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The second face of systems integration: An empirical analysis of supply chains to complex product systems

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ABSTRACT

Systems integration encompasses both system design and management of supplier networks. We examine the "second face" of systems integration related to the organization and management of supplier networks. We analyze a unique dataset on the supply chains for three major U.S. weapon systems to examine how systems integrators balance the economies-of-scope benefits of general-purpose technologies and the benefits of horizontal supplier specialization. We show that horizontal specialization – an establishment's focus on a particular market – differs with distance from the systems integrator. Systems integrators derive the benefits of specialization primarily (though not exclusively) from their direct suppliers, and they access general-purpose technologies from lower-tier suppliers. Some of the lower-tier suppliers themselves integrate complex subsystems, belying the image of the supplier network as a "production pyramid" with simple firms at its base. We further find that the supply chains of the three weapon systems that we study are dominated by facilities whose main line of business is in non-defense markets, because of the large number of lower-tier suppliers that serve commercial markets. This demonstrates the importance of the supply chain as a source of commercial-military integration, linking defense production to the wider economy and casting doubt on the view that there is a "wall of separation" that prevents the U.S. defense effort from gaining access to civilian technologies.

1. Introduction

Systems integration – "the capability to combine diverse knowledge bases and physical components into functioning systems" – is a key characteristic of lead firms in industries such as aerospace, automotive, telecommunications, and computing (Davies et al., 2011: 3). The literature on systems integration discusses two faces, one in system design, the other in the organization and management of networks of suppliers. In the first face, the systems integrator makes key decisions regarding the overall architecture of the complex product system; the form, fit, and function of its subsystems; and design trade-offs among various dimensions of performance (Iansiti and Clark, 1994; Brusoni et al., 2001; Prencipe et al., 2003; Hobday et al., 2005). In the second face, systems integrators coordinate distributed capabilities and learning processes carried out by networks of specialized designers, equipment suppliers, and component manufacturers (Miller et al., 1995; Hobday, 1998; Kogut, 2000; Brusoni et al., 2001; Prencipe et al., 2003; Hobday et al., 2005).

However, attention regarding this "second face" has focused almost entirely on the relationship between systems integrators and their direct suppliers. In part this reflects the assumption that this is the key relationship – that the supply chain takes the form of a "production pyramid" with a hierarchy of technological sophistication and interdependencies. In this view, sophisticated direct suppliers to the system integrator are located at the top of the pyramid and suppliers of basic components and materials are at its base (Walker et al., 1987; Sako, 2003; Hobday et al., 2005). But it also reflects the methodological challenges of gathering data on the multiple tiers of a supply chain. Thus, we know little about the structure of the extended supply chains that support systems integrators, because lower-tier suppliers have not been studied very much.

Systems integration necessarily involves innumerable make-buy decisions by the lead firm that seek both to draw specialized technology into the final product and also to capture economies of scale and scope at the supplier level to reduce the cost of the final product (Harland et al., 2001). Systems integrators may have an interest in fostering specialization among their suppliers and ensuring that suppliers' technology investments and business practices are closely aligned to the integrator's specific requirements (Dyer, 1996; Chatain and Zemsky, 2007). However, there are also circumstances in which it is in the

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interest of both buyer and supplier for suppliers to be more generic, reducing horizontal specialization and dependence on a single market, obtaining horizontal technology spill-overs from other industries, and generating economies of scale and scope. As technologies become more sophisticated and require greater R&D spending, the interest in amortizing the investment across multiple customers and markets increases (Lamming, 1993; Arora et al., 1997). Although this division of labor between suppliers that are specialized to specific customers and those that supply general-purpose technologies to multiple markets has been noted, it has not been the subject of detailed empirical examination. For example, there has been little examination of whether different types of suppliers tend to fall at different tiers of the supply chain.

In this paper, we analyze evidence drawn from a unique dataset on the supply chains for three major weapon systems currently in production in the United States. Systems integration and supply-chain management have taken on considerable importance for firm strategy and public policy in defense. Academics and policymakers have long been concerned about the extent to which firms involved in military production are specialized to the idiosyncratic needs of defense and whether the defense industry is able to access the innovations and economies of scale that characterize high-technology commercial products today. That is, they are interested in the potential economies of scope between commercial and military production (Cowan and Foray, 1995; Molas-Gallart, 1997; Gansler, 2011). By the end of the Cold War, there was a growing view that the military had become isolated from commercial technology and production as a result of technological and economic changes as well as the particularities of contracting with government. Some analysts suggest that a "wall of separation" now divides commercial and military production (Alic et al., 1992; Markusen and Yudken, 1992; Alic, 2007; Gansler, 2011). This argument, though not tested with systematic, recent data, has created great worry in national security circles about the risk that the United States might lose the technological edge that underpins its military power. In response, policymakers have used a variety of instruments to encourage more commercial firms to sell directly to the military and also to expand links between the contractors that act as systems integrators for weapon systems and non-defense (commercial) suppliers – efforts to encourage what they call "Commercial-Military Integration."

Our data enables us to empirically assess the extent to which the supply chain acts as a source of commercial-military integration, linking defense production to the wider economy. The dataset encompasses 616 facilities including a wide range of suppliers at many tiers of the supply chain, in some instances down to the fifth tier.[1] Each facility was legally required to fill out a detailed survey on their business, revenues, customers, suppliers, workforce, and other topics.[2] Studying data from all tiers of the supply chain makes an important difference to our understanding of the second face of systems integration.

We make three substantive contributions. First, we contribute to understanding of the second face of systems integration, especially the extent of systems integrators' active coordination and influence on the supply chain. Systems integrators' organization and management of the supply chain focuses on the first tier, and many suppliers at lower tiers of the supply chain have no direct contact with systems integrators. We show that facilities in lower tiers of the supply chain do not necessarily know that they supply part of a particular complex system (in this case, a weapon system). Many lower-tier facilities do not necessarily see themselves as being aligned to the particular market for the complex system (i.e., defense), let alone to a particular systems integrator. Furthermore, some lower-tier suppliers, even some of those that produce more generic components, are large and technologically sophisticated. This cautions against the view that the production pyramid is a simple hierarchy with less technologically sophisticated lower-tier suppliers at its base.

Second, our empirical evidence lends support to the proposition that industry supply chains are characterised by a division of labor between those suppliers that are specialized to specific customer markets and those that supply general-purpose technologies to multiple markets (Arora et al., 1997). We observe horizontal specialization at the first tier of the supply chain to meet the idiosyncratic needs of the customer, but we observe facilities at lower tiers that sell products or provide services used in multiple end markets (military and commercial), allowing them to capture the benefits of economies of scope. However, we also show that even some lower-tier suppliers are horizontally specialized to the defense market.

Third, we demonstrate the importance of the supply chain as a source of commercial-military integration, linking defense production to the wider economy and casting doubt on the view that there is a "wall of separation" between military production and the broader economy that prevents the U.S. defense effort from gaining access to civilian technologies. We show that the supply chains to U.S. weapon systems include many suppliers that do not focus their sales on the military market. Thus, the supply chain provides many opportunities for commercial firms and firms that serve both commercial and military customers to provide their products and expertise indirectly to the military. The supply chain provides an important mechanism for systems integrators to obtain horizontal technology spill-overs from other (non-defense) industries and to generate economies of scale and scope. Our analysis emphasizes the important role of first-tier suppliers as intermediaries between the defense-specialized systems integrators and commercial firms in the lower tiers.

Our findings have important policy implications. The U.S. government customer does not need to learn to be "more commercial" in its contracting practices, nor do non-defense firms need to learn the byways of government contracting for the defense industry to benefit from technologies in the broader economy. Rather than seek ways to encourage commercial-sector companies to contract directly with government, the Pentagon should focus on monitoring the supply-chain management practices of Tier 1 suppliers to ensure that they are both willing and able to engage with non-defense suppliers.

2. Systems integration, supplier specialization and the defense industry

2.1. The second face of systems integration

The literature on systems integration has emphasized the important role that systems integrators play as lead firms and architects of networks of suppliers. Systems integrators coordinate distributed capabilities and learning processes carried out by networks of specialized designers, equipment suppliers, and component manufacturers (Miller et al., 1995; Hobday, 1998; Kogut, 2000; Brusoni et al., 2001; Prencipe et al., 2003; Hobday et al., 2005). The capability to effectively coordinate and integrate product and service components supplied by a multitude of external suppliers is a key feature of the competitiveness of systems integrators (Davies et al., 2007). To achieve this, systems integrators must know more than they themselves manufacture. Their breadth of knowledge about the range of technologies that comprise the complex system allows them to make decisions on what to source, from

[1] Tiers are measured by supplier's network position – that is, the number of contractual relationships between the supplier and the facility that produces the final product (i.e., the systems integrator).

[2] The survey defined a facility as follows: "A company's capability to provide a set of related products and/or services. A facility often combines physical, cyber, and financial infrastructure; intellectual property; and human capital. Various parts of a facility need not be geographically co-located – for example, a single facility may combine manufacturing operations (a factory) with a geographically separated office building that contains support operations like HR and finance. Often, a facility is a group of related locations at which company employees work, together constituting a profit-and-loss center for the company, and it may be identified by a unique DUNS number." In the literature, facilities are sometimes referred to as plants, factories, or establishments. The blank survey template is available in this article's Supplementary materials.