Between Promise and Performance: Science and Technology Policy
Implementation through Governance Networks

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Abstract: This research analyzes the effects of U.S. science and technology policy on a global strategic alliance network for research and development. During the mid-1980s the U.S. high-technology sector appeared to be collapsing. Industry leaders and policymakers moved to support and protect U.S. firms by creating a program called Sematech. While many scholars regard Sematech as a success, how the program succeeded remains unclear. This study examines the role of an intermediate network mechanism residing between policy and performance. The general proposition is that governments might act to enhance inter-organizational cooperation and firm performance for public ends. This study combines network analysis and longitudinal regression techniques to test the effects of policy on firm network position and technological performance in an unbalanced panel of semiconductor firms between 1986 and 2001. This research suggests governments might achieve policy through inter-organizational innovations aimed at the development and administration of robust governance networks.

Keywords: science and technology policy; public policy; public administration; social network; governance network; inter-organizational network; social capital; strategic alliance; transaction cost economics; resource-based view; semiconductor industry; SEMATECH

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1. Introduction

Government programs for science and technology (S&T) operate under conditions of uncertainty and complexity different from other kinds of governance frameworks (Hall and Lerner, 2010). Many studies on S&T policy rely on theory developed from research programs in economics (Malerba, 2002; Nelson and Winter, 1982), business and organizational studies (Teece, Pisano, and Shuen, 1997), and patenting activities (Hall and Ziedonis, 2001). Work in this area often lacks an emphasis from public policy and administration. Bringing this perspective to the fore, this article synthesizes disparate literatures, combining elements from governance and policy networks (e.g. Klijn and Koopenjan 2015; Ansell and Gash 2007; Provan and Kenis, 2008) with elements from organization theory and strategic management (e.g. Eisenhardt and Schoonhoven, 1996; Stuart 2000). Insights from these literatures are leveraged to analyze an exemplar case of government intervention in the high-technology sector.

This study analyzes the implementation of U.S. technology policy during the early evolution of a cooperative research and development (R&D) network in the semiconductor industry between 1986 and 2001. The focus is on a U.S. Department of Defense (DOD) sponsored consortium, called Sematech, its hypothesized effects on an emerging R&D alliance network, and hypothesized effects on technological performance. The Sematech consortium was formed to provide support for the U.S. based semiconductor industry during the mid-1980s (Macher, Mowery, and Hodges 1998; Browning and Shetler 2000). Many scholars suggest the policy experiment was a success, as the downward trend for U.S. semiconductor market share was reversed and the industry remains among the top five U.S. exports with sales valued at roughly $165 billion, capturing 50% of the global market in 2015 (SIA Databook, 2016).
However, the case presents an interesting theoretical puzzle. A view from public administration might suggest that public support for the consortium lowered R&D costs for private firms, overlooking the relevance of synergies created through an evolving network of relationships. Conversely, a business view might suggest that strategic alliances enhance access to resources for competitive advantage, downplaying government support, protection from foreign participants, and ignoring a major political crisis with national security overtones. Putting the puzzle together requires a pluralistic integration of disparate disciplines and theories (Whetsell 2013). The research question of this article is, *how did Sematech achieve its success given a range of potential theoretical explanations?* An overlooked element is the intermediate network mechanism residing between S&T policy and outcomes. An empirical analysis of this mechanism, as well as its linkages to policy and performance, provides insights into the specific case but also has more general implications for government investment in science and technology.

The theoretical argument of this article is that cooperative governance structures may be useful for addressing market failures on volatile technological landscapes. The more specific theoretical logic suggest that the Sematech consortium represents a mode of network governance (e.g. Klijn and Koopenjan 2015), structured as a network administrative organization (e.g. Provan and Kenis 2008), which decreased the costs of cooperation (e.g. Oxley, 1997), improved access to complementary resources for innovation (e.g. Barney 1991; Eisenhardt and Schoonhoven, 1996), and enhanced the social capital and cooperative capacities of participating organizations for competitive advantage (e.g. Ahuja 2000; Stuart 2000; Zaheer and Bell 2005). The empirical approach of this study is to test hypothesized effects of Sematech membership on the network position of member firms, as well as test hypothesized effects of enhanced network
position on firm level technological innovation. The basic model is that the performance effects of Sematech flow through network position. In addition, this research also tests for spillover effects on strategic allies and potential effects of DOD exit from the consortium.

The following section briefly describes the historical context of the case necessary to establish a timeline of events. Section three synthesizes a set of theories from the public and private sectors to suggest hypotheses. Section four presents the data collection and analysis methods. Section five shows the results of the analysis. Section six discusses the implications of the results. Finally, we close with some concluding remarks about the subject and the study.

2. Historical Context & Case Details

Government investment in science and technology (S&T) has been a central national priority for public policy makers and administrators in the United States since at least World War II (Bush, 1945). In economic terms, S&T are curious sorts of goods. In contrast to basic goods and services, the uncertain and risky nature of S&T activities, as well as the difficulty of appropriating returns on R&D, means they tend to suffer from underinvestment in private markets, despite the more general contribution to economic growth (Arrow, 1962; Partha and David, 1994; Stephan, 1996). Science is often defined as a public good, where other actors cannot be excluded from appropriating its value, and many actors can make productive use of scientific knowledge simultaneously (Samuelson, 1954; Stiglitz, 1999). These insights suggest that pure markets do not provide the necessary resources for the conduct of basic science (Nelson, 1959). In contrast to science, technology has characteristics that make it excludable in many cases (Rosenberg, 1982). Technological processes and products may be patented and sold as private goods. Thus, private returns of technology investment may be appropriated by the
Nevertheless, pure markets for technology also tend to suffer poor incentives, high uncertainty, and weaker appropriability of value than basic consumer goods (Arrow, 1962; Stephan, 1996). The economic logic of S&T market failure has been a part of the rationale for government action since early 20th century. After World War II a mission-based logic emerged emphasizing the role of S&T in national defense and other policy or agency specific objectives. Toward the end of the 20th century a cooperative boundary spanning logic emerged which supported industrial policy and regional economic development (Bozeman 2000; Salter and Martin, 2001).

In the 1980s, the pace of technological change began to challenge older models, undermining the neoclassical distinction between public and private sectors (Smith, 1990), as well as the assumption that technology is exogenous to the production function (Romer, 1990). Exponential increases in technological performance and manufacturing costs accompanying the emergence of the microprocessor led to major changes in the competitive behavior of firms in tech-based sectors. The challenge of maintaining innovation produced significant increases in inter-firm cooperation. Strategic alliances emerged in the 1980s across several sectors. Research documenting increases in R&D-based alliances during this period suggest that private firms were increasingly collaborating to reduce risk and to share costs (Hagedoorn, 2002). Further, alterations in federal anti-trust policy, e.g. the 1984 National Cooperative Research Act, provided a more permissive atmosphere for R&D collaboration between private sector firms (Mowery 1998).

In 1985 Japanese firms took the majority global market share of semiconductor sales. This shocking development was an achievement of the Japanese organizational conglomerate system, known as the keiretsu, which resembled a networked form of organization, designed to
coordinate increasingly costly R&D activities and facilitate quicker development of strategic
technologies. Japanese firms also received strong support from major government R&D
programs (Ham, Linden, and Appleyard, 1998; Sakakibara, 1993). This development suggested
that the Japanese organizational form may have been more resilient and better adapted to
absorbing the risks associated with the new global environment for technological growth.

In response, American leaders in the semiconductor industry and Congress crafted an
innovative policy approach to address the imminent failure of the U.S. based industry. An
alignment between economic and defense interests facilitated consensus on the policy response.
The economic interests emphasized preservation of a top U.S. export, supporting high-quality
jobs, and feeding into numerous other products, i.e. a “platform technology”. The defense
interests characterized semiconductors and integrated circuits as a critical resource necessary to
maintain the cutting edge in high-technology weapon systems (Mowery 1983; Mowery and
Langlois 1996; Mowery 2009).¹ Rather than relying on subsidizing firms directly or imposing
tariffs and trade barriers, industry leaders and policy makers crafted an organizationally-based
policy solution.

The result was the non-profit public-private consortium, Semiconductor Manufacturing
Technology, referred to here as “Sematech”, created in 1987 with support from the Department
of Defense (DOD) and the Defense Advanced Research Projects Agency (DARPA). The
Sematech consortium can be characterized as a type of strategic partnership or alliance (Siegel
and Zervos 2002). The consortium began as a multilateral agreement between DOD/DARPA and
fourteen U.S. semiconductor manufacturing firms, constituting roughly 85% of U.S.
manufacturing capacity. The consortium received roughly $100 million per year for two five-

¹ The interplay of economic and defense interests can be observed in a 1989 Senate Armed Services Subcommittee on Defense Industry and
Technology hearing on The Future of The Semiconductor Industry -- https://www.c-span.org/video/?10092-1/future-semiconductor-industry
year periods from DOD/DARPA. Sematech members contributed a minimum of one-million dollars, or one percent of sales, with a fifteen-million-dollar cap. Members were also required to contribute personnel to joint R&D activities at the Fab One facility in Austin, TX. The consortium excluded foreign firms from participating from 1987-1995. DOD sponsorship and the prohibition on foreign participation ended in 1996, but Sematech continued until the present as a non-profit consortium. Figure 1 shows a timeline of events, which is demarcated into an implementation period, a maturity period, and a post-DOD period based on insights from the extant qualitative literature on Sematech (Grindley, Mowery, and Silverman, 1994; Browning and Shetler, 2000; Carayannis and Alexander 2004; Bonvillian 2013). This timeline is important to the subsequent analysis.

**Figure 1 – Timeline of Significant Events**

| Year | Event Description                                      |
|------|---------------------------------------------------------|
| 1986 | Sematech incorporated                                    |
| 1987 | Operations begin                                         |
| 1988 | DOD facility completed                                   |
| 1989 | Major shift in strategy                                  |
| 1990 | DOD exits, foreign firms permitted, subsidy removed      |

**Figure Notes** – The figure shows the timeline of significant events, which is divided roughly three periods, implementation/DOD, maturity/DOD, and post-DOD period. Two economic recessions occurred during the study period. The maturity phase occurs after a major shift from a focus on horizontal to vertical relationships in the consortium.

3. Literature Review

**Government & Networks.** The literatures on governance networks, collaborative governance, and policy networks provide useful concepts for thinking about the processes and outcomes of cross-sector policy implementation regarding inter-organizational networks (Klijn and Koopenjan 2015; Ansell & Gash 2009; Ansell 2011; Provan and Milward, 1995; Provan and
Kenis, 2008). However, scholars have not sufficiently applied these policy frameworks to science and technology policy. Klijn and Koopenjan (2015:11) define governance networks as “stable patterns of social relations between mutually dependent actors, which cluster around a policy problem, a policy programme, and/or a set of resources and which emerge, are sustained, and are changed through a series of interactions”. In this study, the imminent collapse of a U.S. industry is the policy problem, the policy program is the Sematech consortium, and the general spread of cooperative partnerships in the industry represents an emerging pattern of social relations, which depends on the combination of heterogeneously distributed resources.

Ansell and Gash (2009:544) define collaborative governance as “A governing arrangement where one or more public agencies directly engage non-state stakeholders in a collective decision-making process that is formal, consensus-oriented, and deliberative and that aims to make or implement public policy or manage public programs or assets.” Here the Department of Defense (DOD) enticed U.S. private sector firms to engage in cooperative decision-making to prevent the failure of the U.S. based semiconductor market. The consortium engaged in a highly collocated, face-to-face effort to conduct “pre-competitive” R&D on manufacturing process technology. The combination of heterogeneously distributed resources of member firms suggests the potential for joint advantage. Further, the benefits of the resulting pre-competitive R&D were to be shared among the members and applied for competitive advantage relative to foreign firms, primarily in Japan. DOD played a hands-off role, allowing the firms to establish routines of self-governance and leadership (Beyer & Browning 1999). There were also no restrictions on alliance formation with foreign firms outside of the Sematech consortium (Browning & Shetler 2000).
The concept of a policy network further adds to the study. Many different streams of research fall under the broad framework of policy networks in public affairs, and many different competing definitions have been offered (Borzel 1998). Rhodes (2006) provides a definition that is both useful for the case at hand and broad enough to encompass many other cases. Rhodes (2006: 426) defines policy networks as “sets of formal institutional and informal linkages between governmental and other actors structured around shared if endlessly negotiated beliefs and interests in public policy making and implementation”. From this broad definition flows a more specific conceptual device, called a network administrative organization (NAO). Provan and Kenis (2008:236) define NAOs as separate administrative entities, usually government organizations or non-profits, which serve as governance mechanisms that coordinate and sustain the network of interactions between organizations, whether public, private, or non-profit.

The governance and policy networks concepts have been applied to S&T studies in a few cases. Kash and Rycroft (1998) suggested that network governance is necessary to create shared vision and establish self-organizing governance strategies and structures that coordinate increasingly complex interactions for technological innovation in the micro-electronics industry. Lyall (2007) applies the policy network concept to analyze participatory decision making in Scottish biotechnology sector, suggesting that domination by public sector organizations can suppress requisite self-organization in policy networks. Wardenaar, de Jong, and Hessels (2014) apply network governance concepts to suggest how institutional environment and internal organization lead to different governance forms and coordination approaches among Dutch research consortia.

However, the governance and policy networks literatures have several limitations. The application of these frameworks to S&T policy is somewhat limited. As Laranja (2012)
suggested, network governance lacks a comprehensive theoretical application to S&T innovation. More generally, Berry et al. (2004) suggested there is a lack of attention to policy network evolution. Similarly, Provan, Fish, and Sydrow (2007) suggested that more attention needs to be paid to the dynamics of policy networks over time and the effect of networks on outcomes. There are also limitations regarding the conceptualization of government intervention in private sector networks. In the public administration literature, the focus is often on directive relationships between principals and agents (Provan and Milward, 1995), resource-dependencies (Rethemeyer and Hatmaker, 2008), and power dynamics (Saz-Carranza, Iborra, Albareda 2016). This approach can be limiting in a private sector context, since conceptualizing network relationships in terms of power-based dependencies fails to explain the strategic decision-making processes of private firms. Rather, it may be more useful define the role of government as a potential catalyst for cooperation between competitors on scientific and technological landscapes (Kash and Rycroft 1998). Finally, while the governance and policy networks literatures provide important descriptive concepts (cf. Provan & Lemaire 2012), they do not necessarily motivate specific hypotheses about the effect of government on network dynamics or organizational performance in the S&T context. The following section integrates these frameworks with theories necessary for articulating more localized hypotheses about how the governance network approach might be used to enhance cooperation and innovation in the high-technology sector.

**Transaction Costs, The Resource-Based View, and Social Capital.** The application of transaction cost economics (TCE) provides a robust explanatory framework for strategic alliance behavior in the semiconductor industry (e.g. Oxley, 1997; Yasuda, 2005; Leiblein and Macher, 2009). With the rapidly rising costs of R&D essential to semiconductor manufacturing, vertically integrated but isolated firms in pure competition could no longer maintain the miniaturization
trajectory of Moore’s Law (Epicoco, 2013). Strategic alliances emerged to facilitate the kind of close cooperation necessary for continual innovation. However, cooperation is not frictionless. As Williamson (1981;1985;1991) argued, the transaction costs of cooperation emanate primarily from the uncertainty and opportunism associated with human nature. These factors are particularly salient when cooperative transactions are uncertain, recur frequently over time, and assets are transaction specific, all of which characterize cooperative R&D for high-technology. To reduce transaction costs, cooperative alliances in the semiconductor industry are often governed by a mix of bilateral and multilateral cross-licensing, co-development, and joint venture contracts.

Applying the logic of transaction costs, Oxley (1997) reasoned that transaction costs increase with each additional R&D alliance partner, showing that alliance scope is associated with increasingly hierarchical forms of governance. Multi-firm alliances are common in the semiconductor industry because innovation often requires the application of resources by multiple firms, and greater efficiency may be achieved through a single multilateral governance structure rather than through a series of bilateral agreements. Multilateral alliances may also propagate effects on the broader network of relationships (Persidis and Persidis, 1996; Medcof, 1997; Hwang and Burgers, 1997). In terms of network theory, multi-firm alliances could be treated as cliques, where all possible pathways between partners are realized. This suggests a greater capacity for sharing and combination of resources and especially knowledge (Hage, Jordan, & Mote 2007). Such configurations may also facilitate the emergence of network safeguarding mechanisms (e.g. Jones, Hesterly, Borgatti 1997). However, large multi-firm alliances come with even greater costs (Li et al., 2012; Gudmundsson, Lechner, and Van Kranenburg, 2013).
At a certain point the costs of additional alliance partners may overwhelm the benefits. When the objectives of such alliances are public in nature or when governments view them as necessary to fulfill public objectives, publicly supported governance regimes, such as network administrative organizations (NAOs), might provide a supportive structure. TCE interfaces with the governance and policy networks literature, suggesting that NAOs might reduce the costs of large-scale cooperation. Williamson (1999) makes a very similar argument about the necessity of government to maintain transaction costs between nations embodied in the U.S. Department of State. Synthesizing these insights from the governance networks and transaction cost literatures, we hypothesize that Sematech enhanced the network centrality of member firms by lowering the costs associated with cooperation on pre-competitive research and development.

**H1: Sematech enhances the network centrality of member firms relative to other firms within an emerging strategic alliance network**

The resource-based view (RBV) suggests that firms gain an advantage by applying resources in a competitive environment (Wernerfelt, 1984). Barney (1991:101) defines resources as “all assets, capabilities, organizational processes, firm attributes, information, knowledge, etc. controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness”. The RBV highlights the importance of difficult or impossible to trade (often intangible) resources in explaining performance heterogeneity and persistence (e.g., Barney, 1991; Dierickx and Cool, 1989). The RBV also calls attention to information and knowledge as a resource feeding into organizational performance (Grant and Baden-Fuller,
In the high-technology sector, information, knowledge, and intellectual property are among the most critical resources for competitive advantage.

Extensions of the RBV through social capital theory suggests that social relationships provide access to heterogeneously distributed resources (Eisenhardt and Schoonhoven, 1996; Tsai and Ghoshal, 1998; Nahapiet and Ghoshal, 1998). Social capital theory focuses attention on the ways in which firms seek to leverage their relationships for competitive gain (Burt, 1992, 1997; Lin 1999). Provan & Lemaire (2012) suggest that organizations gain the advantages of social capital when they form network ties. As Walker, Kogut, and Shan (1997) suggest, the resource view of social capital is concerned with the advantages of relationships for individual firms, rather than emphasizing group level processes, such as influence, status, and prestige (e.g. Putnam, 1995; Podolney, Stuart, Hannan 1996). For the purposes of this article, we use Burt’s (1992) conceptualization to suggest why the technological innovation of the firm depends to some extent on strategic alliances.

Previous research has examined the effects of alliance formation on performance and innovation in the semiconductor industry (Eisenhardt and Schoonhoven, 1996; Stuart 2000; Hill, Jones, and Schilling, 2014; Schilling 2015), as well as the effects of firm positioning within alliance networks on performance (Ahuja 2000). Studies have examined the effects of network centrality on organizational performance (Zaheer & Bell 2005; Koka & Prescott 2008). Social capital extensions of the resource-based view suggest that network centrality measures a firm’s access to heterogenous and immobile resources in the network (Walker, Kogut, & Shan 1997). Leveraging these insights, we advance the following hypothesis.
**H2:** *Network centrality enhances the technological performance of firms in the strategic alliance network.*

Connecting the logic of H1 and H2 entails that Sematech membership enhances the technological performance of member firms through enhancements in network position. This logic suggests a mediation model (e.g. Baron & Kenny 1986; Aguinis et al. 2017). Thus, we hypothesize that the direct performance effects of Sematech membership flow through its effects on the network position of member firms.

**H3:** *Network centrality mediates the effects of Sematech membership on technological performance relative to other firms in the strategic alliance network.*

Since network processes are relational we suspect that strategic allies of Sematech members will experience similar enhancements in network position and technological performance relative to firms not directly connected to Sematech members. This is similar to the logic of policy diffusion (e.g. Shipan & Volden 2012), but the focus here is on the policy effects on technological diffusion through network spillovers. The spillover hypothesis was advanced by previous studies (Irwin and Klenow, 1994) but has never been directly applied to this case through network analysis. Here, Sematech is thought to have secondary social capital effects, or spillovers, on allies of Sematech members.

**H4:** *The network and performance effects of Sematech membership spillover onto strategic allies of Sematech members relative to other firms in the alliance network.*
Finally, the timeline of events displayed in Figure 1 suggests that the development of Sematech within the strategic alliance network moved through three periods during the study period: implementation, maturity, and post-DOD. Since technological performance data are not available for the implementation period, the maturity period is compared to the post-DOD period. Quasi-experimentally, this amounts to a removed treatment effect of DOD exit. Thus, the final hypothesis is stated as follows.

\[ H_5: \text{Sematech and network effects are stronger during the maturity period than in the post-DOD period.} \]

4. Methods

Data. To construct a panel for the study period (1986-2001), alliance data were gathered from two sources. First, from 1986-1989 alliance data were gathered from public announcements compiled through press releases and other public news announcements. Second, alliance data from 1990-2001 were extracted from the ICE/IC Insights Strategic Profiles Reports on the global semiconductor industry. The first data source reports only announcements, while the second also reports ongoing alliances. The early data between 1986 and 1989 likely undercounts alliances. Data on firm sales and technological performance were also gathered from these sources. Missing data was gathered from COMPSTAT/CRSP via WRDS, Bloomberg, S&P Capital IQ, and PrivCo. Sematech membership data were acquired from a contact with Sematech. Since data on technological performance is only available starting in 1990, the sample frame for models using technological performance was reduced to 1990-2001.
The network data were constructed in the following manner. All alliances listed in the ICE/IC Insights profiles were aggregated yearly and constructed as symmetrical adjacency matrices, a common method for analyzing whole-networks over time (Wasserman and Faust, 1994). Each year-matrix is one-mode and undirected, with binary values that represent the presence or absence of an alliance edge between firm nodes. Isolates were not included. The edge weights for each year were set to one to handle cross-listing of alliances in the IC Insights profiles. After constructing the yearly adjacency matrices, they were analyzed, and node level network statistics were calculated using the network analysis program Gephi. Node level measures from each whole-network year were then extracted and merged with firm level panel data. Figure 2 shows the development of these networks across the time-period. In these visualizations. A conservative approach is taken in the networks, where ties between Sematech members are not included unless they are alliances external to the consortium.
Table 2.1 – Yearly Strategic Alliance Network 1986-2001

**Figure notes** – The networks are constructed as one mode, undirected adjacency matrices, where edges are alliances and nodes are firms. Red nodes are Sematech members, and red edges are connections with Sematech members. Red nodes in 1986 show the future Sematech members. Nodes are sized by degree centrality. Alliances from 1986-1989 are likely undercounted due to different method of collection.
Sample. Sematech members include large and medium sized integrated circuit manufacturers. The original members included AMD, AT&T, Digital, Harris, HP, IBM, Intel, LSI Logic, Micron, Motorola, NCR Corp, National, Rockwell, and TI. Few changes in consortium membership occurred in the implementation phase; it lost members during the maturity phase; and the consortium increased in size as foreign firms joined in 1996. Despite being prominent firms, the collective performance crisis for U.S. firms (Hof 2011) may temper bias from initial selection into Sematech and subsequent performance. The larger sample of semiconductor firms included in the broader alliance network captured through the IC Insights Profiles. These include a heterogenous group of large, medium, and small firms, as well as manufacturers, suppliers, and pure-play IP foundries. The goals of the consortium partners were different, and their heterogeneity suggest potential gains from trade. A small number of Sematech members were not included in the analysis if they also did not appear in the alliance data from IC Insights. Since firms with no recorded alliances are not included, the analysis is limited only to those firms with alliances.

Measures. Eigenvector centrality (E.Centrality) was chosen as the network position variable characterizing organizational network position. Eigenvector centrality (also called Bonacich centrality) measures how well-connected a firm is to other well-connected firms in the network (Borgatti, Jones, and Everett 1998; Zaheer, Gözübüyük, and Milanov, 2010). This variable captures both direct and indirect effects and is among network measures known to impact firm performance (Uzzi, 1996; Zaheer and Bell, 2005). The variable is suitable to the hypothesis which suggests that being connected to other well-connected firms will enhance access to complementary resources necessary for innovation at the cutting edge.
The variable for technological performance (Tech-Performance) is the minimum integrated circuit feature size that a firm can produce, given yearly data available on manufacturing facilities. This is a unique measure specific to the semiconductor industry, where the minimum integrated circuit feature size is an objective measure of technological sophistication. This variable has been used previously in studies on the semiconductor industry (Eisenhardt and Schoonhoven 1996; Leiblein, Reuer, and Dalsace 2002). Since the measure is defined in terms of a continuously decreasing minimum, this variable is reverse coded to be consistent with performance.

The policy variables include Sematech and S.Partners. Sematech is a nominal variable, taking the value of 1 if the firm is a Sematech member at time $t$, and 0 otherwise. S.Partners is also a nominal variable taking the value of 1 if a firm has a strategic alliance with a Sematech member at time $t$, and 0 otherwise. The control variables include Org.Size and US. We operationalize firm size in terms of annual revenue or sales in millions. Measures such as employee count are likely to be contaminated by the decision to vertically integrate into production or assembly. More specifically, organizational size is operationalized as a three-year moving average of total sales. A moving average was used given the cyclical and volatile nature of sales in the semiconductor industry. Finally, US captures the nationality of the headquarters of the firm; the variable takes a value of 1 for US firms, and 0 otherwise.

**Methods.** The primary method of analysis employed is the mixed-effects model, which combines elements from fixed and random effects models. The mixed effects model is a generalization of the standard linear model, which allows for modeling the means and the variance/covariance of the data (Littell et al., 2006). Mixed models were chosen to account for correlation within repeat observations on firms without loss of meaning regarding fixed firm
characteristics (see Allison, 2005), such as firm nationality, Sematech membership which only occasionally changes for some firms, and for technological performance which often remains identical for multi-year stretches of time. Since the modeling strategy is to compare models in two separate four-year periods (Table 3), there isn’t enough variability to produce useful estimates in fixed effects models. However, robustness checks were conducted using firm and year fixed effects on the full time period (Table 4). In the mixed effects model, the unique firm identifier is the covariance parameter, which is modeled as a random effect for repeat observations over time. The variance components of the random parameter (firm id) include a covariance estimate and a residual. These two pieces of information are used to calculate the intraclass correlation (ICC), which estimates the amount of variability in the outcome accounted for by the firm identifier and the residual (Allison, 2005).

5. Results

Table 1 presents the descriptive statistics and bivariate correlations between all the variables used in the subsequent models. The bivariate correlations show significant relationships between Sematech members (Sematech), network position (E.Centrality), and technological performance (Tech-Performance), and a similar but weaker pattern is observed for allies of Sematech members (S.Partners). Additionally, E.Centrality has a significant positive association with Tech-Performance. The existence of these intercorrelations conform with expectations and suggest the need for multivariate analysis.
Table 1 – Descriptive Statistics and Correlation Matrix

| Variable     | N   | Mean | Std Dev | Min | Max | 1  | 2    | 3    | 4    | 5    | 6    |
|--------------|-----|------|---------|-----|-----|----|------|------|------|------|------|
| 1 - Sematech | 3200| 0.058| 0.23    | 0   | 1   |    |      |      |      |      |      |
| 2 - S.Partners|3200| 0.154| 0.36    | 0   | 1   | -0.106 | 1   |      |      |      |      |
| 3 - Tech-Performance | 966 | 59.317| 29.54 | 1 | 104 | 0.259 | 0.086 | 1   |      |      |      |
| 4 - E.Centrality | 1962 | 0.167| 0.214 | 0 | 1   | 0.464 | 0.191 | 0.468 | 1   |      |      |
| 5 - Org.Size  | 2581| 592.539| 1602 | 0.027 | 26260 | 0.465 | 0.001 | 0.372 | 0.534 | 1   |      |
| 6 - US        | 2986| 0.687| 0.464 | 0   | 1   | 0.076 | 0.003 | -0.155 | -0.029 | -0.100 | 1   |
| 7 - Year      | 3200| 1995 | 4,222 | 1986 | 2001 | -0.037 | 0.097 | 0.538 | 0.105 | 0.116 | -0.086 | 1 |

Table notes: The table shows the descriptive statistics and the correlation matrix of all variables used in the analysis.

Figure 3 shows the comparison of mean values for eigenvector centrality across the study period for 1) Sematech members, 2) partners of Sematech members, and 3) non-members/non-partners. 1986 shows the mean value for future members in 1987 prior to Sematech formation. The figure shows that each group begins at similar levels of network centrality. Then, Sematech members and partners of Sematech members experience dramatic increases in centrality across the period, with reductions after DOD exits the consortium. It should be reiterated that 1986-1989 report only contemporary announcements and do not report ongoing alliances, likely undercounting alliances in the network during this period. Further, a conservative approach was taken for the full analysis in which ties between Sematech consortium members were not included in the networks; hence, productive alliance ties between Sematech members are also underestimated in these models.
Figure 3 – Sematech & Eigenvector Centrality

![Graph showing eigenvector centrality for Sematech members, allies of Sematech members, and non-member/non-allies over a 16-year period.](image)

**Figure notes** - The figure shows the average eigenvector centrality for Sematech members (+), allies of Sematech members (o), and non-member/non-allies (x), yearly across a sixteen-year period. Sematech was formed in 1987. Thus, 1986 shows the centrality of future members in 1987. 1987-1991 is the implementation phase. 1992-1995 is the maturity phase. 1996 is the beginning of the post-DOD phase.

Figure 4 shows the comparison of mean values for technological performance across the study period for 1) Sematech members, 2) partners of Sematech members, and 3) non-members/non-partners. A similar trend to Figure 3 is observed. However, the trend appears much smoother. All firms experience an increase in technological performance across time; Sematech members have lower performance in 1990; but Sematech members and their allies experience greater gains.
Figure 4 – Sematech and Technological Performance

**Figure notes** - The figure shows the average technological performance for Sematech members (+), allies of Sematech members (o), and non-member/non-allies (x), yearly across a twelve-year period. 1992-1995 is the maturity phase. 1996 is the beginning of the post-DOD phase.

Hypothesis tests are presented in Table 2, which has eight mixed effects models, separated by DOD period and post-DOD period. As is illustrated in Figure 1, 1992-1995 represents the maturity period of Sematech, where the consortium receives DOD support and protection; after 1995 represents the post-DOD period, where support is removed, and foreign firms are permitted entry. These four-year windows were chosen to avoid impacts of two major economic recessions occurring around 1990 and 2000. Technological performance data was unavailable during the implementation period, between 1987 to 1990.

Model 1 in table 2 shows that Sematech and S.Partners have much larger estimates on E.Centrality than non-members, providing support for hypothesis one and hypothesis four. Model 2 shows that Sematech members also have a larger estimate Tech-Performance, but S.Partners do not. Model 3 shows that the E.Centrality is significantly associated with Tech-Performance, providing support for hypothesis two. Model 4 shows that when including
E.Centrality in the same model with Sematech, the estimate on Sematech is reduced from 19.452 to 10.039 and the estimate is no longer statistically significant (p, 0.12), providing support for mediation in hypothesis three. Following the mediation analysis procedure by Baron & Kenny (1986), the results of models 1-4 suggest E.Centrality acts as a mediator through which the performance benefits of Sematech flow. The Sobel Test also suggested the indirect effect of Sematech (T-stat, 4.17; p,0.00003) on tech-performance via network centralit is significantly different from zero (see Preacher & Leonardelli 2001).

Hypothesis four, regarding the spillover effects on partners of Sematech members, is supported in some models but not others. Being an ally of Sematech had a significant estimate on E.Centrality but not directly on Tech-Performance. However, the mediation hypothesis may apply to allies of Sematech members since the estimate on the mediator is significant, and the mediator estimate is significant on performance -- Aguinis, Edwards & Bradley (2017) suggest that the direct effect on the outcome variable is actually not necessary to establish mediation. Further, the Sobel Test suggested a significant mediation effect (T-Stat,2.95; p, 0.003).

Very similar patterns are observed in the post-DOD period from 1996 to 1999. However, there are important differences. Model 5 shows that Sematech’s estimate on E.Centrality is larger in the post-DOD period. Yet Model 6 shows a reduced estimate of Sematech on Tech-Performance. Similarly Model 7 shows that E.Centrality has a lower estimate on Tech-Performance. Model 8 shows that Sematech retains a larger estimate despite including E.Centrality in the model, but with a p-value of only 0.063, indicating only a partial mediation effect (e.g. Baron & Kenny 1986). The Sobel Tests for Sematech (T-stat, 2.81; p, 0.005) and S.Partners (T-stat,2.77; p,0.006) showed the indirect effects are statistically different from zero.
These results provide support for hypothesis five, which specifies that estimates in hypothesis one through four are larger during the DOD/Maturity period and smaller in the post-DOD period.

Table 2 – Mixed Effects Models: Mediation Analysis, DOD & Post-DOD Periods

|                  | E.Centrality | Performance | Performance | Performance | E.Centrality | Performance | Performance | Performance |
|------------------|--------------|-------------|-------------|-------------|--------------|-------------|-------------|-------------|
| **DOD Period (1992-1995)** |              |             |             |             |              |             |             |             |
| Intercept        | 0.151***     | 50.49***    | 41.552***   | 43.06***    | 0.116***     | 76.256***   | 71.88***    | 72.744***   |
|                  | (0.02)       | (3.881)     | (3.803)     | (3.921)     | (0.023)      | (3.827)     | (3.995)     | (3.984)     |
| Sematech         | 0.216***     | 19.452**    | 10.039      | 0.263***    | 16.618**     | 10.721      |             |             |
|                  | (0.041)      | (6.899)     | (6.43)      | (0.043)     | (5.826)      | (5.722)     |             |             |
| S. Partners      | 0.036**      | 1.087       | -0.099      | 0.068***    | -2.811       | -4.118      |             |             |
|                  | (0.011)      | (2.117)     | (2.061)     | (0.012)     | (2.236)      | (2.108)     |             |             |
| E.Centrality     | 48.954***    | 46.703***   |             | 23.317***   | 21.067**     |             |             |             |
|                  | (6.624)      | (6.825)     |             | (6.401)     | (6.64)       |             |             |             |
| Org.Size         | 0.00005***   | 0.004**     | 0.003*      | 0.002       | 0.00004***   | 0.002       | 0.002       | 0.001       |
|                  | (0.00001)    | (0.001)     | (0.001)     | (0.001)     | (6.4E-06)    | (0.0009)    | (0.0008)    | (0.0008)    |
| US               | -0.013       | -3.346      | -2.491      | -4.364      | 0.006        | -6.941      | -9.217*     | -9.184*     |
|                  | (0.022)      | (4.455)     | (3.896)     | (4.071)     | (0.026)      | (4.441)     | (4.402)     | (4.381)     |
| Year             | Fixed        | Fixed       | Fixed       | Fixed       | Fixed        | Fixed       | Fixed       | Fixed       |
| AIC              | -767.5       | 2521.2      | 2345.1      | 2333.7      | -668.9       | 2519.2      | 2331.8      | 2313.8      |
| Firm Est.        | 0.012        | 403.79      | 302.09      | 301.89      | 0.025        | 450.15      | 414.08      | 410.99      |
| Residual Est.    | 0.007        | 124.63      | 116.91      | 116.61      | 0.008        | 118.91      | 104        | 100.29      |
| ICC              | 0.619        | 0.764       | 0.721       | 0.721       | 0.762        | 0.791       | 0.799       | 0.804       |
| Num.Orgs         | 196          | 196         | 161         | 161         | 231          | 231         | 192         | 192         |
| N                | 537          | 300         | 283         | 283         | 576          | 281         | 281         | 281         |

Table 3 shows the robustness checks for the process model using two-way fixed effects models with year and organization fixed effects. The fixed effect model estimates the within rather than between organization effect and controls for omitted fixed variables. Due to low variability in Sematech membership and the outcome variable on separate four-year periods, these models are used on the full time period. The models in table 3 show a similar patter with the notable difference that Sematech remains significant in the final mediation model. This is
consistent with combining the DOD and post-DOD periods in one analysis, since membership rapidly changed in 1996 due to entry of foreign firms in the consortium, only a partial mediation effect is suggested by the post-DOD period analysis in table 2. The Sobel Test is not significant (T-stat,1.82; p,0.067), failing to provide support for the mediation hypothesis.

**Table 3 – Fixed Effects Models: Mediation Analysis, Full Period**

|                | Full Period (1992-1999) |
|----------------|-------------------------|
|                | E.Centrality | Performance | Performance | Performance |
| Intercept      | 0.003        | 48.705***    | 46.036***    | 46.374***    |
|                | (0.100)      | (5.563)      | (6.952)      | (6.885)      |
| Sematech       | 0.085**      | 9.906**      |             | 9.660**      |
|                | (0.029)      | (3.523)      |             | (3.449)      |
| S. Partners    | 0.052***     | -1.524       | -1.732       |             |
|                | (0.009)      | (1.535)      |             | (1.517)      |
| E.Centrality   |             |             | 12.456*      | 11.974*      |
|                |             |             | (5.106)      | (5.121)      |
| Org.Size       | 0.000**      | -0.000       | -0.000       | -0.000       |
|                | (0.000)      | (0.001)      | (0.001)      | (0.001)      |
| Firm ID        | Fixed        | Fixed        | Fixed        | Fixed        |
| Year           | Fixed        | Fixed        | Fixed        | Fixed        |
| R2             | 0.835        | 0.864        | 0.865        | 0.868        |
| N              | 1114         | 600          | 564          | 564          |

*p<.05,*p<.01,**p<.001***; standard errors in parentheses

**6. Discussion**

This study casts light on policy implementation through cross-sector inter-organizational networks. The empirical contribution is to reveal a previously invisible domain of cooperative activity. The results suggest policy effects on technological performance outcomes may be partially mediated through an organization’s network position. By examining the dynamics of strategic cooperation in the formal R&D contract network of the semiconductor industry, this
study suggests that network governance can play a part in the recovery and prosperity of the high-technology sector.

This study contributes to the governance and policy networks literatures by suggesting how a technology policy program might be constructed as a device for facilitating cooperation between private-sector firms for public ends (e.g. Ansell and Gash 2007; Provan and Kenis, 2008; Emerson and Nabatchi 2015). Studies of organizational performance often avoid analyzing the relevance of government in explanations of strategic alliance behavior and firm performance, relying only firm-based resources (e.g. Barney 1991) and horizontal social relations (e.g. Burt 1997). Conversely, studies of science and technology policy tend to feature business and economics perspectives. Lambright (2008) examined the politicization of science, suggesting the need for analysis of S&T from a public policy and administration perspective and the need for strengthening relations between government and science. Scholars in public administration have analyzed the downstream process of contracting for military technology, such as the A-12 Avenger (Brown, Potoski, Van Slyke, 2018). But what are governments to do if U.S. markets for these products fail, or if such vendors no longer have access to cutting edge platform technology, especially given the prospect that weapon systems or components must then be purchased from foreign nations and potential adversaries?

This study further extends the governance network, policy network, and network administrative organization (Provan & Kenis 2008) concepts to the areas of science and technology (e.g. Lyall 2007; Laranja 2012; Wardenaar, de Jong, and Hessels 2014). The results suggest that a government sponsored consortium may be conceptualized as a network administrative organization which might affect the network position of key firms in a public policy relevant industry. One advantage of studying Sematech as a governance network (Klijn &
Koppenjan, 2015) and a network administrative organization (Provan & Kenis 2008) is that the theoretical tools used to analyze the private sector have been brought into public focus.

Conversely, rather than conceptualizing the study only using theories common to the analysis of policy networks, such as resource-dependency or principal agent theory, the combination of policy frameworks with theory from business and economics broadens the perspective beyond power asymmetries and dependencies between private firms and central public agencies. Thus, the present study integrates the governance and policy networks frameworks with transaction costs economics, the resource-based view of the firm, and social capital theory, to explain how government action can both remedy market failures and catalyze innovation for increasing returns on investment.

**Limitations.** First, selection bias remains an issue in studies that do not use randomized selection for treatment and control groups. It may be possible that Sematech members self-selected into Sematech because they were already well performing firms. While there is likely some truth to this statement (in relative terms), it is important to bear in mind that Sematech was created to save failing U.S. business from foreign competition. Further, studies that estimate the effects of Sematech (Irwin and Klenow 1996; Link, Teece, and Finan 1996) show positive impacts on performance, but these do not examine the intermediary network effects. Further, the expectation is that Sematech is expected to have spillover effects on partners of Sematech members and on non-members, which further contaminates distinct group effects. Second, the chicken and egg problem between network position and performance persists, since firms that perform well will experience greater popularity in a competence-based collaboration network, i.e. preferential attachment in social networks (Wagner & Leydesdorff 2005). Third, it is unclear how the findings might generalize to other industries. For example, the network administrative
organization model might not generalize effectively to industries with low levels of collaboration, where collaboration accounts for only a small or no portion of performance (cf. Provan & Lemaire 2012). Further, it is also unclear whether this approach would be appropriate in areas where strong principal-agent assumptions are necessary to maintain accountability (e.g. inherently government functions). Finally, the uneven data coverage across variables, the lack of network and performance data on years prior to the creation of Sematech and performance data during early implementation limits the analysis to mostly associational claims. Hence, while we believe the analysis supports the hypothesis, we avoid causal claims regarding the analysis.

7. Conclusion

The conclusions of this study are 1) that science and technology (S&T) are properly viewed as public or quasi-public goods, 2) markets for science and technology are prone to inefficient resource allocation and market failures, and 3) governments might achieve enhanced outcomes in these markets by supporting governance networks that might produce efficient resource allocation and recombination. This study suggests that S&T policies can enhance performance outcomes for firms engaged in strategic alliances by strengthening the institutional bridges that span the boundaries between firms, markets, and sectors. Further, rather than utilizing blunt policy instruments, such as direct subsidies or trade tariffs, the organizationally-based consortium approach might catalyze local level cooperation, stimulate self-organization on dynamic technological landscapes, and enable synergies for collective advantage.

The findings may be generalized beyond the semiconductor industry to other sectors of interest to policymakers. For example, a comparison of the case of Sematech to emerging competition between the U.S. and China on artificial intelligence (AI) is striking. Rather than
treated the issue as a “trade war” with trade tariffs and direct subsidies, implementation of industrial policy on AI could benefit from the network governance approach. Observers have suggested that Sematech is a model of industry-government cooperation (Hof, 2011), which might be applied to other areas. However, this study also points to the limitations of network governance because specific conditions appear to be critical for success. Cooperative policy instruments, such as the public-private consortium model, may be impossible to implement in sectors without a history of cooperative activity or in domains where inter-organizational networks are sparse or non-existent. Further, these types of arrangements may be inappropriate in sectors where strong principal-agent relations of hierarchical dependence are necessary to ensure accountability for inherently governmental functions. Finally, as Kingdon (1984) suggested, collective emergencies are often necessary to produce a cooperative atmosphere and a sense of urgency where leaders at odds might find common ground to pass legislation through windows of opportunity.
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