When and How Entrepreneurs Pivot

"Pivot" is a popular term in the start-up world. If their initial idea doesn't work as planned, entrepreneurs are expected to be ready to pursue a Plan B. But what does it actually mean to pivot – and are entrepreneurs really as open to doing it as they say they are? In a new paper, Wharton management professor Jacqueline "Jax" Kirtley used a field study involving seven early stage firms in the energy and cleantech sector to take a closer look at how these strategic changes actually play out in the startup world. "What is a Pivot? Explaining When and How Entrepreneurial Firms Decide to Make Strategic Change and Pivot," was co-authored with Siobhan O'Mahony, a professor at Boston University's Questrom School of Business. Kirtley recently talked with Knowledge at Wharton about their findings. (Listen to the podcast using the player at the top of the page.)

What Does Pivoting Mean in Business?

"Pivoting" is fundamentally changing the strategic direction or core aspects of a business, usually to adapt to an evolving market. One example is Netflix pivoting from a DVD-by-mail service to online streaming.

An edited transcript of the conversation follows.

Knowledge at Wharton: The term "pivot" is pretty widely used, but can you talk a little bit about what its origins are?

Jacqueline "Jax" Kirtley: The use of the word as a specifically entrepreneurial term comes from Eric Ries and Steve Blank's books on what's now referred to as the "Lean Startup Movement." They talk a lot about how you can use basically the scientific method — making hypotheses about what's going on in your entrepreneurial firm — because there's so much uncertainty for entrepreneurs. They suggest that you can think about explicit hypotheses about what you're doing, and then test them.

And when you test those hypotheses, they either get validated or they don't. And if you look at what the Lean Startup Movement is saying, when your hypotheses are not valid — are not shown to be accurate — you should change. You should pivot your strategy and create new hypotheses and test those. And that's where the word "pivot" came into entrepreneurship — this very specific methodology. But it has been picked up by everybody and their brother, and it's not used that precisely anymore. Now it is used by anybody who wants to talk about how we've changed — we've pivoted, we've pivoted our strategy.

I actually had a student entrepreneur once tell me that they pivot every day. And that doesn't make any sense. You don't really change your strategy every day. In the paper, I specifically refer to the example of Slack and Flickr. [Co-founder] Stewart Butterfield started out making big online video games. And they didn't work, so he changed from running a massive multi-player online video game to Flickr, which is an image sharing website based on technology that was part of the original game. That, we think of as a pivot because it's a massive change. The word "pivot" is very evocative. You think of basketball players who have planted one foot and changed direction but kept that one foot down. We usually think about that as the technology or the firm — there's something you keep, but you change your direction very completely.

So we all talk about pivots as if they are big changes. But we also hear entrepreneurs talk about pivots as little changes. And we've started to see the word come up to refer to anything — politicians pivot, and there was a period a couple of years ago where there were all these self-help articles about how to pivot your life. It has just become this ubiquitous, not specific term, but to entrepreneurs, it still has this very specific — or at least semi-specific — usage. We still talk about entrepreneurs in this way, and we teach it, too. We teach this scientific method of hypothesis-driven entrepreneurship.

So for me, I wanted to get down to, "Well, what is it really, then?" A lot of entrepreneurs will tell you, "We're willing to pivot. We're open to it." But what does that really look like, and what does that really mean? That was something I wanted to understand.

> "A lot of entrepreneurs will tell you, 'We're willing to pivot. We're open to it.' But what does that really look like, and what does that really mean?"

Knowledge at Wharton: How were you able to study this question?

Kirtley: So this paper is coming out of my dissertation study. The dissertation [data] is three years, but the data collection has continued on since then. It's now at, I think, about seven. I went out to the firms multiple times a year, talked to multiple people within the firm, and did interviews over several years, asking: What are they doing? What are the big decisions they're working on? How is the firm evolving?

All the firms in this study are doing some kind of novel knowledge — in many cases, right out of a lab, trying to take it to market in energy and clean tech. So these are very hard-science, very technologically advanced concepts that they're trying to bring out — products and technologies. How does your strategy evolve? How does your technology evolve when you start a firm like that? I showed up on their doorstep every few months and observed what they were doing, talked to different people within the firm about the big decisions going on, about what they were working on, to understand how things were changing.

What this gave me was the opportunity to see the before, during and after of big decisions. That's the basis of this data. If I can see what are the things that lead up to a decision — a big decision about your strategy, about changing your strategy or pivoting — I can get a sense of what actually triggered a decision, and then what are the things you're thinking about during that decision? Some of the pieces within one decision may be related to other decisions, or they may be related to things you were thinking about a year ago that become relevant to that decision-making. And then once you've made the decision, what happens next? This paper doesn't get too much at what happens next. It's mostly focused on the decision-making and the choice to change or not change.

Knowledge at Wharton: As you delved deeper into that decision-making, what did you learn about the nature of pivots, and also the nature of things that were not pivots?

Kirtley: I have seven firms in the data, and they are all firms that were very, very early-stage when I met them. None of them had a product on the market when they first started talking to me, and several of them still don't.

And what I was fascinated by is they all say they're open to change. They're young firms. They know there are things they don't know about what's happening, about what's going to be the case, what's going to work. So they're all open to change.

Knowledge at Wharton: I think an entrepreneur, anyone doing a startup, has to say that, be open to that, to some extent.

Kirtley: Anyone who is an entrepreneur is acting under uncertainty. So that's actually something you would say. Any entrepreneur is acting under uncertainty, in that they're doing something other people don't think is worth it, is right, or is going to work. And they're open to the fact that they might be wrong about some parts, but they're usually pretty clear on the [core strategy] being totally there, and that this is going to work. And this is the strength they have behind their own convictions. In this paper, I look at 93 different decisions where at least one of the options involved changing the strategy.

Knowledge at Wharton: When you say "changing the strategy," is it changing that core belief or technology?

Kirtley: Changing something fundamental about what the firm is doing. So a change in the strategy might be: Are we a service company? Are we a product company? It might be: Are we funding ourselves through grants, or are we funding ourselves through VCs? Are we going to get contracted-out engineers, or are we only going to do work internally? There's a whole bunch of different kinds of things that are part of your strategy, and for these 93 decisions, where at least one of the options they considered was a change, most of the time they didn't change. Most of the time — and that's 72 decisions — they didn't change. As an outsider, very often I was surprised by this. I thought change was the right thing to do.

One example would be a firm deciding whether or not to build a physical prototype of their product — because their full-sized product is about the size of this room, and costs a couple of million dollars to build. So you don't just build one of those just to show off. You can't afford it. But they also thought it wasn't worth designing a small prototype, because they knew anything you could do in a small prototype already existed in the world, and their new technology was only relevant at full-scale.

They thought it would be a waste of time and money to build what they called a "toy." And potential investors kept saying to them, "But you don't have anything that works. You don't have something I can see working." So they asked themselves the question: Should we build a toy just for investor marketing? And that would have been a change in their strategy. They had come up with: How much money do we need to do all this? What are we spending our time on? What activities are we doing? You have to actually design a small version, not just say, "OK, I've got the big one, and I'm going to build a small one." You have to actually make design choices and find the right parts to be able to build something that fits on a table, when the real thing is the size of a room.

They entered that decision process, and to me, as an outsider, I was figuring they were going to build this because they were having a lot of trouble finding money, finding investors, finding even grants. And they decided not to. And it took them a couple more years to get the money they needed to really get their firm started after that decision. Were they right? Were they wrong? I have no idea. But they decided to stay on their path of not building a prototype. What I saw in this study, more often than not, is that the entrepreneurs didn't change their beliefs about what was the right thing to do, what was the right path to take. When you don't change any of the beliefs you hold about the uncertainties you face and the challenges you are dealing with, you're not going to change your strategy.

That was actually one of the first things that I would say this study found: As an entrepreneur, you have beliefs about the things you don't know for sure — the uncertainties. If your beliefs don't change, you don't change your strategy. You stay on course. But every once in a while, in this case, only in about 21 instances, they did change. They did change their beliefs about what to do, about what was going on, about what was uncertain. Their beliefs did get affected.

> "For these 93 decisions, where at least one of the options they considered was a change, most of the time they didn't change."

Knowledge at Wharton: So in that minority of cases, what was going on there? Because it sounds like there was a pretty huge bar to clear to get them to make that change.

Kirtley: Unfortunately at this stage, I don't know exactly which situations cause your beliefs to change and which ones don't. That's future research to do. But what I can see in this data is, in some cases, what the entrepreneurs believed about what they didn't know or what they were unsure about — the uncertainties they faced — and if they were contradicted — that could be, "My belief was wrong. I was wrong about this market." Or "I was wrong about the idea that partners would be willing to pay us or to work with us." So there's some belief that's contradicted by new information. And it might be that the belief is wrong, and it might be just that the belief doesn't align with the strategy we have, that I really do believe that this product is best sold as a component to some else's system, but the someone elses out there don't want to buy it. So I still believe that this product is best entered into the market as a component, but since that's not going to happen, that's not going to work. None of those system-makers want to buy it. I'm going to have to do something else. There's this contradiction.

In those cases, the entrepreneurs exited something. They said, "OK, this is not the right product." And they stopped the product. When the entrepreneurs entered these decisions, they were triggered by the problems and the opportunities — new information that's either unfavorable or favorable. The problems, when they affected their beliefs, led to these exits. There's a contradiction in what I believe, and I need to exit something.

Opportunities — what I saw was the beliefs expanded. So I believe that my microchip technology is going to change the world. Well, then I learned a new piece of information about how to build my product without a microchip, using off-the-shelf electronic components. And what I, as a researcher, found is over time, as this team was deciding, "Well, do I need to make a microchip product? Could I make something that isn't a microchip? — their language changed about those beliefs. Instead of talking about how our microchip technology is going to change the world, as this decision process went on, I heard them say, "Our core technology is going to change the world." Their beliefs expanded. What they believed about their uncertainty, what they believed about what they were doing, grew. And in those cases, they added to their strategy. And in this example, they added a second product. And this is a two or three-year-old firm that hasn't finished the first product, doesn't have all the money they need to get to market on the first product, but they've added a second product, and they think this is worth doing.

And they believe in it. They believe that having two products is going to be valuable. One will get to market sooner, one will give us this, and one will give us that. So they added to their strategy.

What kind of choices are they making? They're making an addition choice, or they're making a subtraction and exit choice. But if you talk about a pivot, if you think about Stewart Butterfield going from a video game to Flickr, that's bigger than one exit or one addition. You look at what you have and what your products are and what you could sell. And you identify, "Well, we have this image-sharing system that we've been using internally, and we could turn that into a product."

This is something that I think kind of gets at the core of the findings about pivots. When you make a choice to change your strategy … it's an incremental choice, but it's a specific choice to add, to exit. You make this specific choice.

A pivot is, "I've changed and redirected my strategy. I was a game company, and now I am a photo-sharing website." That kind of change is actually an accumulation of adds and exits. And over time, you accumulate those. And that time might be a day. That time may be six months.

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One of the firms in my study actually went six months with no product defined. They exited their product, and it took them six months and a couple of different potential addition decisions — potential products they could add — before they decided, "This is the product we're going to sell, and now this is what we're going to do." It took six months of a firm living on grants, with no product defined, and being willing to live in that uncertainty.

When we think about the pivot, we think about these big stories, and we tell them from two miles high. We were a game company. We are now Flickr. What happens on the ground, the decisions — that's really what the unit of analysis is in this study. The decisions are more steps, and they compile, they aggregate into this complete redirection of what we're doing as a strategy and what we're doing now.

Knowledge at Wharton: For those 20-something decisions to make a big change, it wasn't that they all at once decided, "We're just going to make this big pivot." It was really a lot of different things going on over time that added up to a pivot.

Kirtley: It's not a basketball player who plants one foot and turns around completely and changes direction. It is a set of decisions that, when you look over time — I was a product company that was focused on a number of different industries that could all use this energy device. And now, two years later, I will tell you that I am a service company with a set of products targeting one industry in energy. That's a pivot. That's a significant redirection of the firm. But in the case of that firm, there are 18 decisions, and some of them were to change. Some of them were not to change. Some of them you exited — you exited a product — and then that example went six months without knowing what your product is. Some of them, we added a product, or we added a customer, we added a joint venture, a partnership — things that really did change what our activities were, where we used our resources, what our day-to-day strategy was, what our firm did. But really redirecting from "I'm a product firm for lots of markets" to "I'm a service firm with products to one sector of energy" — that takes a lot of decisions.

One of the things I also found really fascinating throughout the data was when I talked casually with these entrepreneurs and their teams, they would say, "Yeah, we're open to pivots." But when we talked about the decisions they were actually making, when we talked about what they're doing today and what they're thinking about, they never used the word. There were, probably in all the data I have, a couple hundred hours of interviews. The word "pivot" was maybe used twice, and it was retrospective, to refer to kind of the era before — and the era now.

Knowledge at Wharton: So they didn't really necessarily even recognize the pivot while it was going on?

Kirtley: For a company that had made this kind of change — we were a product firm; now we're a service firm — they might say, "Well, before we pivoted, we were looking at retail. We had a marketing person start looking into retail. And now that person's role has changed."

> "We need to be careful when you're talking to an entrepreneur who's trying to do their thing today, that they don't assume that that person had it easy and made all these decisions in one minute and was so certain."

That role didn't change in a day. It was over time. But that would be the only time in the data I ever heard these people use the word "pivot." This retrospective [reference] to something that happened, and they're referring to something that happened over the last year or two. But when you talk to them about entrepreneurship in general, they'll say, "Oh, we're open to pivots. We realize that this might not be exact, that things will change." But when they're making these decisions, that's not the word they're using. That's not what they're thinking about. They're thinking about — What do I believe is the right thing now? What is going to work? And how is this firm going to succeed?

Knowledge at Wharton: Your research focuses on hard-science and cleantech firms. Do you feel like the thought process and actual change of strategy is different for them than it would be for say, a tech start-up where the manufacturing costs and overhead might not be as high?

Kirtley: I think it applies either way, although the challenge of it, the beliefs you're holding onto, how hard it is to change — those are going to be different. Maybe this is one of those instances where for a firm that is building a new kind of alternative energy generation, choosing to exit a product might be a slower decision because of what we're doing, whereas deciding one day that this online video game isn't working — that might be a decision I could make faster.

But I think we see, if we look at some of these assumed-to-be easier and faster startups like Flickr — even something like Google, where Google started out, their original business model was, "We're going to license Search Powered by Google. We're going to sell you a hardware device that you put internally to your servers at your office, and we're going to have advertising." But the advertising was actually something they weren't that excited about. When they added AdWords in 2000, that was an addition to the company that was part of a set of decisions that turned them into what they are now, which is the mega-advertising system they are. They only stopped selling those hardware devices that you put internally to the servers in your office two years ago. So they've made choices that are steps of adds and exits, and we talk about the big pivot there, as well.

What my data allowed me to do is look at these extreme cases where maybe it was easier for me to see the choices being made — some of the kinds of changes they were dealing with or considering. But I think it is valid — the findings are generalizable to entrepreneurship in general.

Knowledge at Wharton: What do you think is the value for entrepreneurs, or even for budding entrepreneurs to understand this process a little better?

Kirtley: I think it's the idea that you can pivot and survive. This is one of the things about pivot I think a lot of entrepreneurs like. If I know that this isn't working, I can pivot, and I can still succeed. That's something that is a good thing for entrepreneurs to know. Because most entrepreneurial firms fail. So knowing that there's an alternate — a way to survive, a way to change and move forward — that's a good thing to know.

Assuming that you're going to just make that one choice one day, and you're going to go from being a game to being an image platform — that might be a lot to expect of yourself.

We talk a lot about entrepreneurial heroes when we talk about Facebook and Google and Flickr. We talk about these successful hero entrepreneurs. We need to be careful when you're talking to an entrepreneur who's trying to do their thing today, that they don't assume that that person had it easy and made all these decisions in one minute and was so certain.

I think for an entrepreneur who's facing these challenges — Should I pivot? Did I pivot wrong? Were these decisions right? Did I just change the wrong way? Knowing that all of these stories are more steps and that the big pivot isn't a decision you're making today — that, I think, can be helpful to the entrepreneurs as they're doing these things.

Knowledge at Wharton: So for future lines for this research, where are some other places you'd like to go with it?

> "The optimist in me is attracted to this idea, that these opportunities we stumble over after we've already started the firm are significant to what our firms evolve into."

Kirtley: Well, as I mentioned, I can't say right now why some decisions resulted in beliefs being affected or changed. What's the difference between the ones where the beliefs remained — where they stayed, and nothing changed or nothing was affected?

I would love to be able to find out more about the difference between those, and I think that could be incredibly helpful — especially if eventually there's some way to connect that to how good or bad those decisions become. That's a little idealistic. I'm not sure whether I will get there.

Another thing that I found really interesting in the data — opportunities led to decisions to change more often than problems. We think of it as if my current strategy fails, I'll pivot. That's a very firefighting perspective. It's very negative. But one of the things that this data pointed to is some of these changes are coming more from, "Oh, there's something cool I can also do."

One of the examples of that in the data happens while driving in the customer's truck. The customer starts talking about how "our industry came to a stand-still last winter for two weeks because of weather." And the conversation continues, and the entrepreneurs realize, "Wait a minute, there's a feature to what we're already building that could solve the problem this gentleman just mentioned." This is an opportunity that we have to solve something that's real, that's fundamental, that we didn't know about before. And it's not anywhere near the idea that these entrepreneurs had when they founded their company, but there's something led by these opportunities, led by something more positive and less firefighting. The optimist in me is attracted to this idea, that these opportunities we stumble over after we've already started the firm are significant to what our firms evolve into.

We tell a lot of hero stories when it comes to probably business in general, but definitely entrepreneurship. We love to tell the story of the phoenix rising from the ashes, or the college dropout who became a billionaire. There's a lot of energy that comes from those stories. There's a lot of excitement and motivation that can come from those stories, but there are a lot of important details we don't pay attention to when we just focus on the hero story.

The opportunities that you stumble upon along the way that are significant to what your firm becomes — those really change the story and change it for the better. And I think that's something that's worth understanding more.

Using Pivoting and Real Options to Evolve a Business Model

Posted on September 21, 2015

Nothing is certain, except death, taxes and business decline. It does not matter how much money the current business is making; there is a life cycle for products and technologies, and eventually the business will decline without constant re-priming. Re-priming is essentially an investment decision involving the selection of the right product, the right people, and the right technologies at the right time. Real options theory can help with that decision.

Real options theory can be traced to a 1977 paper by Stewart Myers. They are called *real options* because they are investment decisions in tangible, real things such as a tangible asset, a product, machine or even a process since a process can be perceived. The real options investment decisions for a startup are:

1. Concentrate on executing the existing business model. Focus on selling your existing products and versions.
2. Add more versions to your exiting product line. The current product line looks viable, but needs fine tuning and freshening.
3. Redirect the business in a new direction. Use existing competencies and acquire additional competencies to develop a new product line. Your existing products are not attracting customers.
4. Abandon the current business. Fail fast and go back to the drawing board.

A *real option* is a decision or choice to invest a little or a lot in a corporate asset such as a business model, a product, or a technology. Real options look very much like the relatively recent concept of pivoting a startup. Eric Ries introduced the concept of pivoting and changing business direction in his 2011 book *The Lean Startup*.

> *"Companies that cannot bring themselves to **pivot** to a new direction on the basis of feedback from the marketplace can get stuck in the land of the living dead, neither growing enough, nor dying, consuming resources and commitment from employees and other stakeholders but not moving ahead. pp. 151-152"*

The problem with the pivot concept is that it is a bit simplistic and parochial. The problem with the real options concept, when it is applied rigorously in its academic manifestation, is that it is too abstract and mathematically complex because it is based on stock options concepts.

An Enhanced Pivoting Model that Draws on Real Options

I have expanded on the pivot concept to take advantage of the more comprehensive real options approach by extending the basketball analogy. In basketball the pivot gives you the opportunity to get into the triple threat position. In the triple threat position the player can either pass, shoot or dribble. Check out Kobe Bryant in the triple threat position.). Each game is a continuous series of decisions to shoot, pass or dribble. Each season involves games against some of the same opponents and new opponents with the same shoot pass and dribble decisions. Finally, if the game is too tough, the player and the entire team can just walk off the court, albeit a radical, though sometimes prudent strategy in some situations.

The essence of the model (see Figure 1) is that founders should modify their business model based on the *market potential* and the degree to which the current founders and employees have *core competencies* and *domain expertise* in a particular area.

1. Shoot: Go with the current business model and grow the business as quickly as possible.
2. Dribble: Try to get in a better position by modifying and tweaking the

current business model using versioning and identifying appropriate market niches. Identify mashup artists, and marketing expertise. Focus on product design and prototyping.

3. Pass: Dramatically change the current business model. Use some or all of the core concepts of the existing model. Conduct intense R&D and acquire talent and perhaps even acquire a business with the desired core competencies. Get ready to receive the ball and be in the triple threat position develop a new and improved business model.
4. Abandon the game & fail fast. Leave the game and walk off the court. Your position and perhaps your game is not good enough to compete effectively in this situation. Try to improve your game (domain knowledge). You might even have to find a new court to compete on and introduce a new business model that draws on previous experience and new domain knowledge.

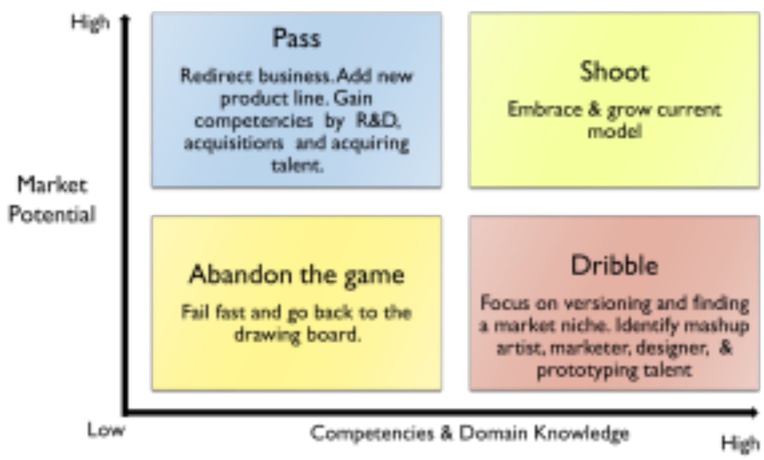

Figure 1: The Triple Threat Pivot Model

Market Potential and Core Competencies

Market potential refers to the size and the growth rate of a market. The size and growth potential of a market accounts to a large extent the attractiveness of a market and often drives the decision making process for startups and legacy businesses. Questions to be answered include determining the absolute size of the market, how much of the market can be reached and your potential to gain market share.

Core competencies are the knowledge, expertise and capabilities of the founders, employees and contained in existing processes. Pivoting and going in a new direction and embracing a new business model is often the key to business survival. But there are implications, because new investments can interact positively or negatively with existing skills and assets of the firm.

(The basic idea behind the model was published in Decision Support Systems.)

Examples of pivoting over the last 150 years

As noted earlier, nothing is certain, except death, taxes and business decline. As illustrated in Table 1, many old and new economy companies have pivoted their way to success. Survival requires adaptation. It is truly a pivot or perish world and pivoters will inherit the revenues.

Real options analysis can be very technical, requiring a significant amount of financial and technical scrutiny. However, using complicated calculations is overkill for startups and small to medium-sized businesses. Real options concepts are nevertheless important.

The takeaway from the perspective of the entrepreneur is that you need to experiment and also need to diversify your portfolio of products and projects under consideration. You need to be constantly aware of the pivot. This does not mean that you have to actually buy machinery, make products, and constantly modify your business processes, but it does mean that you should learn-about many products and technologies related to your business and learn-by-doing and experimenting when an opportunity looks promising. As noted in the previous post, you might consider implementing a Chief Illuminati Officer function and start investing in options to keep your company viable.

Table 1: Old and New Economy Pivots

Company Name	Initial Business	Current Business
American Express	Started as express mail business in Buffalo New York 1850 with merger of Wells and Company and Livingston, Fargo and Company	Financial services corporation
Apple	Launched in 1976 they introduced the Apple I computer.	Sells computers, phones software and sundry electronics items
AT&T	Telephone company established in 1874 to protect Bell patent	Currently a voice, data and internet communications company
Blockbuster Video and Entertainment	Started in 1985 as a home movie and game rental business.	Company is non-existent. Casualty of Netflix and Redbox. Had an unsuccessful pivot to online rental.
Coca Cola	Launched in 1886 to combat morphine addiction. French Wine Coca made of coca, kola nut, and alcohol.	Multinational manufacturer, distributor, and retailer of beverages, concentrates and syrups.
DuPont	Launched as a gunpowder company in 1802.	Chemical company producing neoprene, nylon, Corian, Teflon, Mylar Kevlar, Tyvek, Lycra and refrigerants among others.
Facebook	Started in 2003 as Facemash it was used to compare the hotness of people pictures	Large social networking company
Flickr	Started in 2004 as a developer of MMORPG tools and migrated to a chat room with photo sharing	Video and photo hosting
IBM	Established in 1911 as Computer-Tabulating-Recording Company. Sold scales, time recorders, meat	Designs & manufactures hardware and software, and offers infrastructure, hostin

	and cheese slicers, tabulators and punched cards.	and consulting services for IT and emerging technologies.
Nike	Started in 1964 as Blue Ribbon Sports by when Phillip Knight distributed Tiger and Asics shoes out of his car.	Designer, manufacturer and distributor of sports footwear, apparel, equipment and sports services.
PayPal	Started in 1998 as Confinity a Palm Pilot and cryptography company	After merger with Elon Musk's X.com focused on money service
Pfizer	Established in 1849 and produced an anti-parasitic for expelling worms and citric acid as a flavoring and preservative	Multinational pharmaceutical.
Procter and Gamble	Launched in 1837. Sold soap and candles. Sold Pringles in 2009 and, Jif and Folgers around 2001	Multinational consumer goods company selling pet foods, cleaning agents, & personal care products.
Twitter	Launched in 2005 as a podcasting syndicate for audio and video content.	Large microblogging company
YouTube	Initially conceptualized in 2005 as a video version of online dating site.	Video sharing website

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Real options valuation

Real options valuation, also often termed **real options analysis**,[1] (**ROV** or **ROA**) applies option valuation techniques to capital budgeting decisions.[2] A **real option** itself, is the right—but not the obligation—to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting a capital investment project.[3] For example, real options valuation could examine the opportunity to invest in the expansion of a firm's factory and the alternative option to sell the factory.[4]

Scope

Real options are generally distinguished from conventional financial options in that they are not typically traded as securities, and do not usually involve decisions on an underlying asset that is traded as a financial security.[5] A further distinction is that option holders here, i.e. management, can directly influence the value of the option's underlying project; whereas this is not a consideration as regards the underlying security of a financial option. Moreover, management cannot measure uncertainty in terms of volatility, and must instead rely on their perceptions of uncertainty. Unlike financial options, management also have to create or discover real options, and such creation and discovery process comprises an entrepreneurial or business task. Real options are most valuable when uncertainty is high; management has significant flexibility to change the course of the project in a favorable direction and is willing to exercise the options.[6]

Real options analysis, as a discipline, extends from its application in corporate finance, to decision making under uncertainty in general, adapting the techniques developed for financial options to "real-life" decisions. For example, R&D managers can use Real Options Valuation to help them deal with various uncertainties in making decisions about the allocation of resources among R&D projects.[7][8][9][10] Non-business examples might be evaluating the cost of cryptocurrency mining machines,[11] or the decision to join the work force, or rather, to forgo several years of income to attend graduate school.[12] It, thus, forces decision makers to be explicit about the assumptions underlying their projections, and for this reason ROV is increasingly employed as a tool in business strategy formulation.[13][14][15] This extension of real options to real-world projects often requires customized decision support systems, because otherwise the complex compound real options will become too intractable to handle.[16]

Types of real options

Simple Examples

Investment

This simple example shows the relevance of the real option to delay investment and wait for further information, and is adapted from *"Investment Example"*.none.

Consider a firm that has the option to invest in a new factory. It can invest this year or next year. The question is: when should the firm invest? If the firm invests this year, it has an income stream earlier. But, if it invests next year, the firm obtains further information about the state of the economy, which can prevent it from investing with losses.

The firm knows its discounted cash flows if it invests this year: 5M. If it invests next year, the discounted cash flows are 6M with a 66.7% probability, and 3M with a 33.3% probability. Assuming a risk neutral rate of 10%, future discounted cash flows are, in present terms, 5.45M and 2.73M, respectively. The investment cost is 4M. If the firm invests next year, the present value of the investment cost is 3.63M.

Following the net present value rule for investment, the firm should invest this year because the discounted cash flows (5M) are greater than the investment costs (4M) by 1M. Yet, if the firm waits for next year, it only invests if discounted cash flows do not decrease. If discounted cash flows decrease to 3M, then investment is no longer profitable. If, they grow to 6M, then the firm invests. This implies that the firm invests next year with a 66.7% probability and earns 5.45M - 3.63M if it does invest. Thus the value to invest next year is 1.21M. Given that the value to invest next year exceeds the value to invest this year, the firm should wait for further information to prevent losses. This simple example shows how **the net present value may lead the firm to take unnecessary risk, which could be prevented by real options valuation.**

Staged Investment

Staged investments are quite often in the pharmaceutical, mineral, and oil industries. In this example, it is studied a staged investment abroad in which a firm decides whether to open one or two stores in a foreign country. This is adapted from *"Staged Investment Example"*.none.

The firm does not know how well its stores are accepted in a foreign country. If their stores have high demand, the discounted cash flows per store is 10M. If their stores have low demand, the discounted cash flows per store is 5M. Assuming that the probability of both events is 50%, the expected discounted cash flows per store is 7.5M. It is also known that if the store's demand is independent of the store: if one store has high demand, the other also has high demand. The risk neutral rate is 10%. The investment cost per store is 8M.

Should the firm invest in one store, two stores, or not invest? The net present value suggests the firm should not invest: the net present value is -0.5M per store. But is it the best alternative? Following real options valuation, it is not: the firm has the real option to open one store this year, wait a year to know its demand, and invest in the new store next year if demand is high.

By opening one store, the firm knows that the probability of high demand is 50%. The potential value gain to expand next year is thus 50%*(10M-8M)/1.1 = 0.91M. The value to open one store this year is 7.5M - 8M = -0.5. Thus the value of the real option to invest in one store, wait a year, and invest next year is 0.41M. Given this, the firm should opt by opening one store. This simple example shows that a **negative net present value does not imply that the firm should not invest.**

The flexibility available to management – i.e. the actual "real options" – generically, will relate to project size, project timing, and the operation of the project once established.[17] In all cases, any (non-recoverable) upfront expenditure related to this flexibility is the option premium. Real options are also commonly applied to stock valuation - see Business valuation § Option pricing approaches - as well as to various other "Applications" referenced below.

Options relating to project size

Where the project's scope is uncertain, flexibility as to the size of the relevant facilities is valuable, and constitutes optionality.[18]

- **Option to expand**: Here the project is built with capacity in excess of the expected level of output so that it can produce at higher rates if needed. Management then has the option (but not the obligation) to expand – i.e. exercise the option – should conditions turn out to be favourable. A project with the option to expand will cost more to establish, the excess being the option premium, but is worth more than the same without the possibility of expansion. This is equivalent to a call option.

- **Option to contract** : The project is engineered such that output can be contracted in future should conditions turn out to be unfavourable. Forgoing these future expenditures constitutes option exercise. This is the equivalent to a put option, and again, the excess upfront expenditure is the option premium.
- **Option to expand or contract**: Here the project is designed such that its operation can be dynamically turned on and off. Management may shut down part or all of the operation when conditions are unfavorable (a put option), and may restart operations when conditions improve (a call option). A flexible manufacturing system (FMS) is a good example of this type of option. This option is also known as a **Switching option**.

Options relating to project life and timing

Where there is uncertainty as to when, and how, business or other conditions will eventuate, flexibility as to the timing of the relevant project(s) is valuable, and constitutes optionality.

- **Growth options**: perhaps the most generic in this category – these entail the call option to exercise only those projects that appear to be profitable at the time of initiation.
- **Initiation or deferment options**: Here management has flexibility as to when to start a project. For example, in natural resource exploration a firm can delay mining a deposit until market conditions are favorable. This constitutes an American styled call option.
- **Delay option with a product patent**: A firm with a patent right on a product has a right to develop and market the product exclusively until the expiration of the patent. The firm will market and develop the product only if the present value of the expected cash flows from the

product sales exceeds the cost of development. If this does not occur, the firm can shelve the patent and not incur any further costs.

- **Option to abandon**: Management may have the option to cease a project during its life, and, possibly, to realise its salvage value. Here, when the present value of the remaining cash flows falls below the liquidation value, the asset may be sold, and this act is effectively the exercising of a put option. This option is also known as a **Termination option**. Abandonment options are American styled.
- **Sequencing options**: This option is related to the initiation option above, although entails flexibility as to the timing of more than one inter-related projects: the analysis here is as to whether it is advantageous to implement these sequentially or in parallel. Here, observing the outcomes relating to the first project, the firm can resolve some of the uncertainty relating to the venture overall. Once resolved, management has the option to proceed or not with the development of the other projects. If taken in parallel, management would have already spent the resources and the value of the option not to spend them is lost. The sequencing of projects is an important issue in corporate strategy. Related here is also the notion of Intraproject vs. Interproject options.

Options relating to project operation

Management may have flexibility relating to the product produced and /or the process used in manufacture. As in the preceding cases, this flexibility increases the value of the project, corresponding in turn, to the "premium" paid for the real option.

- **Output mix options**: The option to produce different outputs from the same facility is known as an output mix option or **product flexibility**. These options are particularly valuable in industries where demand is volatile or where quantities demanded in total for a particular good are typically low, and management would wish to change to a different product quickly if required.

- **Input mix options**: An input mix option – **process flexibility** – allows management to use different inputs to produce the same output as appropriate. For example, a farmer will value the option to switch between various feed sources, preferring to use the cheapest acceptable alternative. An electric utility, for example, may have the option to switch between various fuel sources to produce electricity, and therefore a flexible plant, although more expensive may actually be more valuable.
- **Operating scale options**: Management may have the option to change the output rate per unit of time or to change the total length of production run time, for example in response to market conditions. These options are also known as **Intensity options**.

Valuation

Given the above, it is clear that there is an analogy between real options and financial options,[19] and we would therefore expect options-based modelling and analysis to be applied here. At the same time, it is nevertheless important to understand why the more standard valuation techniques may not be applicable for ROV.[2]

Applicability of standard techniques

ROV is often contrasted with more standard techniques of capital budgeting, such as discounted cash flow (DCF) analysis / net present value (NPV).[2] Under this "standard" NPV approach, future expected cash flows are present valued under the empirical probability measure at a discount rate that reflects the embedded risk in the project; see CAPM, APT, WACC. Here, only the expected cash flows are considered, and the "flexibility" to alter corporate strategy in view of actual market realizations is "ignored"; see below as well as Corporate finance § Valuing flexibility. The NPV framework (implicitly) assumes that management is "passive" with regard to their Capital Investment once committed. Some analysts account for this uncertainty by (i) adjusting the discount rate, e.g. by increasing the cost of capital, or (ii) adjusting the cash flows, e.g. using certainty equivalents, or (iii) applying (subjective) "haircuts" to the forecast numbers, or (iv) via probability-weighting these as in rNPV. [20] [21] [22] Even when employed, however, these latter methods do not normally properly account for changes in risk over the project's lifecycle and hence fail to appropriately adapt the risk adjustment. [23] [24]

By contrast, ROV assumes that management is "active" and can "continuously" respond to market changes. Real options consider "all" scenarios (or "states") and indicate the best corporate action in each of these contingent events.[25] Because management adapts to each negative outcome by decreasing its exposure and to positive scenarios by scaling up, the firm benefits from uncertainty in the underlying market, achieving a lower variability of profits than under the commitment/NPV stance. The contingent nature of future profits in real option models is captured by employing the techniques developed for financial options in the literature on contingent claims analysis. Here the approach, known as risk-neutral valuation, consists in adjusting the probability distribution for risk consideration, while discounting at the risk-free rate. This technique is also known as the "martingale" approach, and uses a risk-neutral measure. For technical considerations here, see below. For related discussion – and graphical representation – see Datar–Mathews method for real option valuation.

Given these different treatments, the real options value of a project is typically higher than the NPV – and the difference will be most marked in projects with major flexibility, contingency, and volatility.[26] As for financial options higher volatility of the underlying leads to higher value. (An application of Real Options Valuation in the Philippine banking industry exhibited that increased levels of income volatility may adversely affect option values on the loan portfolio, when the presence of information asymmetry is considered. In this case, increased volatility may limit the value of an option.[27]) Part of the criticism (and subsequently slow adoption) of Real Options Valuation in practice and academe stems from the generally higher values for underlying assets these functions generate. However, studies have shown that these models are reliable estimators of underlying asset value, when input values are properly identified.[28]

Options based valuation

Although there is much similarity between the modelling of real options and financial options,[19][29] ROV is distinguished from the latter, in that it takes into account uncertainty about the future evolution of the parameters that determine the value of the project, *coupled with* management's ability to respond to the evolution of these parameters.[30][31] It is the combined effect of these that makes ROV technically more challenging than its alternatives.

> First, you must figure out the full range of possible values for the underlying asset.... This involves estimating what the asset's value would be if it existed today and forecasting to see the full set of possible future values... [These] calculations provide you with numbers for all the possible future values of the option at the various points where a decision is needed on whether to continue with the project...[29]

When valuing the real option, the analyst must therefore consider the inputs to the valuation, the valuation method employed, and whether any technical limitations may apply. Conceptually, valuing a real option looks at the premium between inflows and outlays for a particular project. Inputs to the value of a real option (time, discount rates, volatility, cash inflows and outflows) are each affected by the terms of business, and external environmental factors that a project exists in. Terms of business as information regarding ownership, data collection costs, and patents, are formed in relation to political, environmental, socio-cultural, technological, environmental and legal factors that affect an industry. Just as terms of business are affected by external environmental factors, these same circumstances affect the volatility of returns, as well as the discount rate (as firm or project specific risk). Furthermore, the external environmental influences that affect an industry affect projections on expected inflows and outlays.[32]

Valuation inputs

Given the similarity in valuation approach, the inputs required for modelling the real option correspond, generically, to those required for a financial option valuation.[19][29][30][33] The specific application, though, is as follows:

- The option's underlying is the project in question – it is modelled in terms of:
    - Spot price: the starting or current value of the project is required: this is usually based on management's "best guess" as to the gross value of the project's cash flows and resultant NPV;
    - Volatility: a measure for uncertainty as to the change in value over time is required:
        - the volatility in project value is generally used, usually derived via monte carlo simulation;[30][34] sometimes the volatility of the first period's cash flows are preferred;[31] see further under Corporate finance for a discussion relating to the estimation of NPV and project volatility.
        - some analysts substitute a listed security as a proxy, using either its price volatility (historical volatility), or, if options exist on this security, their implied volatility.[1]
    - Dividends generated by the underlying asset: As part of a project, the dividend equates to any income which could be derived from the real assets and paid to the owner. These reduce the appreciation of the asset.

- Option characteristics:
  - Strike price: this corresponds to any (non-recoverable) investment outlays, typically the prospective costs of the project. In general, management would proceed (i.e. the option would be in the money) given that the present value of expected cash flows exceeds this amount;
  - Option term: the time during which management may decide to act, or not act, corresponds to the life of the option. As above, examples include the time to expiry of a patent, or of the mineral rights for a new mine. See Option time value. Note though that given the flexibility related to timing as described, caution must be applied here.
  - Option style and option exercise. Management's ability to respond to changes in value is modeled at each decision point as a series of options, as above these may comprise, i.a.:
    - the option to contract the project (an American styled put option);
    - the option to abandon the project (also an American put);
    - the option to expand or extend the project (both American styled call options);
    - switching options or composite options which may also apply to the project.

Valuation methods

The valuation methods usually employed, likewise, are adapted from techniques developed for valuing financial options.[35][36] Note though that, in general, while most "real" problems allow for American style exercise at any point (many points) in the project's life and are impacted by multiple underlying variables, the standard methods are limited either with regard to dimensionality, to early exercise, or to both. In selecting a model, therefore, analysts must make a trade off between these considerations; see Option (finance) § Model implementation. The model must also be flexible enough to allow for the relevant decision rule to be coded appropriately at each decision point.

- Closed form, Black–Scholes-like solutions are sometimes employed.[31] These are applicable only for European styled options or perpetual American options. Note that this application of Black–Scholes assumes constant — i.e. deterministic — costs: in cases where the project's costs, like its revenue, are also assumed stochastic, then Margrabe's formula can (should) be applied instead,[37][38] here valuing the option to "exchange" expenses for revenue. (Relatedly, where the project is exposed to two (or more) uncertainties — e.g. for natural resources, price and quantity — some analysts attempt to use an overall volatility; this, though, is more correctly treated as a rainbow option,[31] typically valued using simulation as below.)
- The most commonly employed methods are binomial lattices.[26][36] These are more widely used given that most real options are American styled. Additionally, and particularly, lattice-based models allow for flexibility as to exercise, where the relevant, and differing, rules may be encoded at each node.[29] Note that lattices cannot readily handle high-dimensional problems; treating the project's costs as stochastic would add (at least) one dimension to the lattice, increasing the number of ending-nodes by the square (the exponent here, corresponding to the number of sources of uncertainty).
- Specialised Monte Carlo Methods have also been developed and are increasingly, and especially, applied to high-dimensional problems.[39] Note that for American styled real options, this application is somewhat more complex; although recent research[40] combines a least squares approach with simulation, allowing for the valuation of real options which are both multidimensional and American styled; see Monte Carlo methods for option pricing § Least Square Monte Carlo.
- When the Real Option can be modelled using a partial differential equation, then Finite difference methods for option pricing are

sometimes applied. Although many of the early ROV articles discussed this method,[41] its use is relatively uncommon today—particularly amongst practitioners—due to the required mathematical sophistication; these too cannot readily be used for high-dimensional problems.

Various other methods, aimed mainly at practitioners, have been developed for real option valuation.[3] These typically use cash-flow scenarios for the projection of the future pay-off distribution, and are not based on restricting assumptions similar to those that underlie the closed form (or even numeric) solutions discussed. Recent additions include the Datar–Mathews method (which can be understood as an extension of the net present value multi-scenario Monte Carlo model with an adjustment for risk aversion and economic decision-making),[42][43] the fuzzy pay-off method,[44] and the simulation with optimized exercise thresholds method.[3]

Other methods focus on real option valuation in engineering design.[45][46] They help quantify the value of flexibility engineered early on in system designs and/or irreversible investment projects. The methods help rank order flexible design solutions relative to one another, and thus enable the best real option strategies to be exercised cost effectively during operations. Example methods include real options analysis based on decision rules,[47][48] which merge physical design considerations and management decisions through an intuitive "if-then-else" statement e.g., *if* demand is higher than a certain production capacity level, *then* expand existing capacity, *else* do nothing. This approach can be combined with advanced mathematical optimization methods like stochastic programming and robust optimisation to find the optimal design and decision rule variables. A more recent approach reformulates the real option problem as a data-driven Markov decision process,[49][50] and uses advanced machine learning like deep reinforcement learning to evaluate a wide range of possible real option and design implementation strategies, well suited for complex systems and investment projects. These methods have been applied in many use cases in aerospace, defense, energy, transport, space, and water infrastructure design and planning.[51]

Limitations

The relevance of Real options, even as a thought framework, may be limited due to market, organizational and / or technical considerations.[52] When the framework is employed, therefore, the analyst must first ensure that ROV is relevant to the project in question. These considerations are as follows.

Market characteristics

As discussed above, the market and environment underlying the project must be one where "change is most evident", and the "source, trends and evolution" in product demand and supply, create the "flexibility, contingency, and volatility" [26] which result in optionality. Without this, the NPV framework would be more relevant.

Organizational considerations

Real options are "particularly important for businesses with a few key characteristics",[26] and may be less relevant otherwise.[31] In overview, it is important to consider the following in determining that the RO framework is applicable:

1. Corporate strategy has to be adaptive to contingent events. Some corporations face organizational rigidities and are unable to react to market changes; in this case, the NPV approach is appropriate.
2. Practically, the business must be positioned such that it has appropriate information flow, and opportunities to act. This will often be a market leader and / or a firm enjoying economies of scale and scope.
3. Management must understand options, be able to identify and create

them, and appropriately exercise them.[16] This contrasts with business leaders focused on maintaining the status quo and / or near-term accounting earnings.

4. The financial position of the business must be such that it has the ability to fund the project as, and when, required (i.e. issue shares, absorb further debt and / or use internally generated cash flow); see Financial statement analysis. Management must, correspondingly, have appropriate access to this capital.
5. Management must be in the position to exercise, in so far as some real options are proprietary (owned or exercisable by a single individual or a company) while others are shared (can (only) be exercised by many parties).

Technical considerations

Limitations as to the use of these models arise due to the contrast between Real Options and financial options, for which these were originally developed. [53] The main difference is that the underlying is often not tradable – e.g. the factory owner cannot easily sell the factory upon which he has the option. Additionally, the real option itself may also not be tradeable – e.g. the factory owner cannot sell the right to extend his factory to another party, only he can make this decision (some real options, however, can be sold, e.g., ownership of a vacant lot of land is a real option to develop that land in the future). Even where a market exists – for the underlying or for the option – in most cases there is limited (or no) market liquidity. Finally, even if the firm can actively adapt to market changes, it remains to determine the right paradigm to discount future claims

The difficulties, are then:

1. As above, data issues arise as far as estimating key model inputs. Here, since the value or price of the underlying cannot be (directly) observed, there will always be some (much) uncertainty as to its value

(i.e. spot price) and volatility (further complicated by uncertainty as to management's actions in the future).

2. It is often difficult to capture the rules relating to exercise, and consequent actions by management. Further, a project may have a portfolio of embedded real options, some of which may be mutually exclusive.[16]
3. Theoretical difficulties, which are more serious, may also arise.[54]

    - Option pricing models are built on rational pricing logic. Here, essentially: (a) it is presupposed that one can create a "hedged portfolio" comprising one option and "delta" shares of the underlying. (b) Arbitrage arguments then allow for the option's price to be estimated today; see Rational pricing § Delta hedging. (c) When hedging of this sort is possible, since delta hedging and risk neutral pricing are *mathematically* identical, then risk neutral valuation may be applied, as is the case with most option pricing models. (d) Under ROV however,[33] the option and (usually) its underlying are clearly not traded, and forming a hedging portfolio would be difficult, if not impossible.
    - Standard option models: (a) Assume that the risk characteristics of the underlying do not change over the life of the option, usually expressed via a constant volatility assumption. (b) Hence a standard, risk free rate may be applied as the discount rate at each decision point, allowing for risk neutral valuation. Under ROV, however: (a) managements' actions actually change the risk characteristics of the project in question, and hence (b) the Required rate of return could differ depending on what state was realised, and a premium over risk free would be required, invalidating (technically) the risk neutrality assumption.

These issues are addressed via several interrelated assumptions:

1. As discussed above, the data issues are usually addressed using a simulation of the project, or a listed proxy. Various new methods – see for example those described above – also address these issues.
2. Also as above, specific exercise rules can often be accommodated by coding these in a bespoke binomial tree; see:.[29]
3. The theoretical issues:

    - To use standard option pricing models here, despite the difficulties relating to rational pricing, practitioners adopt the "fiction" that the real option and the underlying project are both traded: the so called, Marketed Asset Disclaimer (MAD) approach. Although this is a strong assumption, it is pointed out that a similar fiction in fact underpins standard NPV / DCF valuation (and using simulation as above). See:[1] and.[29]
    - To address the fact that changing characteristics invalidate the use of a constant discount rate, some analysts use the "replicating portfolio approach", as opposed to Risk neutral valuation, and modify their models correspondingly.[29][38] Under this approach, (a) we "replicate" the cash flows on the option by holding a risk free bond and the underlying in the correct proportions. Then, (b) since the cash flows of the option and the portfolio will *always* be identical, by arbitrage arguments their values may (must) be equated *today*, and (c) *no* discounting is required. (For an alternative, modifying Black-Scholes, see: [33].)

History

Whereas business managers have been making capital investment decisions for centuries, the term "real option" is relatively new, and was coined by Professor Stewart Myers of the MIT Sloan School of Management in 1977. In 1930, Irving Fisher wrote explicitly of the "options" available to a business owner (*The Theory of Interest*, II.VIII). The description of such opportunities as "real options", however, followed on the development of analytical techniques for financial options, such as Black–Scholes in 1973. As such, the term "real option" is closely tied to these option methods.

Real options are today an active field of academic research. Professor Lenos Trigeorgis has been a leading name for many years, publishing several influential books and academic articles. Other pioneering academics in the field include Professors Michael Brennan, Eduardo Schwartz, Avinash Dixit and Robert Pindyck (the latter two, authoring the pioneering text in the discipline). An academic conference on real options is organized yearly (Annual International Conference on Real Options).

Amongst others, the concept was "popularized" by Michael J. Mauboussin, then chief U.S. investment strategist for Credit Suisse First Boston.[26] He uses real options to explain the gap between how the stock market prices some businesses and the "intrinsic value" for those businesses. Trigeorgis also has broadened exposure to real options through layman articles in publications such as The Wall Street Journal.[25] This popularization is such that ROV is now a standard offering in postgraduate finance degrees, and often, even in MBA curricula at many Business Schools.

Recently, real options have been employed in business strategy, both for valuation purposes and as a conceptual framework.[13][14] The idea of treating strategic investments as options was popularized by Timothy Luehrman[55] in two HBR articles:[19] "In financial terms, a business strategy is much more like a series of options, than a series of static cash flows". Investment opportunities are plotted in an "option space" with dimensions "volatility" & value-to-cost ("NPVq").

Luehrman also co-authored with William Teichner a Harvard Business School case study, *Arundel Partners: The Sequel Project*, in 1992, which may have been the first business school case study to teach ROV.[56] Reflecting the "mainstreaming" of ROV, Professor Robert C. Merton discussed the essential points of Arundel in his Nobel Prize Lecture in 1997.[57] Arundel involves a group of investors that is considering acquiring the sequel rights to a portfolio of yet-to-be released feature films. In particular, the investors must determine the value of the sequel rights before any of the first films are produced. Here, the investors face two main choices. They can produce an original movie and sequel at the same time *or* they can wait to decide on a sequel after the original film is released. The second approach, he states, provides the option *not* to make a sequel in the event the original movie is not successful. This real option has economic worth and can be valued monetarily using an option-pricing model. See Option (filmmaking).

See also

- Option contract
- Opportunity cost
- Monte Carlo methods in finance
- Contingent claim valuation
- Fuzzy pay-off method for real option valuation
- Datar–Mathews method for real option valuation
- Business valuation § Option pricing approaches
- Corporate finance § Valuing flexibility
- Government procurement in the United States § Real options analysis
- Principal–agent problem § Options framework
- Patent valuation § Option-based method
- Contingent value rights
- Present value of growth opportunities
- Volume risk

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Corporate finance and **investment banking**	
Capital structure	- Convertible debt - Exchangeable debt - Mezzanine debt - Pari passu - Preferred equity - Second lien debt - Senior debt - Senior secured debt - Shareholder loan

	• Stock • Subordinated debt • Warrant	
Transactions (terms/conditions)	**Equity offerings**	• At-the-market offering • Book building • Bookrunner • Bought deal • Bought out deal • Corporate spin-off • Direct public offering • Equity carve-out • Follow-on offering • Greenshoe ◦ Reverse • Initial public offering • Pre-IPO • Private placement • Public offering • Rights issue • Seasoned equity offering • Secondary market offering • Underwriting
	Mergers and acquisitions	• Buy side • Contingent value rights • Control premium • Demerger • Divestment • Drag-along right • Management due diligence • Managerial entrenchment • Mandatory offer • Minority discount • Pitch book • Pre-emption right • Proxy fight • Post-merger integration • Sell side • Shareholder rights plan • Special-purpose entity • Special situation

		• Squeeze-out • Staggered board of directors • Stock swap • Super-majority amendment • Synergy • Tag-along right • Takeover ◦ Reverse • Tender offer
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Valuation	• Accretion/dilution analysis
	• Adjusted present value
	• Associate company
	• Business valuation
	• Conglomerate discount
	• Cost of capital
	    ◦ Weighted average
	• Discounted cash flow
	• Economic value added
	• Enterprise value
	• Fairness opinion
	• Financial modeling
	• Free cash flow
	    ◦ Free cash flow to equity
	• Market value added
	• Minority interest
	• Mismarking
	• Modigliani–Miller theorem
	• Net present value
	• Pure play
	• Real options	

- Residual income
- Stock valuation
- Sum-of-the-parts analysis
- Tax shield
- Terminal value
- Valuation using multiples

- List of investment banks
- Outline of finance

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Derivatives market

Derivative (finance)

Terms	Delta neutral Exercise Expiration Moneyness Open interest Pin risk Risk-free interest rate Strike price Synthetic position the Greeks Volatility
Vanillas	American Bond option Call Employee stock option European Fixed income FX Option styles Put Warrants
	Asian Barrier

Options	**Exotics**	• Basket • Binary • Callable bull/bear contract • Chooser • Cliquet • Commodore • Compound • Forward start • Interest rate • Lookback • Mountain range • Rainbow • Spread • Swaption
	Strategies	• Backspread • Box spread • Butterfly • Calendar spread • Collar • Condor • Covered option • Credit spread • Debit spread • Diagonal spread • Fence • Intermarket spread • Iron butterfly • Iron condor • Jelly roll • Ladder • Naked option • Straddle • Strangle • Protective option • Ratio spread • Risk reversal • Vertical spread (Bear, Bull)
		• Bachelier • Binomial • Black

	Valuation	• Black–Scholes (equation) • Finite difference • Garman–Kohlhagen • Heston • Lattices • Margrabe • Put–call parity • MC Simulation • Real options • Trinomial • Vanna–Volga
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	• Contango • Commodities future • Currency future • Dividend future • Forward market • Forward price • Forwards pricing	

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Market issues	• Consumer debt • Corporate debt • Government debt • Great Recession • Municipal debt • Tax policy
• Business portal	

An entrepreneur's dilemma: An optimal stopping rule in pivoting

Though pivoting is widely practiced by entrepreneurs, an optimal stopping rule in pivoting remains unexplored. Proposing an optimal foraging model and accounting for competition in exploiting an opportunity, we identify an optimal stopping rule of 30% gain-to-loss ratio. That is, additional gains are less feasible when 70% of the pivoting across future plausible versions of opportunities are traversed to. The findings have practical implications for entrepreneurs.

1 INTRODUCTION

Can an entrepreneur use an optimal stopping rule in pivoting to newer versions of their current opportunity? Pivoting in startups refers to a "structured course correction designed to test a new fundamental hypothesis about the product, strategy, and engine of growth" (Ries, , p. 149). As evaluations, interpretations, and feedback emerge from an entrepreneur's interaction with the environment, pivoting forms the mainstay of honing a startup's value proposition. Yet, a pivoter's dilemma emerges as entrepreneurs must manage the potential for gains from refining a business opportunity against the risk of loss of limited resources through experimentation, antagonized stakeholders, and reduced legitimacy (Hampel et al.,). As such, the *extent* of pivoting is an important decision for entrepreneurs. With competing vantage points of the ontological worlds in research on entrepreneurial opportunity (Wright & Phan,), our results inform the elements of search and stopping points; similar to the secretary problem (Freeman,), for entrepreneurs. We build on pivoting, a widely used practitioner method, and ask at what point do entrepreneurs stop pivoting across current versions of their opportunity?

In developing their opportunity through entrepreneurial action, entrepreneurs must traverse through a series of potential value creation motifs. During stages of pivoting, entrepreneurs engage in the stay–search–move–adapt cycles—staying in the current version of the opportunity, searching for alternate states to move to, and then adapting. The processes of scouting and assessment of potential loci of possible states to pivot into, allocating recombining, and committing resources to realize change occurs through a series of pivots. How many motifs an entrepreneur must traverse in developing their venture in uncertain and risky environments could be informative. The optimal foraging theory lens allows us to take a holistic view of pivoting journeys of ventures and attempts to delve deeper into the entrepreneurial strategy framework (Gans et al.,) as entrepreneurs attempt to "change in strategy without a change in vision" (Ries,).

To formally develop a model on the optimal stopping point rule for pivoting, we draw on the emerging entrepreneurial pivoting literature (Chaparro & de Vasconcelos Gomes,), literature on optimal stopping point rules (Shiryaev,), and from the optimal foraging model from ecology (Babcock et al., ; Pyke, ; Stephens,). The process of pivoting in startups is akin to optimal foraging—continuing with the current version of the opportunity versus expending energy and resources to pivoting and transitioning to a newer version of opportunity (McNamara & Houston, ; Pyke et al.,). An optimal stopping point in pivoting is especially informative for entrepreneurs making boundedly rational choices in a series of testing and value creation choices. As such, the pivoting process is rooted in a series of sequential steps requiring "foraging" in the quest for value creation in a rugged fitness landscape (Levinthal,). Though reaching the global optimum in rugged landscapes is not feasible through pivoting, understanding an optimal stopping point in the search process to forage through value-creating stages of an opportunity could be important. As entrepreneurs try to be persistent or flexible in pivoting (Crilly,), the optimal stopping rule can be useful under bounded rationality, biases, and fixations with either too much or too little pivoting. Optimal stopping in pivoting adds nuance to the "fail fast and fail cheap" lean startup philosophy by informing entrepreneurs to “fail fast, fail cheap, and stop optimally.” Though an “optimal” stopping point seems counterintuitive under uncertainty (Gans et al.,), optimal stopping point rules (e.g., secretary problem, or the 1/*e* rule) have received significant support in the literature on decision making under uncertainty (Boyarchenko & Levendorskii, ; Hill, ; Ke & Villas-Boas, ; Shiryaev,).

The results show that when the gain-to-loss ratio declines below 30%, entrepreneurs must stop exploiting the current version of opportunity or pivoting from the future versions of the current opportunity. In other words, when about 70% of the improvements in exploiting the current version or pivoting to future versions are achieved, additional gains are less likely. The proposed framework aims to inform the practice of entrepreneurship and complements theoretical frameworks on entrepreneurial opportunities. Exploring the possibility of an optimal stopping point in pivoting is important for the following reasons.

First, the pivoting dilemma is indirectly supported in studies finding mixed support for pivoting (Chaparro & de Vasconcelos Gomes,). Yet, practitioners widely consider pivoting as a “way of venturing” or a process that entrepreneurs must embed in their venture development process. As such, pivoting requires assessment and adaptation to “a sequence of individual and collective events, actions, and activities unfolding over time in context” of startups refining their value propositions (Pettigrew, , p. 338). Entrepreneurial action under uncertainty, therefore, could be further informed by understanding an optimal stopping point in pivoting. During their early years when ventures are in a fluid state (Bahrami & Evans,) with constant changes across multiple dimensions of a venture, an optimal foraging framework could help provide a mode of thinking in managing the pivoting dilemma for entrepreneurs.

Second, time constraints in pivoting over time are rarely discussed. An optimal stopping point in pivoting is an important consideration for entrepreneurs who also have temporal commitments, that is envisioning timelines and facing stakeholder demands to complete venturing tasks within an expected timeframe (e.g., Kickstarter delivery times, or investors' venture exit preferences) (Berends et al.,). While technology, product, or market changes drive pivoting (Kirtley & O'Mahony,), the intertemporal pivoting decisions require search, resource commitment, and adaptation under a closing window of opportunity. As such, pivoting must be temporally bounded and therefore optimal stopping rules could be of interest to entrepreneurs persevering and pivoting in developing ventures within desired time frames. The optimal foraging framework helps move from the event and process of a single pivot to considering the multitemporal process of pivoting.

Third, our framework is agnostic to the school of thought on opportunities. Entrepreneurial opportunity remains an illusive construct (Dimov,). Over the past two decades, the literature on entrepreneurial opportunity represents a complex tapestry of levels of analysis and modes of opportunity identification (Ramoglou & Tsang,). Entrepreneurs search (Fiet,), discover (Foss & Klein, ; Kirzner,), create (Alvarez & Barney,), or develop (Foss & Klein,) opportunities. Based on a recent symposium on “opportunity wars” by Wright and Phan (), in the past two decades, there has been a growing debate around the construct of opportunity. Centered around the notion of whether opportunities are created or discovered, our framework based on pivoting is closer to the notion in Davidsson et al. () who discuss the role of the dynamic agency-centered view that is related to the elements of pivoting—a process of a combination of characteristics, roles, and mechanisms that drive the development of an opportunity. Others have argued that the construct of opportunity must be abandoned (Foss & Klein,) because the very nature of opportunity is in the realm of uncertainty and it can only be identified in the absence of uncertainty. The judgment-based view of opportunity offered by Foss and Klein () focuses on the role of beliefs, actions, and results that drive entrepreneurial action. Dimov () highlights the divergent meanings of the construct rooted in competing for theoretical frameworks or epistemological inclinations. Despite the debates on the construct of opportunity, Alvarez and Barney () highlight the value of continuing theoretical discourse on an opportunity to further enrich our understanding of the construct of opportunity. Instead, our focus is on the practice of pivoting in opportunity development over time. Opportunities are seldom available as Kirznerian arbitrage opportunities. Whether opportunities are created, discovered, or searched for, entrepreneurs invariably change their opportunities, a practice known as pivoting.

In the next section, we discuss the theoretical background on pivoting and optimal foraging theory. Thereafter, we propose our formal model and finally conclude with implications of our findings.

2 PIVOTING AND OPTIMAL FORAGING THEORY

With its roots in critical realism (Bhaskar, , ; Ramoglou & Tsang,), throughout venture development versions of an opportunity are identified, developed, and abandoned (cf. Levinthal,). Starting with an entrepreneurial idea where an entrepreneur imagines a future venture as a combination of resources, people, and place, the early-stage ideas must morph in the face of uncertainty through entrepreneurial action under uncertainty (Knight,). The confluence of technology, customers, place, and time provides a testing bed for the viability of an early version of an opportunity. When facing unknown unknowns, choosing a version of a viable opportunity remains a challenge for entrepreneurs, and as the viability is tested in the environment and in concert with stakeholders, the variances in the value of a version of the opportunity are revealed through pivoting (Gans et al.,).

Pivoting in a lean startup is rooted in a hypothesis testing-based approach where entrepreneurs facing high levels of uncertainty and ambiguity engage in sequential hypothesis testing to develop and adapt their minimum viable product. Lean startup framework is also preceded by the agile framework in software development (Bortolini et al.,) or disciplined entrepreneurship (Aulet,). As a systematic process of testing value propositions continuously, pivoting forms the basis of testing and implementing changes in short cycles to fuel scaling efforts. Pivoting ranges from strategic change (Kirtley & O'Mahony, ; McDonald & Gao,) to adapting business ideas (Berends et al.,). Based on a recent literature review of the entrepreneurial pivoting literature (Chaparro & de Vasconcelos Gomes,), pivoting can be classified as transformation or modification, a strategic decision, correction, and a process or event. Transformation or modification in idea, concept, business model, or hypothesis of value propositions aims towards making significant changes to improve the value proposition. Others refer to pivoting as a change in strategic decisions that lead to strategic change and commitments to improve survival and growth odds (Hampel et al., ; Pillai et al.,). Much pivoting in practice refers to correction in the course of action through hypothesis testing and corrections as entrepreneurs test, exclude and replace ideas (Teece & Linden,). Others consider the practice of pivoting as a process that is a temporally bounded staged-based process (Berends et al.,).

A pivoter's dilemma is rooted in the benefits and costs of pivoting. On the one hand, feedback and newer information realized through entrepreneurial action offer opportunities to reevaluate whether current offerings and configurations must be revised, discontinued, or replaced. However, pivoting also comes at a cost. Entrepreneurs may face identity conflict and face relational constraints in pivoting and may be more reluctant to test their strategies (Hampel et al., ; Leatherbee & Katila,). Pivoting can lead to a loss of legitimacy and support (Zott & Huy,). On the other hand, pivoting also facilitates necessary learning and informs decision-making under resource constraints. Related works on learning and practice in entrepreneurship call for development and adaptation to overcome inertia and pursue iterative experimentation to improve venturing outcomes. Pivoting presents an important mode to help entrepreneurs test their value creation hypotheses to better leverage their resources to realize means and ends (Contigiani & Levinthal,). Identifying an optimal stopping rule for pivoting in startups could help answer—at what point do entrepreneurs stop pivoting? As an intertemporal process of change, we next discuss optimal foraging theory, distinguish it from other related theories, and present a framework of optimal foraging in the context of pivoting.

2.1 Optimal foraging theory and entrepreneurs

To devise an understanding of an optimal stopping point in pivoting, we draw on optimal foraging theory (OFT). OFT proposes that "animals forage in ways such that some currency, such as net rate of energy intake, could not be improved with an alternative strategy" (Pyke, ; Pyke & Starr,). Though optimal foraging theory is rooted in ecology, its parallels with pivoting a noteworthy.

Table 1 provides the parallels between optimal foraging in ecology and its analogy for venturing. We distinguish optimal foraging from related theories on real options, information sampling, and multiarmed bandit problem in Table 2. As illustrated in Step 1 in Figure 1, similar to foragers who conserve energy in the search for one patch to the other, considering the trajectory of the lean startup process, entrepreneurs must also pivot from the current patch (or, the current value proposition) that may be deteriorating or declining to move to another version of value proposition (or, a patch). Based on earlier discussion on pivoter's dilemma, we consider foraging in entrepreneurial context as a process where entrepreneurs "forage" through versions of value propositions of their opportunities so that currency, or that net resource intake, is not negative.

TABLE 1. Optimal foraging theory and pivoting in entrepreneurship

	Foragers	Entrepreneurs
Definition	Optimal foraging refers to "animals forage in ways such that some currency, such as net rate of energy intake, could not be improved with an alternative	Entrepreneurs "forage" through versions of value propositions of an opportunity such that that net resource intake in pivoting is not negative.

	strategy" (Pyke, 1984; Pyke & Starr, 2020)	
Patch	The temporal and spatial nature in which resources (e.g., food) are concentrated.	The current combination of resources and relationships in time and space supports the current value proposition of a venture.
Steps	As the current forage depletes, search *and* travel to the next forage	As entrepreneurs realize their current value proposition is limited, they must search for an alternate mode of value creation (e.g., through incremental hypothesis testing) and reconfigure their venture by expanding resources to "travel" to the newer state of their venture.
Searching time	Energy expended to search for newer patches	Resources and relationships leveraged to identify newer value propositions through hypothesis testing
Travel time	Shorter (longer) travel times to patches expends lesser (more) energy.	Incremental (longer) pivoting to newer value propositions expends lesser (more) relationships and resources, increasing the chances of failure.
Currency	A unit optimized by the organism (e.g., net energy intake in a unit time)	Ensuring survival to experiment with versions of value propositions of an uncertainty
Constraints	Environmental, physiological, learning, and memory constraints that limit foraging efficiency	Environmental, stakeholder, learning, and cognitive constraints that limit experimentation necessary to improve value proposition over time
Goals	Search for food while conserving energy to ensure survival, development, and reproduction	Search for value-creating states of a venture while conserving resources to maintain odds of survival.
	Choice of patch or habitat; choice of food items in a habitat; when to leave the	The decision to continue with the current value proposition of a venture; elements of value proposition to focus on (e.g., elements of a business model

Decisions	current patch; and how to change location within and across the patch (Pyke & Starr, 2020).	canvass most critical to success); whether to pivot; and how to change the existing configuration of resources and relationships to move to a newer value proposition.

TABLE 2. Distinctions among optimal foraging theory, real options, information sampling, and multiarmed bandit models

	Optimal foraging theory	**Real options**	**Information sampling**	**Multi bandit**
Definition	Maintaining net positive rate of value proposition in irreversibly moving from one patch to the next.	Making a smaller initial investment with an option to “exercise” a future opportunity.	A deliberative process of collecting information before committing to the next option.	Explore trade-c simulta or sequ pursuir (exploit versus unknov (explor options maximi payoffs
Normative goal	The decision to stay in the current patch has a larger initial expected value but a decreasing future expected value or traveling to a new patch, an action for which the initial expected value is zero but the future expected	Lower the ex ante risk by not committing to a course of action by ex ante paying a smaller “option” premium (less than the value of the underlying opportunity) in form of investment.	The explicit trade-off is set up between sampling for more information again (the action value for which is driven by the future expected value and cost of sampling) vs. going with the current option based	Choosi explora option expect smaller future e value m higher) overexp option.

	value is larger.		on having enough information samples.	
Managing uncertainty	Eliciting information through experimentation	A go or no-go response as information is revealed	Works in low uncertainty, and information-rich environment where sampling is possible	By con both explora exploita maximi future e value ir uncerta environ
Applications in entrepreneurship	Lean startup where entrepreneurs sequentially move through stages of opportunity development to improve the value proposition.	Fail-forward approaches to entrepreneurial decision making	In more information-rich and less uncertain environments such as venture capital stage of investment or conducting due diligence.	When t venture relative establis such th option exploit current creatin opportu where a venture more experie shifting to a mo uncerta high po value opportu
Stage of the entrepreneurial process	Early stages of opportunity development	Generally, the venture is more established when it operates in more stable environments to develop real options.	Discrete decision tasks in more information-rich and low uncertainty environments	Either t stage o venture cycle o serial entrepr

Consideration set	Refinement of a single business model	The real-options controlled or owned by the decision-maker	A task requiring informational decision making	A portf explora exploita opportu possibi
Overlaps with optimal foraging		Taking sequential gambles as information is revealed.	Assessing the value propositions through a series of experimental testing to decide on pivoting	Assess payoffs and tra distanc patche more p payoffs (explor small p payoffs (exploit
Distinction from optimal foraging		Real options assume a pre-defined opportunity set, whereas optimal foraging requires sequential experimentation that is not limited by ex ante opportunity set. Optimal foraging requires consideration of multiple "outside options" whereas the real options approach requires consideration	Optimal foraging requires judgment-based decision-making as all information may not be available for sampling.	A forag exploit explore foragin and the optimiz explora exploita (seque simulta is not tl In optir foragin there is genera updatir distribu estimat explora exploita instead goal is optimiz currenc surviva

		of controllable options that require ex ante investments.		experin with va propos an opp

Note: Developed based on Averbeck () and Contigiani and Levinthal ().

Experimentation can be costly and to manage pivoting dilemmas, the currency of the entrepreneur—ensuring survival to experiment with value propositions under uncertainty—should not be compromised by net negative resource consumption that could spell failure. In doing so, entrepreneurs must identify the possible patches through hypothesis testing, and then must reconfigure existing resources and relationships to develop a newer value proposition. Though there may be benefits of continuing with the current version of the value proposition, the costs may be reduced survival prospects. In Step 2, the entrepreneur, based on lean startup experimentation considers and develops different value proposition configurations (the dashed lines to three alternate propositions, or potential patches to travel to, for example). Then, identifies version 2 as a new configuration to pivot to. In transitioning to the next value proposition version (or, patch), the cost is incurred in Step 3. As the process repeats, the goal is to engage in pivoting to an optimal level (optimal pivoting; listed in the inverted-U shaped curve in Figure 1) to improve the odds of value creation while ensuring survival. We add that the proposed model is probabilistic but consistent with the assumptions of a wide variety of search algorithms.

Based on the above theoretical discussion, next, we propose our analytical model. In all our models there is no formal interaction between agents as we want to focus on the exploitation of different opportunities by different entrepreneurs. Therefore, we model a "typical" entrepreneur in a possibly large population in a possibly large space of opportunities. Although the interaction between agents is an interesting item in the research agenda it would take us too far away from the basic premises, we set up to explore in this study. In particular, we would complicate the problem using mathematical theory from differential games and diffusion models; such techniques are, usually, used separately in most models we are aware of. Moreover, it would have been substantially more difficult to obtain Equations (8-15) in closed form. The model in Sections 5 and 6 is more easily solved in continuous time (otherwise, the algebra becomes more cumbersome). The model, however, assumes a continuum of opportunities in the searching or opportunity space which may not always be a good assumption. Therefore, we allow for a non-compact space of opportunities in Section 8, but we examine both the continuous and discrete-time case for consistency with the model in Sections 5 and 6.

3 MODEL

3.1 A context of opportunity foraging

For the proposed model, we propose that an entrepreneur starts with a version of an opportunity. Three costs for exploiting the current version of an opportunity are salient—exploiting the current version, searching for alternatives, and transitioning cost to the next version of the opportunity. Using the ecology narrative, cost of grazing in the current patch (exploiting current version of an opportunity), looking around for patches (search for alternative versions or pivots of an opportunity), and then traveling to an alternate patch and the cost of adjusting to that patch (cost of pivoting to another version). Then the cost of "grazing" in the sequential patches (opportunity version 2, 3, ..., and so on) represents the cost of pivoting. Moving from the typical assumptions in optimal foraging, we propose the following assumptions relevant to the context:

1. Use the uniform patch as is because an entrepreneur will "graze" across non-discrete patches.
2. The assumption in optimal foraging theory is that it is 0 at the lower level. However, an entrepreneur could lose money, so this assumption

has to be relaxed (change the assumption to have energy loss).

3. With increasing patch competition (N = 0, 50, 1000, 100,000, 1,000,000), we can consider four trade-offs:

    1. the distance traveled (cost of searching) = the degree of exploration from the base opportunity or the cost of pivoting from the current idea to the next.
    2. the velocity (cost of locomotion) = or the cost of pivoting from the current idea to the next.
    3. the food consumed (cost of handling) = resources consumed to exploit the current version of opportunity.
    4. the three costs in (a)–(c) are constrained so some trade-off is necessary. That is more velocity, shorter distance; low velocity, longer distance; lower cost of handling more resources for search and locomotion.

There is the cost of pivoting to a newer version of the idea (cost of locomotion), distance from the current version of the idea (cost of searching), and resources used to exploit the next version of the idea (cost of handling). Next, we propose the constant absolute risk aversion (CARA), a utility-based optimal foraging model to account for risk aversion in foraging for opportunities.

3.2 The nature of risk-profile in foraging

Motivated by Metrick (), suppose there are individuals with constant absolute risk aversion (CARA) utility:

(1)

where is consumption or wealth. We assume is a draw from a standard uniform distribution. Individuals can engage in employment in which case they receive with certainty. If an individual engages in venturing, there is a probability of success in which case they receive as reward where , and with probability they receive ( ).

Individuals can compute their expected utility using draws for with the number of entrepreneurs. We assume , and we vary only to model "bounded rationality." Results are shown in Figure 2. In Figure 3, CARA is taken from a uniform distribution in , which is more reasonable given the evidence in Metrick (), and additionally, we set . So, in the two cases (CARA uniform in (0, 1) and uniform in), the number of entrepreneurs in a population of 100,000 individuals is as in Figure 4. An additional scenario is examined in which losses are 10 times the certain wage . In this third scenario, with draws, we have , but becomes zero with more draws.

More "rational" individuals (i.e., people that can compute expectations more accurately by using a larger value of *S*) will not become entrepreneurs and entrepreneurs will be few under CARA in the interval (0, 0.0001) but they will much fewer when CARA is (0,1) and losses are not extreme (yellow bar).

3.3 Model

We assume profit opportunities are normalized in the interval . The entrepreneur travels in this (time) interval to discover and pivot to newer versions of opportunities and exploit them conditional on discovering them. The entrepreneur starts at and has limited foraging time to reach the end:

(2)

so her average "velocity" is . Average "velocity" is bounded above by a certain limit which depends on her entrepreneurial capabilities:

(3)

This means that average velocity is abounded above by a certain number so that it cannot become infinitely large, which is quite sensible in practice.

Profit opportunities have density . This density represents how opportunities arise in the environment of the entrepreneur and it has a spatial interpretation.

A common assumption is that, during the time the entrepreneur is at "position" , the profit density follows the classical Lotka-Volterra equation (Arditi & Dacorogna,):

(4)

also known as "functional response" (Holling,), where is a parameter. Let denote the length of time that the entrepreneur spends at "location" . From 4, profitability remaining at "location" after a "presence" or length of exploitation of the entrepreneur is

(5)

This means that profitability is the product of the density of opportunities at location x times the time spent at this location. Overall, *gross profit* acquired by the entrepreneur is given as follows.

(6)

To discover profit opportunities through exploitation or pivoting, the entrepreneur must spend (which represents time costs) and (which represents search costs). There are also "intensity" costs related to the velocity of exploration, denoted 3 well as costs of "handling" present profit opportunities, denoted . Therefore, *net profits* are

(7)

which is revenues minus costs, and after elimination of all constants, we have the following objective:

(8)

subject to the constraints in 2 and 3. Of course, is related to the opportunity trajectory . We assume that the entrepreneur has a finite "section" in which she detects profitable versions of an opportunity (Andersson,). If we assume

(9)

and stands for the inverse function of the trajectory (the "schedule" of the entrepreneur, meaning his "agenda" of visiting locations or opportunities over time), Equation (8) implies

(10)

Following Arditi and Dacorogna (), we define new functions and parameters:

(11)

so that the problem of the entrepreneur is

(12)

with the conditions

(13)

where also for the problem to have a solution and is the derivative of with respect to . This is a calculus of variations problem, and profit remaining after passage is . If we assume that the profit is spatially distributed as

(14)

then one can show (we omit the derivations) that the solution is as follows.

1. If , then , for , and remaining profit is , for . Therefore, the remaining potential profit is equalized in the constellation ("habitat") of profitable ventures.

2. If , then the solution is more complicated:

(15)

Specifically, from Arditi and Dacorogna () given any profit distribution, the entrepreneur will slow down to exploit existing ventures at any point where the profit density is high enough, that is , where the critical value is

(16)

where is a subset of the domain of the profit distribution where the entrepreneur adjusts her velocity of searching for new opportunities, and at its complement, say , the entrepreneur moves as fast as she can and exploits existing ventures to the minimum degree possible. So, from the entrepreneurial perspective, is perceived as empty and as the subset that contains versions of opportunities worth exploring. The classical result of optimal foraging is that an animal will treat the territory as patchy but, in this model, "patchy" is derived optimally, namely the model provides endogenously a schedule by which the entrepreneur will treat the "habitat" as patchy and also provides the optimal strategy that the entrepreneur follows within each patch.

4 NUMERICAL EXAMPLE

From Figure 5, it turns out that the entrepreneur spends a long time until profitable versions of an opportunity are finally exhausted at precisely , yet she makes good progress, and at about half the distance to the end, almost 60% of profit opportunities have been exhausted.

Next, we conduct a numerical experiment by varying the number of entrepreneurs. We keep for all but are uniform draws in the interval (0, 10). We have some kind of "criticality" at . From Figure 6, it turns out that there are many different opportunity development patterns. With 10 entrepreneurs, some of them can exhaust profitable versions of an opportunity after about 40% of the remaining time; with 20 entrepreneurs, some are slower than others (which is also evident in the bottom panel); with 100 entrepreneurs, we have a "criticality" in that most entrepreneurs are quite similar and the spatial distribution has a chaotic pattern indicating cycle-like behavior of opportunity development.

In Figure 7, for low values of (like), the entrepreneur does well until about 50% of time remaining but then more opportunities are left unexploited. With higher values of , the entrepreneur does well until about 50% of the time remaining but then remaining profit opportunities are stabilized or fall slightly when or .

Using

(17)

which is an exponential density, it is easy to see that satisfies the following differential equation for the schedule of the entrepreneur over time:

(18)

Solving this numerically, we get the following strange results in Figure 8. Here, we observe some "strange" behavior in terms of . Using

(19)

it is easy to see that satisfies the following differential equation:

(20)

Solving this numerically, we get the following strange results (Figure 9). We observe some "strange" behavior in terms of as well and most profit opportunities increase (for the most part but in a cyclical manner between periods 300 and 500). If we have ( ), then we obtain the differential equation:

(21)

The solution for the density is shown in panel (a) of Figure 10. In panels (b) and (c), we show the solution (panel (b)) and the phase diagram (panel (c)).

Here, we observe some “strange” behavior in terms of . The attractor in panel (c) corresponds to the logistic map which gives a chaotic behavior for in panel (b). Profit opportunities across versions of opportunity arise as shown in panel (a).

In this case, we obtain chaotic behavior for provided and is close to . The large value of owes to the fact the step for solving the differential equation via an Euler procedure is small (specifically, we have). For chaotic behavior of differential or difference equations, there is a large literature; see, for example, the seminal papers of Lorenz () and Feigenbaum (). Applications include Wu and Zhang (), Sosnovtseva and Mosekilde (), Sterman (), among others.

4.1 Discrete-time optimal foraging

Next, we focus on discrete-time searching as an entrepreneur pivots through versions of an opportunity. If an entrepreneur searches for versions of opportunities which are found in distinct patches, what rule should the entrepreneur use to decide when to leave the current version of their opportunity and pivot to the next version? We assume that due to the costs of pivoting, it takes time to make a successful pivot. The entrepreneur should stay in a given opportunity for some time if there exists a strategy such that from that time on the ratio of expected gain (EG) to expected time to stay in an opportunity ES), exceeds the highest possible long-term average rate of profitability, C. Then, the entrepreneur stays with an opportunity if

(22)

where EG is the average gain from opportunity, ES is the average length of time is an opportunity, and is the long-term average rate of gain, using the given strategy. The purpose is maximizing . Equation (22) just above provides a stopping rule.

For a model using dynamic programming along these lines (Green, , ,), Green () proposed a simpler approximation, on which we rely here. We either discretize gain using a number of customers ( ) or we measure gain in successive classes (again) where a higher number means higher profit.

We assume time is discrete and we begin at time , when customers have been secured or the entrepreneur has reached gain class. We calculate the expected gain and the expected time in the remainder of the opportunity assuming that the entrepreneur decides to go on and search for the next pivot. For each possible pivot found, we denote by , the expected gain and expected time as and respectively.

We can determine whether to stay by checking:

(23)

If 23 is satisfied, then we set , , the expected gain and the expected time for the rest of a class for an entrepreneur finding herself at point and using a strategy that "tries to achieve" rate . After we know what to do at time , for each possible , found by that time, we can go backward, finding what to do at time , then , and so on, until . When we reach we will have

(24)

where is the long-term average rate of gain achieved by an entrepreneur that "tries to achieve" rate *C*. The simplicity of 24 and the argument that leads to it is the first of the two main mathematical points of Green ().
For general time and , we tentatively assume that the forager will go on and search for a newer version of opportunity by , and after that time she will

use the rule that has been built up by working backward to that time. The expected gain and expected time in the remainder of the pivots of opportunity, under that assumption, are given by

(25)

where is the probability that there will be a new version of opportunity in , given that has been achieved in the first periods. To decide whether to go on and search the next opportunity if has been achieved by time , we check if

(26)

So, we can define a “decision function,” , which takes a value of 1 if 26 is satisfied, and a value of 0 if not. Then we have

(27)

4.2 Continuous-time optimal foraging

A continuous-time random search may be viewed as a discrete-time search at an exponentially decreasing rate. Without loss of generality, we assume that each new version of the opportunity is pivoted at a unit rate. This means that if the search were systematic, the opportunity could be searched in unit time. For a random search, the proportion of a product that is searched by time is exactly . Therefore, only proportion will remain unsearched and most of the original opportunity will have been exploited.

If at any time, the gain level remaining in an opportunity equals , then the distribution of the number of classes, , achieved in the next interval of length (a small number like 0.001) will have a binomial distribution with parameters , and . That is, the distribution of when remains in the opportunity is given by

(28)

In turn, we have

(29)

The distribution of , the number of products that are to be found by time , given that the current gain level is , is binomial with parameters and Therefore,

(30)

in which case the stopping criterion is

(31)

5 SIMULATION—IDENTIFYING THE STOPPING ATTEMPTS

We assume time is discrete, , so that searching is (very) costly; we have discrete time periods. In Figure 11, we present the solution of the model with approximate dynamic programming. Panels (a), (b), and (c) correspond to different values of the ratio , which must exceed a certain threshold which is 0.31, and from approximate dynamic programming, it is 0.29 (almost 94% of the optimal). Except when , in all other cases, the optimal policy is a steep increase in the gain-loss ratio that, after reaching a certain time period, drops to zero as a maximum has been reached. In panel (a), this happens at about time period 10–13, in panel (b) at time periods between 13–19, and, finally, in panel (c), we examine the gain-loss ratio for periods 11 and 12, the optimal policy is to abandon the product or opportunity (and implement another) near the end of the horizon, indicating full exploitation of available opportunities. From panel (a), and to some extent in panel (b), we see that the optimal policy is not to exploit fully an opportunity although the cost of switching is rather large. Rather, the optimal policy is to abandon in the third period given that or in period 13 given that . In panel (b), where ranges from 6 to 10, the optimal policy is to abandon rather early when and at nearly period 19 (which almost fully exploits the opportunity) when . Beyond period 12 (panel (c)), there is nothing to explore and it makes sense for an entrepreneur to explore alternative opportunities or product variations, and so forth.

So, with increasing the gain-loss ratio shifts to the right but even with , an entrepreneur would have explored nearly of the available profit. With , by period 17, almost 85% is explored. From panel (c) we see that with , 100% of the opportunity is exploited which is, practically, the same with at about period 10.

Based on the description at the start of this subsection, we have examined a specific parametrization so it is natural to inquire whether different parametrizations make a difference. We ran 10,000 simulations using random *n* (uniform in [1, 150] and search time–uniform (0.1, 100) and the optimal stopping value is 30.28% across all parameter pairs. So, this number holds universally in this class of model.

In addition to the stopping rule, the simulation results provide the following corollaries:

- Corollary 1.

  As the level of competition increases (*N*) shorter time spent in a patch will be desirable, as conserving the cost of handling is important due to lower gains in the current patch and resources can be used for searching.

- Corollary 2.

  For the mid-range competition, the trade-off is strong between managing the cost of searching and the cost of locomotion, where the cost of locomotion might be desirable.

- Corollary 3.

At low competition levels, optimal foraging may not be necessary, but expending three costs equally may lead to an optimal outcome.

- Corollary 4.

  When competition is high, if the cost of searching is too high, it may be best to abandon the opportunity.

6 CONCLUSION

Drawing on optimal foraging literature in the context of CARA, the main inference from our analysis is of a 30.28% stopping rule (loss-to-gain ratio or ~70 gain-to-loss ratio) in the current version of the opportunity or in pivoting to multiple versions of it. Our simulations for continuing with the current version of opportunity or pivoting from it, using CARA utility function, inform entrepreneurs on an optimal stopping rule as they exploit and pivot. The optimal foraging approach allows for consideration of the dynamic nature of the opportunity development process. Rooted in critical realism, the process of opportunity development is driven by chaos, uncertainty, ambiguity, and disruption—that is resolved through experimentation in the context of pivoting and contemporaneous competition. Not only do entrepreneurs develop versions of their original opportunities over time, but also the contemporaneous competition drives the extent of pivoting. Whether opportunities precede their creation or they are created, an entrepreneur must engage in experimentation. A body of work has focused on entrepreneurial action, and optimal foraging adds a context to the entrepreneurial action framework (Klein,) from the perspective of entrepreneurial search in improving an existing opportunity. Our approach is not focused on the intervening processes and micro-dynamics, but consistent with optimal stopping theory, we aim to explain when entrepreneurs can stop pivoting. Our approach has the following theoretical implications.

First, seldom do entrepreneurs exploit the version of the idea they initially start with. Entrepreneurial opportunity research states that opportunities are pre-packaged to be discovered, or call for continued refinement of the discovered opportunity. Yet, others state, the opportunity itself is ambiguous in the early stages so one must dabble through to create and morph an opportunity. Irrespective of the theoretical discourses around entrepreneurial opportunity (George et al.,), entrepreneurs have widely adopted the philosophy of lean startup (Bortolini et al., ; Eisenmann et al., ; Reis,). The lean startup approach calls for pivoting from the initial idea to improve the value proposition. For example, the optimal stopping point rules such as the 37% rule or the secretary problem have been widely used to guide stopping points in uncertain search environments. However, entrepreneurs face a pivoter's dilemma, that is pivoting may improve value proposition, and yet, pivoting may be taxing on scarce resources of a fledgling venture, may sour relationships with stakeholders, and could lower legitimacy (Chaparro & de Vasconcelos Gomes, ; Hampel et al.,). Given pivoting occurs under uncertainty, similar to optimal stopping literature in decision making under uncertainty, there is an optimal stopping point in pivoting. Identifying an optimal stopping rule for pivoting in startups we tried to answer—at what point do entrepreneurs stop pivoting?

Second, we note that an empirical data-based examination of the proposed approach is difficult due to limited mathematical tractability from the best-fit models. The so-called functional relationships are challenging to account for in the optimal foraging context. For example, the messiness of the simultaneous accounts of opportunity development, imitation, pivoting, and so on would imbue significant complexity into the econometrics-based inferences (Martin & Wilson,). Consistent with the predictions in modern physics, probabilistic estimates under a variety of potential opportunity-related outcomes based on optimal stopping rule may inform entrepreneurs as they consider stopping points in the opportunity development process.

Third, as entrepreneurs assess the economic value, newness, and desirability of their opportunity (Denrell et al.,), the process of exploiting and pivoting is akin to optimal foraging—exploiting the current version of the opportunity versus expending energy and resources to pivot and exploit a newer version of their opportunity (McNamara & Houston, ; Pyke et al.,). We attempt to provide an answer through the lens of optimal stopping point theory by drawing on the optimal foraging model while accounting for risk aversion and multiple entrepreneurs exploiting the same opportunity (Babcock et al., ; Pyke, ; Stephens,).

In conclusion, operating in an open system, entrepreneurs must cope with discovery and creation simultaneously through experimentation (Kerr et al.,). Entrepreneurial action improves understanding of the actual world through experimentation (Bhaskar,). The exercised and unexercised causal powers of experimentation among entrepreneurs, as discussed in Martin and Wilson (), can be exercised through creativity, improvisation, bricolage, combinational thinking, among others. The philosophy of critical realism states that causal associations can exist independent of our knowledge and therefore opportunity development through the optimal foraging lens can explain how opportunities emerge through interactions at two levels: (i) entrepreneurs developing current state of opportunity and pivoting from it; and (ii) multiple entrepreneurs also developing and pivoting from the current state of an opportunity. This duality of opportunity evolution at the two levels—the individual and competition among entrepreneurs—adds the necessary variation to use the critical realism lens. In this early effort to identify optimal stopping points, the proposed approach informs a variety of theories in entrepreneurship on real options (McGrath,), lean startup (Ries,), and knowledge search (Eckhardt & Shane,).

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