TALLINN UNIVERSITY OF TECHNOLOGY

School of Business and Governance

Ragnar Nurkse Department of Innovation and Governance

Mario Laul

Financing Firm Level Research & Development in the United States' Solar Photovoltaic Industry: the Case of First Solar, Inc., 2002-2016

Master's Thesis

Advisor: Prof. Dr. Jan Kregel

Tallinn 2017

I hereby declare that I am the sole author of this master’s thesis and that it has not been presented to any other university for examination. All sources used in researching this thesis are fully acknowledged and all quotations properly identified.

Author: Mario Laul

Date: ………………………………… 2017

This master’s thesis meets the established requirements.

Supervisor: Prof. Dr. Jan Kregel

Date: ………………………………… 2017

This master’s thesis is accepted for examination.

Board of examiners of Technology Governance master’s theses: Prof. Dr. Rainer Kattel

Date: ………………………………… 2017

ABSTRACT

The aim of the thesis is to study the financing of research and development (R&D) in the United States' solar energy firm First Solar, Inc. (FS). The thesis asks the following question: how did FS finance its R&D between 2002 and 2016 (including R&D-related acquisitions), and has R&D spending been sensitive to variations in the availability of internal funds (measured by cash flow and holdings)? Relying on data derived from Form 10-k reports, the thesis finds that before the initial public offering (IPO) in 2006, FS financed its R&D through a mix of cash equity contributions, private loans, public R&D grants, and share-based compensation. In subsequent years, R&D expenditure was financed primarily from internal funds provided by operating activities. With one exception, this also applies to R&D-related acquisitions. Although growth in net income and cash holdings is correlated with increased R&D investment, R&D spending shows no or insignificant sensitivity to negative cash flow shocks. Throughout the post-IPO period, FS has been able to increase and maintain its R&D investment levels by managing a large buffer stock of internal liquidity. These results are in contrast to some earlier studies on the financing of R&D in US manufacturing firms, but in line with more recent research.

Keywords: financing R&D; cash flow sensitivity; cash holdings; value of liquidity; R&D smoothing; First Solar; renewable energy innovation

ACKNOWLEDGEMENTS

I would first like to thank my thesis advisor Prof. Jan Kregel. It is no exaggeration to say that Prof. Kregel's course on finance and development during my first semester ended up inspiring the best part of my research and thinking in the following year and a half. Without his most efficient and effective guidance throughout the writing process, it would have taken me much longer to recognize and learn from my mistakes. Naturally, any remaining errors and deficiencies are entirely my own.

I would also like to thank the faculty and staff of Ragnar Nurkse Department of Innovation and Governance. The past two years have been the most intellectually stimulating period of my life thus far and you have all played an important role in this experience. I am especially thankful to Prof. Carlota Perez and Prof. Wolfgang Drechsler whose approachability and trust have had an immensely positive effect on my self-confidence and ambition.

Finally, I am forever grateful to my friends and family for their constant support and encouragement. My deepest gratitude belongs to Marleen Armei whose friendship, patience, understanding, and perceptive criticisms and commentary have all been invaluable to me throughout my studies and beyond.

TABLE OF CONTENTS

INTRODUCTION

It has become universally acknowledged that innovation is one of the key drivers of economic growth and development, and that initiating and sustaining the organizational processes in which innovation is rooted requires a significant amount of resources. For innovation to occur, investments must be made in labor force, physical capital such as plant and equipment, and various other inputs, some of which may be impossible to identify before they are actually needed. Furthermore, these resources must be committed for extended periods of time, and even then success is not always guaranteed (Lazonick 2011, 1-2; Lazonick & Mazzucato 2012, 5-8).

The link between innovation and the allocation of financial resources was first emphasized in the pioneering work of Joseph Schumpeter who initially focused on the role of credit in allowing new enterprises to emerge and innovate, and later on the ability of large established firms to use their profits as an internal source of funding to make innovative activities routine (Schumpeter 2008; 2010). This shift in Schumpeter's focus points to an important aspect of capitalist development: as firms and industries evolve, so does the relationship between innovation and finance. But for decades, very little research was devoted to studying this evolutionary dynamic, and only more recently has the interplay between innovation and financial resource allocation been receiving systematic scholarly attention (O'Sullivan 2004, 245).

Much of this work has focused on firm level investment in one of the most important inputs for innovation – research and development (R&D), generally understood as any activity with the purpose of discovering and developing new or improved knowledge, products, or processes of production (OECD 2001). It has been widely assumed that R&D is more difficult to finance than other types of business investment, primarily due to information asymmetries, moral hazard associated with the separation of ownership and management, and the uncertain, intangible, firm-specific and non-rival nature of R&D outputs. Government subsidies, tax credits, research partnerships, intellectual property laws, and stock-based incentives for top managers have all been suggested as ways to help alleviate this possible gap in investment, although such interventions are not necessarily effective in reducing the high cost of external capital generally associated with financing R&D (Hall & Lerner 2010, 611-612).

The empirical evidence on the sources of R&D finance is mixed. Several studies have concluded that R&D-intensive firms tend to rely on internal finance and that R&D spending is sensitive to variations in cash flow (for example Hall 1992; 2002; Himmelberg & Petersen 1994; Bond et al. 2005). However, there is also evidence that firms use both external equity (for example Brown et al. 2015) and bank debt (for example Mann 2014) to finance R&D, and that cash holdings are a more appropriate measure of internal funds available for R&D investment (for example Brown & Petersen 2011; Hottenrott et al. 2016). These findings suggest that firm-specific and contextual factors play an important role in determining the source and patterns of R&D finance. One way to gain a better understanding of how R&D activities are financed under different circumstances is through case studies of individual companies. Compared to research based on large aggregated data sets, case studies are much more focused and thus provide an opportunity to uncover details that may otherwise go unnoticed. Case studies can therefore be used not only to verify or disprove particular theories under specific circumstances, but also to propose new general hypotheses (Flyvbjerg 2006).

The present thesis aims to study the financing of firm level R&D in a single United States' (US) company – First Solar, Inc. (FS). Over the past decade, solar photovoltaic (PV) industry has emerged as one of the fastest growing industries in the US (TSF 2015), and in 2009, FS became the first pure play renewable energy company included in the Standard & Poor's (S&P) 500 stock market index (FS 2009a). The company was founded in 1990, completed its pilot manufacturing line in 2002, opened a base plant in 2004, and went public in 2006 (FS 2007, 11). Since then, it has grown into one the largest solar panel manufacturers and project developers in the world. Central to its success has been the use of cadmium telluride (CdTe) as a semiconductor, resulting in lower manufacturing costs compared to materials used in competing solar panels. FS claims to invest more in R&D than any other solar company in the world (FS 2017, 6) and has continously improved the energy density of its products, reaching a 22.1% conversion efficiency in 2016, a world record for CdTe-based solar panels (FS 2016a).

In light of previous research on financing firm level R&D, the thesis asks the following question: how did FS finance its R&D between 2002 and 2016, and has R&D spending been sensitive to variations in the availability of internal funds? Given that innovative capabilities are often enhanced through the acquisition of complementary assets (Teece 1986; Carpenter et al. 2003; Phillips & Zhdanov 2013; Dosi et al. 2016, 12), the first part of the research question focuses not only on direct R&D spending, but also on acquisitions involving proprietary technology or R&D-related intellectual property. In the second part of the research question, the thesis focuses on the relationship between direct R&D expenditure and variations in the availability of internal funds. In line with recent studies on the subject (for example Brown & Petersen 2011; Shin & Kim 2011; Brown et al. 2015), both cash flow and cash holdings are used as measures of internal liquidity. The relationship between the sources and patterns of financing R&D and various firm-specific and contextual factors remains beyond the scope of the thesis.

The thesis relies on both quantitative and qualitative data derived from Form 10-k reports (known as annual reports) that publicly traded companies in the US are required to file with the Securities and Exchange Commission (SEC), and from official FS news releases. The thesis limits itself to studying the time period between 2002 and 2016 because R&D-related financial data is not readily available for earlier years when FS was still a private company. The results are analyzed in light of previous research on financing firm level R&D. The thesis thereby tests the validity of theoretical propositions derived from previous studies on the subject. However, the results of the thesis are valid only in the context of FS, and do not allow for making broad generalizations about the financing of R&D in other solar PV companies or the US at large.

The thesis is structured as follows. Chapter 1 provides an overview of both theory and empirical evidence on financing firm level R&D and the sensitivity of R&D spending to the availability of internal funds. Chapter 2 describes the research methodology and the process of data collection. Results are presented in Chapter 3. Chapter 4 discusses the key findings in light of previous studies and their implications for future research. The thesis ends with a Summary.

1. FINANCING FIRM LEVEL R&D: THEORY AND EVIDENCE

1.1 Information asymmetry and the principal-agent problem

The widely held view that firm level R&D is more difficult to finance externally than out of retained earnings, and may therefore suffer from chronic underinvestment, can be theoretically derived from considering two well-known themes in economic research: information asymmetry and the principal-agent problem (Hall & Lerner 2010, 614).[1]

Information asymmetry refers to a situation in which one party of a particular task or transaction has more or better information than another. In the context of financing R&D, the inventor or entrepreneur is generally assumed to have a more complete understanding of the intricacies and the likelihood of success of the planned R&D project than potential investors. Although the ultimate difficulty stems from the fact that neither the entrepreneur nor the investor really know whether the effort to innovate will be successful (O'Sullivan 2004, 257), the entrepreneur may still possess knowledge that, to reduce the ease of imitation by potential competitors, he or she is unwilling to share with financiers, or the latter may find difficult to understand or assess (Hall & Lerner 2010, 614-615). It is therefore not surprising that the stock prices of R&D firms have been found to respond positively to announcements of new debt issues, presumably seen as signs of at least partly overcoming the problem of asymmetric information (Alam & Walton 1995).

The principal-agent problem arises when one party, known as the principal, delegates a task to another, known as the agent. In the context of corporate governance, the problem stems from the separation of owners and managers. Although the latter are expected to act on behalf and in the best interest of the former, managers may instead pursue projects that benefit themselves personally (Jerneck 2015, 151-152). For example, once the firm is public, they may be reluctant to invest in highly uncertain activities such as R&D to avoid being held responsible in the case of

[1] A third theme often discussed in the context of firm level R&D – tax considerations – represents a separate and sizable line of research that is beyond the scope of this thesis (see EC 2014 for an overview).

failure (see Bernstein 2014), especially when ownership is highly dispersed and the capacity of shareholders to communicate with, monitor, and influence managers is limited (on the relationship between ownership concentration and institutional ownership on the one hand, and innovation and R&D expenditure on the other, see Francis & Smith 1995; Bushee 1998; Munari et al. 2010; Aghion et al. 2013). Various measures have been proposed to mitigate this problem, such as reducing the amount of cash available to managers by leveraging the firm, using stock-based compensation to align the incentives of managers with those of the shareholders, and introducing anti-takeover amendments and long-term performance plans to increase managerial security (Hall & Lerner 2010, 615-617), although the efficacy of such policies has been shown to vary across firms and economic circumstances (see for example Cho 1992; Pugh et al. 1999; Johnson et al. 2001; Eng & Shackell 2001; Lazonick 2014; Chemmanur & Tian 2017).

When combined with the inherently unpredictable, intangible and idiosyncratic nature of R&D activities, the principal-agent and information asymmetry problems have important implications for financing firm level R&D. In particular, it is generally assumed that securing external finance is more challenging for R&D than other types of business investment, suggesting a relatively greater role for positive cash flow and internal finance (Kerr & Nanda 2014, 5). The challenge is amplified by the fact that the majority of R&D spending is absorbed by the salaries of scientists and engineers, whose work often results in the creation of intangible assets that can easily be lost if these specialists leave the firm, implying that R&D has a high adjustment cost. Thus, to avoid having to lay off R&D workers whenever faced with temporary volatility in income, firms may prefer to use cash reserves to keep their R&D spending smooth over time (Hall & Lerner 2010, 612). The next section will review empirical evidence in support of these theoretical predictions.

1.2 Sources of finance

1.2.1 Internal finance and R&D-cash sensitivity

Empirical research on financing firm level R&D can be divided into two broad types. The first is concerned with the sensitivity of R&D investment to fluctuations in the availability of internal funds and whether the alleged link between the two varies across companies and over time. The second studies the capital structure and financing of R&D-intensive firms in comparison to non-R&D firms (Hughes 2014, 250).[1]

The first line of research stems from the proposition that, due to financing frictions, R&D spending may be depressed whenever internal funds become unavailable and the firm is forced to turn to external capital markets. As discussed by Himmelberg & Petersen (1994, 38), economists had argued for decades that R&D spending should in most cases be determined by the availability of internal finance, although empirical evidence in support of this hypothesis was scarce at best. One way to test whether the link exists is to see if R&D is sensitive to internal liquidity shocks (Hall & Lerner 2010, 618), thereby extending the seminal work on financing constraints and investment by Fazzari et al. (1988) to specifically R&D. Early examples of such studies include Hall (1992), Hao & Jaffe (1993), and Himmelberg & Petersen (1994), all focusing on US companies, and indeed reporting a positive elasticity between R&D and cash flow, although the link did not exist in the case of large high-tech firms, possibly due to better access to capital markets or higher costs of adjusting R&D spending (Hao & Jaffe 1993).

Subsequent studies have revealed considerable variation between different national contexts. For example, Harhoff (1998) finds that although cash flow was positively correlated with R&D spending in German firms between 1990 and 1994, the effect was not as strong as in the US. Hall et al. (1998) find that, from 1978 to 1989, both investment in general and R&D spending in particular were highly sensitive to cash flow in US firms, whereas the relationship was much more mixed in Japan and France. This finding has been partially confirmed by Mulkay et al. (2000) who also compare manufacturing firms in France and the US. Looking at liquidity constraints and R&D investment in the context of Irish firms, Bougheas et al. (2003) report results similar to those found in the US, as does Bloch (2005) for Denmark and Ughetto (2008) for Italy, with some variation depending on firm age and size. Bond et al. (2005) find that, during the 1985-1994 period, cash flow was positively correlated with R&D in large manufacturing firms in the UK, whereas R&D spending was insensitive to cash flow shocks in German firms. A strong link between R&D and internal finance has also been confirmed in the case of public companies in China (Shi & Wu 2016; Hu et al. 2017). Overall, in most early studies, Anglo-

[1] There is also a third category, closely related to and often overlapping with the other two, which focuses on the dynamic relationship between the sources and patterns of financing R&D and various firm- and industry-specific or contextual factors. This large and complex topic remains beyond the scope of this thesis which limits itself to studying only the sources of financing R&D and the R&D-cash sensitivity in the case of FS.

Saxon economies seemed to exhibit higher R&D-cash flow sensitivity than economies in continental Europe, although with several notable exceptions (Hall & Lerner 2010, 623).

These R&D-specific findings have been supported by research on the relationship between the availability of internal finance and investment in general (see for example Hubbard 1998; Minton & Schrand 1999; cf. Spatareanu 2008) which suggests that capital markets are not perfect substitutes for sudden shortfalls in cash. However, the proposition that the link between investment and cash flow could be considered as evidence of financing constraints has also received strong criticism, primarily on methodological grounds. For example, Kaplan & Zingales (1997; 2000) point out that most early studies do not control for exogenous effects on investment demand and the potential use of external finance. They find that, at least for the large US companies included in their sample, investment-cash flow sensitivity is rarely associated with firms that are usually classified as 'financially constrained' – a categorization that Kaplan & Zingales (1997, 210-211; cf. Fazzari et al. 2000) show to be theoretically ambiguous. This criticism has recently been echoed by Farre-Mensa & Ljungqvist (2016, 34), who suggest that findings which have been attributed to financing constraints may simply "reflect differences in the growth and financing policies of firms at different stages of their life cycles."[1]

More recent studies have been increasingly nuanced. For example, Brown et al. (2009) find that, during the 1994-2004 R&D boom in the US, high-tech firms relied both on internal funds and public stock issuances to finance R&D which was sensitive to financial effects in young, but not in mature firms. Cincera & Ravet (2010) compare manufacturing firms in the US and the European Union (EU) and find that, between 2000 and 2007, cash flow variations had little effect on R&D investment in the US, whereas the opposite was true in the EU, suggesting that US firms have better access to external funding than their European counterparts. Revest & Sapio (2012) review evidence on financing investment by small technology firms in Europe and find that, in the context of relatively underdeveloped high-tech stock markets in most European countries, these firms rely primarily on internal funds while also benefiting from R&D-related tax incentives and public venture capital (VC). To account for the smoothing of R&D spending due to potentially high adjustment costs (see Brown & Petersen 2011; Shin & Kim 2011), Brown

[1] Although the literatures on the sources of R&D finance and financing constraints are largely overlapping, the question of whether and under which circumstances can R&D-cash sensitivity be considered a sign of financing constraints requires an analysis of factors external to the firm such as demand conditions, market development, and technological change. It therefore remains beyond the scope of this thesis which focuses only on whether the link exists in the case of FS or not.

et al. (2015) use cash holdings instead of cash flow as a proxy to test for the presence of financing constraints in European firms between 1995 and 2007. In contrast to several earlier studies referenced above, they find that variations in cash flow have little effect on R&D expenditure, although R&D is positively correlated with changes in cash holdings, suggesting that firms manage buffer stocks of liquidity to keep their R&D investment smooth in the face of reduced cash flow (see also O'Brien 2003 on how innovation-based business strategy is often associated with financial slack).

Combined, these results show that R&D-cash sensitivity varies between countries and over time (Hall et al. 2015, 3). This conclusion has been recently confirmed by Cincera et al. (2016) who find that, in the post-2007 period, R&D spending was once again sensitive to cash flow variations in the EU, especially in younger firms in medium- and high-tech sectors, but not in the US where R&D by both young and mature firms showed little sensitivity to liquidity shocks. However, this does not necessarily mean that the availability of internal funds is unimportant for R&D in US firms. Although the US context may be more conducive to financing R&D also from external sources, as shown by He & Wintoki (2016), between 1980 and 2012, R&D-intensive firms in the US were simultaneously increasing R&D spending and hoarding cash (see also Dittmar et al. 2003 on the role of agency problems in determining cash holdings), which suggests that these firms may indeed be relying primarily on internal funds to finance R&D.

1.2.2 External equity finance

External equity plays an important role in the development of new firms, especially in high-tech sectors. Given that data on financing R&D in private companies is more difficult to obtain, most research in this area has been focused on public equity. Although equity may be more costly than relying on internal funds, it has a number of advantages over debt which, due to information asymmetries, highly variable returns, and lack of collateral, may be particularly difficult to obtain for R&D firms that are young and small. However, after the initial public offering (IPO), which generally permits considerable growth in firm size and improves the overall financial position, the role of equity may gradually decline as other sources of funding become more readily accessible (Rajan & Zingales 1998; Carpenter & Petersen 2002).

Equity finance in the form of public offering of shares is most widely used in countries with well-developed stock markets. For example, Carpenter & Petersen (2002) show that, over the past few decades, young high-tech firms in the US have relied heavily on public equity financing made available through deep and liquid stock markets. Similarly, Brown & Petersen (2009) find that the changing relationship between investment and cash flow in US firms from 1970 to 2006 can at least partly be explained by the growing importance of public equity markets, although this may be less relevant for R&D than investment in general. The widely held view that higher stock market development encourages equity finance is also evident in comparisons of similar companies listed on different exchanges. For example, Blass & Yosha (2003) find that publicly traded R&D-intensive Israeli firms that are listed in the US rely more heavily on equity than those listed in Tel Aviv. The importance of public equity relative to other sources of finance may also be technologically determined. For example, Noailly & Smeets (2016) find that European firms specializing in renewable energy innovation tend to rely more on stock issues than other innovative energy firms, even though they may be listed in the same country.

There is also evidence that firms use external equity as a source of finance for specifically R&D. For example, Kim & Weisbach (2008) find that, between 1990 and 2003, publicly traded US firms used proceeds from both primary and secondary offerings to finance not just capital expenditure, but also R&D. As mentioned above, Brown et al. (2009) report evidence that the 1994-2004 R&D boom in the US was at least partly driven by an increase in the supply of public equity finance. Martinsson (2010), building on the work by Brown et al. (2009), shows that, in the late 1990s and early 2000s, external equity played an important role in the financing of R&D in the UK, but not in continental Europe where access to large pools of public equity has traditionally been much more restricted. Also focusing on the European context, Brown et al. (2015) show that not controlling for stock issues can mislead estimates of the link between cash flow and R&D, and that external equity does indeed play a role in financing firm level R&D in countries with more developed stock markets, in particular Sweden and the UK.

Whether high financial development necessarily leads to more R&D investment, innovation, and economic growth is an issue of ongoing debate (see for example Rajan & Zingales 2001; Levine 2005; Acharya & Xu 2013; Brown et al. 2013; Hughes 2014, especially 261-264; Hsu et al. 2014; Dosi et al. 2016; Tori & Onaran 2017). It is certainly the case that thick markets for new firm stocks, such as those in the US, are relatively more conducive to VC investment in innovative startups (see Hall & Lerner 2010, 624-634 for an overview). In the context of renewable energy in the US, this was particularly evident in the mid-2000s, although VC financing of cleantech firms has decreased dramatically in subsequent years (Nanda et al. 2015; see also Howell 2016 on the role of public R&D grants in attracting VC to invest in renewable energy and especially in solar PV companies). Overall, despite the fact that excessive reliance on external equity may increase short-term pressures and agency costs that could in the long run end up stifling innovation, especially in the case of publicly held firms (Kerr & Nanda 2014; see also Lazonick & Mazzucato 2012, 13-15), in countries with well-developed stock markets, some companies are certainly making use of public equity to finance their investment, including R&D.

1.2.3 External debt finance

As mentioned above, information asymmetries and the high uncertainty of outputs make debt an unlikely source of finance for R&D activities. Furthermore, the lack of tangible collateral often associated with R&D makes it difficult to recover value from R&D firms that are faced with bankruptcy, creating an additional obstacle to securing loan contracts (Hughes 2014, 250). This is supported by the finding that R&D is positively correlated with liquidation costs (Alderson & Betker 1996) and that, on average, R&D-intensive firms tend to have lower debt levels than non-R&D firms (Hall & Lerner 2010, 616-617), although with some country level variation.

For example, Hall (1992) finds that, during the 1980s, debt was a disfavored source of finance for R&D firms in the US, while Bhagat & Welch (1995) report a negative correlation between debt levels and R&D spending in North America and Europe, but a positive one in Japan. Similarly, Bah & Dumontier (2001) find that R&D-intensive firms in the US, UK, Europe, and Japan have lower debt levels than non-R&D firms, although Japanese firms tend to rely more on bank loans than their US and European counterparts. Elkemali & Rejeb (2015) study a sample of European firms between 2002 and 2011 and also find a positive correlation between low leverage and R&D-intensity. Looking specifically at Italian manufacturing firms, Ughetto (2008; cf. Micucci & Rossi 2017) finds that although these firms obtain a considerable share of their financing from banks, debt is rarely used to fund specifically R&D.

However, some recent work suggests that bank loans may play a bigger role in the financing of at least some R&D companies than has traditionally been assumed, especially when firms have assets that can be pledged as collateral which in the case of R&D firms often includes intellectual property. For example, Chava et al. (2013) show that, in the case of public US firms, significant patent activity leads to better and cheaper access to loans by banks that have previous experience in assessing the market value of intellectual property. The positive role of patents as signals to potential investors has recently been confirmed by Hottenrott et al. (2016) in the context of established R&D-intensive firms in Flanders, Belgium. Mann (2014) finds that debt is a commonly used source of finance for innovative companies in the US and that firms often pledge their patents as collateral. Similarly, both Hochberg et al. (2014) and Robb & Robinson (2014) find that, despite the assumed difficulty of financing risky entrepreneurial projects with debt, innovative startups in the US actually make extensive use of bank loans, especially when they hold patents that can readily be sold to and used by other companies.

To conclude, in contrast to theoretical predictions and the results of the majority of earlier studies, it is clear that R&D-intensive firms can and do make use of external debt financing. However, it is less clear whether debt is used to finance R&D activities. Although Mann (2014) does find a positive correlation between increased borrowing and R&D spending in US firms, and although there is some recent evidence that public companies in Europe may be using credit lines as part of their R&D-related liquidity management (Guney et al. 2016), most of the studies referenced above are not explicit on whether bank loans are used to fund specifically R&D.

1.2.4 Public R&D grants

Besides benefiting indirectly from publicly funded education and research (Mowery & Langlois 1996; McMillan et al. 2000; Salter & Martin 2001; Mazzucato 2013), private companies may also be direct recipients of government R&D grants. Although the effectiveness of targeted R&D subsidies depends greatly on institutional (Hall & Lerner 2010, 634) and technological factors, the majority of empirical evidence support the conclusion that grants and other similar measures lead to increased R&D outputs (Hall et al. 2015, 10). The literature on the role of government subsidies in financing firm level R&D is very extensive. For the purposes of this thesis, a brief review with a particular focus on renewable energy companies in the US will suffice.

The general interest in renewables grew considerably in response to the 1970s energy crisis (Venn 2013; see Jerneck 2015 for an in depth overview of the subsequent development of solar PV industry in the US). However, throughout the following decades, due to a strongly marketoriented shift in political attitudes and growing deregulation of the energy sector, energy-related public R&D budgets declined significantly in most developed countries (Dooley 1998; Margolis & Kammen 1999). In the US, this decline reached its bottom of about 2 billion USD per year in the late 1990s. Government support has been gradually increasing since then, with renewables accounting for approximately one fifth of total R&D funds allocated by the Department of Energy (DOE), the main source of energy-related R&D grants in the US (Sissine 2014).

The primary purpose of public grants for firm level R&D is to reduce early stage financial risk and help companies through the so-called 'valley of death' – the critical low cash flow period between initial investment in the development of a new technology and income-generating commercialization (Bürer & Wüstenhagen 2009; Roberts et al. 2010). As emphasized by both Nanda et al. (2015) and Noailly & Smeets (2016), this type of support is particularly important in the context of renewable energy innovation which is generally characterized by long R&D cycles and high capital intensity. Indeed, there is considerable evidence that, in countries with well-developed renewable energy sectors such as Germany, Denmark, the US, China, and Sweden, public R&D support has played an important role in launching this emerging industry, especially when combined with measures of domestic demand creation (see for example Sawin et al. 2001; Klaassen et al. 2005; Jacobsson & Lauber 2006; Lewis & Wiser 2007; Hendry et al. 2010; Hopkins & Lazonick 2012; Mazzucato & Semieniuk 2016).

Looking at DOE's Small Business Innovation Research (SBIR) program for supporting R&D in US energy companies, Howell (2016) finds that, between 1983 and 2013, a total of 884 million USD were awarded to 7,436 companies. In Howell's study, receiving R&D grants is positively correlated with patenting, firm survival, and subsequent financing, although the latter is less evident in the case of solar firms. In other words, R&D grants have enabled US energy companies to make investments that reduce technological uncertainty and often lead to improved access to other types of funding. According to Howell, these results are consistent with the hypothesis that energy innovation is at least partly held back by financial constraints. In the context of the present thesis, the important question is whether FS has received any R&D grants. Although Howell's data is presented in an aggregated form, she makes the following remark in a footnote (Howell 2016, 15): "Among the 23 solar firms that have ever had an IPO, 9 appear in my data; SBIR winners include Sunpower, First Solar, and Evergreen Solar." Thus, FS has been the recipient of at least one R&D grant, although the time and size of the grant remain unclear.

2. RESEARCH METHODOLOGY AND DATA COLLECTION

The thesis takes a case study approach and focuses on the financing of R&D in the context of a single US firm – FS. In light of previous research on financing firm level R&D (see Chapter 1), the thesis asks the following question: how did FS finance its R&D between 2002 and 2016, and has R&D spending been sensitive to variations in the availability of internal funds? The thesis can be described as hypothesis and theory testing because it aims to determine whether and to what degree are the results and theoretical propositions presented in previous studies on the subject verified in the context of a particular firm – FS (Løkke & Dissing Sørensen 2014).

In the first part of the research question, the thesis focuses on the financing of both direct R&D expense and R&D-related acquisitions, defined as acquisitions involving complementary assets such as proprietary technology and R&D-related intellectual property, or the transfer of R&D staff. In the second part of the research question, the thesis focuses on the relationship between direct R&D expense and variations in the availability of internal funds. Since cash flow does not capture the actual extent of funds that are internally available for investment at any particular point in time (Hottenrott et al. 2016, 13), both cash flow and cash holdings are used as measures of internal liquidity. This is in line with recent studies on the subject which have emphasized the importance of firms' active management of internal cash balance to keep their R&D spending smooth over time and especially when faced with negative shocks in cash flow (Brown & Petersen 2011; Shin & Kim 2011; Brown et al. 2015). Given that the thesis deals with a relatively small amount of data, the assessment of R&D-cash sensitivity is based entirely on direct observations and comparisons of relevant financial data.

The results and analysis provided in Chapter 3 and Chapter 4 are based on a thorough examination of both quantitative and qualitative data derived from Form 10-k reports (known as annual reports) that publicly traded companies in the US are required to file with the SEC, and from official FS news releases. Both sources of data are accessible through the company website.[1] Annual reports in particular provide not only quantitative data on R&D spending and financing activities, but also extensive commentary on the sources and use of funds throughout the period under investigation. This allows for deriving the most likely source of finance for R&D even when it is not explicitly identified in Form 10-k financial data.

FS completed its IPO in 2006 and Form 10-k reports have been submitted to SEC and made publicly available in all subsequent years. The annual report from 2006 includes R&D-related financial data and some commentary on the pre-IPO period from 2002 onwards. Therefore, the thesis limits itself to studying the time period from 2002 to 2016 because pertinent data is not readily available for earlier years. It is important to note that relying solely on annual reports means that the analysis is determined entirely by data as reported. In other words, the results are valid under the assumption that Form 10-k data accurately reflects the real R&D spending and financing activities of FS. The possibility of discrepancies between Form 10-k data and reality is minimized by the fact that all annual report financial information is externally audited.

Through a detailed analysis of financing R&D in a single firm, the thesis allows for verifying or disproving theoretical propositions and empirical results presented and discussed in previous studies (see Chapter 1), for example that large manufacturing firms in the US tend to finance their R&D activities primarily from internal funds, or that R&D spending may show little sensitivity to variations in cash flow because firms draw on internal cash balance to keep their R&D expenditure smooth over time. Although the thesis focuses only on FS, its general conclusions may also be valid in the context of other publicly traded renewable energy companies during the same time period. However, verifying this would require additional research with a representative sample of firms. In other words, although a single case study does not verify broad generalizations, it can nonetheless be used to propose new general hypotheses (Flyvbjerg 2006). The results of the thesis can therefore inform future research on financing firm level R&D both in the US renewable energy industry as well as other contexts.

[1] See http://investor.firstsolar.com

3. RESULTS

3.1 Sources of finance for R&D expense

The R&D expenditure of FS consists primarily of salaries and other personnel-related costs, in addition to supplies, laboratory testing, and outside services used in the R&D process. In 2006, the company started recording the amortization and depreciation of R&D-specific equipment and facilities as part of the overall cost of R&D. Between 2006 and 2008, R&D expense additionally included portions of the operating costs associated with the expansion of FS manufacturing and research facilities in Perrysburg, Ohio, although the exact amount of these inclusions is not specified in Form 10-k reports (FS 2007, 34; 2009b, 32; 2017, 58).

From 2002 to 2016, FS reported a total of approximately 1.05 billion USD in R&D expense. As shown in Table 1, R&D spending exceeded net sales in 2002 and 2003, while net income remained negative up until 2005. From 2004 onwards, annual R&D spending began increasing in absolute terms, stabilizing in the range of 125-144 million USD between 2011 and 2016, while fluctuating moderately as a percentage of net sales, averaging at 4.4 percent between 2004 and 2016. As shown in Table 2, government grants represented an important source of funding for R&D activities between 2004 and 2007, especially in 2004 and 2005 when they covered 80 and 38 percent of total R&D expense, respectively. The importance of grants relative to total R&D spending declined in subsequent years, and no grant funding was reported from 2009 onwards.[1] Starting in 2004, FS began using equity to compensate R&D staff. Also shown in Table 2, this type of payment covered approximately one third of total R&D spending from 2005 to 2007, one fifth in 2008, and one tenth between 2009 and 2011. Although still considerable in absolute terms (3 million USD in 2016, for example), the importance of share-based compensation relative to total R&D expense has been declining since 2006. Together, grants and share-based

[1] In addition to R&D grants, FS has also benefited from the Research & Experimentation Tax Credit. As of 2016, the company had a total of 47.5 million USD of R&D tax credit carryforwards (FS 2017, 133).

compensation covered the majority of R&D expenditure in 2004 and 2005, approximately one half in 2006 and 2007, and one fifth in 2008, the year after which grant funding ceased.

Table 1: FS net sales, net income, and R&D expense (thousands USD), 2002-2016[1]

Year	Net Sales	Net Income (loss)	R&D Expense	R&D Expense % of Net Sales
2002	490	(26,224)	6,029	1230.40%[2]
2003	3,210	(28,042)	3,841	119.70%[2]
2004	13,522	(16,771)	1,240	9.2%
2005	48,063	(6,462)	2,372	5.0%
2006	134,974	3,974	6,361	4.7%
2007	503,976	158,354	15,107	3.0%
2008	1,246,301	348,330	33,517	2.7%
2009	2,066,200	640,138	78,161	3.8%
2010	2,563,515	664,201	94,797	3.7%
2011	2,779,832	(63,008)	140,523	5.1%
2012	3,354,920	(42,933)	132,460	3.9%
2013	3,309,616	350,718	134,300	4.1%
2014	3,391,187	395,964	143,969	4.2%
2015	3,578,995	546,421	130,593	3.6%
2016	2,951,328	(357,964)	124,762	4.2%
			1,048,032[3]	4.4%[4]

This leaves the source of finance for the majority of R&D spending unaccounted for, especially from 2006 onwards. Some of this expense is the depreciation and amortization of R&D-related equipment and facilities. The exact amount is unclear, because annual reports do not record this cost in a sufficiently disaggregated form (see for example FS 2013c, 99; 2017, 105), except for the amortization of patents which is negligible, averaging at no more than 1.75 percent of total R&D expense between 2004 and 2016[5] (see for example FS 2014b, 111-112; 2017, 100).

Before the IPO in 2006, the primary sources of liquidity were borrowings from the investment bank Goldman Sachs and the Estate of John T. Walton, loans from the State of Ohio in relation to the construction of a manufacturing plant, and cash equity contributions from JWMA Partners,

---

[1] Source: Form 10-k reports, unless stated otherwise.
[2] Author's calculation, based on Form 10-k data.
[3] Total R&D spending between 2002 and 2016. Author's calculation, based on Form 10-k data.
[4] Average R&D spending as % of net sales, excluding the outlier years of 2002 and 2003. Author's calculation, based on Form 10-k data.
[5] Author's calculation, based on Form 10-k data.

an investment firm that bought FS in 1999.[1] The full details of the Goldman Sachs agreement, including whether any collateral was used to secure the loan, have not been disclosed. Whereas no assets were pledged against the loan from the Estate of John T. Walton, land, buildings, and manufacturing equipment were used as collateral to secure the state of Ohio loans (FS 2007, 43-47). In early 2006, before the IPO, FS sold unregistered securities to a small number of accredited investors, including both Goldman Sachs and JWMA Partners (FS 2007, 28-29). After the IPO in 2006, which generated 302.7 million USD in cash (FS 2007, 43), and a follow-on offering in 2007, which generated an additional 366 million USD (FS 2008, 46), operating activities have been the primary source of internal liquidity. The cash and equivalents balance has been increasing steadily throughout the post-IPO years, reaching 1.35 billion USD in 2016. Debt levels have remained low in most of the period under investigation. Consolidated balance sheets for all years can be found in Appendix A.

Table 2: FS R&D expense, R&D grants, and share-based R&D compensation (thousands USD), 2002-2016[2]

Year	R&D Expense	R&D Grants	Grants % of Total R&D[3]	Share-based R&D Compensation	Share-based Compensation % of Total R&D[3]
2002	6,029	-	-	-	-
2003	3,841	-	-	-	-
2004	1,240	1,000	80.6%	64	5.2%
2005	2,372	900	37.9%	639	26.9%
2006	6,361	900	14.1%	2,348	36.9%
2007	15,107	1,800	11.9%	4,719	31.2%
2008	33,517	900	2.7%	5,967	17.8%
2009	78,161	-	-	8,230	10.5%
2010	94,797	-	-	10,467	11.0%
2011	140,523	-	-	14,984	10.7%
2012	132,460	-	-	7,149	5.4%
2013	134,300	-	-	5,760	4.3%
2014	143,969	-	-	4,417	3.1%
2015	130,593	-	-	4,109	3.1%
2016	124,762	-	-	3,284	2.6%

[1] JWMA Partners, formerly True North Partners, LLC, was started in 1996 by a former FS CEO Michael J. Ahearn and John T. Walton, son of Sam Walton, the founder of retailing corporation Walmart (Fehrenbacher 2011).
[2] Source: Form 10-k reports, unless stated otherwise. Empty box means that no data is reported for that year.
[3] Author's calculation, based on Form 10-k data.

The use of debt and credit facilities has been related almost exclusively to expanding production with land, manufacturing plants, and equipment pledged as collateral (FS 2007, 71; 2009b, 87-90; 2010, 52; 2011b, 98; 2012, 107-110), or the construction of solar power plants (FS 2015, 125; 2016b, 122), although the latter has been financed primarily from working capital (FS 2017, 62). In 2013, FS completed a third public equity offering which generated 428.2 million USD in cash (FS 2014b, 70), intended primarily for acquisitions of solar PV projects and geographic expansion (FS 2013a). Some additional cash has also been provided by the exercise of employee stock options (FS 2009b, 45; 2010, 52; 2011b, 54; 2012, 61), although this has been marginal relative to other sources of finance. Cash flow statements for the 2002-2016 period can be found in Appendix B.

To summarize, apart from the low operating income period before the IPO when R&D expenditure was financed through a mix of public R&D grants, share-based compensation, borrowings from Goldman Sachs and the Estate of John T. Walton, and cash equity contributions from FS parent company JWMA Partners, internal stock of cash has been the primary source of finance for R&D in FS. These funds were first generated by public equity offerings in 2006 and 2007 when grants and share-based compensation still accounted for approximately one half of total R&D spending. From 2007 onwards, operating activities have been the primary source of cash flow, apart from a couple of years that will be discussed in Chapter 3.3. Importantly, there is no indication in Form 10-k reports or official FS news releases that corporate debt or bank loans have ever been used to finance specifically R&D. Although revolving credit facilities have been available and used for "working capital and other general corporate purposes" (FS 2010, 92; 2012, 106; 2016b, 61) which could theoretically include R&D-related expenditures, comments provided in Form 10-k reports are not specific enough to confirm this.

3.2 Sources of finance for R&D-related acquisitions[1]

Between 2002 and 2016, FS made numerous acquisitions of other companies, most of which were solar project developers with no R&D activities or directly R&D-related assets, at least according to comments provided in Form 10-k reports. Examples include the acquisitions of Turner Renewable Energy in 2007 (FS 2008, 71-72), OptiSolar's project pipeline in 2009 (FS

[1] For the purposes of this thesis, only acquisitions involving transfers of proprietary technology, patents, or staff directly engaged in the development of new knowledge or technology are considered R&D-related.

2010, 73-74), NextLight Renewable Power in 2010 (FS 2011, 76-77), and Solar Chile in 2013 (FS 2014b, 109-110). However, there have also been five R&D-related acquisitions: Ray Tracker, Inc. in 2011 (FS 2011a), TetraSun, Inc. and General Electric's (GE) CdTe intellectual property portfolio in 2013 (FS 2013b; 2013d), Skytron-Energy in 2014 (FS 2014a), and Enki Technology in 2016 (FS 2017, 98).

Ray Tracker, Inc. was a PV balance-of-systems[1] and solar tracking technology[2] company that FS acquired in an all-cash transaction worth approximately 23 million USD in 2011 (FS 2013c, 63). The acquisition involved various intangible assets, but had a marginal effect on the historical balance sheets and results of operations of FS (FS 2012, 85). Two years later, TetraSun, Inc., a crystalline silicon PV module startup, was also acquired in an all-cash transaction (FS 2013b). Although the total purchase price was not disclosed, 39.1 million USD of it was assigned to an in-process R&D (IPR&D) project to develop a high efficiency crystalline silicon cell, and 6.1 million USD to goodwill (FS 2014b, 109). The acquisition of TetraSun was intended as a hedge against the possible decline of CdTe technology. However, in 2016, in light of increased CdTe cell efficiencies, FS discontinued its development and production of silicon-based alternatives (Wesoff 2016). There is no indication in Form 10-k reports that FS took on new debt in relation to these two acquisitions which seem to have been financed entirely from cash provided by operating activities. The acquisition of TetraSun may have been financed partly by the 2013 public equity offering (FS 2013a), although Form 10-k comments do not confirm this explicitly.

In August 2013, FS announced a technology partnership and future transaction and purchasing agreement with GE. As part of the deal, FS acquired GE's CdTe intellectual property portfolio, including trade secrets, databases, technological know-how, and other proprietary information relating to solar PV manufacturing processes. In return, GE received 1.75 million shares of FS common stock with an August 5, 2013 market value of 83.3 million USD (FS 2013d; 2014b, 109). Similarly to the TetraSun acquisition, 73.7 million USD of the purchase price was assigned to an IPR&D asset, and an additional 10.1 million USD to goodwill. The acquisition had a marginal effect on the historical balance sheets and results of operations of FS (FS 2014b, 109).

Skytron-Energy is a solar power plant management and data monitoring technology firm that FS acquired in 2014 (FS 2014a). Passing comments in 2014 annual report (FS 2015, 67) indicate

[1] Balance-of-systems includes all components involved in solar PV systems besides the solar panels.
[2] Solar tracker is a device that orients solar energy equipment towards the Sun.

that the acquisition involved cash payments, but the full terms of the deal have not been disclosed, making it impossible to determine for certain the financing of this particular acquisition. In late 2016, FS sold Skytron-Energy to a German firm Liberta Partners (Osborne 2016). The most recent R&D-related acquisition is Enki Technology, a coating materials firm that FS bought in October 2016 for 10.3 million USD in cash with an additional 7 million USD contingent on the achievement of certain production milestones. The whole purchase price was assigned to an IPR&D asset (FS 2017, 98). Again, there is no indication in Form 10-k reports that FS took on new debt in relation to these acquisitions. Instead, R&D-related acquisitions between 2002 and 2016 have been financed entirely by either internal stocks of cash (Ray Tracker, TetraSun, Enki Technology) or common equity (GE's CdTe intellectual property portfolio). As said, the details and financing of the Skytron-Energy deal have not been disclosed.

3.3 R&D-cash sensitivity

As mentioned above, before the public equity offerings of 2006 and 2007, the primary source of internal liquidity were borrowings from Goldman Sachs and the Estate of John T. Walton, and cash equity contributions from FS parent company JWMA Partners. As shown in Table 3, cash flow, dominated largely by income from operating activities (see Appendix B), has been positive throughout most of the subsequent years. As a result, FS has accumulated a considerable stock of internal funds – more than 1.3 billion USD in cash and equivalents as of 2016.

With the exception of the early years characterized by negative or low net income (see Table 1 above), throughout most of the 2002-2016 period, annual R&D spending in absolute terms has been increasing, reaching a plateau of approximately 130-140 million USD between 2011 and 2016. This growth in R&D expenditure has been generally matched with positive cash flow and an increase in cash balance. There are only four years when cash flow has been negative – 2004, 2009, 2011, and 2015. As can be seen from Table 3, R&D spending in absolute terms decreased only marginally in the immediately following years of 2012 and 2016, but increased in 2005 and 2010. In other words, R&D spending shows either no or insignificant sensitivity to cash flow shocks. Comments provided in Form 10-k reports reveal that the 2011-2012 reduction was caused entirely by decreases in share-based compensation (FS 2013, 54) and the 2014-2016 reductions by reduced module testing and material costs (FS 2016, 57) and by general corporate restructuring (FS 2017, 58). There is no indication in Form 10-k comments that R&D spending has ever been decreased due to reduced cash flow or a general lack of funds.

Table 3: FS R&D expense, year-over-year (YOY) change in cash balance, and year-end cash and equivalents balance (thousands USD), 2002-2016[1]

Year	R&D Expense	R&D Expense % of Net Sales	YOY Change in Cash Balance (reduction)[2]	Cash & Equivalents
2002	6,029	1230.40%[3]	489	2,050
2003	3,841	119.70%[3]	1,677	3,727
2004	1,240	9.2%	(75)	3,465
2005	2,372	5.0%	12,841	16,721
2006	6,361	4.7%	290,980	308,092
2007	15,107	3.0%	89,122	404,264
2008	33,517	2.7%	332,175	716,218
2009	78,161	3.8%	(48,518)	664,499
2010	94,797	3.7%	113,858	765,689
2011	140,523	5.1%	(138,702)	605,619
2012	132,460	3.9%	289,368	901,294
2013	134,300	4.1%	420,184	1,325,072
2014	143,969	4.2%	300,791	1,482,054
2015	130,593	3.6%	(380,179)	1,126,826
2016	124,762	4.2%	214,880	1,347,155

Importantly, from the public equity offerings of 2006 and 2007 onwards, due to relatively stable net income from operating activities, FS has been able to build and maintain a large balance of cash holdings. These internal funds have been complemented by an access to a revolving credit facility (FS 2011, 55; 2012, 106; 2017, 119). As a result, occasional reductions in cash flow have had little effect on the company's ability to increase or maintain R&D investment levels, as FS could always draw the necessary funds either from internal cash balance or the revolving credit facility, although, as mentioned above, the comments provided in Form 10-k reports are not explicit on whether credit has ever been used to finance specifically R&D.

[1] Source: Form 10-k reports, unless stated otherwise.
[2] Author's calculation, based on Form 10-k data. Discrepancies between YOY change in cash balance and year-end cash and equivalents balance are due to cash-equivalent assets not included in the calculation of the former which is based only on cash provided by or used in operating, investing, and financing activities (see Appendix B).
[3] Author's calculation, based on Form 10-k data.

4. DISCUSSION

Throughout the 2002-2016 period, FS has relied on a variety of sources of finance. From the perspective of financing R&D, the 15-year period can be broadly divided into two: the early years of 2002-2007, characterized by a mix of cash equity contributions, private loans, public grant funding, and share-based compensation, culminating with the IPO in 2006 and a follow-on offering in 2007; and the later years of 2008-2016, characterized by growing R&D expenditure and a substantial reliance on internal funds generated primarily by operating activities. These findings are hereby discussed in three parts: first, the sources of finance for R&D and R&D-related acquisitions; second, the sensitivity of R&D expenditure to the availability of internal funds; and third, implications for further research.

The results on 2008-2016 and the post-IPO years of the earlier period are in line with a number of studies that have confirmed the ‘Schumpeterian hypothesis’ (Cincera & Ravet 2010, 8) that large established firms, at least in the US, rely primarily on internal funds to finance their R&D activities (for example Hall 1992; 2002; Himmelberg & Petersen 1994; Brown et al. 2009; see also Hall & Lerner 2010, 634-635). The importance of internal finance is also evident in the context of R&D-related acquisitions, all of which were made in the later period when FS had accumulated a considerable stock of cash that the company could use to acquire complementary technology and knowledge assets. The only exception confirmed by the comments provided in Form 10-k reports is the acquisition of GE’s CdTe intellectual property portfolio which was financed entirely by common shares – an example of using corporate stock as currency to enhance innovative capabilities (see Carpenter et al. 2003).

However, high internal liquidity was initially generated by public equity offerings in 2006 and 2007. These coincided with rapid increases in R&D expenditure which more than doubled every year between 2005 and 2009 (see Table 3 above). In other words, public equity has played an important role in the financing and growth of FS. Proceeds from the first two offerings were essential for business expansion that became the basis for subsequent income from operating activities that could be used to not only increase and maintain R&D investment levels throughout the later period but also to make R&D-related acquisitions. This finding is in line with Carpenter & Petersen (2002), Kim & Weisbach (2008), Brown & Petersen (2009), and Brown et al. (2009) who all highlight the important role that deep and liquid public equity markets in the US play in the growth financing of innovative manufacturing and technology firms.

Whereas earlier research suggested that debt is a disfavored and rarely used source of finance for R&D firms in the US (for example Hall 1992; Bhagat & Welch 1995; Bah & Dumontier 2001), more recent studies have found that these companies actually do make use of bank loans and often pledge their intangible assets such as patents for collateral (for example Hochberg et al. 2014; Mann 2014; Robb & Robinson 2014). The results of the thesis are partly in line with these later studies. On the one hand, debt has indeed played a role in the financing of FS, both before and after going public. On the other hand, the data derived from Form 10-k reports is not explicit on whether debt or credit lines have been used to finance specifically R&D. Given that net income was negative up until 2005, it is possible that the pre-IPO loan from Goldman Sachs was used to finance, among other things, R&D activities. However, since bank loans are more difficult to secure for R&D which is characterized by highly uncertain outputs (Hall & Lerner 2010, 616-617) and often by a lack of tangible collateral (Hughes 2014, 250), it is much more likely that during the pre-IPO period, besides public grants and share-based compensation, R&D was additionally financed through cash equity contributions by JWMA Partners and loans from the Estate of John T. Walton which did not require collateral. In the later period, bank loans have been related exclusively to expanding manufacturing and the construction of solar power plants. Although a revolving credit facility has been available for general corporate purposes, data derived from Form 10-k reports does not suggest that credit has ever been used to finance R&D expenditure (cf. Guney et al. 2016).

An important finding of the thesis relates to the role of public grants in financing firm level R&D. Previous research on US energy companies has found that public R&D grants are positively correlated with firm survival and subsequent access to other types of funding, and that FS has been a recipient of the DOE’s SBIR grant at least once (Howell 2016). The thesis finds that FS received grant funding every year from 2004 to 2008 and that grants combined with share-based compensation covered the majority of R&D expenditure from 2004 to 2006 when net income was either negative or very low compared to total R&D spending. Although a single case study does not allow for drawing meaningful policy conclusions, this finding seems to confirm the proposition that public support for firm level R&D is necessary or at least favorable for helping companies through the critical period between the early phases of new product development and income-generating commercialization (Bürer & Wüstenhagen 2009; Roberts et al. 2010; Nanda et al. 2015). On the other hand, given that throughout the pre-IPO years, FS had access to various other sources of finance, it is unlikely that R&D grants were absolutely essential for the commercialization of CdTe-based solar panels, especially since the underlying technology had already been developed in the 1990s and first CdTe panels brought onto the market as early as 2002 (FS 2007, 11).

As discussed in Chapter 1.2.1, the sensitivity of R&D spending to the availability of internal funds as measured by either cash flow or holdings has been shown to vary between firms, national contexts, and over time. In the case of FS between 2002 and 2016, in line with Cincera et al. (2016) and He & Wintoki (2016), the thesis finds that although positive cash flow and growing cash balance strongly correlate with an increase in R&D expenditure, R&D spending shows either no or insignificant sensitivity to negative cash flow. Although in contrast with some earlier studies on R&D-intensive manufacturing firms in the US (for example Hall 1992; Himmelberg & Petersen 1994; Hall et al. 1998), given the high adjustment costs generally associated with R&D (Hall & Lerner 2010, 612) and the relatively high levels of internal cash balance throughout the post-IPO period, this finding is not particularly surprising. Instead, it supports the proposition that large established firms tend to maintain high buffer stocks of liquidity that allow them to avoid cutting back on R&D expenditure even in the face of reduced income (Brown & Petersen 2011; Shin & Kim 2011; Brown et al. 2015). However, although reliance on cash reserves helps explain why R&D spending is not sensitive to short-term volatility in cash flow, in the long run, this is possible only as long as the internal cash balance is continually rebuilt, preferably from operating income and without taking on additional long-term liabilities (Brown et al. 2015, 3). For FS, this has certainly been the case in most years following the IPO in 2006 (see Appendix A and Appendix B).

Finally, the results of the thesis have several implications for further research. For example, the study of the sources of finance for firm level R&D could be broadened to include other publicly traded as well as private renewable energy companies in the US to find out whether there is any variation among different firms. Ideally, this would include making qualitative distinctions between various technologies, types of investment, enterprises, and time periods (O'Sullivan 2004, 259). Such a survey would be a prerequisite for comparing the financing of R&D and innovation in the renewable energy sector with that of other industries, and subsequently, for comparing the US with other countries. If there are differences, both in the financing and outputs of R&D, the next step would be to study the causes of these differences, thus building on the already existing research on the dynamic relationship between finance, innovation, and various firm- and industry-specific and contextual factors, including firm age and size, the nature of innovative activities, ownership structure, organizational frameworks and practices, characteristics of the financial system, and the broader social, legal, and economic context in which innovative companies are embedded.

Given the central role of innovation in the evolution of economic systems and the prosperity and well-being of human populations, this kind of research would have considerable practical value. It is the conviction of the author of this thesis that the study of economic phenomena is not of interest and importance only for the sake of knowledge itself, but also for improving the way in which social institutions, including business firms, are set up and governed – a key determinant of the conditions and quality of human life. Thus, in the context of the topic of this thesis, a more complete understanding of how firms fund their R&D activities and what are the main obstacles and determinants to the successful financing of innovation would inform the design of public policies more conducive to innovative, sustainable, and inclusive economic development.

SUMMARY

Successful innovation requires sustained investment in a variety of inputs. One of these inputs is R&D – the discovery and development of new or improved knowledge, products, or processes of production. The highly uncertain, intangible and idiosyncratic nature of R&D activities, combined with asymmetric information and agency problems, represents a challenge for the financing of firm level R&D. This has led economists to predict that securing external funding for R&D activities is more difficult than for other types of business investment and that R&D firms therefore prefer and tend to rely primarily on internal sources of finance.

The empirical evidence in support of this hypothesis is mixed. Whereas earlier studies on large manufacturing firms in the US found that external capital markets are indeed a disfavored source of finance for R&D and that R&D investment is highly sensitive to the availability of internal funds as measured by cash flow, subsequent research has revealed considerable variation between different companies and national contexts, as well as over time. R&D firms have been found to rely on a variety of sources of finance, including external equity, bank debt, and public R&D grants. It has also been found that R&D investment does not always respond to negative cash flow shocks, and that cash holdings are a more appropriate measure of internal liquidity that companies can rely on for keeping their R&D spending smooth whenever faced with reduced inflow of cash.

The present thesis focused on the financing of firm level R&D in a single US firm, the solar PV manufacturer and project developer FS that went public in 2006. In light of previous research, the thesis asked the following question: how did FS finance its R&D between 2002 and 2016 (including R&D-related acquisitions), and has R&D spending been sensitive to variations in the availability of internal funds (measured by cash flow and holdings)? Importantly, the thesis limited itself to studying only the sources of R&D finance and the R&D-cash sensitivity, leaving out the closely related question on the relationship between the sources and patterns of financing R&D and various firm- and industry-specific or contextual factors. To answer the research

question, the thesis drew on both quantitative and qualitative data derived from Form 10-k annual reports and official FS news releases. The financial data in the first report goes back to 2002 which allowed for the inclusion of four pre-IPO years.

The thesis found that during the 15-year period in question, the financing of R&D in FS has varied. Initially, when net income from operating activities was low, the company relied on cash equity contributions from its parent company JWMA Partners and loans from the estate of John T. Walton and the investment bank Goldman Sachs. The full details of the latter have not been disclosed, although it is unlikely that the loan was used to finance specifically R&D. Between 2004 and 2006, public grants combined with share-based compensation accounted for the majority of R&D expenditure, but the relative importance of both declined after the company went public. The IPO in 2006 and a follow-on offering in 2007 resulted in considerable internal liquidity which coincided with a rapid increase in R&D spending. Subsequently, cash provided by operating activities has been the primary source of finance for both direct R&D spending and R&D-related acquisitions, except for the acquisition of GE's CdTe intellectual property portfolio which was financed entirely by common stock. Although FS has repeatedly taken on bank debt, comments provided in Form 10-k reports do not suggest that debt has been used to finance R&D. Throughout the 2002-2016 period, R&D spending shows either no or insignificant sensitivity to negative cash flow shocks. This result is in contrast to some earlier studies on large US manufacturing firms, but confirms more recent findings. The data clearly show that after going public, FS has managed a large buffer stock of cash that has enabled the company to increase or maintain R&D investment even when faced with reductions in cash flow.

The results of the thesis apply only to FS and do not allow for broad generalizations about the financing of R&D in other solar PV companies or the US manufacturing sector at large. The inclusion of other publicly traded renewable energy companies in future studies would allow for meaningful comparisons between different industries and countries. Combined with previous studies on the subject, such an inquiry would lay the groundwork for studying the dynamic relationship between financing innovation and various firm- and industry-specific and contextual factors, allowing for more informed policymaking for innovative and inclusive economic development – an important topic that remained beyond the scope of the thesis.

ABSTRACT IN ESTONIAN (EESTIKEELNE RESÜMEE)

Töö pealkiri: Ettevõttesisese teadus- ja arendustegevuse rahastamine Ameerika Ühendriikide päikeseenergia tööstuses First Solar, Inc. näitel, 2002-2016

Töö eesmärgiks on uurida teadus- ja arendustegevuse (T&A) rahastamist Ameerika Ühendriikide päikeseenergia ettevõttes First Solar, Inc. (FS). Töö uurimisküsimuseks on: kuidas rahastas FS T&A'd aastatel 2002-2016 (kaasa arvatud T&A'ga seotud omandamised) ning kas kulutused T&A'le on olnud tundlikud muutustele ettevõttesisestes rahalistes vahendites (mõõdetuna rahavoos ning raha ja ekvivalentide jäägis)? Ettevõtte majandusaasta aruannetele tuginevalt leiab töö, et enne aktsiate esmast avalikku pakkumist (IPO) aastal 2006 rahastas FS T&A'd läbi osakapitali sissemaksete, eraleanude, avalike T&A toetuste ning aktsiapõhise tasu. Järgnevatel aastatel oli T&A rahastatud peamiselt äritegevuse tulemusel tekkinud ettevõttesisestest vahenditest. Ühe erandiga kehtis see ka T&A'ga seotude omandamiste puhul. Kuigi kasumi ning raha ja ekvivalentide kasv korreleerub T&A kulutuste kasvuga, ei ole T&A kulutuste määr tundlik negatiivsele rahavoole. IPO-järgsetel aastatel on FS olnud suuteline suurendama ning säilitama kulutusi T&A'le tänu kõrgele ettevõttesisesele likviidsusele. Antud tulemus on vastuolus mõningate varasemate Ameerika Ühendriikide tootmisettevõtete T&A rahastamist uurivate töödega, mis on leidnud positiivse korrelatsiooni T&A kulutuste vähenemise ning negatiivse rahavoo vahel. Küll aga on antud tulemus kooskõlas hiljutisemate uuringutega.

Märksõnad: teadus- ja arendustegevuse rahastamine; ettevõtte rahavoog; likviidsus; First Solar; taastuvenergia; päikeseenergia; innovatsioon

REFERENCES

Acharya, V. V., & Xu, Z. (2013). *Financial Dependence and Innovation: The Case of Public Versus Private.* NBER Working Paper No. 19708. Retrieved January 30, 2017, from http://www.ckgsb.edu.cn/uploads/201409/Acharya_Xu_private_innovation.pdf

Aghion, P., Reenen, J. V., & Zingales, L. (2013). Innovation and Institutional Ownership. *American Economic Review, 103*(1), 277-304.

Alam, P., & Walton, K. S. (1995). Information Asymmetry and Valuation Effects of Debt Financing. *The Financial Review, 30*(2), 289-311.

Alderson, M. J., & Betker, B. L. (1996). Liquidation Costs and Accounting Data. *Financial Management, 25*(2), 25-36.

Bah, R., & Dumontier, P. (2001). R&D Intensity and Corporate Financial Policy: Some International Evidence. *Journal of Business Finance & Accounting, 28*(5-6), 671-692.

Bernstein, S. (2014). *Does Going Public Affect Innovation?* Stanford Graduate School of Business. Retrieved January 11, 2017, from https://www.gsb.stanford.edu/sites/gsb/files/publication-pdf/IPOInnovation%20-%20July2014.pdf

Bhagat, S., & Welch, I. (1995). Corporate Research & Development Investments - International Comparisons. *Journal of Accounting and Economics, 19*(2-3), 443-470.

Blass, A., & Yosha, O. (2003). Financing R&D in Mature Companies: An Empirical Analysis. *Economics of Innovation and New Technology, 12*(5), 425-447.

Bloch, C. (2005). R&D Investment and Internal Finance: the Cash Flow Effect. *Economics of Innovation and New Technology, 14*(3), 213-223.

Bond, S., Harhoff, D., & Van Reenen, J. (2005). Investment, R&D and Financial Constraints in Britain and Germany. *Annales d'Économie et de Statistique, No. 89/80,* 433-460.

Bougheas, S., Görg, H., & Strobl, E. (2003). Is R&D Financially Constrained? Theory and Evidence from Irish Manufacturing Firms. *Review of Industrial Organization, 22*(2), 159-174.

Brown, J. R., & Petersen, B. C. (2009). Why Has the Investment-Cash Flow Sensitivity Declined So Sharply? Rising R&D and Equity Market Developments. *Journal of Banking & Finance, 33*(5), 971-984.

Brown, J. R., & Petersen, B. C. (2011). Cash Holdings and R&D Smoothing. *Journal of Corporate Finance, 17*(3), 694-709.

Brown, J. R., Fazzari, S. M., & Petersen, B. C. (2009). Financing Innovation and Growth: Cash Flow, External Equity, and the 1990s R&D Boom. *The Journal of Finance, 64*(1), 151-185.

Brown, J. R., Martinsson, G., & Petersen, B. C. (2013). Law, Stock Markets, and Innovation. *The Journal of Finance, 68*(4), 1517-1549.

Brown, J. R., Martinsson, G., & Petersen, B. C. (2015). *Do Financing Constraints Matter for R&D?* Centre of Excellence for Science and Innovation Studies (CESIS) Electronic Working Paper Series. Paper No. 394. Retrieved December 10, 2016, from https://static.sys.kth.se/itm/wp/cesis/cesiswp394.pdf

Bürer, M., & Wüstenhagen, R. (2009). Which Renewable Energy Policy is a Venture Capitalist's Best Friend? Empirical Evidence from a Survey of International Cleantech Investors. *Energy Policy, 37*(12), 4997-5006.

Bushee, B. J. (1998). The Influence of Institutional Investors on Myopic R&D Investment Behavior. *The Accounting Review, 73*(3), 305-333.

Carpenter, M., Lazonick, W., & O'Sullivan, M. (2003). The Stock Market and Innovative Capability in the New Economy: The Optical Networking Industry. *Industrial and Corporate Change, 12*(5), 963-1034.

Carpenter, R. E., & Petersen, B. C. (2009). Capital Market Imperfections, High-Tech Investment, and New Equity Financing. *The Economic Journal, 112*(477), 54-72.

Chava, S., Nanda, V., & Xiao, S. C. (2013). Lending to Innovative Firms: The Role of Lender Expertise and Control Rights. *SSRN Electronic Journal*. Retrieved January 30, 2017, from https://www.researchgate.net/publication/256064798_Lending_to_Innovative_Firms_The_Role_of_Lender_Expertise_and_Control_Rights

Chemmanur, T. J., & Tian, X. (2017). Do Anti-Takeover Provisions Spur Corporate Innovation? A Regression Discontinuity Analysis. *Journal of Financial and Quantitative Analysis*, Forthcoming. Retrieved March 24, 2017, from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1572219

Cho, S. (1992). Agency Costs, Management Stockholding, and Research and Development Expenditures. *Seoul Journal of Economics, 5*(2), 127-152.

Cincera, M., & Ravet, J. (2010). Financing Constraints and R&D Investments of Large Corporations in Europe and the US. *Science and Public Policy, 37*(6), 455-466.

Cincera, M., Ravet, J., & Veugelers, R. (2016). The Sensitivity of R&D Investments to Cash Flows: Comparing Young and Old EU and US Leading Innovators. *Economics of Innovation and New Technology, 25*(3), 304-320.

Dittmar, A., Mahrt-Smith, J., & Servaes, H. (2003). International Corporate Governance and Corporate Cash Holdings. *The Journal of Financial and Quantitative Analysis*, *38*(1), 111-133.

Dooley, J. J. (1998). Unintended Consequences: Energy R&D in a Deregulated Energy Market. *Energy Policy, 26*(7), 547-555.

Dosi, G., Revest, V., & Sapio, A. (2016). *Financial Regimes, Financialization Patterns and Industrial Performance: Preliminary Remarks.* ISIGrowth Working Paper 22. Retrieved March 19, 2017, from http://www.isigrowth.eu/wp-content/uploads/2016/06/working_paper_2016_22.pdf

EC. (2014). *A Study on R&D Tax Incentives. Final Report.* European Commission. Retrieved January 8, 2017, from https://ec.europa.eu/futurium/en/system/files/ged/28-taxud-study_on_rnd_tax_incentives_-_2014.pdf

Elkemali, T., & Rejeb, A. (2015). R&D Intensity and Financing Decisions: Evidence from European Firms. *Economics Bulletin*, *35*(2), 1042-1055.

Eng, L., & Shackell, M. (2001). The Implications of Long-Term Performance Plans and Institutional Ownership for Firms' Research and Development (R&D) Investments. *Journal of Accounting, Auditing & Finance, 16*(2), 117-139.

Farre-Mensa, J., & Ljungqvist, A. (2016). Do Measures of Financial Constraints Measure Financial Constraints? *Review of Financial Studies, 29*(2), 271-308.

Fazzari, S. M., Hubbard, G. R., & Petersen, B. C. (1988). Financing Constraints and Corporate Investment. *Brookings Papers on Economic Activity*, *1988*(1), 141-195.

Fazzari, S. M., Hubbard, G. R., & Petersen, B. C. (2000). Investment-Cash Flow Sensitivities are Useful: A Comment on Kaplan and Zingales. *The Quarterly Journal of Economics, 115*(2), 695-705.

Fehrenbacher, K. (2011). *A New Greentech VC to Pitch: Michael Ahearn & His $300M fund.* Gigaom. Retrieved December 4, 2016, from https://gigaom.com/2011/07/18/a-new-greentech-vc-to-pitch-michael-ahearn-his-300m-fund/

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry, 12*(2), 219-245.

Francis, J., & Smith, A. (1995). Agency Costs and Innovation: Some Empirical Evidence. *Journal of Accounting and Economics, 19*(2-3), 383-409.

FS. (2007). *Form 10-k Annual Report 2006.* First Solar, Inc. Retrieved February 12, 2017, from http://files.shareholder.com/downloads/FSLR/3971920352x0xS950153-07-576/1274494/filing.pdf

FS. (2008). *Form 10-k Annual Report 2007.* First Solar, Inc. Retrieved February 12, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS950153-08-367/1274494/filing.pdf

FS. (2009a). *First Solar Added to the S&P 500 Index.* First Solar, Inc. News Releases. Retrieved January 18, 2017, from http://investor.firstsolar.com/releasedetail.cfm?ReleaseID=571596

FS. (2009b). *Form 10-k Annual Report 2008.* First Solar, Inc. Retrieved February 13, 2017, from http://files.shareholder.com/downloads/FSLR/3984886330x0xS950134-09-3635/1274494/filing.pdf

FS. (2010). *Form 10-k Annual Report 2009.* First Solar, Inc. Retrieved February 13, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS1274494-10-7/1274494/filing.pdf

FS. (2011a). *First Solar Acquires Raytracker, Inc.* First Solar, Inc. News Releases. Retrieved January 13, 2017, from http://investor.firstsolar.com/releasedetail.cfm?ReleaseID=573744

FS. (2011b). *Form 10-k Annual Report 2010.* First Solar, Inc. Retrieved February 14, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS1274494-10-7/1274494/filing.pdf

FS. (2012). *Form 10-k Annual Report 2011.* First Solar, Inc. Retrieved February 14, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS1274494-12-15/1274494/filing.pdf

FS. (2013a). *First Solar Announces Public Offering of Common Stock.* First Solar, Inc. News Releases. Retrieved April 11, 2017, from http://investor.firstsolar.com/releasedetail.cfm?releaseid=770731

FS. (2013b). *First Solar to Acquire TetraSun to Expand Addressable Market Opportunity.* First Solar, Inc. News Releases. Retrieved January 13, 2017, from http://investor.firstsolar.com/releasedetail.cfm?ReleaseID=755337

FS. (2013c). *Form 10-k Annual Report 2012.* First Solar, Inc. Retrieved February 14, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS1274494-13-6/1274494/filing.pdf

FS. (2013d). *GE, First Solar Announce Solar Technology and Commercial Partnership.* First Solar, Inc. News Releases. Retrieved January 13, 2017, from http://investor.firstsolar.com/releasedetail.cfm?ReleaseID=783197

FS. (2014a). *First Solar to Acquire Technology Provider Skytron-Energy From AEG Power Solutions.* First Solar, Inc. News Releases. Retrieved March 29, 2017, from http://investor.firstsolar.com/releasedetail.cfm?releaseid=851993

FS. (2014b). *Form 10-k Annual Report 2013.* First Solar, Inc. Retrieved February 16, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS1274494-14-11/1274494/filing.pdf

FS. (2015). *Form 10-k Annual Report 2014.* First Solar, Inc. Retrieved February 16, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS1274494-15-6/1274494/filing.pdf

FS. (2016a). *First Solar Achieves Yet Another Cell Conversion Efficiency World Record.* First Solar, Inc. News Releases. Retrieved January 10, 2017, from http://investor.firstsolar.com/releasedetail.cfm?ReleaseID=956479

FS. (2016b). *Form 10-k Annual Report 2015.* First Solar, Inc. Retrieved February 17, 2017, from http://files.shareholder.com/downloads/FSLR/3971920352x0xS1274494-16-67/1274494/filing.pdf

FS. (2017). *Form 10-k Annual Report 2016.* First Solar, Inc. Retrieved March 10, 2017, from http://files.shareholder.com/downloads/FSLR/4047126812x0xS1274494-16-67/1274494/filing.pdf

Guney, Y., Karpuz, A., & Ozkan, N. (2016). *R&D Investments and Credit Lines.* Social Science Research Network. Retrieved March 19, 2017, from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2681233

Hall, B. H. (1992). *Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?* National Bureau of Economic Research Working Paper No. 4096. Retrieved December 18, 2016, from http://www.nber.org/papers/w4096

Hall, B. H. (2002). The Financing of Research and Development. *Oxford Review of Economic Policy, 18*(1), 35-51.

Hall, B. H., & Lerner, J. (2010). The Financing of R&D and Innovation. In B. H. Hall, & N. Rosenberg (Eds.), *Handbook of the Economics of Innovation* (pp. 610-639). Amsterdam: Elsevier.

Hall, B. H., Castello, P. M.-P., Montresor, S., & Vezzani, A. (2015). Financing Constraints, R&D Investments and Innovative Performances: New Empirical Evidence at the Firm Level for Europe. *Economics of Innovation and New Technology, 25*(3), 1-14.

Hall, B. H., Mairesse, J., Branstetter, L., & Crepon, B. (1998). *Does Cash Flow Cause Investment and R&D: An Exploration Using Panel Data for French, Japanese, and United States Scientific Firms.* EconPapers. Retrieved December 28, 2017, from http://econpapers.repec.org/paper/wpawuwpfi/9902005.htm

Hao, K. Y., & Jaffe, A. B. (1993). Effect Of Liquidity On Firms' R&D Spending. *Economics of Innovation and New Technology, 2*(4), 275-282.

Harhoff, D. (1998). Are There Financing Constraints for R&D and Investment in German Manufacturing Firms? *Annales d'Économie et de Statistique, No. 49/50*, 421-456.

He, Z., & Wintoki, B. M. (2016). The Cost of Innovation: R&D and High Cash Holdings in U.S. Firms. *Journal of Corporate Finance, 41*, 280-303.

Hendry, C., Harborne, P., & Brown, J. (2010). So What Do Innovating Companies Really Get From Publicly Funded Demonstration Projects and Trials? Innovation Lessons From Solar Photovoltaics and Wind. *Energy Policy, 38*(8), 4507-4519.

Himmelberg, C. P., & Petersen, B. (1994). R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries. *The Review of Economics and Statistics, 76*(1), 38-51.

Hochberg, Y. V., Serrano, C. J., & Ziedonis, R. H. (2014). *Patent Collateral, Investor Commitment, and the Market for Venture Lending.* NBER Working Paper 20587. Retrieved January 8, 2017, from http://yael-hochberg.com/assets/portfolio/HSZ.pdf

Hopkins, M., & Lazonick, W. (2012). *Soaking Up the Sun and Blowing in the Wind: Clean Tech Needs Patient Capital.* Financial Institutions for Innovation and Development. Retrieved November 16, 2016, from http://fiid.org/wp-content/uploads/2012/11/Hopkins-Lazonick-Clean-Tech-20121129.pdf

Hottenrott, H., Hall, B. H., & Czarnitzki, D. (2016). Patents as Quality Signals? The Implications for Financing Constraints on R&D. *Economics of Innovation and New Technology, 25*(3), 197-2017.

Howell, S. T. (2016). *Financing Innovation: Evidence from R&D Grants.* Social Science Research Network. Retrieved January 19, 2017, from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2687457

Hsu, P.-H., Tian, X., & Xu, Y. (2014). Financial Development and Innovation: Cross-country Evidence. *Journal of Financial Economics, 112*(1), 116-135.

Hu, J., Guo, L., & Zhu, F. (2017). Regional Financial Developments and Research and Development Investment - Cash Flow Sensitivity: Evidence on Chinese Public High-Tech Companies. *International Review of Finance*, Forthcoming. Retrieved March 22, 2017, from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2919113

Hubbard, G. R. (1998). Capital-Market Imperfections and Investment. *Journal of Economic Literature, 36*(1), 193-225.

Hughes, A. (2014). Capital Markets, Innovation Systems, and the Financing of Innovation. In M. Dodgson, D. M. Gann, & N. Phillips (Eds.), *The Oxford Handbook of Innovation Management* (pp. 248-270). Oxford: Oxford University Press.

Jacobsson, S., & Lauber, V. (2006). The Politics and Policy of Energy System Transformation - Explaining the German Diffusion of Renewable Energy Technology. *Energy Policy, 34*(3), 256-276.

Jerneck, M. (2015). *Sunrise of an Industry: Solar Energy under Financial and Industrial Capitalism in the U.S. and Japan, 1973 - 2005.* PhD Thesis. Lund University.

Johnson, S., La Porta, R., Lopez-de-Silanes, F., & Shleifer, A. (2001). Tunneling. *The American Economic Review, 90*(2), 22-27.

Kaplan, S. N., & Zingales, L. (1997). Do Investment-Cash Flow Sensitivities Provide Useful Measures of Financing Constraints? *Quarterly Journal of Economics*, *112*(1), 169-215.

Kaplan, S. N., & Zingales, L. (2000). Investment-Cash Flow Sensitivities are not Valid Measures of Financing Constraints. *Quarterly Journal of Economics, 115*(2), 707-712.

Kerr, W. R., & Nanda, R. (2014). *Financing Innovation.* Harvard Business School Working Paper 15-034. Retrieved December 8, 2016, from http://www.hbs.edu/faculty/Publication%20Files/15-034_c08817a4-7eac-4c62-b58b-8632585180b5.pdf

Kim, W., & Weisbach, M. S. (2008). Motivations for Public Equity Offers: An International Perspective. *Journal of Financial Economics, 87*, 281-307.

Klaassen, G., Miketa, A., Larsen, K., & Sundqvist, T. (2005). The Impact of R&D on Innovation for Wind Energy in Denmark, Germany and the United Kingdom. *Ecological Economics, 54*(2-3), 227-240.

Lazonick, W. (2011). *The Innovative Enterprise and the Developmental State: Toward an Economics of 'Organizational Success'.* The Academic-Industry Research Network. Retrieved October 29, 2016, from http://www.theairnet.org/files/research/lazonick/Lazonick%20Innovative%20Enterprise%20and%20Developmental%20State%2020110403.pdf

Lazonick, W. (2014). *Taking Stock: Why Executive Pay Results in an Unstable and Inequitable Economy.* Roosevelt Institute. Retrieved November 28, 2017, from http://www.theairnet.org/v3/backbone/uploads/2014/08/Lazonick_Executive_Pay_White_Paper_Roosevelt_Institute.pdf

Lazonick, W., & Mazzucato, M. (2012). *The Risk-Reward Nexus: Innovation, Finance and Inclusive Growth.* Policy Network. Retrieved October 21, 2016, from http://www.policy-network.net/uploads/media/154/8167.pdf

Levine, R. (2005). Finance and Growth: Theory and Evidence. In P. Aghion, & S. N. Durlauf (Eds.), *Handbook of Economic Growth* (1 ed., Vol. 1, pp. 865-934). Philadelphia: Elsevier.

Lewis, J. I., & Wiser, R. H. (2007). Fostering a Renewable Energy Technology Industry: An International Comparison of Wind Industry Policy Support Mechanisms. *Energy Policy, 35*(3), 1844-1857.

Løkke, A.-K., & Dissing Sørensen, P. (2014). Theory Testing Using Case Studies. *The Electronic Journal of Business Research Methods, 12*(1), 66-74. Retrieved January 10, 2017, from www.ejbrm.com/issue/download.html?idArticle=335

Mann, W. (2014). *Creditor Rights and Innovation: Evidence from Patent Collateral.* Social Science Research Network. Retrieved December 19, 2017, from https://papers.ssrn.com/sol3/papers2.cfm?abstract_id=2356015

Margolis, R. M., & Kammen, D. M. (1999). Evidence of Under-investment in Energy R&D in the United States and the Impact of Federal Policy. *Energy Policy, 27*(10), 575-584.

Martinsson, G. (2010). Equity Financing and Innovation: Is Europe Different From the United States? *Journal of Banking & Finance, 34*(6), 1215-1224.

Mazzucato, M. (2013). *The Entrepreneurial State: Debunking Public vs. Private Sector Myths.* London: Anthem Press.

Mazzucato, M., & Semieniuk, G. (2016). *Financing Renewable Energy: Who is Financing What and Why it Matters.* University of Sussex. Retrieved November 30, 2017, from http://sro.sussex.ac.uk/61966/1/2016_12_SWPS-Mazzucato_et_al.pdf

McMillan, S. G., Narin, F., & Deeds, D. L. (2000). An Analysis of the Critical Role of Public Science in Innovation: the Case of Biotechnology. *Research Policy, 29*(1), 1-8.

Micucci, G., & Rossi, P. (2017). Financing R&D Investments: An Analysis on Italian Manufacturing Firms and Their Lending Banks. *Economia e Politica Industriale, 44*(1), 23-49.

Minton, B. A., & Schrand, C. (1999). The Impact of Cash Flow Volatility on Discretionary Investment and the Costs of Debt and Equity Financing. *Journal of Financial Economics, 53*(3), 423-460.

Mowery, D. C., & Langlois, R. (1996). Spinning off and Spinning on(?): the Federal Government Role in the Development of the US Computer Software Industry. *Research Policy, 25*(6), 947-966.

Mulkay, B., Hall, B. H., & Mairesse, J. (2000). *Firm Level Investment and R&D in France and the United States: A Comparison.* National Bureau of Economic Research Working Paper No. 8038. Retrieved February 2, 2017, from https://core.ac.uk/download/pdf/6645885.pdf

Munari, F., Oriani, R., & Sobrero, M. (2010). The Effects of Owner Identity and External Governance Systems on R&D Investments: A study of Western European Firms. *Research Policy, 39*(8), 1093-1104.

Nanda, R., Younge, K., & Fleming, L. (2015). Innovation and Entrepreneurship in Renewable Energy. In A. Jaffe, & B. Jones (Eds.), *The Changing Frontier: Rethinking Science and Innovation Policy* (pp. 199-232). Chicago and London: University of Chicago Press.

Noailly, J., & Smeets, R. (2016). *Financing Energy Innovation: The Role of Financing Constraints for Directed Technical Change from Fossil-fuel to Renewable Innovation.* EIB Working Papers, No. 2016/06. Retrieved March 30, 2017, from https://www.econstor.eu/bitstream/10419/148571/1/87523531X.pdf

O'Brien, J. P. (2003). The Capital Structure Implications of Pursuing a Strategy of Innovation. *Strategic Management Journal, 24*(5), 415-431.

OECD. (2001). *Research and Development - SNA.* OECD Glossary of Statistical Terms. Retrieved April 12, 2017, from https://stats.oecd.org/glossary/detail.asp?ID=2311

Osborne, M. (2016). *First Solar Offloads Skytron-Energy.* PV Tech. Retrieved April 2, 2017, from https://www.pv-tech.org/news/first-solar-offloads-skytron-energy

O'Sullivan, M. (2004). Finance and Innovation. In J. Fagerberg, D. C. Mowery, & R. R. Nelson (Eds.), *The Oxford Handbook of Innovation* (pp. 240-265). Oxford: Oxford University Press.

Phillips, G. M., & Zhdanov, A. (2013). R&D and the Incentives from Merger and Acquisition Activity. *Review of Financial Studies, 26*(1), 34-78.

Pugh, W. N., Jahera, J. S., & Oswald, S. (1999). ESOPs, Takeover Protection, and Corporate Decision-making. *Journal of Economics and Finance, 23*(2), 170-183.

Rajan, R. G., & Zingales, L. (1998). Financial Dependence and Growth. *The American Economic Review, 88*(3), 559-586.

Rajan, R., & Zingales, L. (2001). Financial Systems, Industrial Structure, and Growth. *Oxford Review of Economic Policy, 17*(4), 467-482.

Revest, V., & Sapio, S. (2012). Financing Technology-Based Small Firms in Europe: What Do We Know? *Small Business Economics, 39*(1), 179-205.

Robb, A. M., & Robinson, D. T. (2014). The Capital Structure Decisions of New Firms. *The Review of Financial Studies, 27*(1), 153-179.

Roberts, M. J., Lassiter III, J. B., & Nanda, R. (2010). *U.S. Department of Energy & Recovery Act Funding: Bridging the "Valley of Death"*. Harvard Business School Case 810-144. Retrieved April 3, 2017, from http://www.hbs.edu/faculty/Pages/item.aspx?num=39029

Salter, A. J., & Martin, B. R. (2001). The Economic Benefits of Publicly Funded Basic Research: A Critical Review. *Research Policy, 30*, 509-532.

Sawin, J. L. (2001). *The Role of Government in the Development and Diffusion of Renewable Energy Technologies: Wind Power in the United States, California, Denmark and Germany, 1970-2000.* PhD Thesis. Tufts University.

Schumpeter, J. A. (2008). *The Theory of Economic Development: An Inquiry into Profits, Capital, Interest and the Business Cycle.* New Brunswick and London: Transaction Books.

Schumpeter, J. A. (2010). *Capitalism, Socialism and Democracy.* London: Routledge.

Shi, X., & Wu, T. (2016). Financial Constraints, Financing Channels and Corporations' R&D Investment - Based on Development Phase and Heterogeneity of Operating Cash Flow. *Open Journal of Social Sciences, 4,* 248-260.

Shin, M., & Kim, S. (2011). The Effects of Cash Holdings on R&D Smoothing of Innovative Small and Medium Sized Enterprises. *Asian Journal of Technology Innovation, 19*(2), 169-183.

Sissine, F. (2014). *Renewable Energy R&D Funding History: A Comparison with Funding for Nuclear Energy, Fossil Energy, and Energy Efficiency R&D.* Concressional Research Service. Retrieved April 2, 2017, from https://fas.org/sgp/crs/misc/RS22858.pdf

Spatareanu, M. (2008). The Cost of Capital, Finance and High-tech Investment. *International Review of Applied Economics, 22*(6), 693-705.

Teece, D. J. (1986). Profiting From Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy. *Research Policy, 15*(6), 285-305.

Tori, D., & Onaran, Ö. (2017). *The Effects of Financialization and Financial Development on Investment: Evidence from Firm-level Data in Europe.* Greenwich Papers in Political Economy No. 44. Retrieved April 7, 2017, from http://gala.gre.ac.uk/16089/

TSF. (2015). *National Solar Jobs Census 2015.* The Solar Foundation. Retrieved December 22, 2016, from http://www.thesolarfoundation.org/wp-content/uploads/2016/01/TSF-2015-National-Solar-Jobs-Census.pdf

Ughetto, E. (2008). Does Internal Finance Matter for R&D? New Evidence From a Panel of Italian Firms. *Cambridge Journal of Economics, 32*(6), 907-925.

Venn, F. (2013). *The Oil Crisis.* London and New York: Routledge.

Wesoff, E. (2016). *First Solar Discontinues Its TetraSun High-Efficiency Silicon Experiment.* Greentech Media. Retrieved April 11, 2017, from https://www.greentechmedia.com/articles/read/First-Solar-Discontinues-Its-TetraSun-High-Efficiency-Silicon-Experiment

APPENDIX A

Table A1: FS balance sheet (thousands USD), debt to equity ratio, and total liabilities to equity ratio, 2002-2016[1]

Year	Total Assets	Total Liabilities	Total Debt	Equity (Deficit)	Debt to Equity Ratio[2]	Total Liabilities to Equity Ratio[2]
2002	14,377	58,005	50,000	(43,628)	-1.15	-1.33
2003	31,575	11,019	8,700	20,556	0.42	0.54
2004	41,765	19,124	13,700	22,641	0.61	0.84
2005	101,884	63,490	48,723	13,129	3.71	4.84
2006	578,510	116,844	80,697	411,440	0.20	0.28
2007	1,371,312	274,045	108,165	1,097,267	0.10	0.25
2008	2,114,502	601,460	198,470	1,513,042	0.13	0.40
2009	3,349,512	696,725	174,958	2,652,787	0.07	0.26
2010	4,380,403	925,458	237,391	3,454,945	0.07	0.27
2011	5,782,339	2,163,593	663,648	3,618,746	0.18	0.60
2012	6,356,975	2,783,681	562,572	3,573,294	0.16	0.78
2013	6,876,586	2,408,516	223,323	4,468,070	0.05	0.54
2014	6,720,991	1,729,504	213,473	4,991,487	0.04	0.35
2015	7,316,331	1,767,844	289,415	5,548,487	0.05	0.32
2016	6,867,213	1,654,526	188,388	5,212,687	0.04	0.32

[1] Source: Form 10-k reports, unless stated otherwise.
[2] Author's calculation, based on Form 10-k data.

APPENDIX B

Table A2: FS cash flow, year-over-year (YOY) change in cash balance, and year-end cash and equivalents balance (thousands USD), 2002-2016[1]

Year	Operating Activities (cash used)	Investing Activities	Financing Activities	YOY Change in Cash Balance[2] (reduction)	Cash & Equivalents
2002	(22,128)	(3,833)	26,450	489	2,050
2003	(22,228)	(15,224)	39,129	1,677	3,727
2004	(15,185)	(7,790)	22,900	(75)	3,465
2005	5,040	(43,832)	51,633	12,841	16,721
2006	(576)	(159,994)	451,550	290,980	308,092
2007	205,951	(547,250)	430,421	89,122	404,264
2008	463,067	(308,441)	177,549	332,175	716,218
2009	675,193	(701,690)	(22,021)	(48,518)	664,499
2010	705,492	(742,085)	150,451	113,858	765,689
2011	(33,463)	(676,457)	571,218	(138,702)	605,619
2012	762,209	(383,732)	(89,109)	289,368	901,294
2013	856,126	(537,106)	101,164	420,184	1,325,072
2014	735,516	(387,818)	(46,907)	300,791	1,482,054
2015	(325,209)	(156,177)	101,207	(380,179)	1,126,826
2016	206,753	144,520	(136,393)	214,880	1,347,155

[1] Source: Form 10-k reports, unless stated otherwise.

[2] Author's calculation, based on Form 10-k data. Discrepancies between YOY change in cash balance and year-end cash and equivalents balance are due to cash-equivalent assets not included in the calculation of the former which is based only on cash provided by or used in operating, investing, and financing activities.