Innovation, Resources and Investment Strategies in the US Energy Sector

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Abstract

Recent studies show that the US energy sector’s investment (particularly by the private sector) in technology development and innovation has been declining, lagging behind other sectors in the economy, and mainly focused on the fossil fuel-based areas related to the needs of the oil and gas industry. In this paper, we offer new insights on whether the U.S. energy sector has optimally managed the deployment of different types of slack (unused) resources in pursuing investment in R&D and new technologies vs. existing assets and core efficiencies. Using a multi-industry sample of technology-intensive firms provided by the Boston Consulting Group (BCG), our results provide important evidence showing that, beyond macroeconomic influences, firm-specific factors have played an important role in explaining the energy sector’s observed lack of adaptability. Energy sector’s slack resources and R&D investment profile was found, on average, to be markedly different from those in other sectors. The energy sector did not pursue a balanced investment strategy by simultaneously exploiting existing assets and exploring new opportunities – being ambidextrous. Energy was the most “exploitative” and the least “explorative” sector with the highest (the lowest) average capital expenditures (R&D) intensities among the remaining sectors in the sample. The results also show that, in terms of longer-term profitability, the energy sector was significantly outperformed by the majority of other technology-intensive sectors.

From a public policy perspective, our results call for more effective regulatory and tax policies focused on enhancing private-sector investment in energy innovation. We further believe as more adaptable technology intensive companies achieve higher profitability over time, energy firms will be pressured to better manage the balance between their slack resources and investment strategies to achieve higher performance through innovation.
1 Introduction

Within an intensely competitive and interdependent global landscape, there is a serious need for a revolution in energy technology and innovation to address fundamental risks including energy and national security, environmental sustainability (ongoing reliance on fossil fuel), and economic viability. Recent studies, however, find that overall investment in energy technology and innovation is declining both in the US and globally (Nemet and Kammen, 2007; Wisenthal et al., 2009; and Doolley, 2010). Data from the National Science Foundation (NSF, 2010a,b) shows that energy R&D in 2008 represented less than 0.8% of the total energy expenditure in the US. On the other hand, for the US economy as a whole, the total R&D in 2008 represented 2.8% of the economy making the ratio of R&D to total expenditure 3.5 times lower for energy than for the economy as a whole. Further, Wiesenthal et al. (2009) estimate that in total, U.S. energy R&D was 1.1% of all U.S. R&D in 2007, while in the European Union (EU) member states, energy was 2.9% and in Japan 15.2% of their total R&D expenditures, respectively.

Globally, the decline in energy innovation investment is most acute in the private sector, and particularly in the US, whose innovation and technology deployment decisions drive much of the world’s economic activities. Further, in the US, the private sector’s support for energy R&D has been dominated by fossil fuel-based energy investment, mainly related to the needs of the oil and gas industry. Energy companies have been more committed to create incremental innovation to enhance efficiency in their core businesses (fossil fuel) as opposed to investing more aggressively in breakthrough opportunities in environmentally significant energy areas (wind and solar) and new technologies. As the worldwide demand for energy is expected to increase by about 40 percent over the next twenty years, the energy sector appears to be unprepared (or unwilling) to address emerging technological and environmental challenges and opportunities (IEA, 2009 and EIA, 2010).

Previous studies have taken a macro perspective to study energy innovation. Their findings provide support for the impact of some common factors such as regulatory changes, industry consolidation, and oil price volatility in explaining the aggregate pattern of R&D energy investments over time (Anadon et al. 2011; Henderson and Newell, 2010; Nemet and Kammen, 2007; and Doolley, 2010). While these macro insights have been useful, the economic and strategic dynamics of energy R&D investment at the firm level have remained unclear and unexplored. From a public policy perspective, it is equally important to find out the extent to which firm-specific factors may also play a role in explaining the energy firms’ observed lack of adaptability and commitment to innovation, mainly reflected in a systematic decline in aggregate R&D investment over time.

Building on the earlier research from finance and strategy fields (see, for example, Kraatz and Zajac, 2001; Voss, Sirdeshmukh and Voss, 2008; and Brown and Petersen, 2011), Jalilvand
and Kim (JK) (2012) have recently developed new perspectives on the dynamics underlying the relationship between organizational adaptability, resources flexibility and performance. They contend that under general capital market imperfections (i.e., information asymmetries, costly default and constrained access to capital markets), firms achieve superior performance by maintaining a matched (aligned) position between their overall flexibility (captured by different types of slack resources) and their investment opportunity sets (options to invest in assets in place vs. future growth opportunities and innovation). Their findings show that adaptive firms tend to follow the resources and investment matching principle over time to strike the right balance between the need to enhance efficiency vs. strengthening future viability through innovation and breakthrough technological development. JK’s (2012) approach has direct relevance to examine the dynamics of R&D investment in the US energy sector during the past several decades. Specifically, it will help unravel the question on whether US energy firms have optimally managed the relationship between their overall slack resources and investment strategies. It should further provide policy makers with a more comprehensive perspective on the dynamics underlying the energy sector’s overall investment in innovation and technological development.

The balance of this paper is organized as follows. Section two provides a general background on the US energy sector’s investment in technology and innovation since the inception of the Arab Oil Embargo of 1973. Section three synthesizes the previous literature on organizational adaptability focusing on the relationship between a firm’s slack resources, investment strategies and performance under different market and competitive environments. Empirical propositions pertaining to the resources and investment matching principle are discussed in the fourth section. In section five, data from Compustat industrial files is applied to a sample of multi-industry technology-intensive firms provided by the Boston Consulting Group (BCG) to examine the US energy sector’s overall innovation profile during the period 1999-2011. The energy sector’s resources and investment practices are further compared with those of other technology-intensive industries in biotechnology; communications equipments, electronic equipments, instruments, and components; healthcare equipment and supplies; pharmaceutical; information technology; semiconductors and semiconductor equipment; and software. Conclusions and policy recommendations on energy innovation are presented in the final section.
2 Energy Innovation and R&D Investment in the US

The imperative to accelerate the pace at which better energy technologies are discovered and deployed are emphasized by recent studies on energy innovation (Anadon et al., 2011 and Henderson and Newell, 2010). These studies further emphasize the need to improve the efficiency of these investments, by providing expanded incentives for private-sector innovation, and seizing opportunities where international cooperation can accelerate innovation. In the US, the private sector funds and performs most R&D activities. In 2008, $398 billion worth of R&D was performed by all sectors in the US. Private-sector firms funded $268 billion (67%) of the total expenditures (NSF, 2010a). R&D expenditures represented about 2.8% of the US overall GDP in 2008 (3.5 times larger than R&D investment proportion in the energy sector). The non-federal funding part is estimated at about 1.9% of the GDP (NSF, 2010b). Wiesenthal et al., 2009 found a similar pattern of R&D investment in the EU. The EU-wide low-carbon energy R&D investment totaled €3.32 billion (roughly $4.5 billion) in 2007 which was split 11% by the EU, 33% by member countries, and 56% by the industry.  

Detailed and reliable data on the US private sector energy R&D investment is, however, much more limited. In the US, the vast majority of the energy system is owned by private enterprises. In a recent paper, Dooley (2011) presents two independent datasets that describe investments in energy R&D by the U.S. private sector since the Arab Oil Embargo of 1973. The first dataset is based upon the results of a broad annual survey of more than 20,000 firms’ R&D expenditures conducted by the U.S. National Science Foundation (NSF, 2010 b).2 Accounting for non-profit investments, Dooley (2011) further combines the NSF/Census survey data with two other datasets that describe private sector energy R&D funding carried out by the Electric Power Research Institute (1997, 2001, 2006) and the Gas Research Institute (1997, 2001) - two large nonprofit US energy research organizations. The second dataset comprises a somewhat more focused accounting of energy R&D activities by the U.S. Department of Energy’s Energy Information Agency (EIA) that surveys the R&D activities of a sample of largest U.S. oil and gas companies over the period 1977-2008 (EIA, 2010).3

Figure (1) which is reproduced from Dooley (2011) shows aggregate US private sector expenditures in energy R&D by each of these surveys along with the real price of crude oil. As shown in Figure (1), according to NSF and EIA data, there was a significant surge in energy R&D investment in the immediate aftermath of the Arab Oil Embargo of 1973 reaching as high

1 These estimates do not include any fossil fuel or energy efficiency R&D.
2 Starting with the 2006 survey year, however, the NSF and the Bureau of the Census implemented a new survey instrument that did not contain any questions about energy R&D investment (NSF, 2010a). Hence, the NSF data used by Dooley (2011) covers only the period 1973-2005.
3 A list of the firms surveyed can be found at http://www.eia.doe.gov/emeu/perfpro/CoList.html
as $3.7 billion to $6.7 billion per year (in inflation adjusted 2010 U.S. dollars), respectively, between 1980 and 1982. Investments in energy R&D declined significantly both for the aggregate economy and major US oil and gas companies leveling approximately at $1-$1.8 billion per year in 1999 and began to recover somewhat over the ensuing decade.

According to Dooley (2011), several key factors including the collapse of the oil prices, rapid domestic and global de-regulation of the energy sector, consolidation in the oil and gas industry, and adoption of new production technologies (mainly applied to enhance the efficiency of existing oil and gas operations) have been responsible for the precipitous decline in US energy R&D investment over the decades of 1980s and 1990s. U.S. private sector’s energy R&D investment has been (and still remains) dominated by fossil fuel sources, particularly those related to the needs of the oil and gas industry in enhancing the efficiency of their core businesses. Further, while the private sector’s investments in energy R&D was strongly correlated to real price of crude oil throughout the 1970s and 1980s, its dependence has weakened since the 1990s, possibly indicating a stronger preference for developing non-fossil fuel energy alternatives.
Figure (1): Aggregate U.S. private sector support for all forms of energy R&D (millions of 2010$) compared to the real price of crude oil (2010$/BBL)

3. Organizational Adaptability, Resources and Investment Strategies: A Synthesis

Recently, rapid economic, technological and political changes have significantly increased the level of the global turbulence in the business environment, diminishing corporate profitability and survival rate (Stubbart and Knight, 2006 and Morris, 2009). The decline in corporate survival and performance has inflicted significant economic and social costs globally. It has adversely impacted economic growth and has further slowed down the pace of innovation and discovery in the public and private sectors. As global turbulence has continued to increase, researchers and policymakers have begun to focus on strategies and structures that enable corporations to adapt rapidly to changing environments by emphasizing flexibility, learning, experimentation, innovation and cooperation.

In its most general definition, corporate adaptability is viewed as a dynamic capability directed at building and adapting core financial, operational and managerial competencies to address rapidly changing (turbulent) environments. In this process, managers face the basic question on how to balance the benefits and costs of adaptability to enhance performance (Reeves and Deimler, 2011). At one extreme, maintaining an external focus with an accompanying ability to adapt to market changes may entail significant opportunity costs associated with forgoing existing competencies. At another extreme, by focusing on a narrowly defined product market, an organization could be exposed to the risk of failing to adapt when market changes occur. An established theme in the strategic management literature is that successful firms are ambidextrous – i.e., investment resources are deployed to maintain a high degree of balance between exploitation and exploration and between alignment and adaptability (Gibson and Birkinshaw, 2004; March, 1991; and Tushman and O’Reilly, 1996). Earlier studies often regarded the tradeoffs between exploration and exploitation activities as insurmountable, but more recent research describes ambidextrous organizations that are capable of simultaneously exploiting existing competencies and exploring new opportunities (Andriopoulos and Lewis, 2009; Cao et al., 2009).

More recently, the scope of research on corporate adaptability has been expanded by integrating the fields of strategic change (Rajagopolan and Spreitzer, 1987) and the resource-based view of the firm (Schumpeter, 1942 and Penrose, 1958). In this sense, the relationship between organizational adaptability and performance is hypothesized to be influenced both by the role which is played by a firm’s investment strategies (exploration vs. exploitation) and management of its slack resources (Kraatz and Zajac, 2001; Voss, et al. 2008 and Lee, 2011). Specifically, according to this strand of research, the magnitude and the scope of a firm’s slack resources determine the nature of its investment strategies which may either focus on future growth opportunities or on enhancing the efficiency of its existing assets. Broadly, slack resources can be categorized along two broad dimensions: Absorption and Specificity (uniqueness), emphasizing the different types of resources including financial, operational,
customer relational and human resources (Sharfman et al., 1988 and Voss et al., 2008). While some resources are relatively generic and commonly available, specific and valued resources such as raw material, people, customer relationship are usually specific and are in short supply. Unabsorbed resources such as excess cash, credit lines and unused debt capacity are currently uncommitted and can be redeployed easily within organizations. Organizations also possess absorbed resources such as production capacity and specialized skilled labor that are tied to current operations.

Simultaneously, a growing stream of research has recently emerged in the field of finance focusing on the role of preserving financial flexibility (maintaining appropriate levels of slack resources such as cash and unused debt capacity) to address the needs arising from unanticipated earnings shortfall and new growth opportunities (Gamba and Triantis, 2008; and Byoun, 2008). Focusing on growth options, Myers (1977) and Myers and Majluf (1984) suggest that corporate moral hazard incentives associated with the use of risky debt financing may negatively affect the proportion of a firm’s market value accounted for by its investment in future growth opportunities - normally, a significant part of many firm’s market valuation. More recently, Brown and Petersen (2011) find that firms with significant growth opportunities, but facing financing frictions, appear to build cash reserves when cash flow and stock issues are high and then draw them down in years when equity is less available in order to maintain a relatively smooth path of R&D spending for innovation and growth opportunities. Put differently, their results support the view that firms maintain the trajectory of their R&D investment by actively managing their liquidity decisions.

Previous empirical findings are inconclusive. Miles and Snow (1978), in their typology of organizational strategies (reactor, defender, analyzer, and prospector), postulate that the more active a firm is in its pursuit of new product-market opportunities, the more adaptive capability it will build into its tactical base. However, they find no significant differences in performance among different strategy types. Bourgeois (1980), on the other hand, hypothesized that the relationship between performance and adaptive capability (measured by the presence of slack resources) would be positive, up to a point, then negative; in other words, a curvilinear relationship was hypothesized. McKee, Varadarajan and Pride (1989) found support for a balanced investment strategy approach (external/internal).

4 Organizational Adaptability and Matching of Resources and Investment Strategies

Previous research in strategy has typically treated the process of managing a firm’s slack resources and its strategic investment decisions (choice between efficiency and innovation) separately and in isolation (Kraatz and Zajac, 2001; Voss, et al. 2008 and Lee, 2011). As

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4 These four strategy types reflect a continuum of increasing adaptive capability ranging from the reactor (with relatively little adaptive capability) to the prospector (with the highest level of adaptive capability).
depicted in Figure (2), however, Jalilvand and Kim (2012) characterize the overall relationship between corporate adaptability and performance as being influenced by two broad and interrelated decisions at the firm level: Investment Strategies and Management of Slack Resources. This relationship is further assumed to be moderated by the level of turbulence in the market environment.

Conceptually, this integrative process implies that organizational adaptability and its antecedents are simultaneously determined in sustaining competitive advantages and deriving performance. In this sense, this proposed framework is consistent with a large body of previous research which recognizes that costs and imperfections inherent in markets: information asymmetries, transactions costs, real economies of scale or scope, forms of taxation, etc., may cause substantial economic interactions among a firm's decisions, in addition to those imposed by the basic sources and uses of funds constraints (see Graham and Harvey, 2001; Gamba and Triantis, 2007; and Jalilvand and Harris, 1984).

**Figure (2): Strategic Investment, Slack Resources and Long-Term Performance Process**

Attempting to maximize long-run performance, JK (2012) further contend that firms should simultaneously match (align) their slack resources’ type with the nature of the investment opportunities they are facing. In the long-run, matched firms will outperform rivals with a mismatch between slack resources and investment strategies. Matched firms’ increased
performance reflect economies captured by mitigating costs associated with information asymmetries, avoiding external capital market frictions and lowering risk of default.

The dynamics of the proposed matching principle is depicted graphically in Figure (3) where all firms which have achieved a proper balance between slack resources and investment strategies are located on the Resources-Investment Efficient Frontier (firms A,B and C). In the long run, mismatched firms with inferior performance will be forced to adjust their slack resource and investment profile to move toward a more efficient resources-investment position.
Figure 3: Resource-Investment Efficient Frontier

High Resource Specificity

Unmatched Firm

Firm B

Firm C

Firm A

Low Exploration Orientation

High
JK (2012) offer the following propositions to examine the adaptability/performance dynamics:

**H1:** In the long-run, a firm’s investment strategies are managed to maximize performance by simultaneously exploiting existing competencies and exploring new opportunities – being ambidextrous.

**H2:** In the long-run, a firm’s slack resources and investment strategies are managed to maximize performance by
a) maintaining an optimal balance between high levels of flexible slack resources (i.e., both low absorption and low specificity, such as financial slack) and high exploration-oriented investment, and
b) maintaining an optimal balance between high level of inflexible slack resources (i.e., both high absorption and high specificity, such as production capacity, human resources, etc.) and high exploitation-oriented investment.

JK’s (2012) approach to organizational adaptability is directly relevant to examine the dynamics of R&D investment in the US energy sector. Specifically, it will help unravel the question on whether US energy firms are optimally managing the relationship between their overall slack resources and investment strategies and, hence, the dynamics of their innovation policies.

5 Data, Sample and Variable Definition

We apply data from Compustat industrial files to a sample of multi-industry technology-intensive firms provided by the Boston Consulting Group (BCG). We have two separate empirical objectives. First, we examine the US energy sector’s overall innovation profile during the period 1999-2011. Second, we compare the energy sector’s innovation profile with those of other technology-intensive industries in biotechnology; communications equipments, electronic equipments, instruments, and components; healthcare equipment and supplies; pharmaceutical; information technology; semiconductors and semiconductor equipment; and software.5 Our sample of nine broad industries is represented by 110 companies obtained from a comprehensive list of 417 adaptive and highly adaptive firms collected by the BCG representing 59 industries and 9 sectors in the US economy.6

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5 Energy sector combines Energy Equipment and Services with Oil, Gas, and Consumable Fuels. Information Technology Services combine the IT Services with Internet Software and Services.

6 The list of sample firms of nine technology-intensive sectors used in this study is available from the authors upon request.
According to the BCG, a firm’s degree of adaptability is measured by using an Adaptive Advantage Index (AAI) constructed from a sample of 2,500 US public companies over a six year period, 2005 through 2011. Specifically, a company’s AAI is measured by its industry adjusted cumulative market cap growth rate during seven most turbulent quarters over a six year period, October 2005 through September 2011. Two sample selection adjustments are also made. Firms in the financial sector are excluded because of the potential performance bias introduced by regulatory and government interventions. Similarly, companies with major M&A activities are excluded to control for any performance bias created by corporate restructuring activities. BCG’s detailed procedure in calculating the index is provided in Appendix (A).

Following Brown, Fazzari, and Petersen (2009) and Brown and Petersen (2011), a firm’s innovation profile is characterized by a set of variables describing its overall financial and operational flexibility and the nature of its investment activities. Specifically, it captures the level and type of a firm’s slack resources (cash holdings, long term debt, equity, and plant, property and equipment); and the nature of its investment opportunities and growth prospects (R&D, capital expenditures, sales growth, market to book ratio, and return on asset). These variables are explained below.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Capex)_t</td>
<td>Capital expenditures in period t divided by the book value of total assets at the beginning of period t.</td>
</tr>
<tr>
<td>(R&amp;D)_t</td>
<td>Research and development expense in period t divided by the book value of total assets at the beginning of period t.</td>
</tr>
<tr>
<td>(SalesGwth)_{t-1}</td>
<td>Log of change in net sales between period t and t-1.</td>
</tr>
<tr>
<td>(CashHoldings)_t</td>
<td>Cash and short-term investments in period t divided by the book value of total assets at the beginning of period t.</td>
</tr>
<tr>
<td>(Equity)_t</td>
<td>Common shareholders’ interest in the company at the beginning of period t divided by the book value of total assets at the beginning of period t</td>
</tr>
<tr>
<td>(LTDebt)_t</td>
<td>Debt obligations due in more than one year at the beginning of period t divided by the book value of total assets at the beginning of period t.</td>
</tr>
<tr>
<td>(Property)_t</td>
<td>Cost, less accumulated depreciation, of tangible fixed property used in the production of revenue at the beginning of period t divided by the book value of total assets at the beginning of period t.</td>
</tr>
<tr>
<td>(Market Book)_{t-1}</td>
<td>Market value of assets in period t-1 divided by the book value of total assets in period t-1, where market value of assets is equal to the market value of equity plus the book value of assets minus the book value of equity.</td>
</tr>
<tr>
<td>(Return on Asset: ROA)_t</td>
<td>Gross cash flow in period t divided by the book value of total assets at the beginning of period t, where gross cash flow is defined as (after-tax) income before extraordinary items plus depreciation, amortization and research and development expense.</td>
</tr>
</tbody>
</table>

In the BCG approach, periods of turbulence for a given industry refer to environments when large changes in aggregate demand, competition, operating margins and market expectations occur. In a recent study, Reeves, Haanaes, and Love (2012) also use the BCG sample in to study corporate sustainability as a dynamic capability.
6 Results

Before we proceed with the analysis of our data, a few observations on the implications of using the BCG sample may be in order. Overall, as explained above, according to BCG’s definition, “adaptable” firms are those who have outperformed their industries during several consecutive periods of turbulence from 2005 through 2011. However, in this study, following JK (2012), we offer specific propositions (such as matching and ambidexterity) to explain the financial and strategic dynamics underlying the relationship between organizational adaptability and performance. Hence, a priori, the observation that firms in the BCG sample actually conform to the propositions we have set forth in this paper should be interpreted to provide empirical evidence both in support of our theoretical predictions and the validity of the BCG’s approach in selecting adaptive firms.

The descriptive statistics and one and two tailed comparative t-tests are presented, respectively, in tables (1) and (2). Overall, the results show that the energy firms’ innovation profile, characterized by the pattern of their resources and investment strategies, were, on average, markedly different from those in the other eight sectors (comparison group). Specifically, with the exception of their extensive commitment to capital expenditures investment, the energy sector, on average, has maintained significantly lower R&D, cash holdings, long-term debt, equity, market to book and sales growth among the majority of the other sectors in our sample. Using average return on assets as a measure of long-term profitability, we also observe that five out of eight sectors have significantly outperformed the energy sector. The profitability ratios in the remaining three sectors are not statistically different from that of the energy sector.

<table>
<thead>
<tr>
<th>Variables^1</th>
<th>Energy</th>
<th>Electronic Equipments</th>
<th>Health Care Equipment</th>
<th>Information Technology</th>
<th>Pharmaceuticals</th>
<th>Software</th>
<th>Communications Equipments</th>
<th>Semiconductors</th>
<th>Biotechnology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>1.8683</td>
<td>1.7822</td>
<td>2.4971</td>
<td>2.4849</td>
<td>2.5646</td>
<td>2.8574</td>
<td>2.2992</td>
<td>2.7518</td>
</tr>
<tr>
<td>Assets</td>
<td>Mean</td>
<td>38723.74</td>
<td>990.09</td>
<td>4349.63</td>
<td>16823.06</td>
<td>4500.81</td>
<td>9848.09</td>
<td>1973.19</td>
<td>6953.98</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>8616.10</td>
<td>692.83</td>
<td>2407.33</td>
<td>995.95</td>
<td>758.15</td>
<td>2001.59</td>
<td>642.21</td>
<td>2855.68</td>
</tr>
<tr>
<td>Capex</td>
<td>Mean</td>
<td>0.0779</td>
<td>0.0373</td>
<td>0.0410</td>
<td>0.0538</td>
<td>0.0398</td>
<td>0.0375</td>
<td>0.0429</td>
<td>0.0762</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.0735</td>
<td>0.0274</td>
<td>0.0395</td>
<td>0.0353</td>
<td>0.0313</td>
<td>0.0262</td>
<td>0.0311</td>
<td>0.0536</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Mean</td>
<td>0.0124</td>
<td>0.0510</td>
<td>0.0514</td>
<td>0.0627</td>
<td>0.1048</td>
<td>0.1204</td>
<td>0.1324</td>
<td>0.1371</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.0066</td>
<td>0.0194</td>
<td>0.0436</td>
<td>0.0476</td>
<td>0.0720</td>
<td>0.1085</td>
<td>0.1060</td>
<td>0.1201</td>
</tr>
<tr>
<td>Equity</td>
<td>Mean</td>
<td>0.4130</td>
<td>0.4848</td>
<td>0.5376</td>
<td>0.5176</td>
<td>0.5154</td>
<td>0.5240</td>
<td>0.5642</td>
<td>0.6515</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.4352</td>
<td>0.5065</td>
<td>0.5455</td>
<td>0.6292</td>
<td>0.5459</td>
<td>0.5669</td>
<td>0.6895</td>
<td>0.6965</td>
</tr>
<tr>
<td>LTDebt</td>
<td>Mean</td>
<td>0.1429</td>
<td>0.1796</td>
<td>0.1763</td>
<td>0.1062</td>
<td>0.1652</td>
<td>0.0522</td>
<td>0.1073</td>
<td>0.0990</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.1212</td>
<td>0.0754</td>
<td>0.1819</td>
<td>0.0037</td>
<td>0.1017</td>
<td>0.0024</td>
<td>0.0003</td>
<td>0.0470</td>
</tr>
<tr>
<td>SalesGwth</td>
<td>Mean</td>
<td>0.0636</td>
<td>0.1621</td>
<td>0.1220</td>
<td>0.2857</td>
<td>0.2125</td>
<td>0.2236</td>
<td>0.2594</td>
<td>0.1945</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.0698</td>
<td>0.1501</td>
<td>0.0770</td>
<td>0.1629</td>
<td>0.1205</td>
<td>0.1846</td>
<td>0.1892</td>
<td>0.1534</td>
</tr>
<tr>
<td>CashHoldings</td>
<td>Mean</td>
<td>0.0917</td>
<td>0.1120</td>
<td>0.1307</td>
<td>0.3855</td>
<td>0.2399</td>
<td>0.3700</td>
<td>0.3504</td>
<td>0.3357</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.0616</td>
<td>0.0662</td>
<td>0.0703</td>
<td>0.3920</td>
<td>0.1745</td>
<td>0.3542</td>
<td>0.3380</td>
<td>0.3231</td>
</tr>
<tr>
<td>ROA</td>
<td>Mean</td>
<td>0.1225</td>
<td>0.1328</td>
<td>0.1520</td>
<td>0.0892</td>
<td>0.1617</td>
<td>0.2254</td>
<td>0.1664</td>
<td>0.2635</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.1295</td>
<td>0.1175</td>
<td>0.1600</td>
<td>0.1579</td>
<td>0.1831</td>
<td>0.2248</td>
<td>0.1812</td>
<td>0.2813</td>
</tr>
<tr>
<td>Observations^2</td>
<td></td>
<td>162</td>
<td>138</td>
<td>155</td>
<td>156</td>
<td>158</td>
<td>164</td>
<td>156</td>
<td>200</td>
</tr>
</tbody>
</table>

Fn 1. Variables used in the study are from Brown, Fazzari, and Petersen (2009) and Brown and Petersen (2011).
Fn 2. The sample is provided by the Boston Consulting Group (2012).
Table (2): T-test of Mean Comparisons across Technology-intensive Sectors

<table>
<thead>
<tr>
<th>MarketBook</th>
<th>Difference</th>
<th>Electronic Equipments</th>
<th>Health Care Equipment</th>
<th>Information Technology</th>
<th>Pharmaceuticals</th>
<th>Software</th>
<th>Communications Equipment</th>
<th>Semiconductors</th>
<th>Biotechnology</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0454</td>
<td>0.8575</td>
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<td>1.2256</td>
<td>1.6852</td>
<td>2.2838</td>
<td>1.5434</td>
<td>2.9267</td>
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<tr>
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<td>[t] value</td>
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<td>4.4690</td>
<td>2.1094</td>
<td>5.7768</td>
<td>5.9085</td>
<td>2.7235</td>
<td>3.1914</td>
<td>6.2765</td>
</tr>
<tr>
<td></td>
<td>Pr(</td>
<td>T</td>
<td>&gt;</td>
<td>t</td>
<td>)²</td>
<td>0.7125</td>
<td>0.0000 ***</td>
<td>0.0361 **</td>
<td>0.0000 ***</td>
</tr>
<tr>
<td>Capex</td>
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<td>-0.0406</td>
<td>-0.0369</td>
<td>-0.0241</td>
<td>-0.0381</td>
<td>-0.0404</td>
<td>-0.0351</td>
<td>-0.0017</td>
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</tr>
<tr>
<td></td>
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<tr>
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<td>&gt;</td>
<td>t</td>
<td>)²</td>
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<td>0.0000 ***</td>
<td>0.0005 ***</td>
<td>0.0000 ***</td>
</tr>
<tr>
<td>R&amp;D</td>
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<td>0.0371</td>
<td>0.0924</td>
<td>0.1080</td>
<td>0.1200</td>
<td>0.1247</td>
<td>0.2537</td>
</tr>
<tr>
<td></td>
<td>Pr(</td>
<td>T</td>
<td>&gt;</td>
<td>t</td>
<td>)²</td>
<td>0.0000 ***</td>
<td>0.0000 ***</td>
<td>0.0000 ***</td>
<td>0.0000 ***</td>
</tr>
<tr>
<td>Equity</td>
<td>Difference</td>
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<td>0.1246</td>
<td>0.1046</td>
<td>0.1024</td>
<td>0.1110</td>
<td>0.1512</td>
<td>0.2385</td>
<td>0.1423</td>
</tr>
<tr>
<td></td>
<td>Pr(</td>
<td>T</td>
<td>&gt;</td>
<td>t</td>
<td>)²</td>
<td>0.0080 ***</td>
<td>0.0000 ***</td>
<td>0.0022 ***</td>
<td>0.0009 ***</td>
</tr>
<tr>
<td>LTDebt</td>
<td>Difference</td>
<td>0.0367</td>
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<td>-0.0367</td>
<td>0.0224</td>
<td>-0.0907</td>
<td>-0.0356</td>
<td>-0.0439</td>
<td>0.0521</td>
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<tr>
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<td>)²</td>
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<td>0.0098 ***</td>
<td>0.0614 *</td>
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<tr>
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<td>0.1489</td>
<td>0.1600</td>
<td>0.1958</td>
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<td>0.3385</td>
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<tr>
<td></td>
<td>Pr(</td>
<td>T</td>
<td>&gt;</td>
<td>t</td>
<td>)²</td>
<td>0.0002 ***</td>
<td>0.0150 **</td>
<td>0.0000 ***</td>
<td>0.0009 ***</td>
</tr>
<tr>
<td>CashHoldings</td>
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<td>0.4817</td>
</tr>
<tr>
<td></td>
<td>Pr(</td>
<td>T</td>
<td>&gt;</td>
<td>t</td>
<td>)²</td>
<td>0.0105</td>
<td>0.0079 ***</td>
<td>0.0000 ***</td>
<td>0.0000 ***</td>
</tr>
<tr>
<td>ROA</td>
<td>Difference</td>
<td>0.0103</td>
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<td>-0.0333</td>
<td>0.0392</td>
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<td>t</td>
<td>)²</td>
<td>0.4094</td>
<td>0.0041 ***</td>
<td>0.3717</td>
<td>0.0087 ***</td>
</tr>
</tbody>
</table>

Fn 1. Mean difference between individual industries in the comparison sector and energy sector: Positive (+) values indicate that other sector > energy sector.
Fn 2. When Ha: diff ≠ 0 is statistically significant the results are marked with * (p < 0.10), ** (p < 0.05), or *** (p < 0.01): two-tail tests.
The trend lines in Figures (4) and (5) capture differences in the pattern of slack resources and investment strategies for the energy sector and the comparison group over the entire period, 1990-2011. As shown in Figure (4), starting with 2000, the energy sector and the comparison group experienced diametrically opposite patterns of capital expenditures. The energy sector continued to build its capital expenditures while the comparison group experienced a steady decline. Also, the gap in capital expenditures between these sectors continue to widened post 2000 reflecting a differential focus on investment strategies: core businesses and efficiencies vs. future growth opportunities. It is also worth noting that the capital expenditures expansion in the energy firms’ was strongly correlated with increases in the real price of crude oil which began in 2005. Conversely, the energy firms’ average R&D expenditures were negligible hovering around 1% of total assets during the entire period, 1999-2011. This observation is contrary to the rising pattern of energy R&D expenditures in response to significant increases in crude oil prices following the Arab Oil Embargo in 1973. Rather, under a different oil price regime post 2005, our results suggest that energy firms may have committed their additional revenues obtained from increases in crude oil prices to expand the efficiency and productivity of their existing assets (possibly in fossil fuel) as opposed to investing in future innovation and technology development in wind and solar areas. On the other hand, the comparison group began to systematically increase its R&D expenditures in mid 1990’s while reducing its overall capital expenditures over the same period.

From the point of view of managing the portfolio of slack resources, Figure (5) shows that, as a specific and absorbed type of slack resource, plant, property and equipment (Property) consistently played a more significant role in supporting the energy sector’s overall investment than the position it maintained in the comparison group. While both sectors increased their cash holdings (CashHoldings), the comparison group both maintained higher levels of cash holdings and grew them more rapidly than what occurred in the energy sector. The comparison group’s slack resources and investment behavior over time also appear to be consistent with the implications of proposition H2(a, b) as (i) increases in R&D expenditures are trending positively with increases in average cash holdings and short term securities and (ii) decreases in capital expenditures are positively trending with decreases in plant, property and equipment. On the other hand, in the energy sector, slack resources and R&D or capital expenditures do not appear to be correlated.
Figure (4): R&D and Capital Expenditures Trends: Energy vs. Comparison Group

Figure (5): Cash Holdings and Plant, Property and Equipment Trends: Energy vs. comparison Group
In Figure (6), we further examine the individual sectors’ investment (ambidexterity) profile (proposition H1) by plotting each sector’s average values of R&D and capital expenditures ratios. Not surprisingly, the energy is identified as the most “exploitative” and the least “explorative” sector with the highest (the lowest) average capital expenditures and (R&D) ratios among the remaining eight sectors. On the other hand, with the highest average R&D ratio, biotechnology is the most “explorative” sector which has also achieved a moderate level of exploitative investment. The investment strategies of the remaining seven sectors or industries are more balanced as they appear to be simultaneously exploiting existing competencies and exploring new opportunities – being ambidextrous (Cao et al., 2009; Gibson and Birkinshaw, 2004; and Tushman and O’Reilly, 1996). Interestingly, we also find that sectors characterized by a stronger ambidexterity profile (Communication Equipments, Healthcare Equipment and Supplies, Pharmaceutical, Semiconductors and Semiconductor Equipments and Software) have outperformed the energy sector based on the average return to asset measure of performance.

Figure (6): Ambidextrous Investments for Exploration and Exploitation: Multi Industry Comparison
Finally, in Figure (7), we investigate more directly the resources and investment matching proposition (H2(a, b) by plotting individual sectors based on average values of their overall slack resources specificity vs. the extent of their exploratory investments. A firm’s slack resources specificity measured by [Property, Plant, and Equipment/(Property, Plant, and Equipment + Cash Holdings)] is expected to proxy the extent of the available resources which are already committed to the current operations such as production capacity and specialized skilled labor. Further, the extent of a firm’s exploratory investment is measured by the ratio [R&D/(R&D + Capital Expenditures)]. Again, the energy and the biotechnology sectors are plotted in opposite directions with energy identified as a sector with the highest resources specificity level and the lowest exploratory orientation among all sectors. On the other hand, biotechnology is identified as a sector with the highest level of exploratory investment among all sectors and with a moderate level of resources specificity. The remaining sectors are plotted between these two extreme cases as they are endowed with more moderate levels of resources specificity and exploratory orientation. Overall, in Figure (7), the plot of all sectors (considered to be adaptive by BCG) appear to approximate well our proposed Resources-Investment Efficient Frontier where all firms which have achieved a proper balance between slack resources and investment strategies are expected to be located.

**Figure (7): Matching of Slack Resources and Investment Strategies: Multiple Industry Comparison**
7 Concluding Remarks

In this paper, we examine the firm-specific dynamics of innovation in the US energy sector. We further compare the energy sector’s innovation profile with those of several technology-intensive industries in biotechnology; communications equipments, electronic equipments, instruments, and components; healthcare equipment and supplies; pharmaceutical; information technology; semiconductors and equipment; and software.

Our results provides evidence showing that, beyond macroeconomic influences, firm-specific factors have played an important role in explaining the energy sector’s observed lack of adaptability captured by very low rates of R&D intensity over time. Further, energy sector’s slack resources and R&D investment profile was found, on average, to be markedly different from those in other sectors. The results also show that, in terms of longer-term profitability, the energy sector was significantly outperformed by the majority of other technology-intensive sectors.

We also find that the capital expenditures expansion in the energy sector was strongly correlated to increases in the real price of crude oil which began in 2005. Conversely, its R&D expenditures were negligible hovering around 1% of total assets during the entire period, 1999-2011. This observation is contrary to the rising pattern of energy R&D expenditures occurred following significant increases in crude oil prices post Arab Oil Embargo in 1973.

Unlike the other technology-intensive sectors, the energy sector did not pursue a balanced investment strategy by simultaneously exploiting existing competencies and exploring new opportunities – being ambidextrous. Energy was the most “exploitative” and the least “explorative” sector with the highest (the lowest) average capital expenditures (R&D) intensities among the remaining sectors in the sample. Further, the energy sector slack resources and investment strategies did not conform to our proposed matching principle. On the other hand, for the comparison group, R&D expenditures trended positively with increases in average cash holdings while decreases in capital expenditures also trended positively with decreases in plant, property and equipment.

From a public policy perspective, our results call for a better integration of macro and micro policies including regulatory and tax legislations directed to enhance global energy innovation. We further believe as more adaptable technology intensive companies achieve higher profitability over time, energy firms will be pressured to better manage the balance between their slack resources and investment strategies to become more adaptable and responsive to their changing environments.
Appendix (A): BCG Sample Description

The BCG Adaptive Advantage Index was created using publicly available data for 2,500 U.S. public companies across a wide range of industries. Each company’s BCG Adaptive Advantage Index score was calculated by measuring the weighted-average outperformance of a company’s market-cap growth rates versus the weighted-average market-cap growth rates in its industry during that industry’s seven most turbulent business quarters from October 2005 through September 2011. Throughout the report, this six-year period is referred to as 2006 to 2011. The BCG index categorized companies using the Global Industry Classification Standard (GICS) which was developed by MSC I and Standard & Poor’s. To find definitions of the industries and sectors, see http://www.standardandpoors.com/indices/articles/en/us/?articleType=PDF&assetID=1245186418839.

Outperformance was measured in terms of market-cap growth rates because market-cap correlates strongly with total shareholder return (TSR) and, ultimately, with value generation. It also conveys information about past and potential future performance; also, market-cap data are available in greater detail than are other measures of performance. The fluctuations of stock market prices, typically over shorter intervals, are mitigated since market-cap growth rates were measured over each quarter and averaged over the six-year period.

Periods of turbulence were identified for each industry by assessing turbulence in demand, competition, margins, and capital market expectations. Turbulence in demand and margins was measured by the absolute rate of change in industry revenues and EB IT margins, respectively, per quarter. Turbulence in competition was measured by taking the weighted average of the absolute change in companies’ rankings by revenues within an industry each quarter. To account for company size, we weighted the average using company revenues.

Turbulence in the capital market expectations of an industry was measured by taking the weighted average of the standard deviations of daily market-cap growth rates of the industry’s companies over a quarter. To account for company size, we weighted the average using company market-cap.

These four measures were combined and adjusted for any cross-correlations among them to create a net turbulence metric. This net turbulence metric was used to identify the seven most turbulent periods in each industry; the companies’ average relative outperformance in market-cap growth was then calculated during those seven turbulent periods, as outlined above, to determine its index score.

An index score of 105 means that, on average, the company outperformed its industry by 5 percentage points during a single turbulent quarter - a major achievement in tough times, and a performance effect that can compound significantly over time. If, for example, the turbulent quarters were sequential, such a score would, by compounding over seven quarters, translate into a 41 percent outperformance in market-cap growth over the industry. The level of adaptiveness of each company was determined relative to other companies in its industry: in each industry,
the top 50 percent of companies achieving scores at or above 100 on the adaptiveness index were classified as highly adaptive and the bottom 50 percent as adaptive. The ten largest companies (as measured by revenues) in each industry were then selected to compile these tables.

Companies belonging to the financial sector (as designated by GICS codes) were excluded from the index because government intervention in the sector had a distorting effect on the outperformance exhibited by certain companies. Similarly, we excluded companies whose marked increase in outperformance during turbulent periods was coincident with major M&A activity.
References


