect Intel to retain market share in comparison to AMD, another documented part of the historical record.

Other aspects of the historical record are not well-documented or measured, and this is where we put our efforts. If this narrative is correct, there should be more: we should observe the following:

1. The Centrino program reduced the value of independent cards for expansion slots. Hence, we expect a decline in the sales of independent card makers to fit in expansion slots, and an exit of such firms, and only after 2003.
2. The Centrino program improved the appeal of wireless laptops, which increased the value of wireless routers. We expect to see a rise in demand for wireless routers, and, again, only after 2003.
3. Failure in the card business occurred due to the decline in demand, not due to managerial failures at card organizations. Hence, unlike typical entrepreneurial studies of firm failure, experience and exit in one complementor market is not a "negative signal," and could continue to confer competitive advantage in alternative complementor markets.
4. We predict the difference in the experiences of firms in the SoHo (low-end) and enterprise and broadband (high-end) router markets. Both reached mass market scales after Centrino, and many firms entered. We expect firms with a prior experience in Wi-Fi cards to introduce more complements after the launch of Centrino than those firms who were not active in cards. If the experience provided more advantages in reducing costs of manufacturing than providing appropriate distribution, we expect firms with a prior experience in cards to introduce relatively more products in low-end routers after the launch of Centrino than firms with no prior experience. Related, we expect prior experience

in cards to have no, or even a negative effect, on product introduction in high-end market such as enterprise or broadband routers, where branding and distribution play a more important role.

3. Estimation of the model

We perform two types of analysis, focusing on: the effect of Centrino on the hazard of exit from the Wi-Fi cards (both internal and external) market; the effect of Centrino on product introduction in the markets for Wi-Fi complements (SoHo, Enterprise, and Broadband routers). We combine in our estimations a set of time varying and time invariant covariates to measure respectively: competition in the focal and adjacent market, availability of complementary products in adjacent and distant markets, firms entry time cohorts, downstream and upstream integration, and dummies capturing the effect of Centrino introduction.

3.1. Firm exit from the Wi-Fi card markets

To analyze the effect of Centrino on the hazard of exit from the card market we choose as unit of analysis the firm and we assume that exit occurs when a firm stops certifying new products in the internal or external card market. We estimate the hazard of exit of firm *i* from card market *j* at period *t* by employing the following Cox proportional hazard function:

$$h_{ijt}(X_{ijt}) = h(age_{it})exp\big[\beta_{ij}X'_{ijt} + \gamma_{j1}\cdot Centrino_{jt} + \gamma_{j2}\cdot Cohort_{ij}2\cdot Centrino_{jt} + \gamma_{j3}\cdot Cohort_{ij}3\cdot Centrino_{jt} + \gamma_{j4}Centrino_{jt}\cdot Time\ since\ Centrino_{jt}\big] \quad (1)$$

The γ coefficients account for the effect of Centrino introduction on the hazard rate of the firms in a specific card market. More specifically, γ_{j1} captures the effect of Centrino on the hazard rate of the firms active in market *j*. γ_{j2} and γ_{j3} capture the effect on the hazard rate of those that entered market *j* in the same year or after Centrino respectively. If the launch of Centrino reshaped the market leading to a decline in the sales of independent card manufacturers, and an exit of such firms as in our prediction 1, we should expect a positive relationship between the Centrino variable and the hazard rate of each cohort of entrants. The hazard rate of all firms should increase after entry. In other words: γ_{j1}, $\gamma_{j1} + \gamma_{j2}$ and $\gamma_{j1} + \gamma_{j3}$ should all be positive and significant. The coefficient γ_{j4} captures instead the persistence of the effect of Centrino entry on the hazard rate of the other firms for each market. If the effect is persistent in time γ_{j4} is expected to be positive and statistically significant. If instead the effect fades away, we would expect γ_{j4} to be negative and statistically significant. X_{ijt} is a set of firm and market based variables summarizing observed differences across firms and market couples in terms of firms experience in complementary markets, competition in the card markets, and availability of complements.

3.2. Product introduction in the market for complements

To estimate the rate of product introduction in the market of complements we employ a conditional quasi-maximum likelihood (QML) estimator based on the fixed-effect Poisson model introduced by Hausman, Hall and Griliches (1984).[8] More specifically for each firm *i* we first estimate the following baseline equation:

$$E[y_{ict}|X_{ct}] = exp[\beta_0 + \beta_1 \cdot After\ Centrino_{ct} + \delta_{ct} + \gamma_i] \quad (2)$$

where *y* is the number of products produced by firm *i* in complementary market *c* at time *t*, AFTER CENTRINO$_{CT}$ is an indicator variable that captures the effect of Centrino entry on complementary market *c*, δ_t is a full set of entry year by complementary market *c* variables and γ_i corresponds to a firm fixed effect. If, according to prediction 2, the introduction of Centrino improved the appeal of

[8] The QML estimator produces standard errors that are robust and consistent. They are also robust to arbitrary patterns of serial correlation (Wooldridge, 1997). Standard errors are clustered on company id.

wireless laptops, which increased the value of wireless routers, we would expect β_1 to be positive and significant for all type of routers.

In our additional analyses we then modify equation (2) as follows:

$$E[y_{ict}|X_{ct}] = exp[\beta_0 + \beta_1 \cdot Experienced_{ic} \cdot After\ Centrino_{ct} + \beta_2 \cdot After\ Centrino_{ct} + \delta_{ct} + \gamma_i] (3),$$

where EXPERIENCED$_{IC}$ is an indicator variable equal to one if firm *i* associated with complementary market *c* was active in the card market before entry. In our analysis we will further distinguish among prior experience in any card, prior experience in internal cards only and prior experience in external cards only. If, according to prediction 3, experience in one complementor market continue to confer competitive advantage in alternative complementor markets, we would expect β_1 to be positive and significant for all type of routers. If, according to prediction 4, prior experience in cards had a different effect on alternative complementor markets we would expect β_1 to be positive and significant for the SoHo (low-end) routers only and negative or not significant for the enterprise and broadband (high-end) routers.

4. Data

4.1. The sample of products and firms

The information on Wi-Fi products and firms used in our analysis comes from the *Wi-Fi Alliance certified product database* which collects information on the number of Wi-Fi products certified, divided in several categories. Our analysis considers products such as: Wi-Fi internal and external cards, Wi-Fi Small Office and Home Office (SoHo) routers (low-end), Enterprise routers and Broadband routers (high-end).[9] The time span of our data begins in March 2000 and ends in

[9] Information on some technical characteristics of the equipment (i.e. firmware version, operating system, frequency bands etc.) is also available though not systematically across time and models. Information on prices is not provided.

May 2017. Over this period a total of 8,949 products have been certified (1,369 internal cards; 1,041 external cards; 2,982 SoHo routers; 2,192 enterprise routers and 1,365 Broadband routers). Information are also available on the manufacturers of the equipment which have been consolidated into a total of 298 firms.

4.2. Definition of firm exit and explanatory variables

In this paper we employ the information on the certification date available in the dataset to identify the timing of a firm exit from the internal and external card markets. Specifically, we assume that exit occurs when a firm stops certifying new products in the internal or external card market.

In our analysis of the effect of Centrino entry on firms' exit we employ the following explanatory variables:

CENTRINO_{JT}: this is our first key variable. A dummy that switches to one from the month in which Centrino was launched (March 2003) until the end of the analysis period.

$\text{TIME SINCE CENTRINO}_{JT}$: this is our second key variable. It is defined as the time elapsed since Centrino was launched.

Our list of controls includes a set of time varying variables aimed at capturing the effect of product competition, availability of complements, on the hazard of exit together with entry time and firm fixed effects.

$\text{DENSITY OF SAME MARKET}_{T}$*:* measured in terms of number of cards available for sale in the same market in each time period. $\text{DENSITY OF ADJACENT MARKET}_{T}$: measured in terms of number of cards available for sale in the adjacent market in each time period. Both variables intend to capture the substitutions available to buyers in that specific market.

DENSITY OF ADJACENT HIGHER END MARKET$_T$: measured in terms of number of enterprise routers available for sale in each time period. DENSITY OF ADJACENT LOWER END MARKET$_T$: measured in terms of number of SoHo routers available for sale in each time period. DENSITY OF NON-ADJACENT MARKET$_T$: measured in terms of number of broadband routers available for sale in each time period. These three variables aim at capturing the availability of different types of complement products in the markets for equipment.

COHORT$_{IJ}$ 1, COHORT$_{IJ}$ 2 and COHORT$_{IJ}$ 3: these are dummies equal to one if entry in card market *j* occurred before Centrino (i.e. before March 2003), with Centrino (March 2003), or after Centrino (later than March 2003) respectively and zero otherwise.

ACTIVE IN ADJACENT HIGHER END MARKET, ACTIVE IN ADJACENT LOWER END MARKET and ACTIVE IN NON-ADJACENT MARKET: these are three dummies equal to one if at the time of entry into the focal card market a firm was active in SoHo routers, enterprise routers or broadband routers respectively. They capture pre-entry presence in downstream complement markets.

4.3. Definition of product introduction and explanatory variables

In our analysis a new product is introduced in the market when it is recorded in the *Wi-Fi Alliance certified product database*. For each firm and for each year we count the number of product introductions and, similarly to prior analyses (Greenstein and Wade, 1998), include the firm in the analysis as long as they introduce new products. We run a specification for all the sample and then three separate specifications, one for each type of router. For this analysis we employ the following explanatory variables:

FIRST PRODUCT (ANY MARKET): is a dummy equal to one when a firm introduces its first product in a specific market in a specific year and zero otherwise.

AFTER CENTRINO: is a dummy that switches to one from the year in which Centrino was launched (2003) until the end of the analysis period and zero otherwise. In our further analyses we interact AFTER CENTRINO with:

EXPERIENCED IN CARDS, EXPERIENCED IN INTERNAL CARDS ONLY, EXPERIENCED IN EXTERNAL CARDS ONLY: these are three dummies equal to one if at the time of entry into the focal equipment market a firm was respectively active in the card, the internal card equipment or the external card market respectively and zero if they were not. All our specifications include a suite of entry year time effect (the omitted year being 2003 the year of Centrino launch).

5. Results

In this section we present the results of our investigation of the effect of Centrino on firms exit from the Wi-Fi card market and on new product entry in the market for complements.

5.1. Centrino and firms exit from the card markets

Table 1 reports the descriptive statistics for the variables in our analyses distinguishing between type of cards.

[Insert Table 1 about here]

More firms in our dataset enter the market for external card than the market for internal cards (102 vs. 83). We note that in both markets most firms belong to cohorts 2 and 3 indicating that they entered the market 'with or after' the launch of Centrino. Also, the shares of entrants in cohort 2 and 3 is similar with a slightly higher share of firms entering in internal cards (60%) rather than in external cards (58%). The statistics on downstream integration provide information on the heterogeneity of entrants in the market for Wi-Fi cards. The majority (about 66%) of the entrants in the market for external cards were not producing complements when they entered and 23.5% were producing low-end equipment (i.e. SoHo routers). On the contrary almost all entrants in the market of internal cards were producing complements with rather similar presence across markets for complements (32% in SoHo routers, 29% in enterprise routers, and 35% in broadband).

At the end of our observation period (2016) few firms are still active in each market with a higher proportion surviving in the market for internal cards (7.3%) than in the market for external cards (2%). Figure 2 plots the number of incumbent firms in internal and external cards before and after Centrino (March 2003).

[Insert Figure 2 about here]

It can be noted that following the launch of Centrino the number of incumbents peaks in both markets and then declines generating a shake-out. Both the magnitude and the timing of the event are not the same in the two markets though. The drop in the number of incumbents is sharper in the case of internal than in the case of external cards. It also occurs over a shorter time period.

All in all, these preliminary statistics suggest that similarities exist across card markets in terms of timing of entry especially with respect to the launch of Centrino but differences exist in the composition of entrants and in the rate of exit. This is consistent with the idea that different markets display different product life cycles and raise speculations about whether manufacturers decisions to exit the market could have been tied to the type of their pre-existing investments. It is also consistent with the view that managing the markets was a complex undertaking for the platform leader, Intel, because each complementary component market operated according to its own logic.

Tables 2 and 3 summarize the results of our hazard rate estimations for the external and internal card market respectively.

[Insert Tables 2 and 3 about here]

Model (1) is the baseline specification in which we introduce the control variables and the entry cohort dummies. In Model (2) we add the Centrino dummy which is our key explanatory variable. In Model (3) we interact the Centrino dummy with the entry cohorts. Finally, in Model (4) we add the interaction with the time elapsed since Centrino launch.

Considering the results for external cards first, we see that firms belonging to Cohort 2 and Cohort 3 experience a relatively higher hazard rate than earlier entrants suggesting that entry with or after Centrino was not beneficial for firms. The coefficient estimate of the number of models in the adjacent market for internal cards has a negative effect on the hazard rate suggesting the presence of complementarity rather than substitution between the two types of cards.[10] Finally downstream integration in complements (high end enterprise routers) increases the hazard of exit though this effect is statistically weak and not robust across specifications. We do not find any significant effect of density of markets for complements indicating that availability of complements did not affect the hazard of exit of external card producers.

When we consider the effect of Centrino on the hazard rate of external cards makers, we can see that the launch of Centrino increases the hazard rate of all manufacturers (coeff. $\gamma_{11} > 0$ and statistically significant). This result is robust to the inclusion of further interactions. The negative effect of the launch of Centrino is higher for firms that entered the market after Centrino than for

[10] This result is robust across specifications. As the two markets were growing together, some manufacturers were producing both types of cards.

those that entered before (coeff. $\gamma_{11} + \gamma_{12} > 0$ and $\gamma_{11} + \gamma_{13} > 0$ and statistically significant in Models 3 and 4) suggesting the presence of an earlier mover or an installed base advantage. Among those who did not enter before Centrino Cohort 2 firms do better than Cohort 3 firms in terms of hazard rate (coeff. $\gamma_{11} + \gamma_{12} < \gamma_{11} + \gamma_{13}$). Finally, the overall effect seems to increase as time elapses from Centrino's launch ($\gamma_{14} > 0$ and statistically significant in Model 4) suggesting that the negative effect does not weaken over time. These results are consistent with prediction 1.

Estimates for the internal cards market are summarized in Table 4 instead. Similarities but also differences can be observed with respect to the case of external cards. Again, the launch of Centrino increases the hazard rate of firms in the market. In contrast to what observed in the case of external cards, the size of the effect is rather small and weakly statistically significant only for firms that entered after the launch of Centrino (i.e. Cohort 3). Density of products in the adjacent market for external cards increases the hazard rate indicating a substitution relationship with internal cards for external cards manufacturers. Density of products in the same market tends to decrease the hazard rate. Both effects are robust across specifications. All in all, these results indicate that internal cards makers faced competition from products in the adjacent market. In terms of density of markets for complements, we find that the coefficient estimate of the number of models in the non-adjacent market (broadband router) is positive and significant while the coefficient estimate of the number of models in the higher end adjacent market (enterprise routers) decreases the hazard of exit from the internal card market.[11] This result is robust across specification and marks another important difference with respect to the market for external cards. It seems to suggest that the patterns of exit from the card market depend on the relationship between this market and the evolution of the market for complements and that this relationship varies depending on the type of cards. Finally, no significant effect between downstream integration in complements and the hazard of exit of internal card producers is found.

[11] These differences are probably the consequence of the time lags in the growth of the two markets.

The launch of Centrino has an effect on the hazard rate of internal cards makers similar to the one we have observed in the case of external cards, in the sense that it increases the hazard rate of all firms (coeff. $\gamma_{21} > 0$ and statistically significant and robust across models). Similarly, we find that the increase in the hazard rate is higher for firms that entered the market after Centrino than for earlier entrants (coeff. $\gamma_{21} + \gamma_{22} > 0$ and $\gamma_{21} + \gamma_{23} > 0$ and statistically significant in Models 3 and 4). Again, the overall effect increases as time elapses from Centrino's launch ($\gamma_{24} > 0$ and statistically significant in Model 4). This evidence is consistent with prediction 1. Again, this mix is consistent with a challenge in monitoring a complex set of events.

Alongside these similarities, some important differences can be highlighted. First, the magnitude of the effect of Centrino on the hazard rate is much higher in the case of internal cards than in the case of external cards (coeff. $\gamma_{21} > \gamma_{11}$ in each specification). This is consistent with the relatively sharper drop in the number of internal rather than external card incumbents pattern seen in Figure 2. Second, the effect on the hazard rate is higher for those firms that entered with Centrino than for those that entered after the launch (coeff. $\gamma_{21} + \gamma_{22} > \gamma_{11} + \gamma_{13}$). Additional insights on the difference can be grasped by looking at Figure 3 which plots the survival rates before and after Centrino by type of card market.

[Insert Figure 3 about here]

While there is a clear-cut evidence that the survival estimates of firms in both market are much higher before than after the launch of Centrino, it can be noted that the survival rates display different patterns over time. The proportions of surviving firms drop much faster for internal than for external card makers. It also drops much more regularly suggesting again the presence of differences in the product life cycle between the two types of cards.

In our estimations, we have relied upon the implicit assumption that in the absence of the launch of Centrino the hazard of exit from the card markets would have not been affected. As this assumption is not directly testable because of the absence of a proper counterfactual, we have decided to carry out three placebo tests, whose estimates are reported in Table 4 for both external and internal cards separately.

[Insert Table 4 about here]

In column (1) of the table we report our baseline model (also shown in column (4) in Table 2). Column (2) estimates the same specification as in the baseline model but with only firms that entered the market between March 2000 and December 2002 and with the fictitious Centrino launch date of March 13, 2002 (one year before the actual launch date). In this case, the estimated coefficient of the Centrino dummy is lower and not statistically significant. Further placebo tests are presented in columns (3) and (4). More precisely in column (3) we consider only firms that entered the market between January 2001 and December 2002 with the fictitious Centrino launch date of March 13, 2002 (one year before the actual launch date). In column (4): we use only firms that entered the market before January 2001 with the fictitious Centrino launch date of March 13, 2002 (one year before the actual launch date). In both these cases the estimated coefficients for the Centrino dummy are not significant. We then repeat the same tests in the case of internal cards and get similar (non-significant) coefficients (columns 6 and 7).

All in all, this placebo analysis highlights that differences in the hazard rate before and after the launch of Centrino do not seem to be attributable to other events or trends occurring around the period of Centrino launch. If they were, we would have found similar results of the launch when using a fictitious date or different subsets of entrants in each market.

5.2. Centrino and product introductions in the markets for complements

The evidence presented in the previous section supports the idea that the launch of Centrino reduced the value of independent cards for expansion slots leading to a decline in the sales of independent card makers and an exit of such firms. However, the Centrino program also induced a change in how users were accessing the network from desktop to laptops. Improvement in sales in laptops linked to the availability of Centrino generated externality to wireless complements such as routers. Did the launch of Centrino influence new product introduction in the markets for routers? We test this idea by looking at product introduction overall and then separately by router category (i.e. SoHo, Enterprise and Broadband).

Table 5 summarizes the means and standard deviation for the variables used in the analysis of product entry, the unit of observation is the product year.

[Insert Table 5 about here]

The average firm in our sample introduces nearly 5 routers per year with most products (77%) introduced after the launch of Centrino. The pattern of entry differs across router type, with more products per year introduced on average in the enterprise category (4.71 routers) followed by the broadband category (4.20) and the SoHo category (2.72). The statistics on prior experience provide information on the heterogeneity of entrants in the market for complements. Nearly 30% of router manufacturers were active in the card market (any type) when they started producing complements. One fifth were active in the internal cards only and one fourth in external cards only.

Figure 4 plots the number of products for the whole sample and by category of router.

[Insert Figure 4 about here]

We observe that the overall number of products introduced in the market grows continuously but at different pace over time. After a slow initial growth there is a take-off immediately after the launch of Centrino. This take-off is triggered mainly by the rapid development of the market for (low-end) SoHo routers which experiences a spike after 2003. After a couple of years of stability another phase of rapid growth in the number of complements is observed between 2006 and 2011 driven in this case by the rapid and parallel growth in the number of enterprise routers, SoHo routers and, to a lesser extent, the take-off of the Broadband market. Finally, a further phase of growth starts in 2012 manly as a consequence of a spike in the number of broadband routers.

All in all, this preliminary evidence seems consistent with the idea that the launch of Centrino, while inducing a shake-out in the market for cards, positively contributed to the growth of the Wi-Fi industry through the creation and development of the markets for complementary products. However, the evidence also suggests that there were important differences in the timing, pace, and extent of development of these markets as captured by the pattern of new product introduction. Given these differences, we expect the effects of Centrino on growth to have been uneven across markets, and difficult to manage in real time. To probe further into this possibility, we now turn to our empirical estimation of product introduction.

Figure 5 plots the frequency of product introductions for the whole sample of routers and for each category separately.

[Insert Figure 5 about here]

Though the average number of routers per year varies between 2.7 (SoHo equipment) and 4.8 (whole sample), the distribution of observations tends always to be very skewed. For this reason, we employ a Poisson quasi-maximum likelihood estimator (see equation 2 above) in which the dependent variable is the number of products introduced by each firm in each year of observation. Table 6 reports our baseline results.

[Insert Table 6 about here]

Model (1) considers the whole sample focusing on the firms that have introduced at least one Wi-Fi router in the period under consideration here. We find a significant increase in the yearly number of equipment following the launch of Centrino as suggested by the positive coefficient of the AFTER CENTRINO dummy. Models (2) to (4) repeat the analysis for the same set of specification except that each one of them consider a specific market separately. In each market we find a significant increase in the yearly number of Wi-Fi equipment following the launch of Centrino. This evidence supports prediction 2. The magnitude of the effect, as well as its statistical significance, varies across equipment type. The effect seems relatively smaller in the case of SoHo routers and particularly larger for broadband ones.

We do not have the luxury of rerunning history without Centrino, so there is no way to interpret these findings without some speculation. We speculate that high-end markets start later than So-Ho, so they grow faster both because they are catching-up and because they can benefit from positive externalities from the existing installed base of low-end products as well as from user learning. It is likely that the higher magnitude of the estimated coefficients of the Centrino dummy in the case of Enterprise and Broadband routers (with respect to SoHo) partly reflects these benefits as well as the effect of the launch of Centrino.

To focus on the dynamics of the effect uncovered in Table 6 we re-estimate Model (1) interacting the AFTER CENTRINO dummy with a set of covariates that includes: entry year effects, the dummy capturing the years after the launch of Centrino and the interaction between the AFTER CENTRINO dummy and the dummies corresponding to specific years relative to the launch of Centrino (before and after). We then plot (solid line in Figure 6) the coefficient estimates of the interactions and the 95% confidence interval (dashed lines) around them.

[Insert Figure 6 about here]

The pattern suggests that following the launch of Centrino there is an increase of the coefficients, followed by a decline and then another increase particularly noticeable after 2006. This dynamic is consistent with the idea that the Centrino program stimulated the availability of complements and that the effect was quick and permanent. The finding that the increase is not monotone may have different explanations. It may reflect differences in the product life cycle of the Wi-Fi complements. SoHo routers are relatively cheaper than enterprise or broadband ones which lowers the (switching) costs on the demand side. Lower switching costs lead to shorter product life cycle and a higher frequency of replacement. It might as well reflect differentials in the contribution that each market had to the growth of the overall Wi-Fi industry. Historically, the market for SoHo routers took off first, followed by the market for enterprise routers and finally by the market for broadband. Indeed, another look at Figure 4 confirms that SoHo equipment has an early lead and always accounts for the largest shares of product introduction. Only from 2006 onwards, enterprise routers and broadband routers catch up in terms of new product introductions. As the product life cycle of SoHo routers is relatively shorter and as its share of the total equipment is relatively larger than the others', what happens in this market in terms of frequency of product introduction and replacement ends up influencing the overall dynamic of the industry especially in the early years after the launch of Centrino.[12]

As plausible as it might be, this explanation leaves unsolved the question of why the launch of Centrino led firms to enter earlier and more into SoHo, the low-end, and only later and relatively less into enterprise and broadband, the high-end. Our hypotheses, as reflected by predictions 3 and 4, is that prior experience in a complementor market such as cards could confer competitive advantage in alternative complementor markets. Such experience provided more

[12] Another possibility is related to changes in the design of Centrino. To deal with some shortcomings of the early implementations substantial improvements occurred in 2006/2007 with the release of a new Centrino platform (the 'Santa Rosa') based on the Intel Core Due processor which solved some problems (i.e. short battery life) that had plagued prior generations. We speculate that this improvement might explain the further increase that we observe after 2006. This is a fascinating possibility because it would associate the observed growth of the market for complements with the interplay between the 'original experiment' (i.e. the launch of Centrino) and 'later experiments' (i.e. technological improvements in the original design). The latter changes enabled more technologically sophisticated products such as enterprise and broadband routers.

advantages in reducing costs of manufacturing than providing appropriate distribution, thus firms with a prior experience would introduce relatively more products in low-end routers after the launch of Centrino than firms with no prior experience. In contrast, prior experience in cards would have no, or even a negative effect, on product introduction in high-end market such as enterprise or broadband routers, where branding and distribution instead play a more important role. We analyze this possibility in the next section.

5.3. Further analysis of high and low-end

We carry out additional regressions in which we interact the AFTER CENTRINO dummy with the variable EXPERIENCED_{IC} which is a variable equal to one if firm *i* associated with complementary market *c* has been active in one or more Wi-Fi card market before entry and zero otherwise (see equation 3 above). We further distinguish among experience in any Wi-Fi cards market, experience in internal cards only and experience in external cards only.

Table 7 reports the results of Poisson quasi-maximum likelihood regressions for the whole sample of routers.

[Insert Table 7 about here]

We find that firms with prior experience in Wi-Fi cards introduce more routers after the launch of Centrino than firms without that experience (Model 1). However, the effect is not statistically significant. The same result holds for firms with prior experience in external cards (Model 3). In the case of firms with prior experience in internal cards (Model 2) the effect is negative although it is offset by the positive, and significant, effect of Centrino launch. All in all, the estimates go in the direction of suggesting that prior experience in Wi-Fi cards matters for the extent of product introduction in complements after the launch of Centrino. However, the coefficients are not statistically significant and this result seems to reject our hypothesis.

We next re-estimate the previous model separately for each complementary market.

[Insert Table 8 about here]

Table 8 reports the results for SoHo routers. Model (1) finds that firms with prior experience in Wi-Fi cards introduce more routers after the launch of Centrino than those without prior experience. Model (3) finds that the positive effect is particularly relevant for firms with prior experience in external cards even though the estimated coefficient is weakly significant. The effect is positive but not significant for firms with prior experience in internal cards (Model 2).

Table 9 reports the estimations for enterprise routers.

[Insert Table 9 about here]

In this case we find a positive and significant effect of the Centrino program on enterprise routers introduction. However, this effect is driven by firms without prior experience in Wi-Fi cards. Indeed, after the launch of Centrino, firms with prior experience in cards introduce less equipment than those without prior experience (Model 1). The extent of this negative effect is similar across type of cards though it is particularly negative for firms with prior experience in internal cards (Model 2) than for those with prior experience in in external cards (Model 3).

Finally, Table 10 reports the results for broadband routers.

[Insert Table 10 about here]

Here we find that prior experience in Wi-Fi cards matters though the coefficient estimate is weakly significant (Model 1 and 3). Similarly to the case of enterprise equipment, again we find that prior experience in internal cards has a negative effect (Model 2) on product introduction.

However, further explorations suggest this result is not robust.[13] Our speculation is that broadband routers are quite different products from cards because they are 'distant' along the value chain. Accordingly, we would expect no effect of prior experience on broadband.

Though the sum total of the effects are quite complex and difficult to tease out, this additional analysis supports the idea that the launch of Centrino exerted a positive effect on the development and growth of the Wi-Fi industry because it stimulated the introduction of new products in markets for complements. This effect is particularly evident in the case of low-end SoHo routers and it is mainly due to the presence of firms with prior experience in Wi-Fi cards.

To gain further insights in the different effects that the launch of Centrino had on complementors with prior experience in cards vs. those without experience, we repeat the same exercise done for the whole product sample (see Figure 6 above) only for the subsample of firms active in SoHo routers. Specifically, we re-estimate Model (2) in Table 6 interacting the AFTER CENTRINO dummy with a set of covariates that includes: entry year effects, the dummy capturing the years after the launch of Centrino and the interaction between the AFTER CENTRINO dummy and the dummies corresponding to specific years relative to the launch of Centrino (before and after). We do this for the sample of firms with prior experience in Wi-Fi cards and for the sample of those without prior experience separately. Figures 7a and 7b plot (solid line) the coefficient estimates of the interactions and the 95% confidence interval (dashed lines) around them.

[Insert Figures 7a and 7b about here]

The increase in the estimated coefficients in Figure 7a following the launch of Centrino reflects the overall positive effect of the launch of Centrino on SoHo routers introduction. The pattern is similar to the one observed in Figure 6 for the whole sample of complements although

[13] We further re-estimate the equation using random effects instead of QML Poisson, the positive coefficients for broadband routers are no longer significant and we are left with the negative effect of prior experience in internal cards.

the magnitude of the effect is smaller for SoHo. Different is the pattern observable in Figure 7b. In this case the estimated coefficients are negative right after the launch of Centrino, they decrease further for one year and then increase but stay negative until 2007. The effect becomes positive only after 2007, five years after the launch of Centrino.[14]

This further analysis of the SoHo market reveals that the overall positive effect of the launch of Centrino on product introduction observable immediately after the launch of Centrino is the result of a composition between two effects that go in opposite directions. Firms without prior experience in Wi-Fi cards, on average, introduce relatively less products. Firms with prior experience in cards, on average, undergo an immediate increase in their product introduction which more than offset the decline.

All in all, this evidence further supports our prediction 4 that prior experience in Wi-Fi cards mattered for the introduction of complements after the launch of Centrino. As prior experience provided more advantages in reducing costs of manufacturing than providing appropriate distribution, firms with a prior experience in cards benefited more and introduced relatively more products in low end routers. In contrast, prior experience in cards provides no benefit, or even has a negative effect, on product introduction in high end market such as enterprise or broadband routers, where branding and distribution played a more important role.

6. Conclusions

In this paper we examine Intel's launch of Centrino, and analyze how this program restructured the supply chain for laptop. We provide a narrative of key actions, offer a framework of its consequences for complementary markets, and link the framework to testable predictions for specific markets. We then collect data and test these predictions on outcomes in several related complementary markets.

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[14] Given the improvements that Centrino underwent in 2007 (see footnote 12) we speculate that the positive effect that we are observing in Figure 7b here in the case of SoHo routers might be an externality of the growing demand for enterprise and broadband routers. In addition, changes to Wi-Fi openness over the next few years also could have played a role (Kim, 2019).

The overall findings are consistent with our framework. We show that the launch of Centrino increased the likelihood of exit from both Wi-Fi cards markets, and we find that the magnitude of the effect was largest for internal cards. We also show that the launch of Centrino's stimulated product introduction in the markets for complements overall, and find the effect varied across type of routers. Finally, we show that experience with producing Wi-Fi cards shape the likelihood of survival as a router provider. Prior experience in Wi-Fi card contributed to product introduction in SoHo routers, but was not beneficial for the introduction of Enterprise and Broadband routers.

The findings in each market cannot be understood in isolation of each other. They are consistent with the broad theme of this paper, that it is possible for a platform leader to restructure an entire supply chain. And, indeed, our findings show that Intel could and did so with its Centrino program. More concretely, these outcomes were the outgrowth of coordinated action by Intel to restructure the supply chain for laptops in a direction that benefited Intel's interests.

The analysis has implications for studies of platform leadership. For example, they suggest the negotiations between platform leader and provider of complementary services can take a wide lens to plans, negotiations, and consequences. That especially holds for firms who must recognize when market opportunities shift as part of broader set of changes orchestrated by the platform leader.

The most difficult question is whether a platform leader should undertake such a restructuring. While this study analyzed one (successful) example, it also highlights some of the downsides. Intel's actions illustrate the challenges of managing so many complex changes at once. Simultaneously restructuring so many complementors produces winners and losers inside the platform leader's organization and among complementors, which creates numerous conflicts for the leadership to manage. All these factors will place pressures on a platform leader to both commit to a program around which complementors can make investments and adjust it when new information reveals new circumstances, adding to the conflict and complexity.

Accordingly, this experience does not teach the general lesson that all platform leaders should restructure their supply chain whenever possible. It teaches, instead, that platform leaders restructuring a supply chain can succeed, but only if the managerial challenges are overcome, as happened here. Management must invest in considerable time and effort into developing the capabilities to monitor and manage the complexity and unanticipated outcomes, as well as adapt to the needs of situation.

As with any study of a strategic action, our inferences are limited by the singularity of historical events in a single system. We cannot compare outcomes with an alternative history in which Intel does not take action. That necessarily implies that research progresses one strategic action at a time, and one system at a time. In this sense, research about restructuring platform supply chains is limited by the paucity of other systems in which a large platform leader has taken actions across many existing complementary markets. This paucity increases the value of additional investigations of other examples that help identify when (and when not) a platform leader succeeds in realizing its aims, and why (not). Strong candidates for investigation arise in mobile platform markets (e.g., i-Tunes and Android), social media (e.g., Facebook's migration to smart phones), the cloud (e.g., Microsoft's migration of many applications), and other areas in which technologies remain fluid (e.g., autonomous vehicles). Such cases can help research further understand the mechanisms for shaping complementary markets and will help illuminate the limitations of actions by a platform leader.

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Table 1: Means and Standard Deviations for firm exit from Internal and External Wi-Fi cards

	External Cards		Internal Cards	
Firm exit variables	**Mean**	**SD**	**Mean**	**SD**
Firm exit	0.980	0.139	0.927	0.260
Density of same market	376.451	371.928	375.168	438.368
Density of adjacent market	384.392	431.633	365.433	361.747
Density of markets for complements				
Adj. higher end market (Enterprise routers)	252.794	416.747	273.927	511.939
Adj. lower end market (SoHo routers.)	568.941	704.328	581.614	777.849
Non-adjacent market (Broadband routers)	157.470	275.791	172.325	336.803
Downstream integration				
Active in adjacent higher end market	0.058	0.236	0.289	0.456
Active in adjacent lower end market	0.235	0.426	0.325	0.471
Active in non-adjacent market	0.049	0.216	0.349	0.479
Entry cohorts				
Cohort 1 (entry before Centrino)	0.420	0.496	0.400	0.492
Cohort 2 (entry with Centrino)	0.080	0.270	0.070	0.260
Cohort 3 (entry after Centrino)	0.500	0.502	0.530	0.502
#of observations	102		83	

Table 2: Effect of Centrino entry on firms' exit from the external Wi-Fi cards market.

	External Wi-Fi cards			
	(1)	(2)	(3)	(4)
Density of same market (external cards)	0.008	0.011*	0.008	0.009
	[0.007]	[0.006]	[0.006]	[0.007]
Density of adjacent market (int. cards)	-0.009**	-0.013**	-0.011**	-0.013***
	[0.004]	[0.005]	[0.004]	[0.005]
Density of markets for complements				
Adj. higher end market (Enterprise routers)	0.005	0.008	0.007	0.007
	[0.008]	[0.007]	[0.007]	[0.007]
Adj. lower end market (SoHo routers)	0.0004	-0.0001	0.001	0.002
	[0.008]	[0.008]	[0.008]	[0.008]
Non-adjacent market (Broadband routers)	-0.002	-0.005	-0.005	-0.006
	[0.011]	[0.011]	[0.011]	[0.011]
Downstream integration (dummies)				
Active in adjacent higher end market	0.576	0.487	0.369	0.369
	[0.333]*	[0.326]	[0.334]	[0.347]
Active in adjacent lower end market	-0.069	-0.163	-0.129	-0.146
	[0.258]	[0.236]	[0.216]	[0.232]
Active in non-adjacent market	-0.767	-0.838*	-0.809*	-0.864*
	[0.474]	[0.482]	[0.482]	[0.502]
Cohort 2 (entry with Centrino)	0.869**			
	[0.341]			
Cohort 3 (entry after Centrino)	1.449***			
	[0.552]			
Effect of Centrino entry				
Centrino dummy (γ_{11})		2.745***	3.080***	2.011***
		[0.406]	[0.373]	[0.579]

Centrino dummy x Cohort 2 (γ_{12})			-1.073***	0.027
			[0.290]	[0.532]
Centrino dummy x Cohort 3 (γ_{13})			-0.503	0.567
			[0.487]	[0.649]
Centrino dummy x Time since Centrino (γ_{14})				0.002***
				[0.0005]
$\gamma_{11} + \gamma_{12}$			2.006***	2.039***
			[0.461]	[0.468]
$\gamma_{11} + \gamma_{13}$			2.576***	2.578***
			[0.580]	[0.585]
Log Pseudo likelihood	-343.81	-314.41	-311.50	-305.88
Chisq	68.91***	62.67***	120.82***	193.88***
No of observations	4,233	4,233	4,233	4,233
Time at risk	169,450	169,450	169,450	169,450
No of firms (failures)	102(100)	102(100)	102(100)	102(100)

Notes: estimates result from Cox semi-parametric regressions. The dependent variable is the hazard of exit from the external Wi-Fi card market. Density variables are monthly time varying. Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3: Effect of Centrino entry on firms' exit from the internal Wi-Fi cards market.

	Internal Wi-Fi cards			
	(1)	(2)	(3)	(4)
Density of same market (internal cards)	-0.113*	-0.022***	-0.170***	-0.020***
	[0.007]	[0.005]	[0.006]	[0.007]
Density of adjacent market (ext. cards)	0.010	0.017**	0.012*	0.013*
	[0.007]	[0.007]	[0.007]	[0.008]
Density of markets for complements				
Adj. higher end market (Enterprise routers)	-0.014**	-0.021***	-0.018***	-0.021***
	[0.007]	[0.006]	[0.006]	[0.007]
Adj. lower end market (SoHo routers)	0.001	0.003	0.005	0.007
	[0.006]	[0.006]	[0.006]	[0.006]
Non adjacent market (Broadband routers)	0.024**	0.036***	0.027***	0.029**
	[0.012]	[0.009]	[0.010]	[0.011]
Downstream integration (dummies)				
Active in adjacent higher end market	-0.289	-0.358	-0.376	-0.433
	[0.308]	[0.297]	[0.260]	[0.287]
Active in adjacent lower end market	-0.396	-0.259	-0.190	-0.172
	[0.258]	[0.221]	[0.207]	[0.240]
Active in non-adjacent market	0.091	0.186	0.256	0.378
	[0.281]	[0.258]	[0.246]	[0.265]
Cohort 2 (entry with Centrino)	0.195			
	[0.375]			
Cohort 3 (entry after Centrino)	1.008*			
	[0.581]			
Effect of Centrino entry				
Centrino dummy (γ_{21})		3.469***	3.753***	2.602***
		[0.515]	[0.472]	[0.654]

Centrino dummy x Cohort 2 (γ_{22})			-0.492	0.614
			[0.618]	[0.785]
Centrino dummy x Cohort 3 (γ_{23})			-1.045**	0.056
			[0.455]	[0.793]
Centrino dummy x Time since Centrino (γ_{24})				0.004***
				[0.001]
$\gamma_{21} + \gamma_{22}$			3.261***	3.216***
			[0.794]	[0.806]
$\gamma_{21} + \gamma_{23}$			2.708***	2.659***
			[0.642]	[0.700]
Log Pseudo likelihood	-257.7545	-218.5638	-216.7866	-209.5701
Chisq	53.96***	80.74***	114.24***	133.49***
No of observations	2,952	2,952	2,952	2,952
Time at risk	125,283	125,283	125,283	125,283
No of firms (failures)	83(77)	83(77)	83(77)	83(77)

Notes: estimates result from Cox semi-parametric regressions. The dependent variable is the hazard of exit from the internal Wi-Fi card market. Density variables are monthly time varying. Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4: Effect of anticipating Centrino launch date on exit from the Wi-Fi cards markets

	External cards				Internal cards		
Effect of Centrino entry	Baseline results	Placebo 1	Placebo 2	Placebo 3	Baseline results	Placebo 1	Placebo 2
Centrino dummy (γ_{11})	2.011***	0.142	2.404	15.259	2.602***	1.498	2.085
	[0.579]	[1.079]	[2.378]	[13.514]	[0.654]	[1.172]	[1.190]
Centrino dummy x Cohort 2 (γ_{12})	0.027	--	--	--	0.614	--	--
	[0.532]				[0.785]		
Centrino dummy x Cohort 3 (γ_{13})	0.567	--	--	--	0.056	--	--
	[0.649]				[0.793]		
Centrino dummy x Time since Centrino (γ_{14})	0.002***	0.011***	0.011	0.066**	0.004***	0.0154***	0.029***
	[0.0005]	[0.003]	[0.009]	[0.028]	[0.001]	[0.005]	[0.006]
$\gamma_{11} + \gamma_{12}$	2.039***	--	--	--	3.216***	--	--
	[0.468]				[0.806]		
$\gamma_{11} + \gamma_{13}$	2.578***	--	--	--	2.659***	--	--
	[0.585]				[0.700]		
Log Pseudo likelihood	-305.88	-79.27	-46.44	-4.525	-209.5701	-42.4423	-27.3136
Chisq	193.88***	115.22***	19.65**	12088.18***	133.49***	39.14***	73.79***
No of observations	4,233	2,483	1,500	911	2,952	1,511	1,260
Time at risk	169,450	118,359	72,195	42,673	125,283	77,621	64,020

No of firms (failures)	102(100)	43(42)	26(25)	16(16)	83(77)	33(30)	27(24)

Notes: Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%. All models are estimated using Cox semi-parametric regressions. The dependent variable is the hazard of exit from the external (internal) Wi-Fi card market. All models use the same specification as our preferred one shown in Table 2 (Table 3) column (4). Column (1): preferred model. Column (2): Placebo 1 uses *only* firms that entered the market between March 2000 and December 2002 with the fictitious Centrino launch date of March 13, 2002 (one year before the actual launch date). Column (3): Placebo 2 uses *only* firms that entered the market between January 2001 and December 2002 with the fictitious Centrino launch date of March 13, 2002 (one year before the actual launch date). Column (4): Placebo 3 uses *only* firms that entered the market before January 2001 with the fictitious Centrino launch date of March 13, 2002 (one year before the actual launch date). For internal cards we do not estimate the model for Placebo 3, as only 3 companies entered the market for internal cards between January 2001 and December 2002. They all exited.

Table 5: Means and Standard Deviations for product entry analysis

Product entry variables	Mean	SD
All sample		
Any equipment	4.868	9.954
First product (any market)	0.039	0.194
After Centrino dummy	0.777	0.415
Specific market		
SoHo routers	2.725	5.114
First product in SoHo	0.344	0.182
Enterprise routers	4.713	10.843
First product in Enterprise	0.158	0.124
Broadband routers	4.200	6.663
First product in Broadband	0.154	0.123
Prior experience		
Experienced in cards	0.270	0.444
Experience in Internal cards only	0.200	0.400
Experienced in External cards only	0.249	0.432

Table 6: Effect of Centrino entry on the number of routers

	All sample	SoHo	Enterprise	Broadband
	(1)	(2)	(3)	(4)
After Centrino	0.911***	0.493**	0.959*	1.700***
	[0.222]	[0.255]	[0.493]	[0.349]
Log pseudo-likelihood	-3309.53	-1822.37	-1002.4	-579.47
No of obs.	1,274	991	439	286
No of firms	143	118	59	44
Chisq	25.40***	4.55*	5.11*	28.49***

Notes: estimates result from conditional quasi-maximum likelihood Poisson regressions. The dependent variable is the total number of equipment in the year of observation. All models incorporate a dummy for first product entry. Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7: Number of routers and prior experience in Wi-Fi cards. All sample

	All sample		
	(1)	(2)	(3)
After Centrino	0.659	1.234***	0.745
	[0.584]	[0.348]	[0.504]
After Centrino x Experienced in cards	0.239		
	[0.629]		
After Centrino x Experienced in internal cards only		-0.404	
		[0.419]	
After Centrino x Experienced in external cards only			0.167
			[0.554]
Log pseudo-likelihood	-3135.03	-3306.57	-3184.47
No of obs.	1,342	1,342	1,342
No of firms	211	211	211
Chisq	40.56***	30.96***	28.91***

Notes: estimates result from conditional quasi-maximum likelihood Poisson regressions. The dependent variable is the total number of equipment in the year of observation. All models incorporate a dummy for first product entry and a dummy for prior experience in card production. Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 8: Number of routers and prior experience in Wi-Fi cards. Sub-sample of SoHo (low-end) routers

	SoHo routers		
	(1)	(2)	(3)
After Centrino	-0.508	0.029	-0.215
	[0.362]	[0.316]	[0.325]
After Centrino x Experienced in cards	1.072**		
	[0.451]		
After Centrino x Experienced in internal cards only		0.522	
		[0.409]	
After Centrino x Experienced in external cards only			0.785*
			[0.426]
Log pseudo-likelihood	-1786.31	-1820.21	-1801.86
No of obs.	991	991	991
No of firms	118	118	118
Chisq	33.93***	6.04	8.31*

Notes: estimates result from conditional quasi-maximum likelihood Poisson regressions. The dependent variable is the total number of equipment in the year of observation. All models incorporate a dummy for first product entry and a dummy for prior experience in card production. Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 9: Number of routers and prior experience in Wi-Fi cards. Sub-sample of Enterprise (high-end) routers

	Enterprise routers		
	(1)	(2)	(3)
After Centrino	2.104***	2.027***	1.914**
	[0.691]	[0.622]	[0.901]
After Centrino x Experienced in cards	-1.591**		
	[0.657]		
After Centrino x Experienced in internal cards only		-1.642**	
		[0.710]	
After Centrino x Experienced in external cards only			-1.398*
			[0.822]
Log pseudo-likelihood	-991.12	-991.63	-994.09
No of obs.	439	439	439
No of firms	59	59	59
Chisq	23.48***	17.51**	20.18***

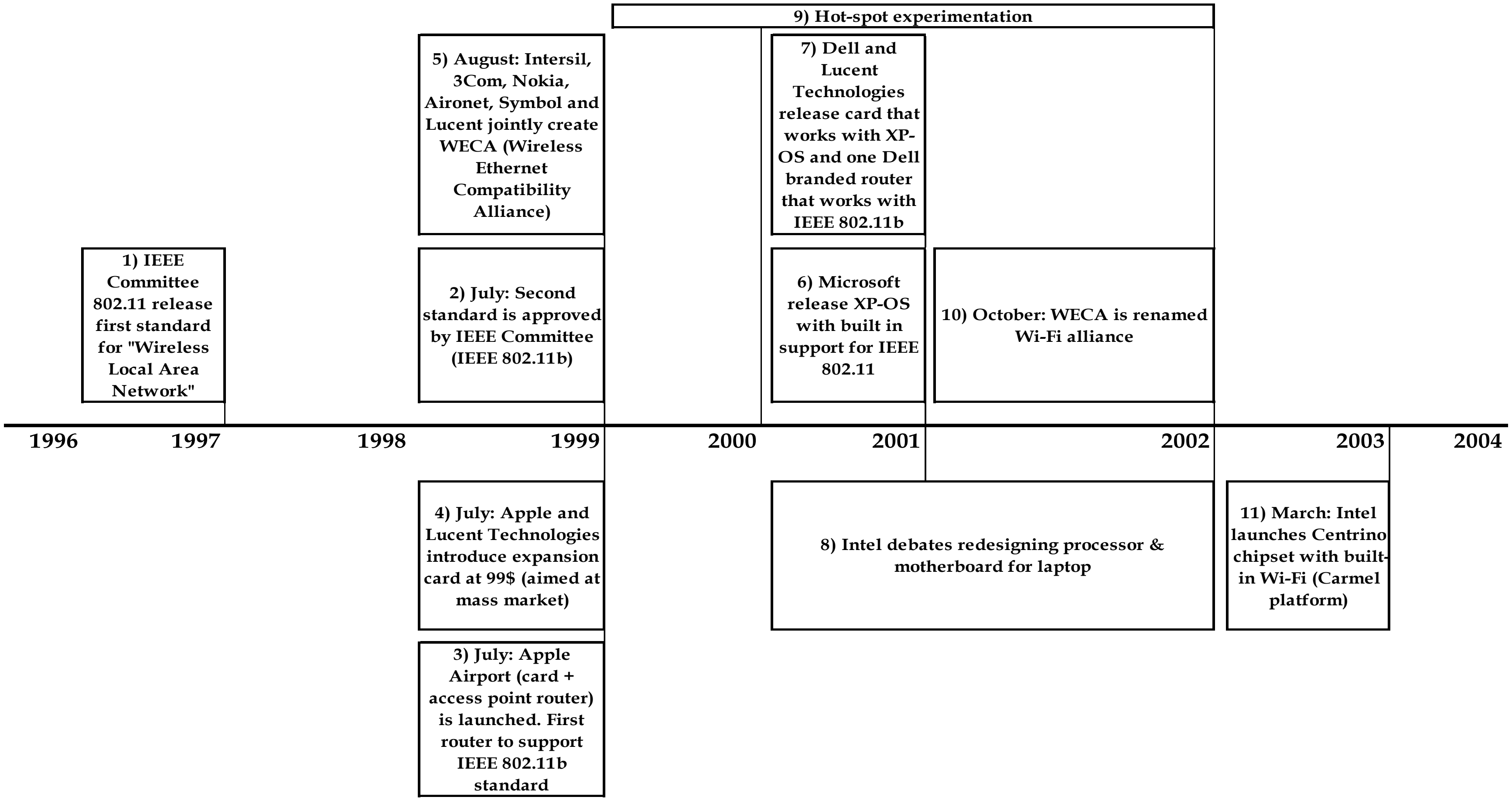
Notes: estimates result from conditional quasi-maximum likelihood Poisson regressions. The dependent variable is the total number of equipment in the year of observation. All models incorporate a dummy for first product entry and a dummy for prior experience in card production. Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 10: Number of routers and prior experience in Wi-Fi cards. Sub-sample of Broadband (high-end) routers

	Broadband routers		
	(1)	(2)	(3)
After Centrino	0.429	2.123***	0.514
	[0.349]	[0.060]	[0.335]
After Centrino x Experienced in cards	1.191*		
	[0.616]		
After Centrino x Experienced in internal cards only		-1.270***	
		[0.089]	
After Centrino x Experienced in external cards only			1.106*
			[0.607]*
Log pseudo-likelihood	-546.34	-577.44	-548.49
No of obs.	286	286	286
No of firms	44	44	44
Chisq	21.78***	20.53***	20.33***

Notes: estimates result from conditional quasi-maximum likelihood Poisson regressions. The dependent variable is the total number of equipment in the year of observation. All models incorporate a dummy for first product entry and a dummy for prior experience in card production. Robust standard errors clustered on company id are reported. * Significant at 10%; ** significant at 5%; *** significant at 1%

Figure 1a: Timeline of events in the development and commercialization of Wi-Fi products (until the launch of Centrino)



Notes on events significance: 1) Gains attention of Steve Jobs who contacts Lucent Technologies with a proposal; 2) Fixes a number of flaws discovered in the first release; 5) Formed for conformance testing to certify interoperability; 7) First 802.11b system for Windows based laptops; 8) Requires re-orienteering firm and supply chain to laptops instead of desktops; 9) Many firms involved; 10) 802.11 is rebranded as "Wi-Fi.

Source: Authors' elaboration based on: Lemstra, W., Hayes, V., Groenewegen, J. (2011): Annex 2, and other sources.

Figure 1b: A representation of the supply chain before the launch of Centrino

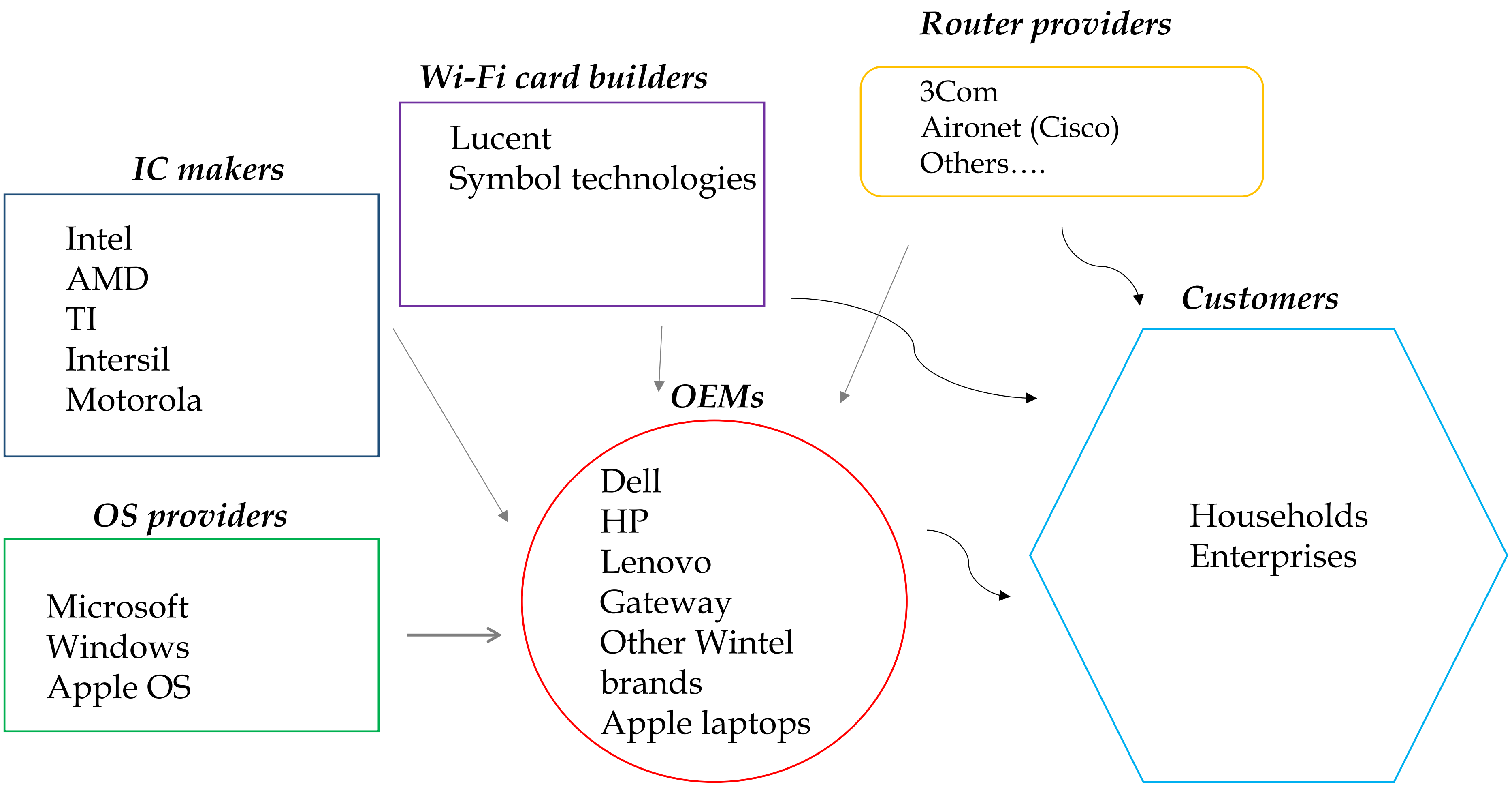
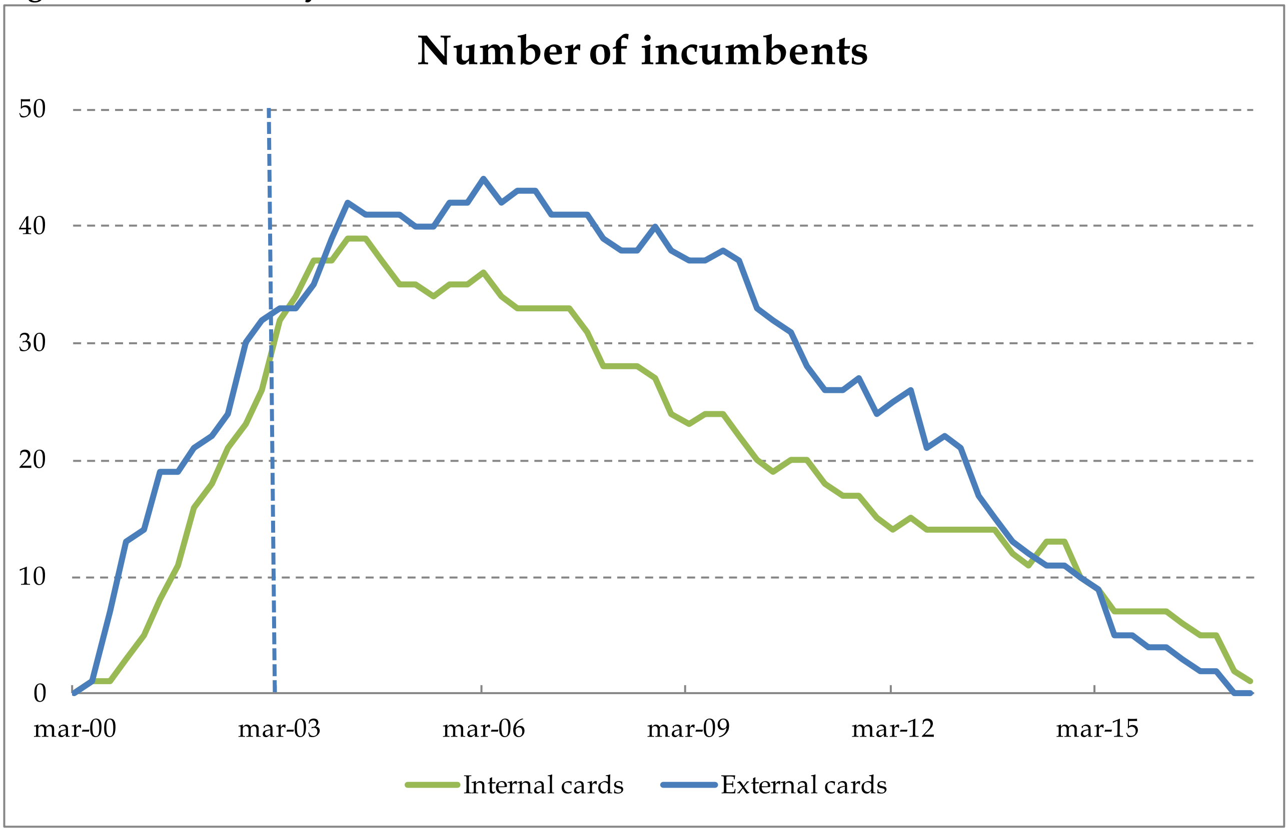


Figure 2: Centrino entry and incumbent firms in the Wi-Fi cards market



Notes: the graph plots the number of incumbent firms in the internal and external Wi-Fi card market before and after the introduction of Centrino (March 2003).

Figure 3: Effect of Centrino on the hazard rate of firms by Wi-Fi card type

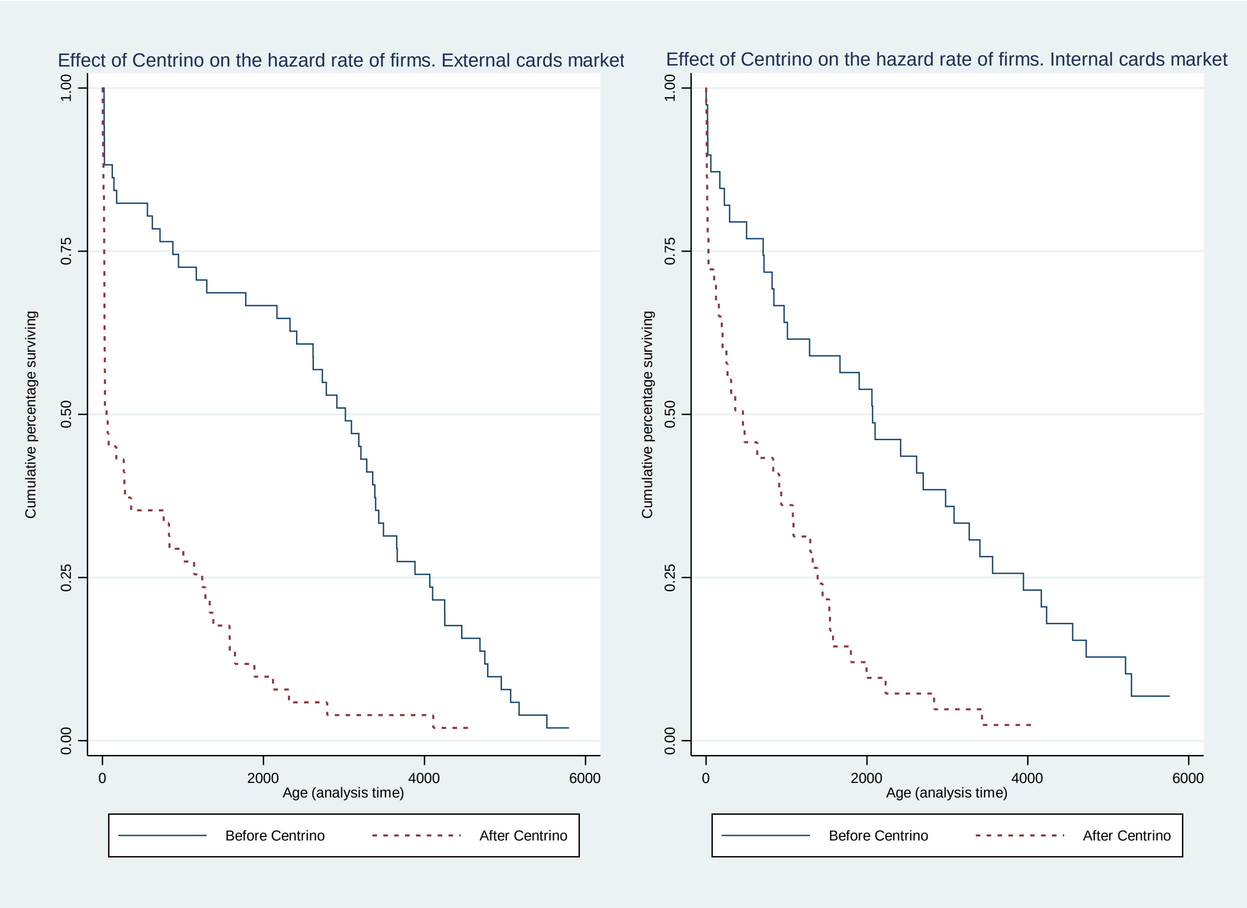
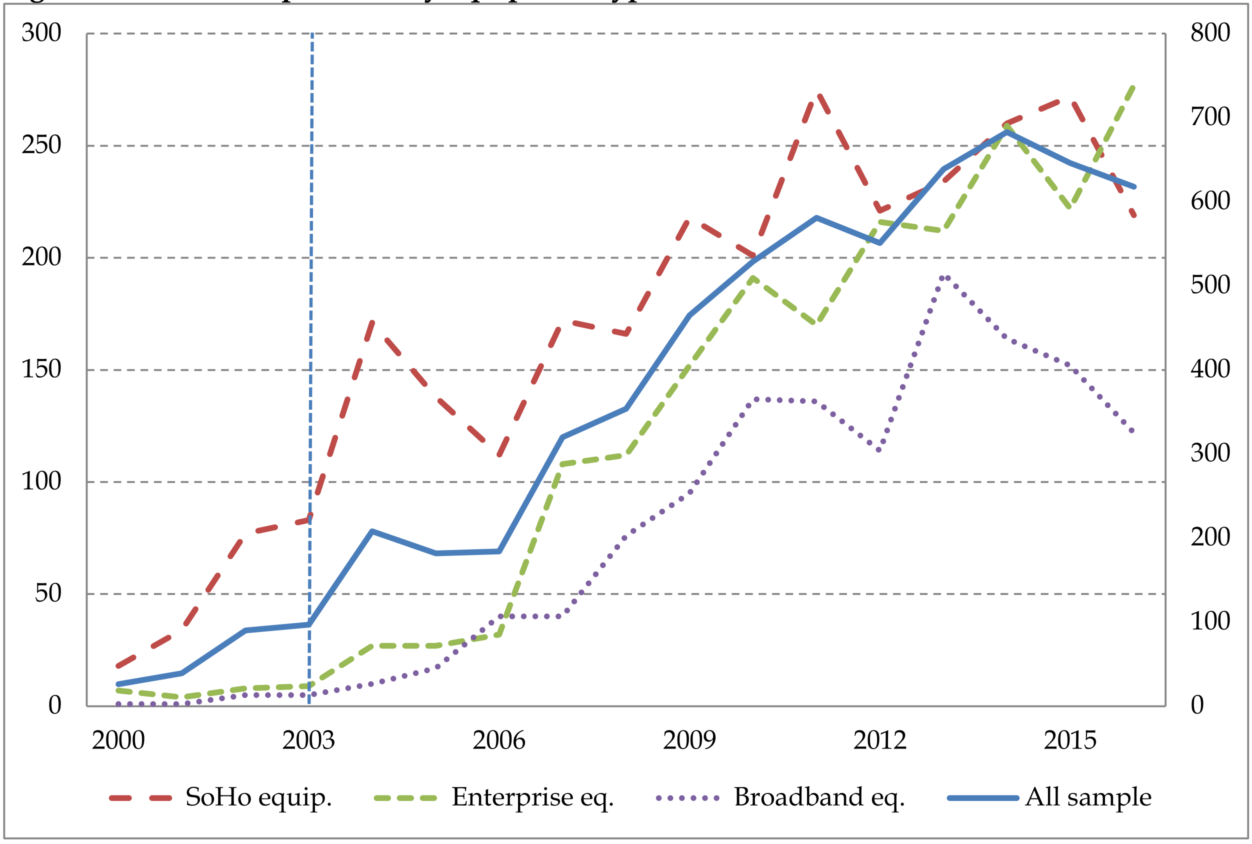


Figure 4: Number of products by equipment type



Notes: the graph plots the number of products in the Wi-Fi equipment markets before and after the introduction of Centrino (March 2003).

Figure 5: Frequencies of products introductions by equipment type

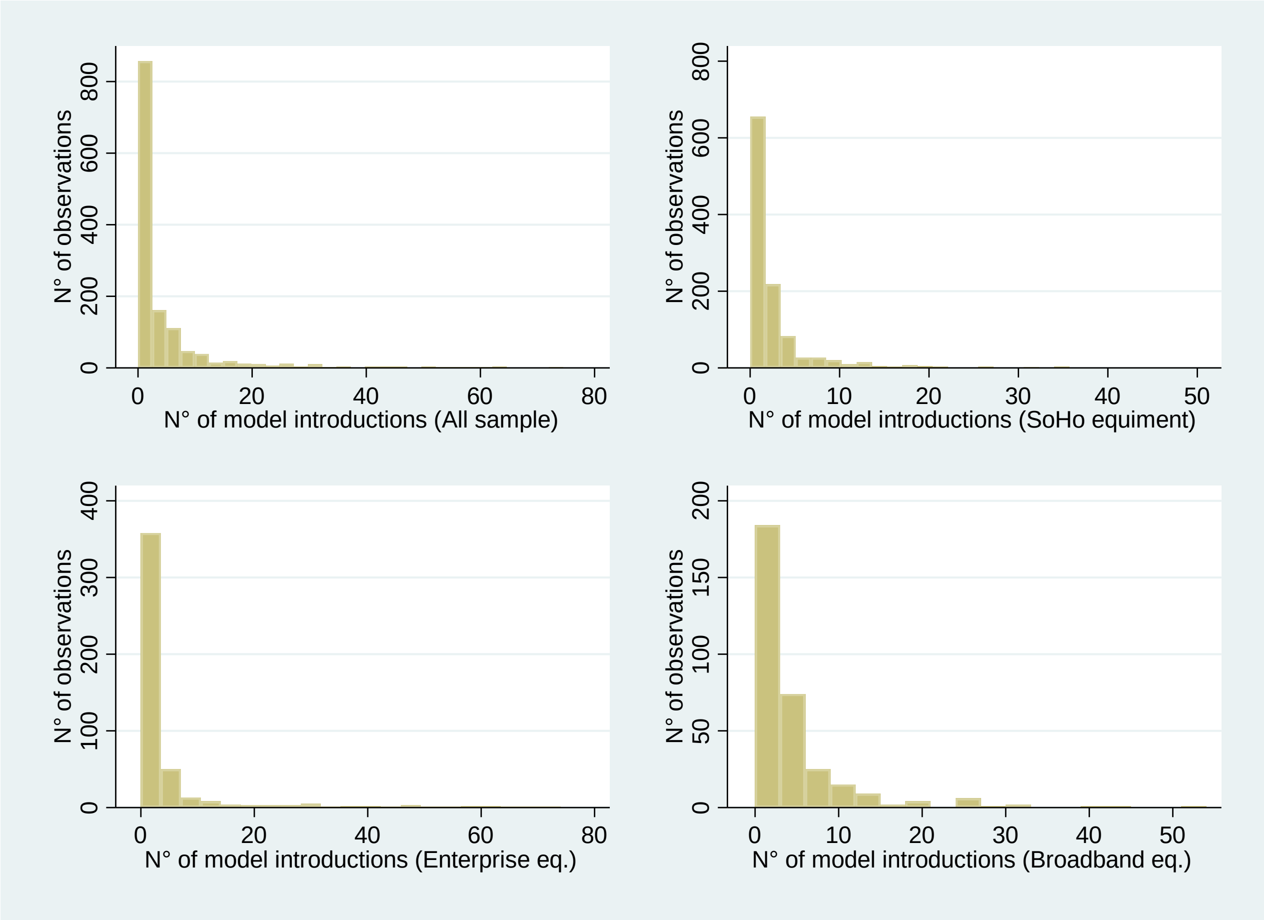
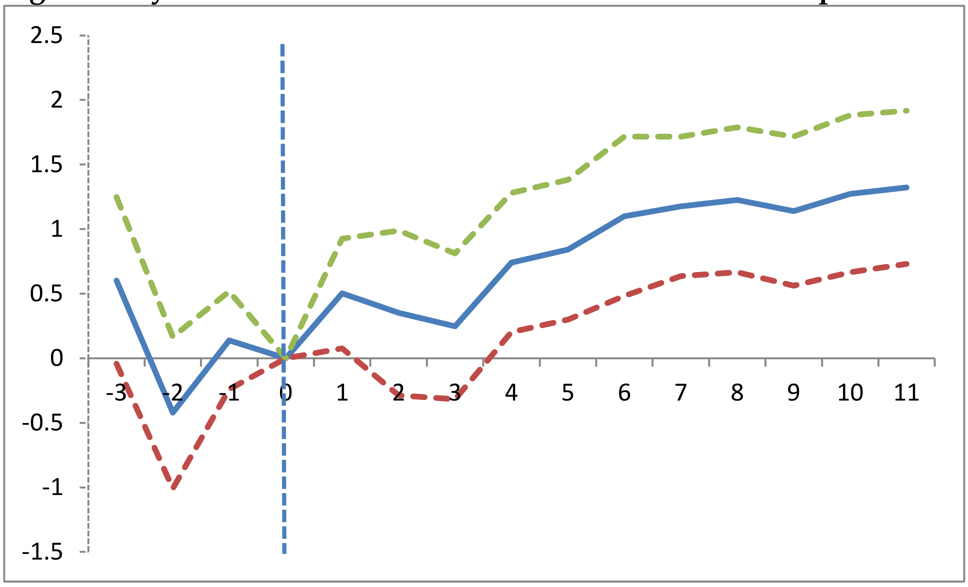
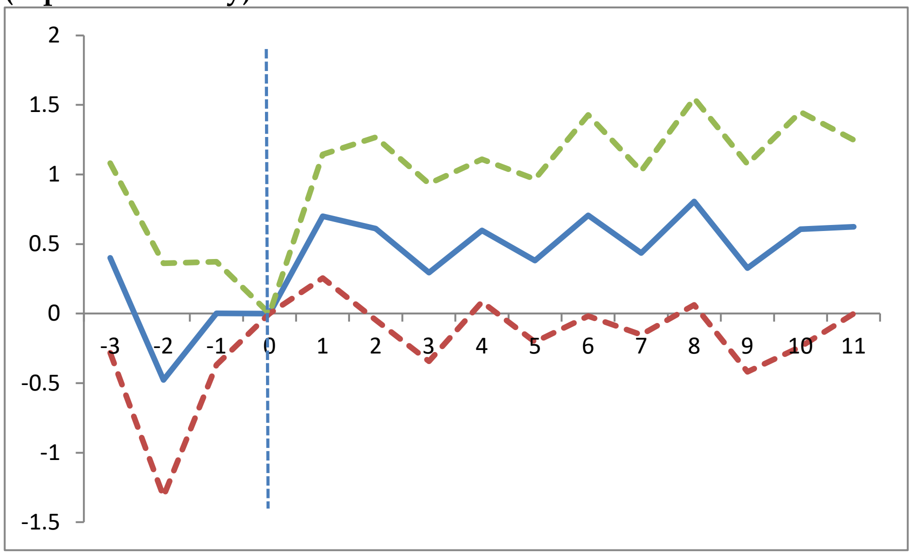


Figure 6: Dynamics of the Centrino effect. Results for all sample



Notes: the solid line corresponds to the coefficient estimates of Poisson quasi-maximum likelihood regressions in which the total number of routers in the year of observation is regressed against entry year effects, the dummy capturing the years after Centrino entry and the interactions of the Centrino dummy with variables corresponding to three years before Centrino entry, two years before Centrino entry, … , ten years after the year of Centrino entry, eleven years after the year of Centrino entry and above (the omitted variable is the year of Centrino entry). The 95% confidence interval (computed on the basis of robust standard errors clustered on firm id) is plotted in dashed lines.

Figure 7a: Dynamics of the Centrino effect. Results for the sample of SoHo routers (experienced only)



Notes: the solid line corresponds to the coefficient estimates of Poisson quasi-maximum likelihood regressions in which year of observation is regressed against entry year effects, the dummy capturing the years after Centrino entry and the i with variables corresponding to three years before Centrino entry, two years before Centrino entry, … , ten years after th years after the year of Centrino entry and above (the omitted variable is the year of Centrino entry). The 95% confidence robust standard errors clustered on firm id) is plotted in dashed lines. Figure 7a includes SoHo firms in the sample with Figure 7b includes only SoHo firms without such prior experience.

APPENDIX

Table A1: A detailed mapping of Wi-Fi supply chain participants

Role in Wi-Fi supply chain	Notes	Company name	Notes
Integrated circuits makers		Intel	Launch Centrino in March 2003; Leader in the integration of Wi-Fi functionality in laptops;
		Texas Instruments	Involved in early production for Wi-Fi chipset. Supported an alternative (to Centrino) design to implement IEEE 802.11 standard;
		AMD	Enter the Wi-Fi chipset market in November 2002 with the Am1772 WLAN chip set and a mini-PCI card reference design kit supporting the IEEE 802.11b WLAN standard;
		Broadcom	Leader in Wi-Fi chips for gateway and routers;
		Agere Systems	Enter the Wi-Fi chipset market in July 2003 with the WaveLAN chipset; Chip technology unit dissolved in 2004;
		Conexant	Enter the Wi-Fi chipset market in May 2003 with a IEEE 802.11b-compliant WLAN baseband processor;
		Intersil	Former semiconductor unit of Harris Corporation; Become independent in early 2000; Sell its WLAN unit to Globespan Virata in 2003; Globespan Virata merge with Conexant in 2005;
		NCR	Early developer of Wireless LAN card (915 MHz) in September 1990; Acquired by AT&T in 1991; Change name into AT&T Global Information Solutions (GIS) in 1994;
Wi-Fi equipment builders (cards, routers, switches)	Large firms	AT&T	Acquires NCR in 1991; Divested in 3 independent firms in 1996: AT&T-GIS; Lucent Technologies (retains WLAN/Wi-Fi activities);
		Lucent Technologies	Created in 1996; In 1999 release the earliest IEEE-802.22 compliant (Wave-LAN);
		Motorola	Early developer of Altair Wireless LAN cards (18GHz band);
		Agere Systems	Established as a subsidiary of Lucent Technologies in 2000; Spun-off in 2001 retaining the WLAN/Wi-Fi activities; End of 2001, holds 50% of market

			share for Wi-Fi products (including OEMs channel); In 2002 sell its WLAN infrastructure to Proxim; Discontinue WLAN developments in 2004;
		Proxim	Among the early sponsors of the Wireless LAN Association (precursor of the Wi-Fi alliance); Acquire the WLAN infrastructure of Agere Systems in 2002;
		Harris/Intersil	Work with 3Com to integrate its products within the 3Com line; In 2002 sell its WLAN technology to Conexant;
		Symbol Technologies	Work with 3Com to integrate its products within the 3Com line;
		Aironet	Established in 1994 by Telxon RF division; Release a early proprietary 900MHz wireless cards; Acquired by Cisco Systems in 2003;
		Linksys	Established in 1988; Release the first Wi-Fi router in 1999; Acquired by Cisco Systems in 2003; In 2013 sold to Belkin;
	Small firms	Xircom	Leader in manufacturing of Wi-Fi cards; Acquired by Intel in 1999;
		BreezeCom	Established in 1992; Merged with Floware Wireless in 2001;
		WaveAccess	Pioneer of fast Wi-Fi cards; Acquired by Lucent technologies in 1998; Closed in 2001;
Networking companies (Wired LAN card/equipment suppliers)		3Com	Leader of Wired LAN equipment, founding member of Wi-Fi Alliance;
		Xircom	Leader supplier of Ethernet port adapters;
		NEC (Japan)	OEM;
		Solectek	OEM;
		OmniNet	Proponent of LAN over phone cables;
		ARCNet	Proponent of LAN over phone cables;
Computer manufacturers and vendors (OEMs)		Apple	Launch Apple Airport card + access point in July 1999;
		Dell	Miss agreement with NCR in 1992 for WaveLAN for PCs;
		Toshiba	Laptop vendors;
		Compaq	
		Hewlett Packard	
		IBM	
Network Management OS-Software providers		Microsoft (MS-LAN Manager)	In 2001 release XP-OS with built in support for IEEE 802.11;

		Novell (Netware)	
		Banyan Vine	
Offshore developers and manufacturers of equipment	Outsourcing partner of equipment manufacturers	Universal Scientific Inc. (USI) (Taiwan)	World's largest wireless LAN card manufacturers; Subcontractor partner of Agere Systems; Become an ODM specialized in wireless in 2002 after Agere Systems sells its business unit to Proxim;
	Outsourcing partners of PC vendors	Ambit	
		Compal (Taiwan)	Supply for Dell, Acer, Toshiba among others;
		Alphatop (Taiwan)	Started as manufacturer of iBook for Apple;
		Gemtek (Taiwan)	Established in 1996; Started as OEM then became an ODM;
System integrators, distributors and value-added resellers		Computerland Softel Ingram Micro/D	Early involvement in WLAN development;
Access providers	Wireless ISPs (WISPs)	MobileStar	Established in 1996; Provide early access points in Starbucks locations; Acquired by VoiceStream in 2001;
		VoiceStream T-Mobile	Cellular communication company acquired by T-Mobile in 2002;
		Plancom	Established in 1995, pioneer of wireless access in public places; Change name into Wayport in 1996; Acquired by AT&T in 2008;
		Deep Blue Wireless	Established in 2001, merged with WiFiFee in 2009;
		FatPort (Canada)	Established in 2002, still active;
		NetNearU	Established in 1997, acquired by ViaSat in 2014;
		SurfandSip	Established in 2000, still active;
		Airwave Adventures	Established in 2003, acquired by TengoInternet in 2016;
		Harbor Link Network	Established in 1998;
		Hotpoint Wireless	Established in 2002, still active;
Customers	Enterprise Market	J.C Penney, Littlewoods, Younkers, House of Fraser, Victoria's	Early target: narrow scale (1990);

		Secret, Stop & Shop, Wal-Mart	
	Education Market	Carnegie Mellon University	First large-scale implementation (1993);
	Household Market		Office, Home, Internet 'hotspots' (after 1999);

Note: Authors' elaboration based on several sources