VILNIUS UNIVERSITY
BUSINESS SCHOOL

DEEPTECH ENTREPRENEURSHIP PROGRAMME

Lukas Grigaravičius

MASTER THESIS

Privatus ir viešasis finansavimas JAV agrotechnologijų sektoriuje (2010-2025): poveikis technologijoms ir augimui	***Private vs Public Funding in U.S. Agtech (2010-2025): Impact on Technology and Growth***

Supervisor: Prof. Saulė Mačiukaitė Žvinienė

SUMMARY

VILNIUS UNIVERSITY BUSINESS SCHOOL

DEEPTECH ENTREPRENEURSHIP STUDY PROGRAMME

LUKAS GRIGARAVIČIUS

PRIVATE VS PUBLIC FUNDING IN U.S. AGTECH (2010-2025): IMPACT ON TECHNOLOGY AND GROWTH

Supervisor: Prof. Saulė Mačiukaitė Žvinienė

Master's thesis was prepared in Vilnius, in 2025.

Scope of Master's thesis - 66 pages.

Number of tables used in the FMT - 6 pcs.

Number of figures used in the FMT - 1 pcs.

Number of bibliography and references - 34 pcs.

The FMT described in brief: This thesis examined how public and private financing timing affects technological development and initial growth of U.S. agtech companies from 2010 to 2025. The focus was on when capital enters a company and how different entrance orders of capital influence management of innovation risk in a slow cycle sector rather than on the total amount of capital invested into companies.

Problem, objective and tasks of the FMT: The thesis addresses a gap in the current knowledge base about how public and private capital enter companies in a repeating manner over time and specifically in slow cycle sectors with large amounts of technical uncertainty. The objective of the thesis is to determine how the sequence of funding sources influences technological development and the early growth of agtech companies. The tasks of the thesis are:

1. To examine literature on innovation finance and interaction between public and private capital.
2. To develop a database of U.S. agtech companies.
3. To categorize companies by their public-private funding sequences.
4. To compare technological and early growth outcomes of each category of funding sequence.
5. To interpret the findings for investors and policymakers.

Research methods used in the FMT: The thesis uses a quantitative research design using company-level comparative analysis. Methods employed included descriptive statistics and matched comparison between funding and sequencing categories. Observables were used to measure outcomes, such as SBIR phase completion, patent production and a structured technology readiness proxy.

Research and results obtained: Results indicated that funding sequence affected the developmental paths of the companies studied. Companies that followed a Public-to-Private funding sequence demonstrated greater progression through public validation stages, as well as slightly greater levels of observable technological readiness. On the other hand, companies that followed a Private-to-Public funding sequence showed significantly greater patent intensity but lower completion of public funding milestones.

Conclusions of the FMT: In conclusion, the results indicate that funding sequences can function as a governance mechanism for managing innovation risk. Funding provided publicly has the greatest impact in decreasing early stage technical uncertainty while funding provided privately has the greatest potential for supporting later stage commercialization and scaling. Matching the type of capital to the primary development-stage risks experienced by the company enhances capital use efficiency and increases innovation outcomes in agtech.

Information about the publication of FMT results or adaptation for publication: The findings of the FMT will not be formally published.

SANTRAUKA

VILNIAUS UNIVERSITETO VERSLO MOKYKLA

AUKŠTŲJŲ TECHNOLOGIJŲ VERSLO PROGRAMA

LUKAS GRIGARAVIČIUS

PRIVATUS IR VIEŠASIS FINANSAVIMAS JAV AGROTECHNOLOGIJŲ SEKTORIUJE (2010-2025): POVEIKIS TECHNOLOGIJOMS IR AUGIMUI

Darbo vadovė: Prof. Saulė Mačiukaitė Žvinienė

Magistro darbas parengtas Vilniuje, 2025 metais.

Magistro darbo apimtis - 66 puslapiai.

Magistro darbo metu panaudotų lentelių skaičius - 6 vnt.

Magistro darbo metu panaudotų figūrų skaičius - 1 vnt.

Magistro darbo metu naudotos literatūros ir šaltinių skaičius - 34 vnt.

Magistro darbo trumpas apibūdinimas: Darbo metu yra nagrinėjama, kaip viešasis ir privatus finansavimas veikia JAV agrotechnologijų sektoriaus įmonių technologinę plėtrą ir ankstyvą augimą laikotarpiu nuo 2010 iki 2025 metų. Pagrindinis faktorius yra ne investicijų dydis, tačiau, kada ir kokiu būdu kapitalas patenka į įmonę ir kaip skirtingos investavimo sekos gali paveikti inovacijų rizikos valdymą agrotechnologijų sektoriuje.

Magistro darbo problema, tikslas, uždaviniai: Pagrindinė problema yra ribotas supratimas apie viešojo ir privataus kapitalo sąveiką įmonių kontekste. Tai ypatingai aktualu sektoriuose, kur vyrauja didelis techninis neapibrėžtumas. Šio darbo tikslas yra ištirti, kaip finansavimo šaltinių pasirinkimo tvarka veikia agrotechnologijų įmonių plėtrą ir pradinius augimo etapus. Užduotys:

1. Išnagrinėti literatūrą, susijusią su inovacijų finansavimu bei viešojo ir privataus kapitalo sąveika.
2. Parengti JAV agrotechnologijų sektoriaus įmonių duomenų bazę.
3. Suskirstyti įmones pagal viešojo ir privataus finansavimo sekas.
4. Palyginti skirtingų finansavimo sekų technologinius ir ankstyvojo augimo rezultatus.
5. Interpretuoti gautus rezultatus investuotojams ir programų administratoriams.

Magistro darbo metu taikyti tyrimo metodai: Šio darbo metu buvo naudojamas kiekybinis tyrimas, pagrįstas įmonių lyginamąja analize. Naudoti metodai apima aprašomąją statistiką bei palyginimus tarp skirtingų finansavimo kategorijų. Rezultatams vertinti taikyti rodikliai, kaip

SBIR/STTR etapų įgyvendinimas, patentų skaičius, technologinės parengties lygio indikatorius.
Magistro darbo tyrimo rezultatai: Tyrimo rezultatai atskleidė, kad finansavimo tvarka turi reikšmingą poveikį įmonių plėtrai. Įmonės, naudojančios viešojo-privačiojo finansavimo modelį, pasiekė didesnę pažangą viešojo finansavimo etapuose ir šiek tiek aukštesnį technologinės parengties lygį. Tuo tarpu įmonės, pasirinkusios privataus-viešojo finansavimo seką, turėjo gerokai daugiau patentų, tačiau jų viešojo finansavimo etapų rodiklis buvo žemesnis.

Magistro darbo išvados: Apibendrinant galima teigti, jog finansavimo tvarka yra mechanizmas inovacijų rizikai valdyti. Viešasis finansavimas yra veiksmingiausias sprendžiant technininius neapibrėžtumus ankstyvose stadijose, o privatus finansavimas geriausiai tinka komercializavimo ir plėtros etapams.

Informacija apie magistro darbo viešinimą: Magistro darbas ir/ar rezultatai nebus skelbiami viešai.

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INTRODUCTION

Capital has been entering U.S. agricultural technology (agtech) companies at levels never seen before since 2010 through 2025. Both publicly traded and private entities invested in agtech companies. Venture capital, corporate venture capital, private equity firms, and government agencies, were investing simultaneously in many of the same companies and at the same time. Larger funding rounds became more common and venture capital began to flow into many agtech companies more frequently than ever before. A very optimistic narrative surrounded agtech during this period. Agtech could improve crop yields, lower input costs, lead to better climate outcomes, and provide necessary modernized systems to a sector that has been deemed inefficient for decades (Bloom et al., 2019; OECD, 2021).

However, relying only on volume of investment provides limited insights. Large sums of money raise the question: did various sources of funding result in fundamentally different companies? Capital is not simply money. Each source of capital brings its own set of expectations, restrictions and incentives. Some capital absorbs some of the technical risk associated with a new technology. Other capital stimulates the commercialization of a new technology. Still other capital restricts an entrepreneur's ability to make choices years prior to the point at which they will actually face such choices. While large sums of money are being invested in agtech companies, the exact way in which various sources of capital impact company trajectory remains poorly defined.

This thesis starts from the assumption that capital is not neutral. From where capital originates, when capital arrives, and the form capital takes are all important. All three of these variables impact how a technology is developed, how an entrepreneur manages internal risk, and how long a company can afford to experiment with new ideas. In the case of agtech, this is not a minor consideration. Long-term development cycles exist in the field. Biological systems develop on their own timelines. Seasons dictate the timing of field trials. Regulatory processes take place over extended periods of time. Teams receive feedback on their technologies later than needed to allow timely course corrections (Auerswald & Branscomb, 2003; Teece, 1986).

As a result, many of the financial decisions entrepreneurs make about their agtech companies represent either opportunities to advance in the development cycle of their products or the need to stall until later in the development cycle. Founders who are fortunate enough to secure non-dilutive public funding are able to continue to experiment with their technologies for longer periods of time than they otherwise could without having to enter the market too early. Entrepreneurs who secure corporate venture capital can rapidly gain access to the market for their products, but in doing so, they also limit their strategic options. Venture capitalists can accelerate the rate at which entrepreneurs can bring their products to market, but the presence of venture capital increases the potential costs of entrepreneurial failure.

These distinctions are observable in how entrepreneurs behave, and they are reflected in the number of patents these companies tend to file, the degree of technology readiness that exists in their products, the adoption rates of pilots, and in terms of overall survival and exit outcomes (Griliches, 1990; Hall et al., 2005).

There is a lot of literature that focuses on the financing of innovation. However, much of this literature views funding as an event rather than as a process. For example, companies are typically classified as either funded or unfunded. Similarly, support is modeled as either present or absent. This model of funding is useful for simplifying the complex issues involved in the financing of innovation. However, it is incomplete. Most funding arrangements occur in sequence rather than in isolation. Public R&D grants may lower the amount of uncertainty associated with a project (in early-stage) without giving the grantee greater control over the project (David et al., 2000; Bronzini & Piselli, 2016). Corporate investors may give grantees access to markets, but they may also impose significant constraints on strategic options available to grantees (Chemmanur et al., 2014). Venture capital may enable entrepreneurs to accelerate development of their products, but it also exposes them to significantly higher downside risks (Kortum & Lerner, 2000). In reality, companies experience sequences of funding events, not single funding events.

Therefore, the primary objective of this thesis is to identify the nature of the relationship between the types of capital and/or the sequence in which they are deployed and the resulting technology and early-growth performance outcomes of U.S. agtech companies between 2010 and 2025. The focus of this thesis will be on technology-driven agtech companies that are developing software, data platforms, robotic, sensor-based systems, and biological inputs. Although these categories of technology vary in terms of both the capital intensity required to develop them and the risk profiles associated with each category, they share the same agronomic, regulatory and market constraints.

The central research question posed in this thesis is straightforward: how does the organization and sequence of public and private funding affect the technological and commercial paths followed by agtech companies? While the central research question present in this thesis is academic in nature, the suggestions of the answers to this question are very practical. Founders must decide when to seek non-dilutive funding versus private funding. Investors must select funding products that best match the stage and uncertainty profile of their portfolio companies. Policymakers must determine if public funding is complementary to or replacing private investment in the funding of innovation (Mazzucato & Semieniuk, 2017).

Without a clear understanding of how different funding pathways impact the trajectory of agtech companies, many of these decisions are made based on conventional wisdom/narrative. This thesis seeks to provide a basis on which founders, investors and policymakers can make funding decisions based on evidence rather than simply relying on instinct and guesswork. In particular, this thesis will examine the relationships between different funding pathways and technology readiness, patent filing, the transition from pilots to products, follow-on funding, company survival and exit outcomes. These outcomes will be examined collectively to assess the efficiency with which different forms of capital translate into progress over time.

To accomplish this goal, this thesis will proceed in a series of steps. First, this thesis will analyze existing literature related to financing of innovation, public R&D funding and commercialization of technologies. Second, this thesis will develop a dataset of individual U.S. agtech companies active between 2010 and 2025, which links funding events to observable outcomes. Third, detailed comparisons of funding sequences will be used to evaluate the differences in developmental trajectories shown by companies that received different funding sequences. Finally, the findings will be translated into actionable advice for founders, investors and public agencies.

In terms of innovation financing research, the primary contribution of this thesis is to provide a new perspective on the timing and sequence of the various funding options available to an entrepreneur or startup in addition to focusing on the amount of capital they are able to raise. Historically, most innovation financing research has treated public and private funding vehicles (e.g., grants, venture capital) as independent entities when examining their effect on innovation. This thesis will examine the relationship between the sequence of funding vehicles and both technological development and early stage growth results. Due to the high levels of required capital, the lengthy duration of R&D, and the sequential changes in risk profile, the agtech industry represents a theoretically relevant setting for conducting such an examination. The thesis also identifies the different capital sequences and the corresponding innovation pathway and measurable performance outcomes.

This thesis employs a mixed approach to address the central research question. The quantitative analysis of this thesis uses descriptive comparisons and time-based measures to track the outcomes of agtech companies following funding events.

While this thesis addresses the central research question above, there are a number of limitations to the analysis presented. The outcomes of private companies are observed imperfectly. Proxies are employed to measure technology readiness and commercialization milestones. Disclosure of funding information varies among companies and over time. The selection of companies and the timing of funding events likely introduce biases into the analysis that cannot be completely eliminated.

Finally, this thesis does not intend to advocate for or against capital. Rather, this thesis intends to understand capital in the context of agtech. Agtech is a space in which technology development progresses at a slower pace compared to the expectations placed upon entrepreneurs and investors. As a result, the manner in which capital is structured often helps explain if an entrepreneur is given sufficient time to demonstrate that an idea is viable.

1. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

1.1. Capital, Risk, and Reality of Building Technology

Capital is not put into markets or business models at the beginning of an innovation process. Instead, capital is introduced before we understand whether an idea will be successful or not. Before we can define costs and time frames, capital is provided. Capital introduces an element of innovation finance that sets it apart from other types of corporate finance.

Technological companies face at least three constraints related to their finances. First, technological companies find it difficult to raise funds due to the fact that others know less about the company than those within the company. Most assets associated with technological companies are intangibles that may require years to generate positive cash flow. Validation or proof of success typically occurs late in the development process. Second, returns on investment made by technological companies are highly irregular. Delayed financing can result in lost value even though the fundamental idea behind an innovation is valid. As a result of these factors, a company's capital structure becomes a strategic decision and not simply a mechanical decision based on financial considerations.

There are several forms of private capital markets that have been developed to address the uncertainty present in the technological innovation process. These include venture capital, corporate venture capital, growth equity and private equity. All of these forms of private capital provide funds with clear expectations regarding the level of risk taken and the type of exit expected. The methods used are typical to traditional corporate finance approaches, however, these are employed in areas of the economy that are characterized by significant amounts of uncertainty and where the learning process is extended over a period of time (Brealey, Myers, Allen, 2020).

One of the key characteristics of venture capital is its ability to learn through time. Funds are released in stages. At each stage, the investor evaluates the progress of the company based on a set of assumptions. If there is no progress, the investor may withdraw. However, if the uncertainty surrounding the viability of the company diminishes, the investor may provide additional capital to the company. Rather than viewing the entire technological innovation process as a single bet, this approach views it as a series of options. As such, valuation is not viewed as a conclusive assessment of the company's worth. It is seen as a dynamic benchmark.

The use of private capital is expensive. Any dilution of ownership is permanent. However, private capital provides much more than money. It provides both a sense of urgency and individuals who may provide access to partnerships and expertise. Both of these factors can lead to the acceleration of the product to market and the reduction of indecision. While these benefits may be difficult to measure, they can be critical to the ultimate success of a company.

A second layer of private capital exists in the form of corporate venture capital. Corporate investors seek to acquire financial returns from their investments. However, they also seek to acquire access to technologies, to optional future products, and to knowledge. In agtech, access to distribution channels, to regulatory experience, and to field trial capabilities can be much more valuable than capital. However, since these types of access are outside the traditional cost of capital models, they are often overlooked in favor of more tangible measures of a company's success.

As a result of the uncertainty that characterizes biological systems and the regulatory environment that surrounds them, the expected upside from an investment in agtech is significantly greater than in many other sectors. Since the length of time required to realize the potential of an agtech company can be lengthy, and since the failure modes of such companies can be very difficult to identify and separate from success, it is often difficult to attract early-stage private capital even when the potential of the company is generally evident.

It is this gap that creates the opportunity for public funding. Programs such as SBIR/STTR, USDA/NIFA grants, and ARPA-E are examples of programs that exist to fill the gaps created by the limitations of private capital markets in the early stages of innovation in agtech. These programs do not seek to replace private investors. Instead, they seek to create an environment in which subsequent private investments are possible.

Lerner (1999) suggests that companies that receive SBIR funding have outperformed comparable companies, particularly in those geographic locations where there is a strong presence of private capital. This is an important finding. For public funding to be effective, it should operate in parallel with existing private capital markets. Operating independently of private capital markets does not increase the effectiveness of public funding (Howell, 2017). Howell (2017) supports Lerner's findings by demonstrating that R&D grants increase the likelihood of survival, the creation of patents, and the follow-on of funding. Public funding acts to decrease uncertainty during periods of greatest uncertainty.

ARPA-E takes this line of reasoning even further. ARPA-E seeks to fund ideas that appear unreasonable relative to conventional market-based criteria. Research conducted by the National Bureau of Economic Research has demonstrated that ARPA-E awardees undertake more risky and ambitious research efforts than they would have undertaken absent ARPA-E funding (Howell, Johnson & Papageorge, 2020). Public funding reduces the penalty for being incorrect early in the innovation process, thereby increasing the value of being correct later in the process.

Public funding can send signals to private capital providers. Technical review processes that are competitive signal to private capital providers that someone else has performed the hard work of evaluating the technical feasibility of the proposed innovation. Such a signal reduces the perceived risk of technical failure, and therefore reduces the cost of capital available to the company. Public funding does not displace private funding. Instead, public funding shifts the nature of the risks that private funding addresses.

What is most important is the sequence in which public and private funding occur. Public and private funding do not combine linearly. The timing of the occurrence of public and private funding helps explain the impact of the funding. Public funding reduces technical risk. Private funding prices market risk. Therefore, when public funding is received prior to private funding, private funding recipients are faced with a clearer decision-making environment. Valuations are increased, discount rates are decreased and rounds of funding are more likely to be obtained. There is evidence that suggests that when public funding is received prior to private funding, there is an increase in the rate of patenting, more follow-on private funding is received, and the survival of the company is improved (Howell, 2017; Howell et al., 2020).

Public funding can be beneficial to companies at later stages of the process. Once some market momentum has been established, public funding can provide a means to continue research activities without diluting ownership. Public funding can also be used to deepen intellectual property or support regulatory-related activities. From a financial viewpoint, public funding provides a mechanism to preserve the value of ownership interests while continuing to make additional technical investments.

The companies that are most successful in agtech rarely depend on a single source of capital. Public funding absorbs the uncertainty of the early stages of innovation. Venture and corporate capital drives products into the marketplace. Strategic partners help scale. Later stage investors focus on the execution of strategies. Each form of capital performs a different function.

Agtech illustrates a clear point of view concerning optimal capital structure. The optimal capital structure of an agtech company is not fixed. The optimal capital structure of an agtech company varies as uncertainty decreases and/or increases. Agtech companies that align the type of capital received with the stage of the company's development will progress at a faster rate and recognize failure earlier. Agtech ventures that fail to align the type of capital received with the stage of the company's development will likely stagnate, unaware of the reason for their lack of progress.

The remainder of this section will examine capital structure decisions. Capital structure is important, however, capital structure is not important only in terms of the amount of capital available. Timing, the form of capital, and the purpose of the capital are equally important.

1.2. Why Agtech Is Different Compared to Other Sectors

The agtech sector exists in a position of structural discomfort. It is based at the core of biology, hardware, data and regulation. Each of these sectors is by default slow. When combined, they are even slower. This is a characteristic that distinguishes agtech from those sectors where innovations are based on software and how investment capital reacts to it.

Software-based innovations allow for rapid testing. Code is developed, deployed, broken and then repaired in short iterations. Agtech-based innovations, on the other hand, are dependent upon physical trials of biological response and/or variations in climate along with regulatory adherence to existing systems. Feedback loops exist between weeks, and sometimes seasons, and even years. Consequently, agtech companies must integrate deep technical risk and very real friction related to commercial adoption, thereby influencing how investors perceive timing, capital intensity, and exits.

To provide analytical clarity, agtech is defined in this thesis as only technology companies that develop improvements to agricultural productivity, efficiency, sustainability and/or input performance utilizing proprietary products/systems. The definition of biological innovation including microbial inputs and biostimulants, hardware/robotics including sensing systems and autonomous equipment, digital/data platforms including farm management software and geospatial analysis, and supply chain/post-harvest technologies including quality sensing and logistics optimization. Farming operations/commodity producers are excluded from this definition. Only technology ventures are included.

Each category of agtech differs from a financing perspective regarding the way capital functions and pressures them due to the differing characteristics of each category. Examples include differing cost curves, development time lines and failure modes. While a biological product and a farm management platform may both be referred to as agtech, they should not be treated similarly in terms of a capital structure conversation. Treatment of similar agtech products as interchangeable only increases the risk involved as opposed to clarifying the risk involved.

Longer and more uncertain development cycles in agtech occur for several reasons. Slow feedback is provided by biological systems. Validation of a microbial input or crop protection product via rapid iteration is impossible (or at least very difficult and capital intensive). Validations must be performed across multiple growth cycles, soil types, weather patterns and/or multiple seasons. Data develops slowly. Capital is utilized prior to gaining confidence in a product's performance. Higher technical uncertainty is maintained for longer than is typical for investors.

A different constraint is introduced by hardware, sensing and robotics. Prototyping is capital intensive. Durability testing of products in the field is unavoidable. Reliability and safety are critical since the equipment is intended to operate in proximity to people, animals and/or valuable assets. Similar to hardware, each iteration of software will consume capital. A design flaw discovered late can make years of work worthless.

An additional constraint is added by regulations. Depending upon the category of their product, biological products, sensing systems and certain digital tools must meet the requirements of the USDA, EPA, or FDA. Timelines are extended and investor discount rates are increased by the review process required for regulatory approval. Even when approval is probable, uncertainty surrounding timing alone decreases present value. Friction is added by adoption. Farmers do not behave as early adopters of software do. Agricultural production systems vary greatly depending upon regional, crop, soil profile, and/or farm size characteristics. Changing production systems is risky. Most distribution requires trusted third parties such as agronomists, cooperatives, OEMs, and/or input retailers. These add risk and delay the receipt of revenue.

Together, these constraints create longer R&D cycles and slower commercialization pathways. Patient capital is required during early stages to support ambiguity. Capital capable of supporting manufacturing, logistics, and partnership with distribution channels is required during later stages. Typically, a single funding source does not support both phases well.

Revenue dynamics are reflective of this reality. Revenue generated from the adoption of agtech is slower than revenue generated from the adoption of SaaS solutions because there are significant and real switching costs associated with changing operational processes. Mistakes made by farmers are costly and revenue is typically received after successful completion of pilot programs. Acquisition costs are significantly higher due to the need to acquire customers. The payback period is longer because value is evaluated over seasonal cycles. Many companies bundle hardware, software and/or services to generate revenue throughout the entire production system. From a private equity perspective, this generates delayed revenue curves and unattractive early cash flow and increases dependence on external capital.

Additionally, agtech is more capital-intensive than many other sectors of innovation. Prior to charging a reasonable price, agtech companies must validate their products technically and in the field. This places significant reliance on public funding sources including grants, angel capital and early venture capital. Public R&D funding sources such as SBIR and USDA NIFA also provide critical support for experimentation that is difficult for private markets to finance. Without public funding sources, many agtech ventures would be uninvestible in their early years. There is substantial evidence demonstrating strong crowding out effects resulting from public funding (Lerner, 1999; Howell, 2017; Howell et al., 2020).

Liquidity outcomes are reflective of these constraints. Exit strategies in agtech tend to be acquisitions rather than initial public offerings. Consolidation is common in crop inputs, robotics, and farm management systems. Large incumbent players purchase innovative products instead of competing with them. This influences investor expectations and emphasizes the importance of strategic capital and access to channels.

Success in agtech commercially almost always relies upon factors beyond just technology. Intermediaries, including OEMs, cooperatives, ag retailers, input distributors and vertically integrated processors, between innovation and scale, influence pricing power, margin structures, and speed of expansion. For growth equity and later-stage investors, these relationships are as important as product performance.

From a portfolio manager underwriting perspective, risk in agtech breaks down into several categories. Technical risk concerns whether the product functions reliably. Manufacturing risk concerns whether the product can be manufactured at scale. Regulatory risk concerns approval and compliance. Adoption risk concerns how farmers will react to the product. Channel risk concerns access to distribution. Profitability risk concerns unit economics once scale is achieved. Each risk category affects discount rates and capital allocation decisions.

Agtech ventures with unresolved technical or adoption risk face significantly higher costs of capital. Ventures with validated technology and strong channel partners receive premium valuations. This is not about a story/narrative. It is about uncertainty. Capital flows towards clarity, regardless of the pace of growth.

The above explanation provides insight as to why capital structure in agtech cannot remain static. Different risk factors dominate at different stages. Capital that supports one stage can be damaging in the next stage. An understanding of these differences is necessary prior to examining how public and private funding interact with respect to the agtech lifecycle, the subject of the next section.

1.3. How Capital Enters U.S. Agtech

The United States agtech financing includes a wide variety of funding options and is not based solely on one type of funding. Instead, the agtech financing ecosystem is composed of a layered combination of venture capital, corporate strategic investments, growth equity, private equity, government sponsored R&D programs, and state-level innovation programs.

Each of these funding vehicles have a different way of pricing risk and each of these funding vehicles will have their own set of expectations for the company being funded. Each funding vehicle will influence the direction of the company.

To understand how an agtech company transitions from initial technical proof-of-concept to commercial scale implementation, it is necessary to understand the behaviors of these funding options in practice rather than simply how each funding option is defined in theory.

Since 2010, private capital has accounted for the majority of agtech investment with venture capital serving as the primary component of this private capital. Venture capital investors are generally willing to underwrite uncertainty regarding agtech investments, however, this willingness is contingent upon certain conditions including: governance control over the company, staged financing, and a generally identified pathway to liquidity (usually through acquisition or public listing) (Gompers & Lerner, 2004; Brealey et al., 2020). As a result, venture capital is typically concentrated in areas of agtech that allow for scalable applications, such as, robotics, digital platforms, and biological inputs with repeatable economic models.

As with the amount invested in the company, the structure of the venture capital funding is equally important. Funding is delivered in stages. With each stage, a portion of the uncertainty is resolved. Additionally, with each funding round, valuation is reset and the expectations placed on the company are increased. With each funding round, governance rights held by the investor are expanded.

Corporate venture capital operates under a different model than that of traditional venture capital. In contrast to the financial goals of venture capital, corporate venture capital seeks to obtain strategic positioning. As a result, corporate venture capital invests not only to generate returns, but also to gain access to new technologies, distribution channels, regulatory knowledge, and products to those currently offered by the corporation (Dushnitsky & Lenox, 2006). Unlike financial venture capital, corporate venture capital's willingness to invest in a company is based upon the ability of the technology to fit into the existing product portfolio and distribution channel of the corporation (Dushnitsky & Lenox, 2006).

This distinction is particularly relevant in the context of agtech. Commercial viability of many agtech technologies is heavily dependent on integration into existing systems. Corporate venture capital can significantly increase the probability that a product reaches the market by providing the company with access to these systems. However, corporate venture capital also poses significant alignment risks for the company. The strategic priorities of the corporation can change rapidly, decision-making cycles can become longer, and the degree of fit between the technology and the existing products and distribution channels of the corporation can limit the company's optionality (Dushnitsky & Lenox, 2006).

Growth equity and private equity investment typically occur after the technical validation of the company's products have been demonstrated. Growth equity and private equity focus on the operational aspects of the company's activities. Specifically, growth equity and private equity evaluate manufacturing efficiency, gross margin, distribution partnerships, scalability, etc. (Brealey et al., 2020). The role of growth equity and private equity is not to determine if the technology is viable, but rather if it can be scaled in a predictable manner over a given timeframe.

Federal government programs for funding R&D in agtech operate under a completely separate model than private capital. Federal programs such as SBIR/STTR, USDA-NIFA, and ARPA-E exist due to the fact that private capital consistently underinvests in early-stage innovation projects characterized by high levels of uncertainty and extended timelines (Hall & Lerner, 2010). SBIR and STTR collectively allocate over $3B annually in non-dilutive funding (SBIR.gov). Studies have shown that awards made by these programs increase the likelihood of survival, patenting, and subsequent follow-on private investment (Lerner, 1999; Howell, 2017).

Government funding provides more than just capital. Government funding sends signals. Competitive peer-reviewed processes used to award grants reduce informational misalignment between founders and investors. Grants awarded to companies confirm that the technological claims made by the company have been reviewed. Grants lower the perceived probability of failure and decrease the cost of capital in later rounds of funding. Government funding does not replace private funding. Government funding changes the timing and the manner in which private funding becomes available.

Of particular importance to agtech are USDA-NIFA funded programs. USDA-NIFA funded programs provide funding for multi-year validation studies, field trials, and applied research that private investors commonly do not fund because of the lengthy lag between receiving data and acting on that data. For example, USDA-NIFA funding is frequently required in order for companies developing soil microbiome-based products, biostimulant-based products, and specialty crop technologies to reach technology readiness levels sufficient to begin commercializing their products and to mitigate the high level of risk associated with commercializing these types of products (Clancy & Moschini, 2017).

ARPA-E plays a more targeted role in the agtech financing ecosystem. ARPA-E was established to support technologies that appear unreasonable to the marketplace, but have the potential to drive major impacts. Research conducted by the National Bureau of Economic Research found that ARPA-E funded companies are more likely to pursue riskier and more ambitious R&D paths than their non-ARPA-E funded peers and that ARPA-E funded companies are more likely to receive additional private funding (Howell et al., 2020). Within agtech, this typically pertains to technologies at the core of energy systems, engineering, and biological design.

State-level innovation programs are an additional layer to the agtech financing ecosystem. Although smaller in scope, state-level innovation programs provide funding for pilot-scale deployments, reduce early capital expenditures, and connect companies to regional agricultural networks. Because of their geographic presence to production systems, state-level innovation programs are uniquely positioned to facilitate early market validation and regional scale-up efforts.

What ties the various components of the agtech financing ecosystem together is sequencing. Blended capital structures are a common occurrence in agtech due to the fact that no single source of capital is suitable for every phase of the company's development. Typically, the most usual capital structuring pattern is public-to-private. Public funding absorbs early-stage technical uncertainty. Private funding is entered into by investors who face reduced risk due to the earlier absorption of technical uncertainty by public funding. There is empirical evidence demonstrating the strong complementarity between these two sources of funding. Public funding enhances the likelihood of survival, increases patenting activity and increases the likelihood and size of venture funding (Lerner, 1999; Howell, 2017). In addition to increasing the likelihood of successful venture funding, public funding decreases the discount rate of the company and increases the valuation of the company.

There are examples of the reverse capital structuring pattern occurring in agtech. For example, companies developing robotic or digital agtech products may raise early-stage venture or corporate funding to develop products, then utilize public funding to further enhance research capabilities or satisfy regulatory requirements. In this scenario, public funding serves to extend the R&D runway of the company without the loss of equity value.

Companies operating successfully in the agtech space are typically operating under blended capital stacks. Public funding addresses early-stage technical uncertainty. Venture capital enables accelerated market entry. Corporate funding facilitates access to markets and credibility. Private equity enables scale. This layered capital structure represents a practical division of labor across the various types of capital, consistent with broader innovation finance theory (Hall & Lerner, 2010).

Collectively, the U.S. agtech financing ecosystem is not fractured. Rather, the U.S. agtech financing ecosystem is a complementary system. Private capital provides speed, governance, and market discipline. Understanding the nature of the relationships between these elements is central to the analysis presented below.

1.4. What Progress Actually Means in Agtech

Before we discuss how funding structures affect agtech performance, we have to define what defines an outcome. The fact that a new product or service exists is a weak indicator of successful innovation. In finance, innovation outcomes correspond to reductions in various types of risks and, with each type of risk being reduced, the way in which future cash flow will be viewed, the value of a company, and the likelihood of additional investment occur (Hall & Lerner, 2010; Brealey, Myers & Allen, 2020).

The reduction in risk occurs over time and in a series of steps. For example, technology must first function properly. Next, it must perform consistently. After that, someone must be willing to buy the technology. Then, the technology must grow without collapse. Finally, there must be a pathway to liquidity. At each stage, a different level of uncertainty is removed, and at each stage, the valuation of a company increases.

To facilitate analysis, this thesis categorizes innovation outcomes into three general categories: technology, commercial, growth outcomes. Technology outcomes represent whether the technical uncertainty associated with a product or service has been resolved. Commercial outcomes represent whether validated technology has resulted in market traction. Growth outcomes represent whether a company can achieve scaling, attract continuous capital, and create a liquid event for investors. These three categories represent the entire journey from concept to liquidity event.

This conceptualization is important, because investors systematically price risk. A company does not obtain value through its ability to raise capital. It obtains value when investors perceive that uncertainty has been reduced in a manner that they can understand and fund.

Table 1 illustrates this relationship between the logical reduction of risk and observable outcome metrics and their financial implications. Instead of viewing outcomes as general performance indicators, Table 1 represents the connection between each of the metrics, the specific uncertainty that each metric addresses, why each reduction of uncertainty is relevant to investors, and how each metric is represented in the agtech industry.

Risk Category	Outcome Metric	Reduces	Why It Matters to Investors	Relevance to Agtech
Technical	TRL progression, patent output	Uncertainty whether the technology works reliably	Raises probability of commercial success, lowers discount rate	Critical due to biological variation, hardware durability, regulatory dependencies
Market	Pilot conversion, customer validation	Uncertainty about user demand and ROI potential	Helps underwriting confidence, supports valuation growth	Farmers adopt slower, conversion signals genuine value
Scale	Retention, unit economics, revenue repeatability	Uncertainty about repeatability, margin structure	Supports growth equity or PE investment conviction	Essential for operations involving hardware, supply chains, services
Financing	Follow-on rounds, valuation increases	Probability of capital deficit	Increases probability of faster development	High burn rates and long validation cycles are central in agtech ventures
Exit	M&A, IPO	Liquidity	helps explain investor IRR and fund performance	Exits dominated by acquisition

Table 1. Innovation Risk Categories and Associated Outcome Metrics

There is a significant lesson in Table 1. There is no one metric for measuring the process of innovation. All metrics answer different questions. They constitute a sequential progression of risk resolution which parallels the way in which capital is applied and re-priced over time.

Technological results answer the first fundamental question: does innovation work? In agtech, this question is quite difficult to answer rapidly. Technologies must perform across all crop types, seasons, climates and operating conditions. Progression from the lower levels of TRL 6-7, at which level the technology has been validated through field testing, significantly increases the probability of technical success and thereby increases the expected enterprise value of the company.

Publicly funded patent activity provides an additional indicator. Patents, claims, and citations provide information about originality and the ability to defend a patent. The literature previously referenced indicates that public funding will increase the number of patents and improve the quality of those patents, further solidifying the relationship between public capital and the reduction of early-stage risk (Lerner, 1999; Howell, 2017; Howell et al., 2020). Stronger intellectual property reduces the risk of loss due to competition prior to commercialization.

The commercial outcome of the technology indicates whether the technical success is translated into actual use. Pilot conversion is particularly informative in the agtech space. Farmers are very much conservative users and adopting new technologies involves operational risks. One mistake can result in exponential losses. If a pilot is converted to repeated use it implies that the technology provides measurable value in a real-world environment. This signal has much greater weight than early indications of interest.

Timing of commercialization also matters. Delayed commercialization prolongs periods of negative cash flows and increases dilution risk. Because agtech is subject to seasonal limitations and regulatory delays, the speed of commercialization is heavily influenced by capital allocation strategies. Many companies which miscalculate this timing exhaust available capital as a result of running out of money rather than the failure of the technology.

Long term growth reflects if a company can survive long enough to have impact. Continued investor support, evidenced through subsequent financings, preserves the options available to a company and is typical of sustained confidence in its prospects. Research consistently supports the conclusion that initial public funding increases both the probability and magnitude of private round funding (Howell, 2017). The survival rate is a second metric for evaluating performance and is particularly relevant in industries with extended product development times and high capital burn rates.

Exit outcomes are representative of the ultimate stage of risk resolution. Exits in the agtech space are almost exclusively the result of strategic acquisitions by other companies rather than public offerings. These companies purchase proprietary technology to either protect or expand their market share. It is at this stage that the investment risk taken in the earlier stages of the business cycle is ultimately priced and rewarded for the investor.

Table 2 illustrates the differences in which public and private funding influence each category of the outcome measures. Public and private funding do not compete for a place in the portfolio of investments, instead, they operate on different portions of the risk stack.

Outcome Metric	**Effect of Public Funding**	**Effect of Private Funding**	**Interpretation**
TRL Progression	Strong effect. Grants reduce early-stage uncertainty	Medium effect. Investors often require near-field validation	Public funding is essential for early technical development
Patent Output	Increases both quantity and quality (Lerner, 1999; Howell, 2017)	Indirect due to resource availability and milestone pressure	Public grants help IP formation in deep-tech domains
Pilot Conversion	Limited direct influence	Strong, as commercialization teams, sales channels, and CVC collaborations speed-up adoption	Private funding primarily drives market entry
Follow-On Funding	Strong effect. Increases VC investment (Howell, 2017)	Depends on traction. helps explain valuation trajectory	Public-to-Private pathways show strong added benefits
Survival	Higher survival rates documented in SBIR recipients	Depends on milestones and burn rate discipline	Blended sequencing improves flexibility
Exit Outcomes	Indirect foundations via IP and technical maturity	Direct influence through scale, partnerships, M&A readiness	Private capital ultimately helps exit

Table 2. Influence Public vs Private Funding on Innovation Outcome Metrics

When analyzed as a whole, these tables show the divisions in how capital is used to mitigate risk for the different types of capital. Public capital primarily addresses the risk associated with developing new technologies and conducting R&D, while private capital addresses commercialization and execution risks.

While both public and private capital have an effect on the ability of companies to grow and eventually exit their venture, the two do so through very different mechanisms and at various points in the process of the company's life cycle. Understanding this difference is important in providing a methodical approach to evaluating the sequence of capital use in agtech. Capital sources are not replaceable in their roles to provide funding, their role will depend on which risks they help to mitigate, and when they are provided to the company.

The outcome metrics presented above provide the foundation for the analysis that follows to allow for the evaluation of funding paths not by the total amount of funding received, but by the degree to which they provide certainty over time.

1.5. Why Timing Matters More Than Capital Volume

Funding can occur early or late, timing is more important than the amount of money raised. Timing is difficult to identify when the focus is solely on total dollars raised. Agtech is different. While all innovation is risky, some risk occurs at different times. Therefore, capital arriving too early or too late can solve the wrong problem.

There are two types of capital: public and private. Both types of capital have been developed to address different types of risk. Public funding is designed to address uncertainty that has not yet been quantifiable. Once uncertainty narrows, private capital is designed to quantify and capitalize on that narrowing uncertainty. As such, the sequence in which these forms of capital are allocated will shape financing probability, company valuation, and ability to achieve market scale.

The literature on R&D finance generally illustrates this. Long-term uncertainty is the largest barrier to private investment (Hall & Lerner, 2010). Public programs such as the Small Business Innovation Research program (SBIR), U.S. Department of Agriculture's National Institute of Food and Agriculture (NIFA), and Advanced Research Projects Agency - Energy (ARPA-E) were created because private markets fail to provide proper funding when timelines are long and outcomes are uncertain. Instead of creating new value, these programs serve as risk reducers. They reduce variability, thereby increasing the expected enterprise value.

Venture capital, corporate venture capital, growth equity and private equity, however, operate very differently. They use funds to finance the commercialization potential, scalability and liquidity of a company. They also assume that many of the basic technical issues facing a company are either resolved or near resolution. If these assumptions are violated, the capital provided will not be successful.

The most commonly accepted and empirically proven funding sequence for deep technologies and agtech is public funding first and then private capital second. This sequence parallels the structure of innovation risk. Public funding provides a foundation for reducing technical uncertainty. Private capital provides funding for commercializing and scaling companies.

Howell (2017) suggests that companies that receive early R&D grants are significantly more likely to obtain venture capital later. Lerner (1999) suggests that companies that received public grants perform better than comparable companies in the long-run, particularly if private capital is available. NBER data demonstrate that public funding appears to influence companies to transition to higher impact research areas that private investors would not otherwise support. The mechanism is relatively simple. As technical uncertainty decreases, private investors apply lower risk-adjusted discount rates. Valuations increase. Investor willingness to invest increases.

For agtech, this sequence of public funding followed by private funding is particularly beneficial since achieving meaningful field validation can take between one to three years. TRL progression, regulatory documentation, and early patent work consume capital for extended periods prior to generating realistic revenue. Public funding serves to bridge this gap. Companies which enter the private market after this process of minimizing risk, typically experience higher conversion rates from investor meetings to receiving term sheets, higher pre-money valuations, as well as lower founder dilution, and more frequent follow-on rounds, and greater survival through extended development cycles. This public-funding-first model followed by private funding represents the typical deep-tech path. To reduce uncertainty, invest, and then scale.

The reverse model is present although to a lesser extent in biological agtech. Robotics, automation, and digital platforms have shorter commercialization cycles. Companies may raise early venture or corporate capital to develop products, secure pilot customers or generate initial revenue. At this point, public funding enters the picture, not to establish proof-of-concept, but to enhance the underlying technology platform.

From a financial perspective, this is low-cost capital being applied to an already ascending valuation curve. It creates optionality without increasing dilution. Companies following this path of funding often differentiate their funding sources. Venture capital continues to fund the commercialization of the product. Public funding supports the development of parallel research initiatives. The funding structure described above is more prevalent in automation and analytics than in biological inputs, where technical risk remains the dominant risk for a longer period of time.

Stronger agtech companies do not generally follow a single funding path. Stronger agtech companies have multiple layers of capital. Public funding reduces the technical uncertainty associated with early-stage biological inputs. Venture capital funds the acceleration of hiring and market entry. Corporate venture capital funds access to distribution channels, agronomic networks, and regulatory approvals. Growth equity or private equity provides funding for manufacturing, logistics and consolidation.

The layered capital structure of stronger agtech companies illustrate the practical division of labor among various capital types, as illustrated in the broader literature on innovation finance (Hall & Lerner, 2010). Each type of capital assumes the risk that it is best positioned to manage. Public funding manages scientific uncertainty. Venture capital manages early commercialization risk. Corporate venture capital manages the risk associated with adoption and integration. Private equity assumes operational and scaling risk.

Timing affects every outcome metric referenced in Section 1.4. Public funding early in the life cycle has the greatest effect on TRL progression and exploratory research. Public funding increases the number of patents issued to a company, allowing it to engage in deeper technical development. Pilot conversion increases when venture or corporate capital funds sales and deployment activities. Follow-on funding becomes more likely when early milestones are validated. Survival increases when non-dilutive capital is paired with disciplined private investments. The likelihood of exit increases when corporate or later stage investors align development with the needs of established industry players.

Based on the literature and the empirical evidence within the agtech sector, there are three general funding patterns exhibited by agtech companies. Public-to-private funding sequencing is the preferred funding sequence for biological input and hardware innovations requiring prolonged field validation. Private-to-public funding sequencing is more commonly observed in data platforms, analytics and robotics. A fully blended funding stack is linked to the highest capital efficiency due to each funding source being used in the area where it generates the greatest value.

This logic establishes the observable framework for the remainder of the paper. Funding paths are not being evaluated as abstract concepts. Instead, the funding paths are being evaluated as sequences, in terms of how well they reduce uncertainty over time.

1.6. How Funding Turns Into Outcomes

The prior analysis is associated with a simple conclusion. Innovation success in agtech does not occur by accident and does not occur with equal frequency based upon the form of capital provided to the company. Success occurs through a series of incremental risk reductions. With each step, there is a decrease in a particular type of uncertainty. Each type of capital is more appropriate to address a particular type of uncertainty. Therefore, when capital arrives in an incorrect sequence, it addresses the wrong issue.

Venture capital, corporate venture capital, growth equity and private equity and public capital are not interchangeable. They accomplish different tasks. Public capital is used to absorb science and early product development uncertainty. Venture and corporate capital are utilized to eliminate the initial commercialization risk. Growth equity and private equity focus on scaling and executing operations. Since these risks develop sequentially versus simultaneously, the structure and sequence of capital inflow will play a major role in determining the overall performance of an enterprise.

The core constructs in the conceptual model presented within this analysis are funding structure, capital sequencing and innovation outcomes. Capital sequencing captures more than the type of funding a company receives, but when the funding was received. Timing is a factor. A grant received in the early stages of technical development is not equivalent to receiving the same grant subsequent to the initiation of commercialization. Sequencing establishes which risks are resolved initially and which are unresolved.

Innovation outcomes are the observable signs that uncertainty is diminishing. Examples include technical indicators such as TRL advancement and patent activity. Commercial indicators include pilot conversion and early revenue. Long-term indicators include follow-on financing, survival and exit events. Collectively, they illustrate how a company progresses from an idea to a relevant entity in the marketplace.

The interactions between funding structure and sequencing produce unique influence pathways. Public funding typically has the greatest impact at the beginning of the process, when the amount of technical uncertainty is high. Research indicates that grants allow companies to progress through TRL stages, conduct field trials and establish stronger intellectual property positions (Lerner, 1999; Howell, 2017). Once these uncertainties begin to decline, private investors are increasingly willing to provide capital to companies at higher valuations. From a financial perspective, public funding decreases the risk premium associated with future rounds of private funding.

Private funding suggests its influence at a later stage of the process, specifically when commercialization becomes the constraining issue. Venture capital and corporate venture capital enable companies to hire commercial teams, fund pilots and gain access to distribution networks. In agtech, this transition is more challenging due to the slow pace of adoption, the existence of true switching costs and the difficulty of achieving early traction. Private capital is instrumental in transitioning companies from technical validation to market presence.

When public and private funding are delivered in the correct sequence, a layered risk transfer effect occurs. Public funding reduces technical uncertainty. Private capital accelerates commercialization. Each funding source addresses a unique problem. That is why blended funding structures are more likely to achieve superior results compared to single source funding strategies. Single source funding structures result in duplication of effort, whereas blended funding structures result in compounding of effort.

This effect is particularly evident in agtech, where biological, environmental and operational risks converge. Rarely does a failure occur due to a single unresolved uncertainty. Failure occurs when multiple unresolved uncertainties converge at the same time. Layered capital structures reduce the likelihood of this occurring.

A summary of these relationships is shown in Figure 1, which illustrates the conceptual model linking funding structure and capital sequencing to different outcome categories. The figure illustrates how capital flows through risk-reduction pathways to shape technology, commercial and growth outcomes over time.

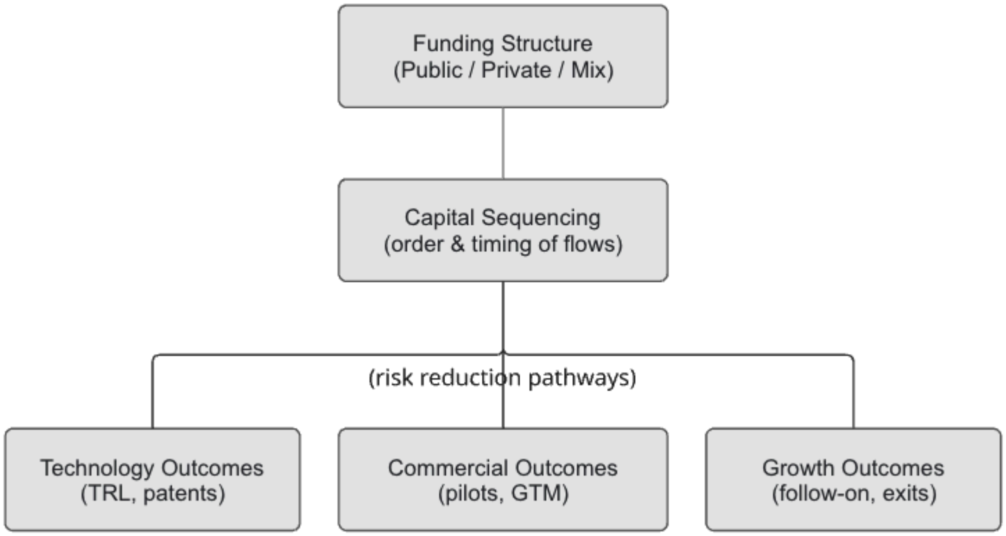

Figure 1. Conceptual Model Linking Funding Structure and Capital Sequencing to Outcome Categories

A key implication of this model is that the effectiveness of a funding type is based on the timing of the funding type. Public funding received too late in the process may have limited ability to mitigate early technical risk. Private funding received too early in the process may lead to premature commercialization or compression of the research runway. Sequencing serves as a mediator in the relationship between funding types and outcomes.

Companies that time their funding with respect to their respective risk profiles are expected to demonstrate greater performance. Public funding during the early stages of technical development. Venture capital during the commercialization phase. Growth oriented capital during the scale-up phase. Companies that rely on a single funding source or whose funding is mismatched to the stage of development are expected to experience lower performance.

The conceptual model established in this section provides a link between theoretical perspectives and empirical analysis. The model clarifies the nature of the relationships that are expected to exist between funding types and outcomes, including public funding and technological outcomes, private funding and commercial outcomes, and blended funding and growth outcomes. Additionally, the model outlines the mechanisms that explain how funding types translate to identifiable measures of performance.

1.7. Why Deep-Tech Struggles to Get Financed

Deep-tech agtech shares multiple similarities to many other innovation sectors, which rely heavily on science, require long-term investments in R&D, and engineering, have extended development cycles, and are subject to regulatory environments that both slow down product availability and reduce the ability to rapidly iterate. Additionally, similar to energy technologies, advanced materials, and biotechnologies, deep-tech projects generally require many years before a startup generates revenue. Historically, capital markets have had difficulty dealing with this specific profile, not because the opportunity is unclear, but due to the high degree of uncertainty regarding commercialization (Hall & Lerner, 2010; Mazzucato, 2013).

The greatest challenge for deep-tech startups is timing. Large sums of capital are required well before the commercial viability of a startup can be demonstrated. Funding in the early stages typically includes costs for developing prototypes, conducting field trials, collecting data, and obtaining regulatory compliance. Although these activities are required to develop a product, they do not generate revenue. Therefore, it is typical for a minimum of two to three years to elapse from the initial funding until the first revenue is generated. Between these two events, the startup will operate with sustained negative cash flow and provide little to no information to investors about its progress toward commercial viability. Research has shown that the mismatch between the need for capital and the number of milestones available to measure a company's progress is sufficient to constrain private investment at an early stage (Auerswald & Branscomb, 2003).

Deep-tech startups also have a unique risk-accumulation issue. For many industries, risks occur sequentially and can be resolved individually. However, for deep-tech, risks tend to stack. An example would include biological inputs that function in a laboratory environment but fail in controlled greenhouse environments, perform not as expected over multiple growing seasons, or face regulatory challenges related to the environmental or human health dangers of those biological inputs. If a single risk event occurs, it could potentially negate all prior work done by the company. This cumulative uncertainty cannot be diversified away or mitigated solely through process improvements (Teece, 1986).

As a result of this structure, investors apply higher discount rates and expect a higher return on their investment for early-stage deep-tech investments. From a purely financial perspective, this is a reasonable expectation since the investor is taking on higher levels of uncertainty. However, the result of this approach is mechanically to decrease the expected value of an early-stage investment as the time horizon for resolution of that uncertainty extends. Research suggests that, under conditions of prolonged uncertainty, private investors frequently delay investment into early-stage deep-tech ventures not based upon a misunderstanding of the potential of the venture, but due to the fact that the numbers no longer make sense (David, Hall, & Toole, 2000).

Another structural barrier facing early-stage deep-tech startups is the inability to pledge collateral for debt financing. Typically, startups that involve deep-tech do not possess tangible assets that can be liquidated in the event the venture fails. Although intellectual property may be valuable, it is difficult to estimate its value in advance and is typically illiquid. Thus, while equity is the predominant source of financing for early-stage startups, equity is typically expensive to raise under conditions of high uncertainty, thereby narrowing the universe of potential investors and exacerbating early-stage financing gaps (Gans & Stern, 2003).

Together, these factors create a structural financing gap within the deep-tech marketplace. While capital is needed most in the earliest phases of a venture, it is least available to entrepreneurs at these times. Publicly funded initiatives play a significant role in bridging this financing gap. Programs such as SBIR, STTR, and ARPA-E are specifically designed to finance high-risk, high-reward research that is unlikely to be financed by private capital. Research has shown that publicly-funded programs increase the likelihood that companies will engage in more aggressive research efforts, improve the chances of company survival, increase the rate of patenting, and ultimately lead to more private investment in subsequent rounds (Lerner, 1999; Howell, 2017; Howell et al., 2020).

Similar to deep-tech, agtech also inherits many of the challenges presented above. Agtech has slow feedback loops, biological performance is highly dependent on the environment, development is capital-intensive, there is always some degree of regulatory oversight, and in addition to the above, agtech faces a unique adoption problem. Farmer’s operating margins are extremely thin, and the costs of switching equipment are extremely high. Even if an agtech solution works effectively, it may be slow to gain traction among farmers due to the financial, behavioral, and operational constraints faced by farmers (Klerkx, Jakku, & Labarthe, 2019).

Therefore, the sequencing of capital is important in agtech compared to many other innovation markets. Public funding can assist in absorbing scientific and technical uncertainty in the early stages of development. Once the viability of a product or service is clear, private funding can be leveraged to accelerate scaling and market entry. Finally, strategic and corporate funding can be utilized to address issues related to distribution, trust, and adoption at the farmer level. When funding is sequenced properly, companies are less likely to stall between developmental milestones and more likely to move forward steadily.

Therefore, the purpose of financing is not merely to raise additional capital, but to manage time. Capital should bridge gaps between developmental stages and allocate risk to the type of funding best suited to absorb that risk. Not only does the type and timing of funding affect the amount of capital raised by a company, but whether the company is able to remain viable long enough to resolve the uncertainty inherent in its innovation path.

This conceptual framework strengthens the central claim of this thesis, that capital sequencing affects innovation outcomes. Due to the scientific uncertainty, regulatory barriers, and slow adoption, agtech provides a particularly useful platform to examine how various types of capital interact over time. Understanding these interactions is important to assessing the performance, growth, and capital efficiency of a company throughout the entire developmental lifecycle.

1.8. What This Section Establishes

In this section, we identify an important and straightforward thesis. Agtech is not yet one more sector in which innovations occur, it is a domain based on deep technology. Deep technology domains are characterized by long development cycles for product creation and they involve high levels of both technical and regulatory uncertainty, and they have limited commercial opportunities due to seasonal constraints on sales and production activities. Because of these characteristics, initial progress is difficult to assess and early success is difficult to validate. Therefore, financing difficulties are not random occurrences, they are structural by default.

The literature explains why private capital is hesitant to invest in the early-stage period of any deep-tech domain. Because there is a great deal of uncertainty associated with investments in the early stages of deep technology development, and because the time required to bring products to market may be very long, private investors will generally step back. The purpose of government funded research programs, including SBIR/STTR programs funded by USDA NIFA, and ARPA-E, is to provide an alternative source of funding that can mitigate some of the risks inherent in the early stages of deep technology development. Specifically, the purpose of these programs is to reduce the amount of scientific and technical risk faced by start-up companies, and to encourage them to pursue development of their technologies. There is considerable evidence that participation in these programs increases the probability of the survival of companies, improves the strength of intellectual property, and encourages subsequent investments from private sources.

Private capital enters into new developments at different points in time. Venture capital, corporate venture capital, growth equity, and private equity enter the funding process once the commercial viability of the technology has been demonstrated. At this point in the development of the company, the focus of the investor is on assisting the company to enter the market, to gain acceptance by customers, to establish a distribution channel, and to achieve scale. Corporate venture investors also provide additional support to the emerging technology by establishing connections between the technology and existing systems within the corporation, e.g., through manufacturing, regulation, or other established channels. Each form of capital contributes value to the development of the company, but only if it addresses the correct issue.

An important finding of this section is that funding type and timing are not interchangeable. Public and private capital address different types of risk, and how they interact helps explain whether a company makes progress toward reaching technical milestones, suggests commercial viability, and survives long enough to scale its business. Therefore, sequencing matters. Public funding is most effective when it occurs early or simultaneously with private investment. Private capital becomes the deciding factor in determining the direction of the company during commercialization and growth, while public funding does not function during those phases of the company's development.

Blending and sequentially funding companies at appropriate times fits the developmental path of agtech companies better than funding companies at a single time. If each type of capital enters at the time when it is most relevant to the risk that is currently dominating the company, then the company's rate of progress will be accelerated. However, if the capital flows into the company at inappropriate times, i.e., when the dominant risk is being addressed incorrectly, then the company's progress will be stalled. Stalled progress will not be due to any deficiency in the technology, it will simply be the consequence of addressing the wrong type of uncertainty.

The conceptual model outlined in Section 1.6 integrates all of these findings and concepts into a single flow diagram. This model illustrates how funding structure and capital sequencing influence technology, commercial, and growth outcomes. The model identifies which relationships should be the most significant, and why, and provides a direct link between funding decisions and observable performance.

Therefore, this model serves as a guide for the empirical study that follows. In the next section, these ideas are translated into quantifiable variables. The sequence of funding for companies is defined using actual investment data. The outcome of the funding decisions is measured using technology, commercial, and growth metrics. Choices regarding methodology were made with the underlying theory in mind, so the analysis focuses on testing specific mechanisms rather than identifying possible associations among variables.

2. METHODOLOGY

2.1. Research Design

In this study, we use a company-level research design based on a quantitative method to analyze the relationship between the sequence and timing of public and private investments and technological advancements and early growth of U.S. agtech companies from 2010-2025. In this research, we consider each company as an observational unit. We are not looking to measure causation due to treatment effects, but instead to establish patterns of difference in funding approaches to achieve various outcomes between companies.

Our study uses a comparative cross-sectional design. We are examining a fixed number of agtech companies and tracking them over time is not part of our conceptual framework. Our goal is not to represent the dynamic process of decision making within each company, but to compare the observable outcomes of those companies that have received funding in different sequences at similar levels of development.

Comparative study designs focusing on agtech companies are typical in studies on public innovation financing where causal identification cannot be performed or may be theoretically inappropriate (Howell, 2017; Lerner, 1999).

Our research design is based upon innovation financing theory that asserts that there are many forms of capital available and they can resolve various types of uncertainty. Technology companies that are in their initial stages of development experience various types of risk, including technical feasibility, regulatory compliance, and market acceptance. Therefore, it is rare that the order in which capital is invested into a company is coincidental. Often the order in which capital flows into a company is a direct result of where the company believes its most significant uncertainty lies at a particular point in time (Arrow, 1962) (Mazzucato & Semieniuk, 2017).

Long development times and uncertainty related to biology make it important for companies engaged in agtech to carefully match the type of capital being used to the level of development of the company.

The empirical analysis focuses on three key constructs: the sequence of capital inputs, technological progress, and the dynamics of early growth. The sequence of capital represents the chronological order of a company's first public funding and first private funding event. Technological progress is measured using the extent to which a company has reduced technical uncertainty. Early growth dynamics is measured using the presence and timing of the company's receipt of private funding. Receipt of private funding is viewed as an outcome that suggests market validation of the company, and not as an out of place input. This view is consistent with previous research that treats private funding as a strong signal of confidence and not as neutral to funding (Kortum & Lerner, 2000) (Hellmann & Puri, 2000).

Due to the non-random and strategic nature of the allocation of public grants and the receipt of private funding, this research does not focus on quasi-experimental or causal inference techniques. Company-specific characteristics that are difficult to quantify (such as founder ability, technological judgment, and network access) influence funding outcomes, so causal claims cannot be made about the results of this research. Additionally, the sample size of this research is small and selective funding processes limit credibility of causal claims. Rather, this research will emphasize transparency, alignment with theory, and careful comparison of observable outcomes, consistent with best practices in descriptive innovation finance research (Hall et al., 2001; David et al., 2000).

2.2. Data and Sample Construction

The empirical research will rely on a defined sample of 50 U.S. agtech companies (that were operational) during the years of 2010-2025. The sample is not intended to represent all components of the agtech ecosystem, but rather to provide a limited scope of inquiry into how capital is sequenced during the initial stages of developing agricultural technologies.

Each company represents the unit of analysis for the sample. Each observation refers to a single company that has received public funding for innovative purposes via either the U.S. SBIR program, the STTR program or both. In order to analyze funding sequences and outcomes of technological development, the data source requires that there be some publicly available information regarding the funding histories and technological developments of each company.

The sample size is intentionally restricted because the development of early stage agtech is highly diverse. Technologies vary significantly in terms of development paths and funding requirements. Commercialization timeframes are lengthy, and publicly available data may be incomplete or inconsistent. Expanding the sample beyond companies that have verifiable evidence of receiving public funding would negatively impact the overall quality of the data and minimize the internal consistency of the dataset. Therefore, the dataset emphasized the quality and reliability of the data over the quantity of data collected.

Data related to the receipt of public funding are linked to SBIR and STTR grants. The following programs are identified and selected for several reasons. First, they represent one of the largest portions of federally funded innovation capital for early stage, technology-based companies in U.S. agtech. Second, the format of these grants is standardized and properly documented. Finally, the classification of grants as Phase I or Phase II of the SBIR/STTR program provides a clear indication of the technological progress of a company.

Funding data from private investors are also tracked at the company level and are obtained from various sources including venture databases, press releases and corporate communications. The dataset contains indicators of whether private capital has been raised by each company, the year in which private funding was first received by each company and the total amount of private funding received by each company when disclosed.

While private funding is used as a proxy for market validation and is not considered to be a precise measure of a company's success or value, the dataset does not include detailed information about the structure of rounds of investment, nor the identity of investors involved in syndicates. The objective of the study does not require such details to be included in the dataset. The study focuses on the timing of the flow of funds, not the complexity of the deals.

The sequence of funding (capital sequencing) is determined by comparing the year in which a company receives its first public funding with the year in which a company receives its first private funding. Based on this comparison, each company is classified into one of four mutually-exclusive categories: Public-to-Private, Private-to-Public, Public Only, or Blended. A blended company receives both public and private funding in the same year. The sequence category is used as the key explanatory variable of the study.

In addition to categorizing funding sequences, the dataset tracks a simple timing metric representing the difference in years between the date of a company's first public funding event and the date of its first private funding event. This timing metric is measured at the year level, reflecting the limitations of available data.

This methodological approach goes hand-in-hand with previous studies of public innovation finance. Those studies have used fixed samples of companies that have received government grants to examine downstream technological and financial outcomes of those grants rather than to estimate causal relationships between public innovation funding and outcomes across the entire population.

2.3. Variable Definition and Operationalisation

Operationalizing outcomes at the company level is done using a restricted number of generally identifiable and conservatively selected variables based upon available information in the public domain. The decision to do so reflects the reality of innovation within the agtech space. As there are significant inconsistencies in disclosure, detailed operational information is extremely scarce. Due to these factors, any attempts to be overly precise may result in unreliable results rather than more insightful ones. Therefore, the variables chosen emphasize consistency and comparability across companies.

Variables for funding, both public and private, are defined at the level of the first observed funding event. Funding that was obtained through federal programs (SBIR/STTR) is defined as public. Private funding is identified by the first publicly announced instance of private capital investment into the company. Both of these initial funding events establish the basis for constructing the central explanatory concept of the study: funding sequence.

Capital sequence is represented through a categorical variable, Sequence_Category, which identifies companies based on the timing of their first public and first private funding events. Companies were categorized into one of four mutually exclusive categories: Public-to-Private, Private-to-Public, Public Only, and Blended. The assignment of the category is purely mechanistic and does not imply causation. This is similar to other studies of innovation financing that treat funding as a company characteristic, not as an intervention (Cumming, Grilli, & Murtinu, 2017).

In addition to the categorical measure of funding sequence, a continuous variable, Time_Between_Public_and_Private_Days, records the absolute difference in days between the date of the first public and first private funding events. This variable captures how quickly funding events occur in relation to each other, without implying directionality, which is inherently contained within the funding sequence category.

Progress toward technological development is measured through two observable indicators. The first is patent activity, counted at the company level based on publically available patent filings. The count of patents is used to represent formalized inventive output, not the quality of patents nor their economic value. The use of patent counts to represent inventive activity is typical in innovation research, and it represents an imperfect, yet informative measure of inventive activity (Griliches, 1990; Hall, Jaffe, & Trajtenberg, 2005).

The second indicator is a structured technology readiness proxy (TRL_Proxy), scored from 1 to 7. Assessments of direct technology readiness are unavailable for private companies, especially during the early stages of development. Therefore, the proxy is developed using a rule-based methodology that incorporates SBIR phase participation, observable pilot activity, and commercialization signals. It captures relative maturity, not absolute technical readiness, and is used for comparative purposes only. The conceptual base for the TRL_Proxy is grounded in accepted frameworks for assessing technological maturity when facing uncertainty (Mankins, 1995).

Additional variables, such as total private capital raised, are provided for contextual description. These variables are not considered control variables in sense. Rather, they provide background information for interpreting differences across funding sequences.

In general, the operationalization strategy highlights transparency, replicability, and similarity with the research question. All variables are derived directly from data fields in the observable data. This represents a deliberate tradeoff between measurement precision and reliability in the data, consistent with previous empirical research in early stage innovation finance.

2.4. Construction of Funding Sequencing Variables

The funding sequence was created using a simple, rule-based method based on the timing of the first publicly funded and privately funded funding events at the company level. The purpose of creating the sequence is to classify companies rather than interpret their funding sequences. Therefore, there are no embedded assumptions concerning causation, funding quality, or investment intensity within this process of classification.

Firstly, the earliest year of public funding for each company is determined via the earliest available SBIR/STTR award. Secondly, the earliest year of private funding for each company is established through the earliest reported amount of private funds raised. Both types of funding (public and private) were harmonized to the year-level of precision in all cases. This decision was made due to the limitations associated with publicly disclosed data and to maintain uniformity throughout the various data sets.

Through utilizing both of the above-mentioned date stamps, each company will be classified into one of the four possible mutually-exclusive funding sequencing categories:

1. Public-to-Private sequencing will apply when the first public funding event occurs prior to the first private funding event.
2. Private-to-Public sequencing will apply when the first private funding event occurs prior to the first public funding event.
3. Public Only sequencing will apply when public funding has been recorded however, no private funding has been disclosed.
4. Blended sequencing will apply when both public and private funding occurred during the same calendar year.

These four categories of sequencing are included within the variable Sequence_Category, and shall serve as the primary variable of interest in the analysis of this thesis.

In addition to the categorical sequencing, a second variable, Time_Between_Public_and_Private_Days, has also been incorporated into the dataset. The Time_Between_Public_and_Private_Days variable measures the absolute time gap in days between the first public funding and the first private funding years. However, it does so without consideration of the direction of the funding sequence, therefore, Time_Between_Public_and_Private_Days does not represent a directional measure of the proximity of funding events.

Separate and distinct consideration of the direction of the funding sequence from the time distance between funding events will assist in reducing redundancy and simplify the analysis and interpretation of the results. Companies that do not have an observable record of private funding or those companies that have insufficient information to calculate the time gap, will be excluded from the time gap calculation however they may still be considered in the categorical sequencing if applicable.

The development of the sequence methodology used to create the funding sequence variables, is transparent. Therefore, every funding sequence assignment can be directly linked to two discrete and observable funding dates. Additionally, the sequence methodology is robust to minor discrepancies in the reporting of funding events that are common among early-stage private companies. Furthermore, the methodology can be easily replicated without the use of any subjective judgments.

The final funding sequence variables will provide a clear and consistent basis for comparing funding patterns among the companies within the sample.

2.5. Analytical Approach

This study is an evaluation of how U.S. agtech different funding sequences relate to differing degrees of technological development and early growth. The purpose of this study is comparative. Evaluations of the company's outcomes are compared across funding paths to identify if there are patterns of consistency that can be identified based on the theoretical model of funding sequence described in Section 1.

These funding sequences were categorized into different groups using the Sequence_Category variable (the order in which public and private funding first occurred). Each category forms the basis of all subsequent comparisons. The purpose of this study was not to rank companies or predict the success of companies. The focus of this study is if certain funding sequences produce systematically different outcomes. The study consists of three steps:

1. Descriptive statistics were used to provide an overview of the key variables of interest for each category of funding sequence. These variables included the number of patents filed by each company, the technology-readiness proxy, the number of times each company participated in an SBIR phase, and the length of time from the first public funding event to the first private funding event for each company. This provided an initial overview of the extent to which both technological and funding-related outcomes differed among the various categories of funding sequences.
2. Comparisons of the outcomes of each category of funding sequences were analyzed to determine if there existed consistent differences in technological development and funding progression among companies who followed the different funding sequences. The primary focus was to evaluate the direction and relative magnitude of the differences between the categories, rather than the statistical significance of such differences.
3. Variations in the degree of technological development among the funding sequences were assessed. Specifically, this step was designed to examine if the degree of difference in the timing of the funding sequences (i.e., shorter or longer intervals) were related to greater levels of observed technology readiness among companies who followed funding sequences with the same sequence category. An examination of the degree of variability within each funding sequence category was also conducted to provide additional contextual information without increasing the scope of the analysis beyond comparative description.

The results of the analysis will be discussed in terms of the conceptual framework presented in Section 1, which views funding sequence as one method of mitigating technological and commercial risk over time. The objective is to assess whether the observed patterns in the data are consistent with these expectations, not to assert causal effects.

2.6. Validity, Reliability, and Limitations

Although the approach in this study was systematic and transparent in terms of methodology, the conclusions reached in this study must be interpreted within a framework of significant limitations imposed by both the data and the research design.

Internal validity is established through the process by which the three main variables were developed. The funding sequence variable was developed based upon the chronological date of the first public and first private funding event for each company, with uniform rules being applied to all companies within the sample to limit the potential for subjectivity in determining funding sequence classifications. Technology related outcome variables were developed using proxies, including SBIR phase participation, patent counts, and an organized technology readiness proxy. Each of these types of measures have been frequently employed in innovation research due to the fact that many studies lack direct means of assessing technical maturity.

Both public funding awards and private funding decisions are made strategically by companies and are likely influenced by company-specific characteristics (e.g., founder experience, network access, etc.) that cannot be completely accounted for through observation. As such, because these factors are not randomly assigned, any observed differences between the sequencing categories can only be interpreted as associations versus causally-related effects.

Consistency is supported by the use of publicly documented and reproducible data sources. Award data associated with SBIR and STTR programs are systematically recorded, and private funding data are sourced from publicly-disclosed data sources. All variables are created using identical and consistently-applied rules to all companies included in the sample. Data in the database can be recreated using the same inputted data and all results can be traced back to observable data.

In addition, while public funding award data are systematically recorded, private funding data rely upon voluntary disclosure by funders. Private funding data may be incomplete, especially for companies in the early stages of their development, or companies that are privately-held. There may be some funding events that are not publicly reported, which may result in the under reporting of private capital flows. Although there may be some variation in the completeness of private funding data among companies, this is a limitation present in much of the existing research in entrepreneurship and venture financing and is therefore not a limitation unique to this study.

The most significant limitation of the analytical method employed in this study is the relatively small sample size of 50 companies analyzed. While the sample size is adequate for a structured comparative analysis, it limits the use of more complex statistical methods and limits the ability to generalize beyond the sample of companies used in this study. In addition, the data are cross-sectional in nature rather than longitudinal in nature. Therefore, the analysis captures the observed outcomes at one point in time rather than continuously throughout the development trajectory of the companies studied.

Additionally, the use of proxy variables also introduces uncertainty into the measurements. Patent counts are not precise of the quality of patents nor the economic value of the patented technology. Similarly, the technology-readiness proxy provides an indication of relative technological maturity rather than a technically accurate measure of technological maturity. These proxy variables were selected to allow for a comparable analysis of companies with different levels of technological development rather than to attempt to obtain a detailed technical assessment of each company's technology.

The analysis is limited to only SBIR and STTR programs as the source of public funding for these companies. It is possible that other public funding programs have also contributed to the innovation activities of the companies studied. However, these programs were intentionally left out from the study to maintain uniformity in the type of public funding available to all companies within the sample and to ensure that all companies studied had the opportunity to receive either government or private funding. While this restriction to SBIR/STTR programs limits the scope of the study, it increases the comparability of the results obtained from the companies studied.

Lastly, the focus of this thesis is on agtech companies located within the United States, therefore, it limits the applicability of the research findings to other geographic areas (e.g., Europe) that have different innovation systems, different capital market structure, and/or different public funding directions. The U.S. is one of the most developed and best documented agtech financing environments, however, there could be differences in how funding flows through and in terms of sequencing due to differing institutional conditions (e.g., different public support mechanisms and/or different private capital markets). Further, while this thesis has found systematic relationships between funding sequences and observed outcomes, these represent associations and not direct causation. The results should be viewed as providing evidence for the existence of a consistent relationship between funding sequences and observed outcomes, but do not provide evidence for the existence of determinate effects.

3. RESULTS

3.1. What the Sample Looks Like

U.S. agtech companies with early-stage public funding through the SBIR and/or STTR programs, between 2010-2025, are the subject of an empirical study based on a sample size of 50 companies. Focusing the sample to SBIR and/or STTR participants provides a basis for comparing companies at the same point in the innovation financing process. All companies have used the same program conditions, which provide standardized public funding for early-stage technological development. Programs such as the SBIR and STTR are well-known as the primary mechanism of U.S. public innovation policy for support and boosting early-stage technology companies (Howell, 2017; Lerner, 1999).

Agtech companies represented in the sample include a variety of agtech technologies, including biological input technologies, digital agriculture platforms, sensing and monitoring systems, and automation solutions. The sample represents a variety of agtech technologies and reflects the complex and very much fragmented nature of agtech innovation. Unlike other industries, where there may be one dominant technology that leads innovation, agtech has several different technologies emerging in parallel, and the sector is developing in many different ways. Other research on agricultural and life sciences innovation has found that the development trajectory and the type of technologies being developed in these fields also shows signs of significant diversity (Jakku & Labarthe, 2019).

While all of the sample companies had public funding available to them by definition, the amount of private capital each company could raise varied significantly. Two-thirds of the sample (66%), were able to secure private funding at least once during their development stage, while the remaining companies relied primarily on public funding. This variability in private funding availability is consistent with prior research that has shown that the ability of early-stage technology companies to attract private investment can vary greatly, even when these companies have achieved similar levels of technical progress (Toole & Tripodi, 2006; David et al., 2000). Differences in funding paths represent the primary source of empirical variation examined in this study.

Similar to the funding path, there is a great deal of variation among the sample companies in terms of technology-related outcomes. While the number of patents produced by each company varies greatly, ranging from none to a large number, the average number of patents produced per company is 19.3, and the median number of patents produced is 11.5. The difference between the mean and the median indicates that the distribution of patent output among the sample companies is positively uneven, suggesting that a relatively small number of companies produce a disproportionately large number of patents. Similar to the patent output data, the number of companies that successfully transitioned through the various phases of the SBIR program also exhibits a high degree of variability. Sixty percent of the sample companies progressed to Phase II, indicating that a substantial portion of the sample companies successfully completed the feasibility phase and proceeded to the next stage of the program. However, it should be noted that successful completion of Phase II is generally seen as an indication of technical validation rather than as an indicator of ultimate commercial success (Howell, 2017). Therefore, Phase II serves as a structured evaluation period rather than as a guarantee of market viability.

As previously stated, the TRL proxy is used to approximate overall technological maturity of the companies in the sample. Based on this proxy, the average TRL value for the sample companies is 4.5, and the median TRL value is 5.0. Given that the vast majority of sample companies have achieved a TRL of 4 or greater, it appears that most sample companies have progressed beyond the conceptual phase of their respective projects and are actively engaged in either prototype development, prototype validation, or early-stage commercialization. The TRL distribution for the sample is consistent with what would be expected for companies that are transitioning from publicly funded research to privately funded commercialization (Mankins, 1995).

Finally, the descriptive characteristics identified above illustrate the diversity of early-stage agtech companies, as well as the common challenges associated with these companies. As a result of focusing the sample on companies receiving early-stage public funding through the SBIR and/or STTR programs, all companies are at similar stages of public funding involvement, but have pursued vastly different funding sequences and levels of private capital access, intellectual property development, and technological maturation. This combination provides an appropriate empirical context for evaluating the relationship between funding sequence and observable innovation outcomes.

Metric	Value
Number of companies	50
Companies with private funding (%)	66%
Average patent count	19.3
Median patent count	11.5
Companies with SBIR Phase 2 (%)	60%
Average TRL proxy (1-7)	4.5
Median TRL proxy (1-7)	5.0

Table 3. Descriptive Statistics of the Sample (N=50)

The descriptive statistics, which follow here, will be used as a base for the analysis presented in this study. These descriptive statistics are also indicative of significant differences in the funding progressions, technology developments and other company level variables among companies that have been created to allow an examination of whether or how different funding sequences affect observable outcomes.

3.2. How Companies Sequence Their Funding

The following part provides an overview of how companies in the sample are allocated into the different funding sequences. It is intended to provide context for the subsequent comparisons of the outcomes of company' use of funding. A company's funding sequence is determined by the relative timing of the company's first public and first private funding event, each company is therefore placed in one of four mutually exclusive funding sequence categories.

Funding sequence	Number of companies	Share of sample
Public only	17	34%
Private-to-Public	16	32%
Public-to-Private	11	22%
Blended	6	12%

Total	**50**	**100%**

Table 4. Distribution of Funding Sequencing Categories (N=50)

There were more Public Only companies than any other type of company in the sample and they accounted for 34% of total sample size. Public Only companies are those that received SBIR/STTR funding, but did not raise any observable amounts of private capital during the time frame of the study. As such, this funding sequence is typical of the development timelines and high levels of technical uncertainty that are characteristic of many early-stage agtech ventures, and it is not uncommon for some agtech technologies to continue through extended R&D phases before they transition to commercial financing.

There was also a similar number of companies in the sample that followed a Private-to-Public funding sequence, these companies accounted for 32% of the sample. In the case of companies that follow a Private-to-Public funding sequence, companies obtain private funding before obtaining funding from the SBIR/STTR programme. This finding suggests that a significant proportion of companies are able to enter the SBIR/STTR pipeline after demonstrating some form of market-based validation or after receiving some form of backing from investors. This funding sequence may be more likely to occur in segments of the industry where prototype/pilot versions of products can be created before companies engage with public funding mechanisms.

In the sample, 22% of companies are classified under the Public-to-Private funding sequence. Companies in this category get public funding before obtaining private funding. Such funding sequence is consistent with the stated goals of the SBIR/STTR programmes to reduce initial technical risk associated with developing new products and to facilitate private investment at a later stage.

Finally, 12% of companies in the sample are classified as Blended, indicating that both public and private funding occurred in the same year. The Blended funding sequence may indicate that companies quickly transitioned between funding sources and/or that the process of obtaining public and private funding was occurring simultaneously as the technology being funded matures.

In general, the distribution of companies indicates a considerable amount of variability in how companies in the agtech sector fund their development using combinations of public and private funding. The fact that all four funding sequences were represented in the data provides a sufficient basis for analyzing whether there are differences in either technology development and/or early growth outcomes among companies depending upon the timing and order of the company use of capital.

3.3. Technology Outcomes Across Funding Paths

This section compares and contrasts observable technology output across categories of funding sequencing, this includes patent activity, progression to SBIR phase II, and a technology readiness proxy. Combining these three data points provides a systematic way to observe how the development of a company's technology evolves based on its funding sequence.

Funding sequence	Avg. patent count	Median patent count	Share with SBIR Phase 2	Avg. TRL proxy
Public Only	8.2	5.0	76%	4.53
Public-to-Private	9.9	9.0	73%	4.73
Private-to-Public	26.7	19.0	38%	4.38
Blended	27.8	11.5	50%	4.50

Table 5. Technology Outcomes by Funding Sequence

There are some notable trends in the data. Companies that follow a public only funding sequence and companies that follow a public to private funding sequence demonstrate the greatest proportion of their companies (approximately 75%) to have progressed past SBIR phase I and into phase II. The ability of these companies to receive additional funding suggests their ability to continue validating the technical viability of their ideas within the SBIR process and their willingness to stick to the phased development model of the program.

In contrast, the number of patents generated by companies in the private to public and blended funding sequences are significantly higher than those in either of the public first funding sequences. The total number of patents generated by companies in these two funding sequences far exceed the total number of patents generated by companies in the public first funding sequences. There are several possible explanations for why companies that have attracted private funding earlier in their development may be pursuing intellectual property at a faster rate, one possible explanation is that companies that are receiving private funding may place a greater value on protecting their intellectual property and thus may seek to obtain a greater number of patents. Another possible explanation is that companies that are being funded privately may be developing a broader array of technologies and/or they may be seeking to protect a wider array of technologies and therefore may be pursuing a greater number of patents.

On the other hand, companies that have received private funding earlier in their development and companies that have received a combination of public and private funding are less likely to have advanced to SBIR phase II. These different patterns suggest that patent production and SBIR phase II participation are not correlated. Companies may produce a large amount of intellectual property and still not develop to the extent that they participate in the later stages of public funding. Companies that are being funded primarily by private investors are less likely to advance through the various stages of the public funding process because the primary goals of their development activities are driven by the interests of their investors rather than the need to meet the requirements of a public funding agency.

The technology readiness proxy was similarly stable across all categories of funding sequence. The average values were between 4.4 and 4.7 and indicated that the vast majority of companies are converging towards similar levels of technical maturity within the timeframe of the study. The highest average technology readiness proxy was found in the public to private funding group and indicates that the companies in this group had followed a development pattern in which public funding supported the initial stage of development prior to entering the development stage supported by private funding.

Overall, the findings of this study support the conclusion that funding sequence is related to distinct technology development profiles. Innovation finance theory suggests that different types of capital are designed to address different forms of uncertainty at specific stages in the innovation process, a pattern supported by the data. Funding sequences in which companies rely initially on public funding are most directly related to the technical validation process established by government agencies, whereas funding sequences in which companies rely initially on private funding are most directly related to the generation of visible intellectual property (i.e., patent production). These differences should not be interpreted as an indication that one type of funding sequence is better than the other, but rather that they represent alternative methods of documenting and demonstrating the progress of a company's technological development.

3.4. Does Timing Between Funding Sources Matter

In the last part of this study we are going to find out if the time gap between first public money and first private money is linked to the differences in observable technology outputs. While the order in which funding sources enter capture the time order, the timing study is focused on how long it took for each company to make the transition. Are there differences between companies that transitioned from public to private money fast and companies that took their time.

Only companies that had access to both public and private money can be compared in terms of timing. Comparing the timing of funds entering companies will only be relevant for companies that transitioned from public to private money. For these companies, the amount of time (in days) between the date of first public money and the date of first private money was used as an indicator of the funding gap.

The median funding gap for the sample is 365 days. That is what is being used to divide the companies into two groups. One group consists of companies whose private money entered after their public money within a year. The other group consists of companies whose private money did not enter until after a year or more. This division allows for a comparison of companies that transitioned from public to private money quickly versus companies that transitioned slowly.

Funding gap group	**Companies (N)**	**Avg. gap (days)**	**Avg. patent count**	**Median patent count**	**Share with SBIR Phase 2**	**Avg. TRL proxy**	**TRL dispersion (SD)**
Short gap (<1 year)	20	256	20.5	12.0	50%	4.50	0.51
Long gap (>1 year)	14	1,278	21.4	19.0	57%	4.57%	0.51

Table 6. Technology Outcome by Funding Gap Length

Firstly, the average technological maturity for the two groups is almost identical. The average TRL proxy for the two groups differ only slightly and the standard deviation of the TRL values for the two groups are also identical. These statistics indicate that companies achieve a similar level of technological readiness regardless of how quickly or how slowly private capital follows public capital.

Secondly, the patent activity for the two groups differed somewhat. The companies with larger funding gaps exhibited higher median numbers of patents filed, however, the average number of patents filed for both groups were virtually identical. Therefore, while longer delays may lead to more R&D activities prior to the entrance of private capital, they do not appear to generate significantly more overall IP production.

Finally, the percentage of companies that advanced to the SBIR Phase II program were nearly equal for the two groups. While the percentage of companies with longer funding gaps advancing to Phase II was slightly higher, the difference is so small that it is not possible to conclude that the speed of funding is related to advancing through the public program.

Therefore, the results above support the conclusion that the effect of the time it takes for private capital to follow public capital is secondary to the effect of the order in which funding occurs. While the time period between the public and private funding of companies may affect the decisions made by companies, the evidence collected in this study does not provide sufficient evidence to conclude that the time period has an impact on observable technology outputs for companies funded in this manner.

The findings above provide additional support for the interpretations developed in previous sections of the section. It appears that the order in which funding occurs is more important than the timing of when the funding occurs. Although the results of this thesis are in line with theoretical views on sequencing as opposed to speed, the theoretical views suggest that resolving the proper type of risk at the right time is more important than increasing capital inflow. Early stage public funding supports the development of technologies over a wide range of timelines. Private capital enters at different times because the timing of its entry depends upon the company's strategic plan, industry characteristics and market conditions rather than a specific timing threshold.

4. INTERPRETATION OF CAPITAL SEQUENCING IN AGTECH

4.1. Capital Sequencing as a Way to Allocate Risk

Capital sequencing for agtech in the U.S., however, is not just a timing problem. Capital sequencing provides a way to allocate different forms of risk for a company's life cycle. How public and private capital are sequenced affects how a company manages uncertainty, communicates progress to outside stakeholders, and makes developmental decisions internally (Mazzucato, 2013).

Government funding for innovation, especially for projects funded by SBIR and STTR programs, exists to fund projects with technical promise, but whose commercial potential is unclear. The SBIR and STTR programs are constructed for projects where the feasibility of the project can be proven, but the ultimate success of the project may not come for years. Once the feasibility of the project has been established, private capital will generally enter into the venture to support the transition from development to commercialization, scaling, and executing (David, Hall, & Toole, 2000).

Therefore, capital sequencing dictates both when capital is introduced, and which party assumes what form of uncertainty at each stage of the development process. Evidence of this distinction is evident within the data set. The results of the analysis therefore do not identify new categories of risk, they simply show how identified theoretical risk categories are displayed in the sequence of observable funding. Companies that were funded by public money before receiving private funding were generally farther along in their progression through the SBIR program and had slightly greater degrees of technological readiness observed. This pattern is consistent with a development model that uses early public funds to help manage the fundamental scientific and engineering uncertainty inherent in a product or service. Thus, for companies that receive public funding prior to receiving private funding, public funding seems to function as a safe environment in which to test ideas, collect evidence and reduce downside risk prior to experiencing commercial pressures (Auerswald & Branscomb, 2003).

Companies that have utilized a Private-to-Public capital sequencing model show a significantly different profile. These companies have much greater numbers of patents filed, but fewer phases completed within the SBIR program. This would suggest that the initial efforts of these companies are focused on securing intellectual property rights, rather than completing specific technical milestones associated with the SBIR program. Therefore, patents do not serve as proof of successful publicly sponsored research for these companies, but rather as a means to secure future revenue streams. Patents provide valuation, bargaining power and credibility for investors during a time when the uncertainty of the company's future performance is still high (Gans & Stern, 2003).

Thus, capital sequencing helps explain the method of validation for the company. Companies that utilize a Public-first capital sequencing model rely upon milestone-based technical validation, which corresponds to the goals of publicly sponsored programs. On the other hand, companies that utilize a Private-first capital sequencing model rely upon establishing ownership, control and future entitlement to value. While both models can ultimately result in the same level of technical maturity, they achieve this goal through different governance structures to manage uncertainty.

For investors, capital sequencing is a means to manage downside risk rather than to maximize returns. Companies that follow a Public-first capital sequencing model utilize public funding to shift the early technical risk to an external entity. Therefore, private investors can invest at a point in the company's development cycle where significant technical feasibility risks have already been mitigated. This reduces the likelihood of technical failure at the outset and enhances the productivity of private capital utilization (Cumming, Grilli, & Murtinu, 2017).

Companies that follow a Private-first capital sequencing model assume more of the early technical risk and investors respond by requiring greater protective measures at the beginning of the relationship. Greater patent filing activities in these companies support this objective by providing the basis for claims to future revenues, thereby compensating for unmitigated uncertainty. This behavior is consistent with the underlying assumptions of corporate finance theories, which says that investors with higher levels of uncertainty will demand greater mechanisms of control and protection (Brealey et al., 2020).

One of the key conclusions based on the data analysis is that there is no one optimal capital sequencing model. Rather, capital sequencing appears to depend on the degree of alignment among the characteristics of the technology being developed, the expected duration of the development process, and the tolerance of investors to risk. As such, in agtech, where technological development occurs in a slow feedback loop due to the involvement of biology, regulatory compliance, and field testing, capital sequencing enables capital structures to accommodate technological realities rather than force premature commercialization.

As a direct consequence of the data analysis, there are several policy implications. First, government funding programs appear to be most effective when they complement private funding sources rather than attempt to replace them. Second, the existence of a significant number of companies using the Public-to-Private capital sequencing model in the dataset implies that SBIR and STTR programs primarily function as a screening and preparation mechanism. That is, they identify technically viable projects and mitigate uncertainty prior to the introduction of private capital.

Finally, the results suggest that public programs should not be evaluated solely based on commercialization metrics over the short term. Companies that make rapid progress through the SBIR program, but fail to attract private investment, demonstrate that public funding can provide a valuable period of time for technical development, even if commercialization is delayed or does not occur at all. In agtech, where time-to-market is by default long, such an outcome may be efficient, regardless of the extent of private follow-on investment.

Previous studies have shown that early-stage public R&D grants increase the likelihood of later-stage private investment when those grants focus on the technical feasibility of the proposed technology rather than its market potential (Lerner, 1999; Howell, 2017). The data analysis in this study reinforces those findings. Thus, policies that aim to mitigate risk and preserve optionality appear to be more suitable for agtech than policies that promote rapid commercialization.

In conclusion, the evidence indicates that capital sequencing serves as a governance structure for innovation risk. The sequencing of capital helps explain which uncertainties are addressed first, which parties bear those uncertainties, and which signals are important at each stage of the development process. The primary concern is not whether public or private capital comes first. Rather, the primary concern is whether the selected sequence of capital aligns with the natural risks of the technology being developed. When the selected sequence of capital aligns with the technological realities, various capital sequencing models can be successful. However, when the selected sequence of capital does not align with the technological realities, even well-funded companies can experience difficulties.

4.2. Public Funding as Structured Technical Validation

Empirical findings of Section 3 illustrate that public funding in U.S. agtech acts less as a direct stimulus for faster commercialization and more as a framework for structured technical validation under uncertainty. The latter is more frequently observed in those companies following the Public-to-Private and Public Only paths, which showcase high rates of SBIR Phase II progressions and reach similar levels of technological maturity, though with radically different private funding outcomes.

As stated in the National Science Foundation's 2020 Budget Request, the NSF SBIR and STTR programs provide seed money to support research and development projects that would not typically receive support from private capital at early developmental stages. Examples include feasibility studies, prototype development and testing, and field experimentation. Each of these activities is expensive, time consuming, and has default uncertainty. Therefore, they create new knowledge and do not generate cash flow. The data also suggest that companies that obtain access to public funding in their earliest stage will typically organize their product development to focus upon completing each of these types of activities. As a result, they will progress toward established technical milestones and generally focus less on identifying market relevant indicators.

The high frequency of participation of public first companies in Phase II awards of the SBIR program supports this assertion. Phase II awards of the SBIR program require applicants to establish that their proposed project addresses the initial technical issues associated with the proposed technology and that additional development of the technology is warranted. By requiring this demonstration, the government establishes structure for the applicant company. The company must identify the specific hypothesis that it intends to test, document the results of prior experiments, and demonstrate what progress it made in addressing the identified technical issues. Thus, while public funding will often provide a subsidy for research, it also influences the manner in which experimentation is conducted and introduces discipline into the experimentation process without diluting the quality of the experiment.

The required discipline of the experimentation process fits the reality of developing agricultural technologies. Agricultural technologies must function across seasons, soils, climates, and operating conditions. The learning curve of agricultural technologies is steep. Results are highly variable. Quantifying early performance across all of these variables in a single measure is difficult. Public funding of these technologies provides both the time and the financial resources to resolve the uncertainty surrounding the behavior of agricultural technologies without obligating the companies to commit to commercialization at too early a stage. It also permits companies to resolve technical questions before the pressure of growing the business impacts decision making.

From a policy perspective, the results of this study suggest that the primary way to evaluate the success of public funding of innovation should be based on its ability to reduce technical uncertainty and preserve optionality for future financing. A number of previous studies have shown that public R&D grants are most effective when provided early and used to support feasibility rather than scale (Lerner, 1999; Howell, 2017). Consistent with this evidence, the results of this study show that the use of public funding to support the early stages of development of agricultural technologies is likely to be successful in reducing technical uncertainty and preserving optionality for future financing. However, pressuring public funding programs to attract commercialization investors and to rapidly translate research into products and services risks undermining the fundamental competitive advantage of public funding.

On the other hand, the transition from public to private funding is still an important point for many of the companies in this sample. The fact that a substantial proportion of companies followed a Public-to-Private path suggests that public funding can successfully prepare companies for market-based financing once the major uncertainties surrounding the performance of the technology have been resolved. While public funding is not a substitute for private capital, it does influence when and how private capital becomes involved.

In summary, the findings of this study place public funding at the base of the financing stack for agricultural technologies. It supports experimentation, absorbs uncertainty of early stage development, and supports better informed decision-making regarding allocation of private capital later in the development cycle.

4.3. Intellectual Property as a Sequencing Signal

These results confirm that there are sequencing-based differences in how agtech financing is affected by the presence of intellectual property. Specifically, companies in the Private-to-Public and Blended pathways tend to generate substantially more patents than companies in the Public-First pathway, however, these companies actually experience less movement into SBIR Phase II. These two findings together suggest that the number of patents generated is not merely an indicator of the technical activity of a company, but instead a form of signal that is shaped by the requirements of private investors.

Agtech investments generally have little immediate short-term revenue visibility and have long development times. The significant biological and regulatory uncertainty present in the field means that, even after early validation has been demonstrated, there is still considerable uncertainty surrounding potential future returns. As a result, private investors seek to limit their downside exposure while preserving upside opportunities. Patents provide a method to achieve this by providing a formal claim to future uncertain cash flows and a basis for controlling outcomes when they cannot be confidently valued.

The evidence indicates that companies who engage private capital early on in the process of developing new agtech products respond to these incentives by prioritizing patent generation. Therefore, intellectual property in these cases appears to be less a byproduct of publicly funded research and more a necessary precondition to access private investment. This finding is consistent with prior literature demonstrating that venture capitalists use patents as both a tool to screen prospective investments in high uncertainty environments, and as a governance tool to manage the risk of imitation (Howell, 2017).

Notably, the fact that private-first companies generate a larger volume of patents than public-first companies does not imply that they possess greater technological maturity. The relatively stable nature of the technology readiness proxy across all sequencing categories provides strong evidence that patent intensity and technological progress are not directly related. Instead, patents appear to act as financial instruments embedded in the innovation process and serve as alternatives to observable performance metrics as a basis for control mechanisms. From a corporate finance perspective, this is important because when project outcomes are uncertain and when assets are largely intangible, determining ownership rights becomes critical to making investment decisions. According to Brealey, Myers, and Allen (2020), under such circumstances, control mechanisms replace observable performance metrics. In agtech, where it is difficult to evaluate technologies early, and where validating technologies completely and accurately is expensive, patents serve as proxies for control, rather than as evidence of readiness.

The evidence presented in this study also supports the fact that private capital is not only dependent on the availability of public funding. Rather, private capital will enter when the specific constraints associated with the private capital provider are satisfied. Although public funding can reduce technical uncertainty, it does not eliminate concerns related to market structure, scale, or defensibility of competitive positions. Therefore, some companies elect to pursue private capital first by creating an intellectual property portfolio that mitigates unresolved technical risk.

From a sequencing perspective, private-first pathways allow companies to choose between early technical validation and increased appropriability. Venture capitalists will accept higher technical risk in exchange for more generally defined claims on future value. In contrast, public-first pathways create an inverse relationship by prioritizing the demonstration of feasibility before the need for ownership and resultant control issues dominate the governance of the company. Neither pathway is inherently better or worse. Both represent alternative approaches to managing uncertainty in the context of capital constraints.

Finally, from a policy perspective, the findings of this study provide a cautionary note regarding the interpretation of patent counts as a direct measure of the success of public funding programs. In the case of companies pursuing private capital first, the volume of patents generated is likely to be influenced primarily by the requirements of private investors rather than the scope of publicly supported research. Additionally, the lower patent intensity exhibited by public-first companies is unlikely to be indicative of reduced innovation. In many cases, the lower patent intensity observed among public-first companies will reflect a developmental stage where companies are engaged in learning rather than formal appropriation.

Ultimately, the evidence presented here suggests that intellectual property occupies a unique position at the core of finance and innovation. The role of intellectual property is contingent on the sequencing of capital used to fund its development. Intellectual property is not only the outcome of research, it represents a strategic asset that functions differently depending on whether the capital provider governing the company at an early stage is public or private.

4.4. Why Order Matters More Than Speed

One of the more subtle findings of this study is that the time between public and private funding is not nearly as important to understanding the technological outcomes of agtech companies as is the order in which public and private funding occur.

Section 3.4 of this analysis provides evidence that companies with short and long intervals between their public and private funding rounds achieve roughly equivalent levels of technological maturity and demonstrate similar rates of patent activity. This finding challenges a commonly held belief in venture finance that quicker transitions from one funding round to another lead to better innovation performance.

The reasons for this result will be clearer once we take a step back and examine the nature of agtech innovation itself. Agtech does not function similarly to other sectors where speed can be generated solely through the application of capital. Agricultural innovation timelines are constrained by the biological cycle of plants, environmental variability, and seasonal variation. Field trials typically have annual or multi-year cycles. Results of field trial performance may only be observable after a full growing season. There are physical limitations to innovation timelines in agriculture. Capital cannot significantly shorten these timelines.

Therefore, the time between public and private funding often represents the rate of learning rather than inefficiency or delay. Companies that require a longer interval to transition from public to private funding are not necessarily slower or weaker. They are likely working within the normal tempo of agricultural experimentation. This provides an explanation for why the data show that longer funding intervals are not associated with lower measured technology readiness. This observation is consistent with the broader literature on innovation finance, which indicates that innovation speed is highly specific to the sector and that financing models optimized for rapid iteration environments do not transfer well to sectors with slow feedback loops (Brealey, Myers & Allen, 2020).

While timing is limited by the constraints of the technological environment, the order in which capital sources enter helps explain how risk is managed. Public-first and private-first pathways place companies in different incentive, pressure, and validation regimes regardless of the time between funding rounds.

Public-first pathways allow companies to address early technical uncertainty using public funds. After addressing feasibility and validating their product concept, companies face commercialization pressure. Regardless of whether private capital enters six months after the last public funding round or two years after the last public funding round, the structure of the pathway remains the same. Private investors invest after some level of technical risk has been mitigated. The results indicate that it is the structure of the pathway, not the time frame of the interval, that helps explain technology outcomes.

Private-first pathways establish governance earlier. Private investors accept technical risk up front and respond by requesting greater control and protection. Intellectual property becomes more prominent and development priorities are adjusted to provide signals that support valuation and ownership. Although public funding may occur shortly thereafter, the initial governance structure has already influenced company behavior. Timing can rarely undo the initial assignment of risk and control.

Therefore, the data show similar levels of technology readiness among the various timing groups but there are significant differences in technology readiness based upon the capital sequencing category. Once the order of capital entry is determined, subsequent timing variations occur within that framework and do not redefine it.

In the venture community, speed is often used as a synonym for quality of execution. Faster fundraising and faster transition from one funding round to another are generally viewed as indicators of a company's strength. The findings here suggest that the assumptions underlying this reasoning are poor at early stages of agtech. Quicker transitions between funding rounds do not consistently result in higher technological maturity. This does not mean that speed is irrelevant. Rather, it means that speed is secondary to alignment. Capital that is provided prior to the resolution of the relevant uncertainty creates additional pressure while providing no additional learning opportunities. Capital that is provided later, but at the appropriate stage, provides greater opportunity for deployment.

Investor constraints also influence company behavior. Private investors are subject to fund lifecycle and return target constraints that limit their willingness to tolerate extended development periods. When private capital enters early in the development process, these constraints shape company behavior, regardless of how quickly follow-on funding is received. In public-first pathways, these pressures are delayed. Therefore, companies are able to navigate through the technically demanding phases of development without the immediate pressure of private return expectations.

This provides an explanation for why companies that experience longer public-to-private funding intervals do not show poorer technology readiness outcomes. Delayed private governance preserves optionality and reduces the need to optimize company performance based on investor-centric metrics during early stages of development.

From a policy perspective, the findings above suggest that public innovation programs should not be judged on speed to private capital metrics. If timing were the primary determinant of success, then faster transitions to private capital would be associated with higher levels of technological maturity. However, the data do not support this conclusion. Rather, public funding appears to be most successful when it enables companies to develop at a pace driven by their learning requirements, not by financial benchmarks.

As previously mentioned, prior research suggests that public R&D grants increase the probability of subsequent private investment when they reduce uncertainty rather than accelerate timelines (Howell, 2017; Lerner, 1999). The findings presented here support that prior research by demonstrating that the order of capital entry has a much greater impact on technology outcomes than the time frame separating public and private funding rounds.

Overall, the evidence from this study suggests that the evaluation of capital sequencing in agtech should be based on order, not speed. Since agtech is governed by biological and environmental realities, the sequence of capital sources helps explain which risks are addressed first and who assumes those risks.

4.5. Implications for Investors and Policymakers

Implications of the conclusions presented here for private and public actors financing agtech innovations are significant. The conclusions indicate that the timing and manner in which capital is provided matters in ways that cannot be inferred solely from funding volume or the speed with which funds are disbursed. Therefore, the effectiveness of public and private capital is dependent upon when they enter the innovation process and which types of uncertainty they are required to absorb (Brown et al., 2012).

As a result, agtech financing is not primarily about providing additional capital, it is about coordinating capital with uncertainty. As such, there will be direct implications of this distinction regarding how investors interpret signals of potential investments and how policymakers design programs aimed at supporting private investment in agtech (Kaplan & Lerner, 2016).

Private investors will need to understand immediately that participating in public funding programs, especially those associated with SBIR and STTR, should not be viewed as indicative of a lack of market orientation. Early public funding in agtech typically indicates that the technology requires additional and further technical validation prior to meaningful commercial pursuits (Stephan, 2014).

The study's results show that companies that follow a Public-to-Private sequence will experience higher SBIR Phase II progression rates and will exhibit similar levels of technological maturity compared to companies financed privately at the earliest stages of development. To investors, this suggests that initial public funding serves as preinvestment derisking. The use of public funding to reduce technical uncertainty early in the development process does not resolve questions related to market size, scalability or business model. Those issues remain to be resolved using private capital.

Contrary to a common bias among venture capitalists that label companies receiving public funding as grant dependent, the results of this study indicate that this view is often misguided. In agtech, public funding supports projects that are inherently less suitable for private capital due to extended timelines and limited short-term visibility of returns on investment, not due to the fact that the underlying opportunity does not possess value (Samila & Sorenson, 2010).

Additionally, the study found that a company's observable metrics represent not only its inherent quality, but the governance regime in place while the company was developing. Companies that seek public funding at the earliest stages of development tend to have more extensive experimental data and a more precise understanding of the technical constraints facing their project, however, they typically have lower early revenue and/or go-to-market signals. On the other hand, companies that receive private funding at the earliest stages of development tend to have more favourable intellectual property portfolios and clear commercialization narratives, however, they typically carry higher levels of unresolvable technical risk.

By acknowledging these differences, investors can create more accurate structures for their dealmaking, timelines and expectations. Failure to acknowledge a company's sequencing history may lead to a mispricing of risk, premature scaling pressure, and disappointment from a mismatch in expectations rather than poor execution.

A second implication involves the issue of speed. The results of the study reveal little correlation between shorter public-to-private funding gaps and higher technological maturity. For investors, this means that being patient can provide a competitive advantage in agtech (Ewens et al., 2018).

Investors who are used to working in digital or platform-based sectors often associate speed with quality. In agtech, this is a dangerous assumption. Many delays are structural and not managerial. Biological systems, regulatory approval and seasonal cycles impose constraints on agtech innovation that cannot be accelerated simply by providing more capital. Investors who treat slow progress as poor performance may overlook viable technologies that are constrained by factors beyond managerial control.

This has implications for the design of funds. Investors who have limited time to operate funds or exit horizons may be structurally at a disadvantage in agtech. Investors with longer duration capital and flexible expectations for returns may be better positioned to invest at times when uncertainty has decreased and value creation is clearer.

Additionally, the study found that the association between private-first sequencing and higher patent counts warrants caution in evaluating the quality of innovation based on IP metrics. High patent intensity should not be interpreted as an indicator of superior innovation quality. In some cases, high patent intensity represents a rational response to investor demands for protection when technical risk remains unresolved. Investors should therefore evaluate IP portfolios within the context of sequencing history and development stage, rather than as standalone indicators of performance.

From a policymaker's perspective, the study raises concerns regarding evaluation frameworks that focus primarily on the speed with which companies access private capital or rapidly commercialize their products. The presence of a large Public Only group with strong SBIR Phase II progression suggests that public funding can support extended periods of technical development without subsequent private investment. In agtech, where time-to-market is in nature long, this can be socially beneficial even if commercialization is delayed.

Research studies have shown that public R&D funding is most effective when focused on feasibility and experimentation rather than scale (Lerner, 1999; Howell, 2017). The results of the current study confirm that this principle applies to agtech. Policymakers would therefore be unwise to press public programs into mimicking early-stage venture capital, as this could undermine the comparative advantages of public funding.

The results of the study also suggest that policymakers should design public programs with capital sequencing in mind. Instead of imposing commercially oriented performance metrics too early in the development process, public funding can maximize its impact by focusing on structured technical validation and knowledge generation. This prepares companies for later private investment, rather than trying to replace it. This does not mean that commercialization should be ignored. Rather, commercialization should occur when it is appropriate. Public funding is most effective when technical uncertainty is the primary constraint. Private capital is more effective in later stages of development, when scaling and execution become the limiting factors.

Policymakers who require continued public funding to be tied to rapid commercialization may be creating distorted incentives, encouraging companies to prioritize short-term signals (such as patents or prototypes) rather than long-term learning. The study's results demonstrate that public-first companies can attain similar levels of technological maturity, regardless of when private capital is invested.

Finally, the study highlights the importance of designing policies specific to the sector. Agtech is fundamentally different from fast-cycle sectors. Biotechnology, environmental considerations and regulatory approvals introduce unavoidable delays. Generic innovation policy frameworks applied uniformly across all sectors could produce suboptimal results in agtech.

Collectively, the results of the study indicate that effective agtech financing is contingent upon the interactions between investors and policymakers through sequencing. Public and private capital play complementary roles. Public funding helps to reduce uncertainty and expand the opportunity set. Private capital adds discipline, scale and market orientation once feasibility has been demonstrated.

However, sequencing will determine how these roles are distributed over time. Misalignment of the sequencing roles (i.e., public funding forces early commercialization or private capital is introduced prior to when technical risk is manageable) will reduce capital efficiency and increase the likelihood of failures. Strategies based upon a sequencing aware approach will enable each type of capital to perform optimally.

The major implication of this study is that innovation outcomes and capital efficiency in agtech improve when capital is coordinated with the primary risk at each stage of development. Therefore, in agtech innovation finance, sequencing, not scale, is the key lever.

4.6. Contribution to the Literature and Future Directions

The focus of the research is to provide an example of how the sequence of the entrance of public and private capital in a very long cycle innovation industry defines how they interact with each other. Most of the literature looks at public and private funding as separate and independent inputs into innovation. However, this research changes the focus of the discussion from the fact that there is funding to the nature of the funding and the order in which it is provided to a company (David et al., 2000; Mazzucato, 2013).

There are three types of contributions made by the research, which include conceptual, empirical, and methodological.

Conceptually, the primary contribution is to define capital sequencing as a mechanism to manage uncertainty in an innovation finance context. While the majority of the literature on innovation finance has been concerned with if public funding attracts or scares private funding, or if publicly funded companies generally perform better than privately funded companies, the literature assumes that funding sources can be added together in a linear fashion. The findings of this research suggest that this is not always the case. The order in which capital is provided to a company helps explain which risks are mitigated first, what validation signals are most important, and which entity will be responsible for managing the uncertainty at each developmental stage (Gans & Stern, 2003; Teece, 1986).

The capital entry sequences of a company determine how early technical uncertainty is distributed among entities. If a company receives funding from the public sector before receiving funding from the private sector, then the public sector absorbs the early technical uncertainty. On the other hand, if a company receives funding from the private sector before receiving funding from the public sector, then the early technical uncertainty is supported by the private sector investors and the risk is compensated through stronger claims to future value, most typically through the granting of patents. This perspective may help explain why many prior studies on the effectiveness of public innovation funding have reached ambiguous conclusions. Public funding does not have a uniform effect on innovation finance. The effects of public funding depend upon how it interacts with private capital over time. In this way, this research builds upon prior work that emphasized the role of early-stage derisking, but did not explicitly model sequencing dynamics (Howell, 2017; Lerner, 1999).

Another conceptual contribution of the research is the distinction between the order of capital entry and the timing of capital entry. The results of the research indicate that the order of capital entry is more strongly related to technology outcomes than the speed of transitioning between funding sources. Therefore, the research addresses a frequent assumption that rapid commercialization is equivalent to successful innovation in a slow cycle sector like agtech. More importantly, the research indicates that alignment of capital with the appropriate developmental stage is more important than the speed of commercialization (Auerswald & Branscomb, 2003).

Empirically, the research uses data on 50 companies in the U.S. agtech sector to demonstrate that there are systematic differences in technology outcomes based upon the type of capital entry sequence used by the companies. Companies that followed a public-first pathway experienced progression through the public validation stages more frequently than companies that followed a private-first pathway. Companies that followed a private-first pathway experienced greater patent intensity, but less engagement with public milestones. The results of this research indicate that capital entry sequencing is associated with distinct development paths for companies, even when the companies achieve similar levels of technological maturity.

Methodologically, the research develops a sequencing-based framework for analyzing innovation finance at the company level. The framework does not consider funding as a continuous flow or an aggregate measure. Instead, the framework considers discrete financing events, which include the first public funding and the first private funding received by a company. The use of an event-based perspective is consistent with how financing decisions are made in practice and minimizes reliance upon aggregate measures that contain substantial amounts of noise (Kaplan & Lerner, 2016).

By distinguishing between categorical sequencing and continuous timing, the research separates the concepts of order and speed. Additionally, the research suggests how a rule-based technology readiness proxy can be constructed to represent technical maturity using publicly observable signals when direct measures of technical maturity are unavailable (Mankins, 1995). The methods developed in the research are not limited to the agtech sector and can be applied to other slow-cycle, capital intensive innovation sectors.

The research points to several potential verticals for future research. First, the application of the sequencing framework to larger samples and additional sectors would facilitate the assessment of the generalizability of the sequencing framework. Second, future research could develop relationships between early-stage sequencing patterns and later-stage outcomes such as company survival, exits, or post-commercialization performance. Third, research could compare capital efficiency across sequencing pathways, particularly in regards to publicly funded capital. Fourth, cross-country studies could explore how institutional design affects sequencing dynamics. Fifth, qualitative research could supplement the findings of this research by exploring how founders, investors, and program administrators perceive and negotiate sequencing decisions.

CONCLUSIONS AND RECOMMENDATIONS

This thesis builds upon prior literature examining innovation financing through identification of capital sequencing as an alternative approach to manage innovation risk within agtech companies. This thesis does not treat public and private capital as substitutes for one another, rather, it showcases that these two types of capital function in a different way, yet complement each other at different stages of company development. The key contribution of this thesis is that funding outcomes are not just determined by funding type, but also by timing and order of capital entry relative to the major technological and commercial risks of the company.

This thesis examined how funding sequences affect technology development, and early growth outcomes in U.S. agtech companies, and the overall impact of public and private funding on those same companies from 2010 through 2025. As opposed to studying if public or private funding is more beneficial independently, the focus of this research was on how public and private funding sources were ordered, and how those sequences affected innovation trajectory in a sector that defines itself with extended development periods, significant technological uncertainties, and limited ability to commercialize.

Combining funding history data from 50 U.S. agtech companies based on their participation in SBIR/STTR, patent data, SBIR phase progression data, and a proxy measure for TRL, the research methodology used was descriptive and comparative in nature. Therefore, the analysis was designed to provide a transparent and accurate representation of how agtech innovation occurred, and to align with theoretical aspects of innovation finance as opposed to making causal claims about the relative merits of public versus private funding.

Results indicated that capital sequencing had an association with the way agtech innovation occurs, even when companies reached similar levels of technological maturity, as determined by patent production and funding level.

Companies that followed a Public-to-Private funding sequence demonstrated significantly higher rates of formalized technical validation, including a greater rate of successful completion of SBIR Phase II, and marginally higher levels of technological readiness as measured by TRL. It appeared that public funding was being used to validate early scientific and engineering uncertainty prior to attracting private capital. On the other hand, companies that followed a Private-to-Public funding sequence produced significantly more patents but had much lower engagement with public validation processes. These companies appeared to have an early emphasis on the demonstration of applicability and investor-facing signaling, rather than meeting milestones.

Another key finding was that the sequencing effects were larger than the timing effects. There was little correlation between the amount of time there was between funding events and technological maturity or patent production. Agtech, as a sector, is subject to numerous constraints that limit the rate of development, including biological systems, environmental variability, and regulatory requirements. Therefore, the manner in which capital entered into the process mattered more than the speed at which companies transitioned from one funding source to another.

Collectively, the results suggest that public and private capital serve different yet complementary functions in supporting agtech innovation, and that the effectiveness of each form of capital depends more on the manner in which they are sequenced, as opposed to the independent presence of either form of capital.

The research presented in this thesis contributed to the innovation finance literature in three primary manners.

First, the thesis advanced a sequencing-based perspective on public-private interactions by reframing capital structure as a means of allocating different types of risk throughout development stages. Additionally, the thesis provided explicit distinction between ordering effects and timing effects, thus adding conceptual clarity to debates that frequently identified rapid commercialization with effective innovation.

Second, the thesis provided empirically derived, company-level data from the agtech sector, which is an area that is currently underrepresented in quantitative research despite the economic and social relevance of this area.

Lastly, the thesis provided methodological contributions by illustrating how event-based sequencing variables, and proxy measures of technological readiness, may be constructed in a transparent manner utilizing publicly available data. The proposed methodology will allow researchers to develop practical frameworks for analyzing innovation finance in areas where direct measures of technological progress are difficult to obtain.

Both investors and policy makers are expected to gather relevant implications from the findings.

For private investors, participation in public funding programs should be viewed as a signal of derisking technical uncertainty, rather than as an indication of dependence on grants. A sequencing-based view of companies development can assist private investors in establishing appropriate expectations and governance structures, and in deploying capital consistent with the primary risks associated with agtech innovations at various development stages.

For policymakers, the results are indicative of the need to evaluate public innovation programs not solely on the basis of speed-to-commercialization or the immediate follow-on investment from private capital. In agtech, public funding appears to be most productive when it serves to provide structured technical validation and preserve future options, rather than attempting to drive premature market outcomes.

The research findings also provide an approachable framework for founders to make decisions about their early-stage financing strategies in an environment of high levels of uncertainty. The sequencing approach is one that focuses on matching the type of investment with the major risks facing the business at each point in time rather than simply making decisions based upon either available capital or a desire to maximize valuations. The thesis found that in industries like agtech (where technical validation, regulatory compliance and biological factors will normally happen prior to large scale commercialization) that funding structures for early-stage companies have the ability to dramatically influence innovation paths through enabling companies to continue to test, validate, adjust their models as needed until they are pressured into a product-market fit model by their investors.

There are several limitations to the research presented in this thesis. The sample size of the dataset is fixed and relatively small, and therefore limits the ability to statistically generalize the findings to all agtech companies. Additionally, technology outcomes are represented by proxy variables that approximate, but do not completely represent technological or commercial success. Lastly, the analysis focuses on SBIR/STTR as the primary public funding vehicle, and does not include other public programs or international contexts.

Therefore, the limitations of this research present multiple verticals for future research. Larger and cross-sectoral datasets could be developed to assess if the sequencing effects identified in agtech apply to other innovation domains. Additionally, assessing the linkages between sequencing patterns and longer-term outcomes, such as company longevity, exit, or productivity increases, will enhance our understanding of the economic significance of sequencing effects. International comparative studies will enable researchers to better understand the role of institutional design in shaping public-private complementarity.

In conclusion, this thesis suggests that capital sequencing is a critical but often overlooked aspect of innovation finance. In agtech, where uncertainty persists and development cannot be rapidly accelerated due to biological systems, environmental variability, and regulatory requirements, effective financing is dependent more on who bears which risks, and when, as opposed to how fast capital is deployed.

By focusing on funding structure as opposed to funding volume, the thesis contributes to a more grounded understanding of how public and private capital may interact to support complex, long-term innovation.

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