How Can Impact Investors Enable Systems Change? Exploring the Theory and Practice of an Emerging Field

by

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Submitted to the System Design & Management Program
in partial fulfillment of the requirements for the degree of

Master of Science in Engineering and Management

at the

Massachusetts Institute of Technology

February 2024

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ABSTRACT

Contemporary challenges, such as climate change and inequality, are complex and systemic. There has been an increasing awareness of "systems change" in the impact investing community, recognizing the limitation of the traditional approach (investing in a single company or technology) to create meaningful impact in entrenched socio-technical systems. However, a big gap between awareness and action still exists, as the concept of "systems change" or "systems thinking" remains too abstract for most impact investors to adopt in their day-to-day operations. The objective of this study is to address this gap by investigating pioneering case studies in an emerging field of investing with explicit consideration of system change. Through comparing multiple cases, developing an in-depth empirical study, and building a simulation model, this thesis sheds some light on the theory and practice of this emerging field. The results highlight how impact investors have great potential to help enable systems change by operationalizing systems theories, building collectives with stakeholders, and developing a strategic portfolio to influence the system dynamics instead of an isolated innovation or intervention.

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Acknowledgments

I'm grateful to come to MIT at the right time when the field I'm passionate about is just emerging. I want to thank my advisor Jason Jay for his guidance, wisdom, and sense of humor that kept me motivated and on the right track in finishing this work. I was afraid that nobody would care or be interested in the niche idea I wrote in my statement of purpose when applying for MIT, and yet the first day I pitched it to Jason I was convinced that I had found my thesis advisor. I have heard from many people that writing a thesis is a nightmare, but I enjoyed it a lot along the journey (ok, maybe not so much in the last two weeks) mostly because of Jason's support.

I want to thank Joe Hsueh, Brian Blankinship, and Ivan Huang who led me into the world of systems thinking. They have changed how I see the world (of course, in feedback loops) and indirectly influenced my decision to come to MIT. I want to thank Dominic Hofstetter and friends at the TransCap Initiative for their trust in this research partnership because they kindly provided the funding when the whole project was still vague, and that's what made this thesis possible (in other words, true additionality). I want to thank Alie Korijn, the TWIST community, Jesse Fink, and people at ReFED who inspired me in so many dimensions on my thesis topic, helping me recognize that my mental model was limited.

I want to thank the MIT System Dynamics Group for all the intellectual stimulation during my time at MIT. I have learnt so much from Professor John Sterman, Hazhir Rahmandad, David Keith, Vicky Yang, and Johan Chu who showed me what is possible with a rigorous process and creative mind. I enjoyed working with the PhD students in the group who made me feel I'm part of their community, which has been so important for me to finish the work. I also want to thank William Ou for his wisdom and our conversation on complexity science that helped me think more clearly about the topic, the MIT SDM community and my friends in Cambridge who have been part of my life in these 2+ years. You all have made me feel at home even though I'm 13,000 km away from Taiwan.

Finally, I want to thank my partner Jean Ma and my family and friends back home who have been my tremendous support in the past years. Jean always encourages me when I am down and exhausted, values my work when I doubt myself, and gives me emotional support and endless love when I feel disconnected. The love from my family and the alpha community has also always kept me engaged with my work and my life, I'm so proud to be their son, brother, and friend.

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Chapter 1

Introduction

Impact investing, defined by The Global Impact Investing Network as “investments made with the intention to generate positive, measurable social and environmental impact alongside a financial return,” is a rapidly growing industry with over 1 trillion USD assets under management (Hand, Ringel, and Danel 2022). The promise of doing well while doing good has attracted both individual and institutional investors. However, a quote from an experienced impact investor, reflecting during the COVID-19 lockdown, describes an important realization:

> *"The past decade ultimately validated our thesis on the future of food with incredibly strong financial returns, particularly with the IPO of Beyond Meat (an alternative protein company). But at the end of the day, we launched a public company that is now reactive to quarterly earnings. The food system is not transformed by this single company. Alternative protein investors are fighting each other when they should be fighting the industrialized, extractive food system. And in the big picture, alternative protein is not a silver bullet.* ***When we invest in making an impact at an isolated company level, we might make incremental progress, but the effort lacks context within complex and interconnected systems.****"*

This realization is not entirely new. The “Impact Investing Handbook” recognized the importance of considering the complexity of the system in which investors operate and positioned impact investors as “intentional system changers” who use investment capital to change systems (Godeke and Briaud 2020). The vision hasn’t fully translated into practice, as the essential tension between the *practicality* of impact investing and the *complexity* of systems change is difficult to navigate.

Investing is an inherently pragmatic activity. Investors allocate capital to concrete projects producing measurable outcomes and, in most cases, being accountable to relevant stakeholders such as resource owners or family members. Pragmatism usually forces impact investors to narrow their focus, reduce the complexity of the problem, and employ a deterministic view—believing their investment leads to certain outputs, which then create certain outcomes in the world. This mentality strives to make larger tasks actionable and create a sense of progress, even if it oversimplifies reality. Systems change, by contrast, requires a more holistic systems view that illuminates the vast interconnectedness and embraces the fundamental uncertainty of the world. Complex systemic challenges like climate change and inequality are often dynamic, persistent, and uncertain. They are dynamic because the phenomenon, the challenges, and the opportunities are not static or in equilibrium but change over time. They are persistent because people have tried to fix the problem, but the existing attempts are often inconsistent and experience resistance. They are uncertain because multiple stakeholders (human agency) interact with social and technical factors, resulting in unpredictable, adaptive dynamics. These complexities can potentially create "analysis paralysis," delaying the urgent actions needed to tackle the contemporary challenges. They also make accountability difficult, as the impact measurement in uncertain and complex systems is far from established. Thus, the tension between the practicality of impact investing and the complexity of systems change is what investors have to face when they intend to invest for systems change.

The philanthropy sector has increasingly embraced systems change to address societal challenges. Programs such as the Shifting Systems Initiative,[1] launched by Rockefeller Philanthropy Advisors and a group of philanthropic organizations in 2016, have recognized the need for collaborative efforts and systems thinking to address systemic issues effectively and presented several inspiring case studies learnings. Several other initiatives also emerged locally and globally to share emerging practices and test new tools to facilitate systems change, such as the work done by Ashoka in Switzerland and Co-Impact at the global scale.[2,3] In addition, Catalyst 2030 authored an open letter inviting donors to shift funding practices to support systems change more effectively, and it has already been signed by 1,265 organizations (Updated on October 23, 2023).[4] These initiatives have provided valuable insights into the challenges and opportunities of driving systems change through philanthropic interventions.

On the other hand, systems change remains an abstract concept for many investors. It is not operationalized for broader adoption by the impact investing industry, whose

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[1] https://www.rockpa.org/project/shifting-systems/
[2] https://www.ashoka.org/en-ch/program/funding-systems-change
[3] https://co-impact.org/
[4] https://shiftingfundingpractices.catalyst2030.net/

primary focus is still on point solutions—single technologies and single startups to fix a problem without touching the underlying system structure that generates the problem in the first place. Many impact investing practices conflate investor impact with company impact, where the additionality of investors' capital or effort on real-world change is not critically examined (Kölbel et al., 2020). Even when the investor impact is truly additional and realized, it's not always clear how an investor's single-point solutions, based on a sequential theory of change, would lead to systems change ("Getting Started with Systems Mapping & Impact Management" 2023). The mantra of finding the silver bullet to change the system while assuming the necessary societal contexts are exogenous and favorable is pervasive but might not be realistic, as suggested by the opening quote from the experienced impact investor. This mismatch implies that a sustainable system transformation would not necessarily occur if we only considered practicality while ignoring complexity, even when we close the trillion-dollar funding gap to achieve the Sustainable Development Goals (SDGs) (Kulkarni et al. 2022).

Some pioneers in investing with a focus beyond isolated firms include Omidyar Network, who made a case for a sector-based approach to impact investing, leveraging the full spectrum of investment capital to "prime the pump" for sector-level change (Goldman, Paula, and Matt Bannick 2012). In recent years, the combination of the keywords "system" and "investing" has become increasingly popular, indicating the growing interest in exploring investment approaches that target systemic challenges (For private impact investing, see Spengler et al. 2019. For public investing, see Burckart and Lydenberg 2021). People used terms like "system-level investing" (Burckart and Lydenberg 2021), "systemic investing" (Hofstetter 2020), "investing for systems change" (Korijn and Fort 2024), "transformative investment" (Penna, Schot, and Steinmueller 2023), and "systems capital" (Hannant et al. 2022) to describe their new concepts of investing. These pioneers are experimenting with different ways to operationalize *systems theories,* making them more accessible and actionable to balance the tension between practicality and complexity. Communities of practitioners exploring these new approaches, such as TCI (TransCap Initiative), TWIST (Together We Invest in Systems Transformation), and FEST (Financial Ecosystems for Systemic Transformation), aim to align the activities and enable more investment capital flow into systems change and transformation. However, the definition and focus vary among these practices. The empirical studies and theoretical frameworks of this new investment paradigm remain too scarce to facilitate funders' understanding, accelerate adoption, and support resource allocation decisions considering the dynamic complexities of the systems.

Therefore, this thesis attempts to address the empirical and theoretical gap through a bottom-up inquiry journey, operating from the premise of a quote attributed to science fiction author William Gibson— "The future is already here; it's just not very evenly distributed." Specifically, the thesis addresses two central questions:

Empirical question: How do impact investors behave when "investing for systems change," given the tension between practicality and complexity?

Design question: How might we support investors' systemic practice and intervention strategy to enable systems change?

Chapter 3 *Theory Building from Multiple Case Studies—An Emerging Field of Investing for Systems Change* explored the empirical question by looking into 26 self-reported case studies of investing for systems change and captured the investors' behavior. We organized the choices investors made and clustered these case studies into four emerging archetypes of investors' mental models of how systems change occurs. Chapter 4 *Theory Building through a Simulation Model Grounded in Single Case Study—Strategic Portfolios in Systemic Investing* explored the design question by examining investors' intervention strategy in one case study. We formalized the investor's mental model, complemented by the system context, into a simulation model to investigate the investor's implicit assumptions and explore intervention strategies to enable systems change under various conditions. By shedding light on the practical choices and intervention strategy in the new investment paradigm, this thesis hopes to help provoke reflexivity among investors who intend to change systems and contribute to the broader adoption of systemic investing practices that facilitate systems transition.

Chapter 2

Literature Review

Although impact investing has been widely studied, the emerging field of investing with explicit consideration of system complexity and systems change is understudied. As mentioned in the introduction, there has been an increasing number of "manifestos" from advocates for such new ideas (e.g., Spengler et al. 2019; Hofstetter 2020; Hannant et al. 2022). The main arguments are generally two-fold. First, the challenges we face today are systemic and complex, requiring the intervener to understand the system holistically and embrace uncertainties in systems change. Second, investors are more likely to catalyze positive systems change through multiple mechanisms of influence and working across asset classes. For instance, Hofstetter (2020) posits that the core logic of this new field is that investors should have "strategic portfolios—collections of investments deliberately composed and governed to unlock combinatorial effects and nested within a broader system intervention approach." The claim has not been investigated empirically yet, but what has been studied are the two critical questions embedded in their arguments:

(a) Can investors have an impact on the real world, and if so, how?
(b) How does systems change occur?

Below, the literature on these two questions is reviewed.

Investor impact
Understanding whether and how investors can actually have an impact on the real world has been a critical research area as the impact investing industry grows (e.g., Brest, Gilson, and Wolfson 2018; Kölbel et al. 2020; Brest and Born 2013; Marti et al. 2023). At the most basic level, researchers differentiate between social value/impact-aligned investment and social value/impact-creating investment, where the latter is what really generates the change in social or environmental outcomes (Busch et al. 2021; Brest, Gilson, and Wolfson 2018). To further clarify the role of investors in impact-creating processes, Brest and Born (2013) and Kölbel et al. (2020) point out the difference between investor impact and company impact, where investors only

achieve impact through changing the company's activities that ultimately change the social and environmental parameters. They thus stress the importance of investors critically assessing whether their activities lead to ultimate changes in outcomes that would not have occurred otherwise. To achieve such additionality, there must be apparent causal effects on how an investor's action enhances the quality or quantity of an enterprise's socially valuable activities, in other words, the explicit investor "impact mechanisms" (Kölbel et al. 2020).

Brest and Born (2013) suggest that such investor impact mechanisms can be monetary, such as providing capital to under-capitalized companies, or nonmonetary, from providing technical assistance and helping attract conventional investors to improving the broader enabling conditions for social enterprises. Some of the nonmonetary impact mechanisms are targeting beyond the company level to an entire sector, and the authors acknowledge that it becomes a speculative task to estimate the value of such contribution.

Kölbel et al. (2020) review empirical studies and delineate three general investor impact mechanisms. Firstly, shareholder engagement, a well-supported concept in the literature, underlines the role of investors in influencing companies through direct involvement. However, the success of this mechanism varies and is contingent on associated costs, limiting this mechanism's effectiveness in transformative change. Secondly, capital allocation becomes pivotal when external financing conditions limit a company's growth; investors can intervene to lower capital costs or enhance access to finance. The third mechanism, indirect impacts, receives less empirical support and calls for more studies on establishing the causal chain of, for example, how investors' stigmatization action leads to changes in company activity.

Marti et al. (2023) extend the indirect impact mechanism in the context of public investing. They define "field building" as investors using their public voice, distinct from private voice (shareholder engagement) or market voice (portfolio screening), to interact with other stakeholders in the field that may influence the company. In their conceptualization, investors can (a) exercise direct impact on companies, (b) exercise indirect impact via other investors, and (c) exercise indirect impact via institutional context. This new perspective calls for "understanding shareholder impact as a distributed process" (Marti et al. 2023).

In the world of private impact investing, an investor's additionality is usually exercised through providing capital to undercapitalized enterprises (investor impact) that create additional social or environmental values (company impact). Some investors exercise indirect impact through non-monetary mechanisms, although the empirical evidence of the additionality of these mechanisms is not yet well-established. The tool "theory of change" thus serves as a crucial practitioner framework within the impact investing industry, outlining the causal pathways through which activities lead to desired outcomes (Colby, Stone, and Carttar 2004). Brown (2020) and Jackson (2013) emphasize that investors should have a well-defined theory of change for an explicit purpose, providing a structured approach to more rigorously and transparently conceptualize, communicate, and evaluate societal and environmental impact enabled by investors.

However, limitations of the sequential causal logic embedded in the current theory of change methodology are increasingly recognized, calling for the industry to adopt a systems approach or systems theory (e.g., Schlütter et al., 2023; "Getting Started with Systems Mapping & Impact Management" 2023). The critique centers on the inadequacy of a sequential theory of change to capture the (a) broader context and external parameters that influence outcomes, (b) unintended consequences and potential trade-offs of interventions, and (c) complex relationships and feedback loops within the social and economic systems. This failure to consider the complexity of the challenge at hand thus limits the impact investors can have. Schlütter et al. (2023), in their recent article *Missing the Impact in Impact Investing Research – A Systematic Review and Critical Reflection of the Literature*, argue that "...to ascertain the impact created by II [Impact Investing], the whole system needs to be investigated, including the hierarchies between different actors...Attention should also be paid to the consequences of interactions between levels." The request naturally leads to the other critical question of interest in various communities: How does systems change normally occur?

Systems change

In the grassroots movement and social change community, practitioners often see systems change as shifting "the system dynamics or conditions that created a problem in the first place and entrench the problem in society" (Social Innovation Generation 2014). Kania, Kramer, and Senge (2018) further categorize these conditions, ranging from more explicit policies, practices, and resource flows to more implicit relationships, power dynamics, and mental models, which are often interdependent. Since the explicit conditions are more visible and easier to measure, they gain the most attention and are the target for many change-makers. However, Kania, Kramer, and Senge (2018) argue that the implicit conditions should also be taken care of concurrently for the impact to last.

Many other empirical works on social change support the importance of implicit conditions on systems change (e.g., Rayner and Bonnici 2021; Crutchfield 2018; Scharmer 2016). The changes in the semi-implicit conditions (relationship and power dynamics) are observed to be fundamental in many social movements (Rayner and Bonnici 2021; Crutchfield 2018). Rayner and Bonnici (2021) further synthesize the lessons from the ground and operationalize them into four practices to achieve the change in these conditions: developing collectives centered on lived experience; empowering decision-makers with lived experience; creating platforms for peer-to-peer learning; and disrupting policies that favor the status quo. Investigating one layer down into the most implicit condition (mental model), Scharmer's work on "Theory U" (2016) explores how the undesired results in the outer systems are caused by the lack of awareness of the inner place from which attention and intention originate. "Theory U" provides a wealth of stories, examples, exercises, and practices to enable leaders and systems to co-sense and co-shape an emerging future and is now adopted by many systems change practitioners worldwide (Presencing Institute 2022).

Alternatively, systems change is often conceptualized as a structural change of a "socio-technical system" in the sustainability transition community (Köhler et al. 2019; Markard, Raven, and Truffer 2012). Socio-technical systems combine social and technical elements, including technology, infrastructure, supply network, user practice, market, and regulations, which interact to fulfill specific societal functions, such as transportation and communication (Geels 2004). When transitions happen, the system shifts from one dominant configuration of these elements to another, often driven by the emergence and diffusion of niche innovations and external pressures for sustainability (Schot and Geels 2007; Geels 2011). Transition studies have offered valuable process insights into the co-evolutionary nature of social and technical factors and key phenomena such as path dependency and emergence (Seto et al. 2016; Geels et al. 2017).

The multi-level perspective (MLP) framework proposed by Geels (2004; 2011) provides a useful lens for understanding and analyzing these transitions, considering the interplay between social, technological, and institutional factors at different levels:

1. The core level, a *socio-technical regime*, refers to the incumbent industry, technology, policy, culture, science, market, and a dominant set of rules, norms, and practices that govern the behavior and interactions of actors within a particular socio-technical system.

2. The *landscape,* a level above the regime, represents the broader societal context of transitions, encompassing the exogenous cultural and political factors that influence and shape the possibilities and constraints for change.
3. A level below the regime, the *niche,* is a protected space where new and innovative practices, technologies, or ideas (that are initially unstable but have the potential to break through radically) can emerge and develop.

Based on the observation of historical transition, four transition pathway typologies are formulated depending on the combinations of timing and nature of multi-level interactions (Geels and Schot 2007; Geels et al. 2016). Some transition pathways are more bottom-up and niche-driven (Schot and Geels 2007), while some involve incumbent reorientation and adjustments in formal rules (Berggren, Magnusson, and Sushandoyo 2015; Geels et al. 2016.). The pathway concept has since emerged as an effective tool to help map out possible futures, plan suitable responses, facilitate learning, and bridge diverse perspectives and analytical approaches (Rosenbloom 2017; Turnheim et al. 2015). However, the role of investors in this transition process and the theoretical conceptualization between finance and MLP are generally understudied (Naidoo 2020; Geddes and Schmidt 2020). The recent exception is Penna, Schot, and Steinmueller (2023) who propose a set of new rules of investment aligned with transition theories and call for further research to operationalize these rules.

To navigate the dynamic complexity of social systems change or socio-technical system transition, changemakers need to adopt suitable sense-making techniques carefully. Although the best strategy in complex adaptive systems with fundamental uncertainties (where cause and effect are only coherent in retrospect) is known as probe-sense-respond, some stable patterns in complex space can be “exploited” as intelligence to inform hypothetical cause-and-effect relationships in the system (Kurtz and Snowden 2003). However, as the aforementioned empirical studies suggest, even when the causal relationships between elements are knowable, they are often non-linear, interdependent, and embedded with feedback loops and time delays. Systems thinking and modeling have been recognized as important tools to enhance decision-maker’s limited mental models and enable collective sense-making (e.g., Stroh 2015; Meadows 2008; Sterman 2000; Senge 1990; Voulvoulis et al. 2022; Grewatsch, Kennedy, and Bansal 2023). Using system thinking tools to understand the system at hand enables stakeholders to align their mental models and discover interventions at “high leverage points” or “sensitive intervention points,” where small efforts create outsized impact or trigger phase transition (Abson et al. 2017; Farmer et al. 2019; Meadows 1999). Thought leaders in the space of systems change have further suggested moving from a theory of change to a "theory of transformation" (Patton 2019) or "theory of systems change" (Stroh 2009), both of which emphasize integrating multiple interventions for greater momentum and recognize the complex interaction between outputs in multiple levels over time.

Pulling all the literature together, a temporary conclusion is as follows:

1. Impact investors can have a direct impact through capital allocation to under-capitalized firms to increase their quality or quantity of environmental or socially valuable activities.
2. Impact investors can have a direct impact through non-monetary mechanisms (e.g., shareholder engagement or technical assistance) that help firms increase their quality or quantity of environmental or socially valuable activities.
3. Impact investors might have an indirect impact through nonmonetary mechanisms targeting other investors or stakeholders (e.g., policymakers or enabling environment), recognizing that investor impact is a distributed process.
4. Impact investors have a better chance to enable systems change by developing collectives to engage and empower stakeholders on the ground, understanding the system holistically at multiple levels (instead of stopping at a sequential theory of change), identifying high leverage points and potential transition pathways, and using all the investor impact mechanisms above (1-3) to shift both explicit and implicit conditions.

This temporary conclusion thus motivates the two research questions mentioned in the introduction:

1. *How do impact investors behave when "investing for systems change," given the tension between practicality and complexity?*
   Do they try to understand the system and actually do system sensemaking? If so, to what extent, and how do they do it? Do they interact with stakeholders, and how do they work with the niche and regime actors? What levers do they use to realize impact?
2. *How might we support investors' systemic practice and intervention strategy to enable systems change?*
   How might investors identify high-leverage points? How might interventions be combined to shift conditions? Can we operationalize strategic portfolio construction by carefully considering interdependency?

Thanks to the thought leaders in the space who have published the manifestos mentioned above, their ideas have drawn the attention of investors with first-hand experience in systems change and helped create communities of practice and learning networks. These networks create the empirical context for our study that addresses these questions.

Chapter 3

Theory Building from Multiple Case Studies—An Emerging Field of Investing for Systems Change

This chapter explores the variety of approaches practitioners consider within the emerging field of investing for systems change. Given the tension between practicality and complexity, investors are experimenting with ways to operationalize systems theory, and there is no single standardized roadmap for doing so. Investors employ various tools to map the system, its causal mechanisms, value chains, and stakeholder relationships for different purposes. Many emphasize designing multiple interventions that address the interconnected nature of the challenges but connect those levers using different logic. We consider all of these under the same umbrella of "investing for systems change." By examining multiple case studies and analyzing their characteristics, this chapter provides insights into emerging investor practices, mental models, challenges, and potential pathways for investors seeking to catalyze systemic change.

3.1 Methodology

3.1.1 Introduction

To answer the empirical question—How do impact investors behave when "investing for systems change," given the tension between practicality and complexity? —the aims of this study are:

1. Developing a typology to characterize a variety of investors' efforts when they are investing for systems change.
2. Analyzing investors' theories of how their efforts can lead to systems change.

The purpose of this chapter is to describe the research design and methodological limitations of our comparative case study analysis within a specific practitioner community.

3.1.2 The Research Design

This study employs multiple case study designs to investigate and analyze the various forms of investing for systems change. Since investing for systems change is an emerging field, a case study approach is beneficial for building theory, especially when the phenomenon being studied is complex and poorly understood (Eisenhardt 1989; Eisenhardt and Graebner 2007). Specifically, multiple case studies are utilized to understand the various practices according to their within-group similarities and between-group differences (Stapley et al. 2022; Eisenhardt and Bourgeois 1988).

Sampling

We relied on the TWIST (Together We Invest in Systems Transformation)[5] working group to sample our cases. TWIST is a global community of investors, practitioners, and facilitators, actively deploying capital and/or facilitating processes for systems change, including private fund managers, high-net-worth individuals, family office managers, private investment advisors, foundations, and systems change consultants. It was formed in May 2022 following discussions about investing for systems change at the Katapult Future Fest, with initial participants gathered from impact investors present at that event. Participation in the group grew organically as more people heard about the collaborative and wanted to participate in the sharing and learning. At the time of writing, there were 55 working group members from 39 organizations in the group.

This sampling strategy is inherently biased toward the investors who believe that collaboration and sharing of best practices are valuable and thus join the TWIST community. Still, the willingness to share early efforts and the focus on collective learning in this community allows us to collect relevant data that is otherwise unavailable. The TWIST working group members focus on various issues in their investment strategy and represent different combinations of private investing entities (Figure 1) This group thus offers us reasonably diverse samples and the possibility to answer our research questions.

[5] The initial name of the group was "IMP+," which referenced the earlier Impact Management Project (IMP) that aimed to define and measure impact investing; the group's original intent was to extend that original framework to incorporate investing for systems change. More information about TWIST can be found on its website: https://www.wearetwist.org/

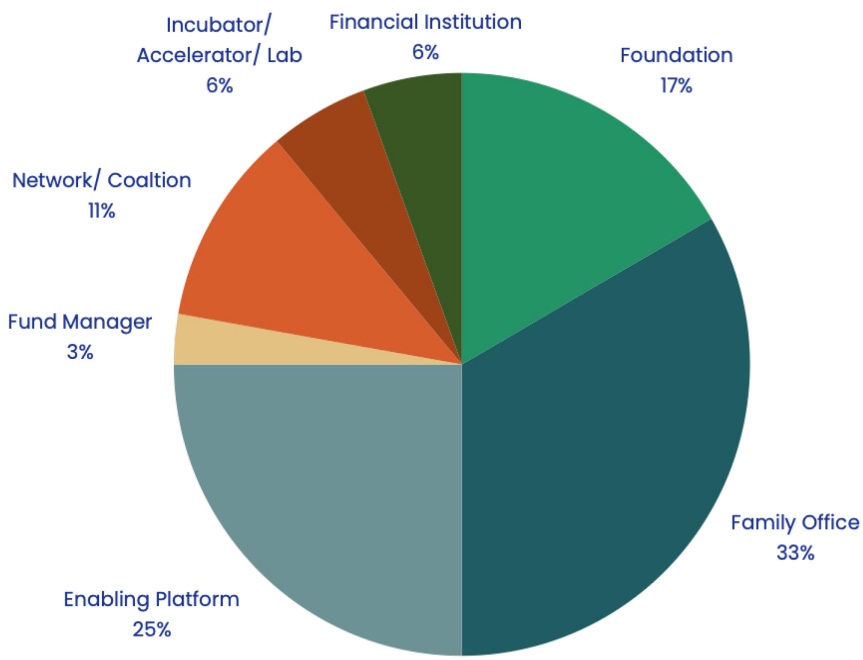


Figure 1. Investing entities of the TWIST working group member (Source: TWIST)

Data Collection

In partnership with the TWIST community, all data was primarily collected through participating in 26 working group sharing sessions (summarized in Table 1) over 8 months from September 2022 to April 2023. In each sharing session, one of the members presented the investing work he/she has been involved in and created a space for discussion, which normally took 1 to 1.5 hrs. The session was recorded and transcribed. One important feature of our data collection is that it directly involved the participating informants, so our research bore some resemblance to participatory action research (Chevalier and Buckles 2013). TWIST working group participants explicitly joined the group to help clarify their thinking and advance their efforts. To help them organize their presentation of their case studies, the working group organizers provided them a template to fill in ahead of time, which also served as a data source for our case study analysis. For presentations 1-22, the TWIST organizer, Alexandra Korijn, primarily authored that template design with input from the working group members. For presentations 23-26, a revised template version included categorization suggested by our research team based on the emerging themes from our initial analysis.

Table 1. Overview of case studies

Ref	Case Name
01	Library of Things
02	Apolitical
03	Regenerative Alpine Region
04	Fair by Design Fund
05	Venture Ecosystem Building
06	Osa Regenerative Rainforest Economy Lab
07	Sedai Economic Zone
08	Fairphone
09	Pharmakina
10	Koko Networks
11	VisVires New Protein Fund II (VVNP II)
12	The Fink Family and ReFED
13	Women's World Banking Fund II
14	FAES
15	1000 Ocean Startups Coalition
16	Small Giant
17	Regen Melbourne
18	Connovo Venture Builder
19	Grassroots Community Engaged Investment
20	Purpose
21	Tidal Impact
22	Rainfall - Tokenization of Impact & Universal Earned Income
23	Hawaii Investment Ready
24	Break Free from Plastics
25	Systemic Investing in Swiss Mobility Prototype (Net Zero Mobility)
26	Tara Health Foundation

Data Analysis

The qualitative case study data was coded through an abductive process, iterating between coding guided by theory and grounded, inductive coding. We drafted the coding framework *deductively* by conducting literature reviews in socio-technical transition and social systems change studies mentioned in Chapter 2. This initial coding framework was utilized to organize the case study data when we participated in the presentation. We then adapted the coding *inductively* during the data collection process and finalized the codebook after rewatching all 26 case recordings. The final codebook (Table 2) was applied to each case to finish the coding process. We recruited another working group member to code the data independently using the codebook to ensure the internal consistency of the coding process. The resulting data of each case contain a) codes relevant to our study, b) quotes from case presenters, and c) initial subjective observations by the researchers.

This coding strategy allowed us to compare the commonalities and differences across cases. Emerging patterns and theory were visualized by tabular displays and graphs (Miles and Huberman 1984), which form the basis for defining the "archetypes" of investing for systems change. Specifically, we use the standard k-means clustering method to group cases with similar investor practices into archetypes (Pham, Dimov, and Nguyen 2005). Cases in each archetype were selected to build internal validity, relevant literature was compared to sharpen the construct definition, and the process was iterated until marginal improvement became small (Eisenhardt 1989).

3.1.3 The Methodological Limitations

The present study has four major limitations due to these methodological choices. First, because of the limited data availability and the sampling strategy adopted in this study, the result is biased on private wealth impact investing for systems change. It did not include efforts driven by governments, development finance institutions, or institutional investors. Further, while the TWIST working group is global and welcomes anyone who identified themselves as investors for systems change to join, the exposure is limited. We make no claim of completeness and representation of the whole private wealth group that is investing for systems change.

Second, the current study is primarily based on self-reported data from investors' early efforts, and triangulation of evidence is difficult at the moment. This is the first attempt to characterize the field, and we expect to continually update the characterization as data becomes more available.

Third, because the researchers and organizers collaborated on the case study template for working group participants, our codebook not only described the data but helped produce it. It is, therefore, quite likely that there are interesting and important features of the case studies that were not captured through this data sampling and collection methodology and will emerge through other scholars' reviews of our research. In particular, because participants would use our typology to describe themselves in a community of peers, we specifically endeavored to strike a balance between supporting self-reflection and critical thinking on the one hand but to make the categories "non-judgmental" in a certain sense. This balancing act led to an approach where we gathered data about intent, practice, and the theory of change that connects intent to practice. Further judgment of the effort's potential efficacy, validity, or legitimacy would require additional analysis of the plausibility and coherence of these three elements. In subsequent papers, we include some attempts at that analysis.

Lastly, although it's mentioned by several community members that the outer efforts of their investments are inseparable from their inner conditions, in this study, we didn't investigate the relationship between investors' inner development and investing for systems change because of data scarcity. Very little qualitative data was successfully gathered from the TWIST case study template question: "What aspects of your inner life, practices, and journey have influenced your work?" Future research can modify the research method and shine some light on whether and how the inner development of investors supports the outer success of investing for systems change efforts.

Table 2. Codebook typology of investing for systems change

Topic	Input Options	Description
1. Investor Intentionality: Intended Systems Change		
1.a System Boundary		
SDG Mapping (Primary and secondary)	17 SDGs	Primary intent(s) of investor
	17 SDGs	Secondary co-benefit(s) that investors also intend to create
Issue	Specific	Primary intent focus on 1-2 specific SDG
	General	Primary intent has no focused SDG but general impact
Geography	Local	Within a specific community or city
	National/Regional	Within a specific country or countries with similar characteristics
	Global	No geography focus

Current State	Qualitative Input	The current reality of the system which investor cares about
1.b Change Goal		
Future State	Qualitative Input	The ideal system investor envisions to create, serving as the north star of the investor's effort
Change type	Optimization	Incremental innovations that improve the efficiency of the current dominant practices without changing the configuration of the socio-technical system
	Partial redesign	Disruptive innovation in technology or business model that change the parts of the system
	Transformation	Fundamental reconfiguration of the combination of technology, user practice, policy, industry structure, etc.
Pacing	# of years	The expected timeframe for reaching the goal specified above
2. Investor Practice: Systemic Approach		
2.a Systems Understanding	Value Chain & Process	Understand the major value chain and functional process in the system.
	Causal Mechanisms	Understand the important causal mechanisms and/or structural feedback loops in the system.
	Stakeholder Relationships	Understand the relationships of relevant stakeholders and their power dynamics in the system.
	Paradigms & Values	Understand the underlying paradigms and values that create the current system.
2.b Capital Deployment Method		
Asset Class	Single asset	Create change through only one asset class
	Cross asset	Create change through multiple asset classes, including philanthropy
Decision Power	Capital owners decide	Capital owner decides where and how much to allocate money
	Capital owners decide, involving consultation with stakeholders	Capital owner works with stakeholders to include multiple perspectives and feedback before deciding where and how much to allocate money
	Stakeholders decide	Stakeholders directly participate in deciding where and how much to allocate money
2.c Levers of Change		
Solution Experimentation	- Owned by investor - Funded by investor, with extra investor	Help to experiment and test the immature solutions that can directly prevent/address the challenge defined in 1. a
Solution Scaling		Help to scale the proven solutions that can directly prevent/address the challenge defined in 1. a

Orchestration & Network	contribution - Funded by investor - Engaged through partnership with others - Not involved	Foster collaboration and network of actors in the field that can potentially accelerate the solution development
Data & Knowledge		Generate knowledge or data that are important for the field to address the challenge
Human Capitals		Build human capitals (professionals/leaders) to advance the field
Physical Infrastructure		Build shared physical infrastructures that are critical for solution to function properly
Established Company Behavior		Change the established companies' behavior to facilitate solution development or directly prevent/address the challenge defined in 1. a
Social Norm & Public Awareness		Shift social norms and public awareness of the challenge
Policy & Regulation		Influence the policy, regulation, and standards that are critical to address the challenge
2.d Impact Indicators Used	Qualitative Input	Major metrics investor conceptualizes and track impact they created
2.e Boundary Objects Used	Qualitative Input	The tangible objects investor used to facilitate communication and collective actions with other stakeholders
3. Connection between Intentionality & Practice		
3.a Theory of Systems Change	Qualitative Input	The causal logic and assumptions of how the combination of systemic approaches (described in 2) can lead to systems change (described in 1)

3.2 Developing a typology of practitioner case studies

To make sense of the variety of efforts by investors aiming for systems change, we developed a typology framework in the codebook produced through the abductive process described in the methodology section (3.1.2). On the highest level, the typology distinguishes the investor's intentionality (intended systems change), investor practice (systemic approach), and the logic/mental model of how their practice can lead to systems change (theory of systems change). While the investors share some degree of intentionality for systems change, they focus on very different "system boundary" and "change goal," which we broke down further in this section. We also had a more detailed look into the practice of investing for systems change from the perspective of investors' "system understanding," "capital deployment methods," and "levers of change." We left the discussion about investors' theory of systems change to section 3.3 with an analysis of the emerging archetypes.

3.2.1 Investor Intentionality: Intended Systems Change

Investors pursuing systems change have more ambitions than isolated impacts produced by single companies. To make the intentionality of systems change clearer, investors ask two basic questions— "what system do I want to change?" & "What do I want to change the current system toward?" The first question refers to the "system boundary" of the effort, and the second refers to the "change goal" envisioned by the investors and stakeholders in the system boundary. These are the two fundamental attributes that must be clearly defined when describing the intentionality of systems change as they help the investor prioritize actions and communicate the focus of the effort.

3.2.1.1 System Boundary

A system boundary specifies the unit of analysis underlying the investor's claim of creating systems change. This subjective choice involves investors' concerns and assumptions about what to include and exclude to balance practicality and complexity. Many different dimensions can be utilized to define a system boundary, ranging from more straightforward geospatial characteristics to more subtle variables within the system, and one can keep adding dimensions to make the definition of a system boundary more complex. A sharply defined system boundary and a description of the current reality within this boundary make the system change effort tractable and prevent stakeholder misunderstanding. Here, we included two major dimensions to describe the boundary: geography specificity and issue specificity.

Geography specificity describes an investor's geospatial focus when pursuing investment for systems change. Whether investors focus the scope of effort on a specific community, city, country, region, or global scale can greatly influence their practice. Most cases have a static geographic focus, while some investors choose to start with narrower boundaries but plan to expand to larger scales over time. Issue specificity, on the other hand, describes investors' outcome focus when pursuing investment for systems change. Although not directly specified by investors, we use UN Sustainable Development Goals (SDGs) to define issues for two reasons. First, most investors are familiar with the framework, so it is a good starting point to describe investors' intentionality on the outcome. Second, the SDGs are used by other actors participating in systems change, such as governments, international institutions, and corporations. While we recognize that all SDGs are interwoven with each other (Song and Jang 2023), the level of aggregation and the focus on contemporary systemic challenges make the framework useful to characterize the boundary of what aspect(s) within the defined geography the investor wants to change. We define intentionality as “issue-specific” if the investor primarily focuses on one to two SDGs and “issue-general” if the investor targets multiple SDGs or is issue-agnostic.

By integrating the two dimensions, a simple differentiation about the system boundary investors aim to create systemic change is formed. For example, investors can focus their effort on a global, issue-specific system change, such as encouraging a circular economy in the consumer goods industry, or they might pursue a local, issue-general system change, such as urban “doughnut economics” action in a city (targeting multiple planetary boundaries and social foundations, see Raworth 2017). Table 3 summarizes the different system boundaries with examples from the case studies.

Table 3. System boundary of investor’s intentionality

		Issue	
		Specific	**General**
Geography	**Local/ City**	Local, specific issue system change (7.7% of case studies) Example: Food Production System in Hawaii	Local, multiple-issue system change (15.4% of case studies) Example: Urban Doughnut Economics Action in Melbourne
	National/ Regional	Regional, specific issue system change (34.6% of case studies) Example: Education System in Mexico	Regional, multiple-issue system change (7.7% of case studies) Example: Regenerative Alpine Economy
	Global	Global, specific industry system change (23.1% of case studies) Example: Consumer Goods Circular Economy	Global, capitalism/political infrastructure change (11.5% of case studies) Example: Steward-ownership Business

To make the system boundary more explicit, some investors further specify the type of socio-technical system (for instance, agriculture or transportation system, see Geels 2004) or natural ecosystem (for instance, forest or ocean ecosystem) where investors focus on change to achieve the intended outcomes. A socio-technical system specifies the “form”—a configuration of elements such as technology, supply network, user practice, and social norms—that delivers a core societal “function”—providing healthy food, transporting people and goods, or keeping people safe from violence—during which there might be some “externalities”—generating pollution, inequality, or biodiversity loss. An investor might focus on changing the “form” to remove “externalities” while keeping the core “function” the same (i.e., decarbonize the mobility system), changing the “form” to innovate the core “function” without taking care of “externalities” (i.e., a tunnel mobility system with less congestion), or change all three at the same time. Therefore, besides the geography and issue focus, a system boundary with a specific socio-technical system further helps to clarify the range of stakeholders and elements relevant to the systems change effort.

3.2.1.2 Change Goal

Systems change is a process of evolving the system from one state to another, thus requiring investors to describe the desired state or a transition direction of the system in their intentionality. This desired state of the system, similar to the concept of “mission” described by economist Mariana Mazzucato (2021), might not be articulated by investors alone but co-created by a group of system stakeholders. We categorize investors’ system change goals based on how disruptive they are compared to the system's current state. We adopted a commonly used framework in sustainability transition research to qualitatively distinguish the types of change effort as “system optimization,” “partial system redesign,” or “system transformation” (Geels, Elzen, and Green 2004). System optimization refers to incremental innovations that improve the efficiency of current dominant practices without changing the socio-technical system's configuration. Partial system redesign refers to disruptive innovation in technology or business models that changes parts of the system. System transformation refers to the fundamental reconfiguration of technology, user practice, policy, industry structure, etc. Besides the three desired states, pacing is another important parameter in articulating the change goal. Since no system changes overnight, it’s important for investors to consider the expected timeframe for reaching the desired state. Figure 2 presents a rule of thumb for the impact potential that can be achieved through different change types over an estimated time horizon.

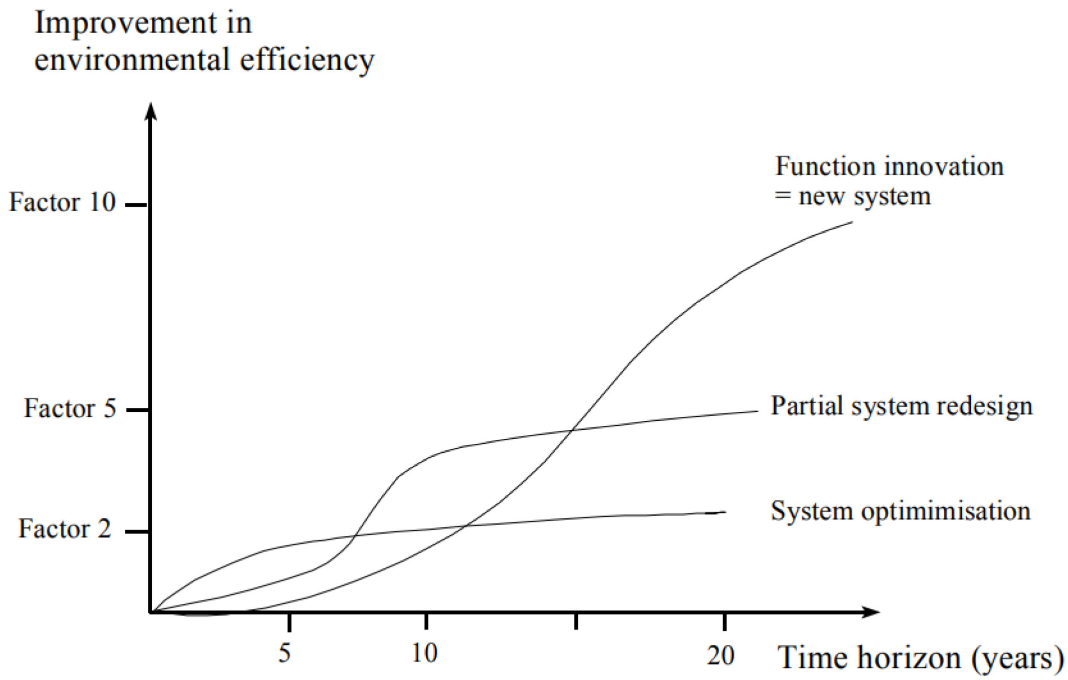


Figure 2. Comparing system optimization, partial system redesign, and system transformation (Source: Weterings et al., 1997: 18)

We found no intentionality in system optimization in the 26 case studies, indicating this group of investors has no interest in incremental improvement (here we only examine the intention, while the outcomes of these cases are unknown at this stage and might include optimization as a result of their efforts). Investors who aim to redesign the system partially articulate their vision of disrupting technology such as "*...a new food supply chain that produces better quality and sustainable protein and improves food safety, traceability, and food waste*". Those pursuing system transformation often go beyond technologies and challenge the underlying rules of current systems by envisioning, for instance, *"a world where communities are more connected and in collaboration, spending less money on things and ultimately contributing to the degrowth of the global economy in line with needs of people and planet, not infinite growth."*

When combining the articulation of desired state and pacing, some investors find it useful to use "phase" to distinguish short-term and long-term ambition. The short-term desired state is considered a steppingstone or necessary "soil" for the long-term desired state to thrive, and this phased approach spares room for emergence to happen. The Three Horizons Framework proposed by Bill Sharpe (2016) provides a simple process to guide dialogue about the "horizons," representing different phases and multiple competing systems involved: H1 (represents "business as usual" and the managerial perspective), H2 (represents "transition and innovation" and the entrepreneurial perspective), and H3 (represents "emerging pockets of the future" and the visionary perspective). The framework offers a basis for conversation about the interaction of the three horizons and the interrelated pattern for navigating a chosen future. Take the Net-Zero Mobility Switzerland project, for instance. Their short-term ambition level (the H2) is to "partially redesign the mobility system from fossil fuel dependent to electrification," while the long-term ambition level (the H3) is to "catalyze the transformation towards a low-carbon, climate-resilient, just and inclusive Swiss mobility system."

3.2.2 Investor Practice: Systemic Approach

Investors pursuing systems change often have more sophisticated practices than impact investors. Every case has its own flavor of what the approach should look like, so we follow the same inquiry structure and examine the underlying practice: (a) how do investors make sense of the system when investing for systems change, (b) how do investors deploy their capital to achieve their goals, and (c) what levers do they use to realize impact. These three questions correspond to the following sections on investors' system understanding, capital deployment methods, and levers of change.

3.2.2.1 System Understanding

Investors develop their system understanding before investing for systems change. They either look for existing research on the system or initiate their own sense-making process, either internal or participatory, if no satisfactory one fits their purpose. This is usually where systems thinking comes into play, while the term "systems thinking" can mean different things for people from diverse backgrounds. Different choices and combinations of the system sense-making technique, such as ecosystem mapping, causal loop diagramming, or social network analysis, shape investors' system understanding. We summarize investors' four major system understandings and how investors utilize these understandings in Table 4. Each case study could involve multiple system understandings if the investor adopts a combination of various perspectives.

Table 4. Investor’s system understanding

Systems understanding	Description	How investor utilizes this understanding	Popularity in the case studies
Value Chain & Process	Understand the major value chain and functional process in the system.	1. Target specific problems at each stage along the value chain or process to identify opportunities with the highest impact 2. Target the integration of different parts of the chain to amplify positive impact	50.0%
Causal Mechanisms	Understand the important causal mechanisms and/or structural feedback loops in the system.	1. Target critical factors along the causal chain to ensure the impact happens 2. Target reinforcing loops to amplify the positive impact or avoid vicious cycles 3. Target balancing loop to drive corrective action to stabilize the system or overcome inertia in the existing system	26.9%
Stakeholder Relationships	Understand the relationships of relevant stakeholders and their power dynamics in the system.	1. Target the most connected and influential players in the network to maximize impact 2. Target building the necessary connection of people to enable or realize impact	30.8%
Paradigms & Values	Understand the underlying paradigms and values that create the current system.	1. Target shifting the problematic mindsets and rules stakeholders have to sustain the intended impact	38.5%

Value Chain & Process

Investors aiming to change a specific socio-technical system are driven to find problems in how current systems deliver societal functions (such as transportation or education). This usually requires an outline of the core value creation process and different types of actors and activities involved, normally resulting in visual representations like ecosystem maps or process maps presented in Figure 3 and 4. Understanding the value chain and processes in the system is the most popular among case studies. Investors can use this to gain a comprehensive understanding of the industry landscape of the current socio-technical system and navigate the complexities of the market. This understanding also allows investors to analyze the overlooked or missing stages, which they have the ability to influence and look for interoperability among portfolios along the value chain to compound the financial and impact return. Take Tara Health Foundation, for instance. To create long-term sustainable solutions that improve access to equitable reproductive health in the US, Tara Health Foundation collaborated with other funders to develop contraception, abortion, and maternal health systems maps (Figure 4 shows the contraception process map) to identify different opportunities for intervention with private capital. In the case of contraception, the value chain starts from R&D, regulatory, and pricing to reimbursement, service provision, care seeking, and patient experience. Private investing opportunities were identified from the gap and potential analysis in these systems maps, such as developing new non-hormonal technologies for contraception, building innovative delivery models for abortion care, and overcoming implicit bias in maternal health.

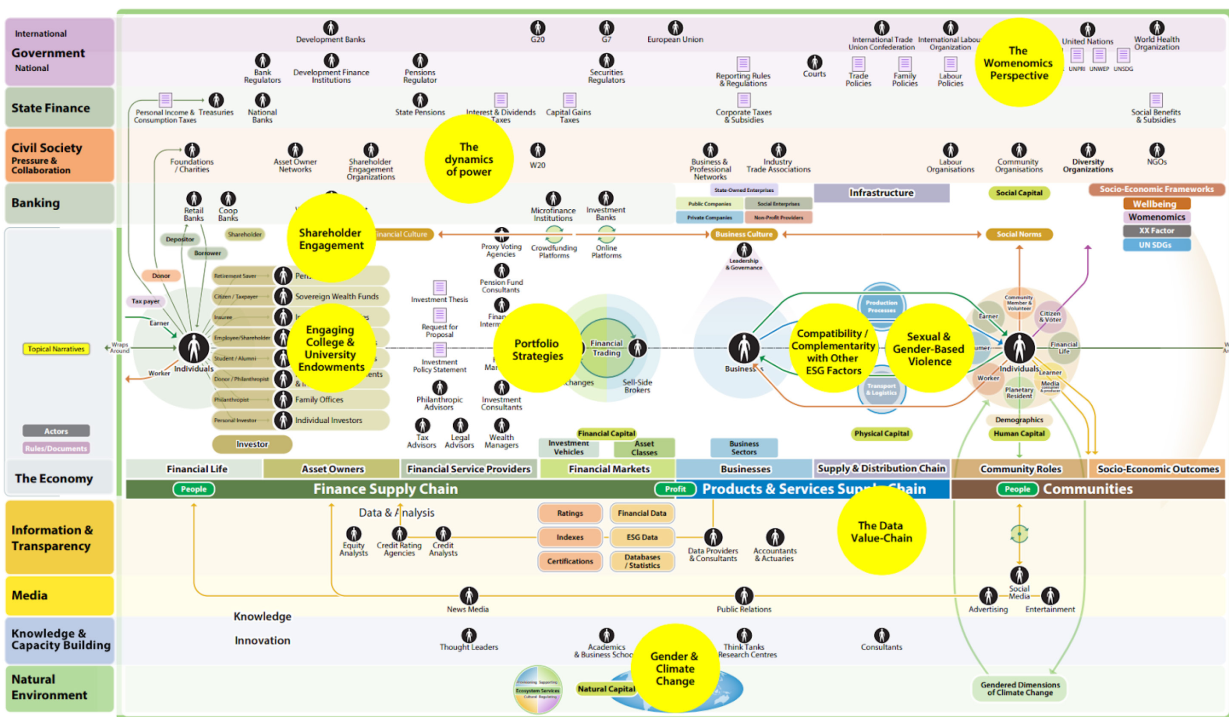


Figure 3. The Gender Finance Ecosystem Map developed by Nexia[6]

[6] For a detailed walkthrough of the ecosystem map, see https://nexial.co/maps/gf/#/?on=Map&openl=EconFramework,1&open=GenderFinance,GF-Investing,GenderFinanceInvestors&panx=2050&pany=1200&zoom=1.0&wpane=355&epane=380&unoInfo=WelcomeReset

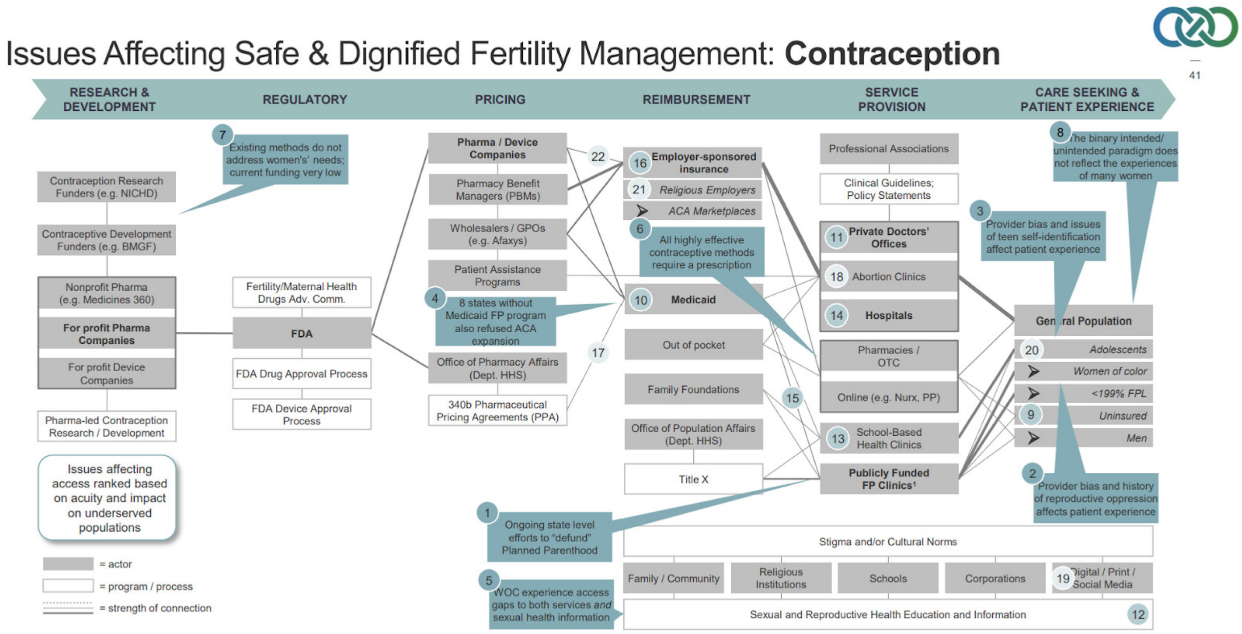


Figure 4. The US Contraception Process Map developed by Tara Health Foundation[7]

Causal Mechanisms

Many investors are influenced by Donella Meadows's work on "Thinking in Systems" and convinced that to change a system, it is not enough just to tweak the parameter but to find higher "leverage points" in the system, where small efforts can produce an outsized impact on the system's dynamics (Meadows 2008). One of the important leverage points lies in strengthening desirable feedback loops and weakening undesirable ones. To identify these feedback mechanisms, causal relationships among key variables are often mapped using the causal loop diagramming method, which originated from the field of system dynamics (Sterman 2000; Stroh 2015). Figures 5 and 6 show some examples of investors using such a causal lens to make sense of the system. The advantage of understanding causal mechanisms is to enhance our mental model of how problems emerge from the complex interaction of various contextual factors in the system and how interventions could lead to changes in specific indicators of the problems. With this system understanding, investors can focus their attention and form intervention strategies to trigger reinforcing feedback loops or influence critical causal chain factors. Take the TransCap Initiative's Net-Zero Mobility Prototype in Switzerland. Based on their desk research and stakeholder interviews, the team constructed a causal loop diagram (Figure 6) to pursue a low-carbon, climate-resilient, just, and inclusive Swiss mobility

[7] For the whole investment case based on the systems maps, see https://cdn.givingcompass.org/wp-content/uploads/2019/06/25090639/RHIA_InvestmentCase.pdf

system. The map was used to identify key dynamics and facilitate stakeholder dialogue to prioritize the six leverage points that can trigger important reinforcing feedback loops, ranging from infrastructure installation capacities to car-disincentivizing urban spatial planning. The team then looked for investable and non-investable interventions against these leverage points and formed a strategy articulating how combining these interventions would lead to a change in system dynamics following the causal mechanisms formulated in the diagram.

Although expressed by many investors in the TWIST community as an important task, understanding causal mechanisms currently only appears in about one-fourth of the case studies in our sample.[8] As a growing number of impact investors are interested in exploring techniques in mapping causal mechanisms, Impact Frontier published an industry whitepaper to lay out potential ways investors can start integrating this system understanding into their impact management practices ("Getting Started with Systems Mapping & Impact Management" 2023).

[8] After seeing several cases that had used causal mapping, there was a request made by TWIST members to have a session on causal systems mapping, delivered by experts in the field.

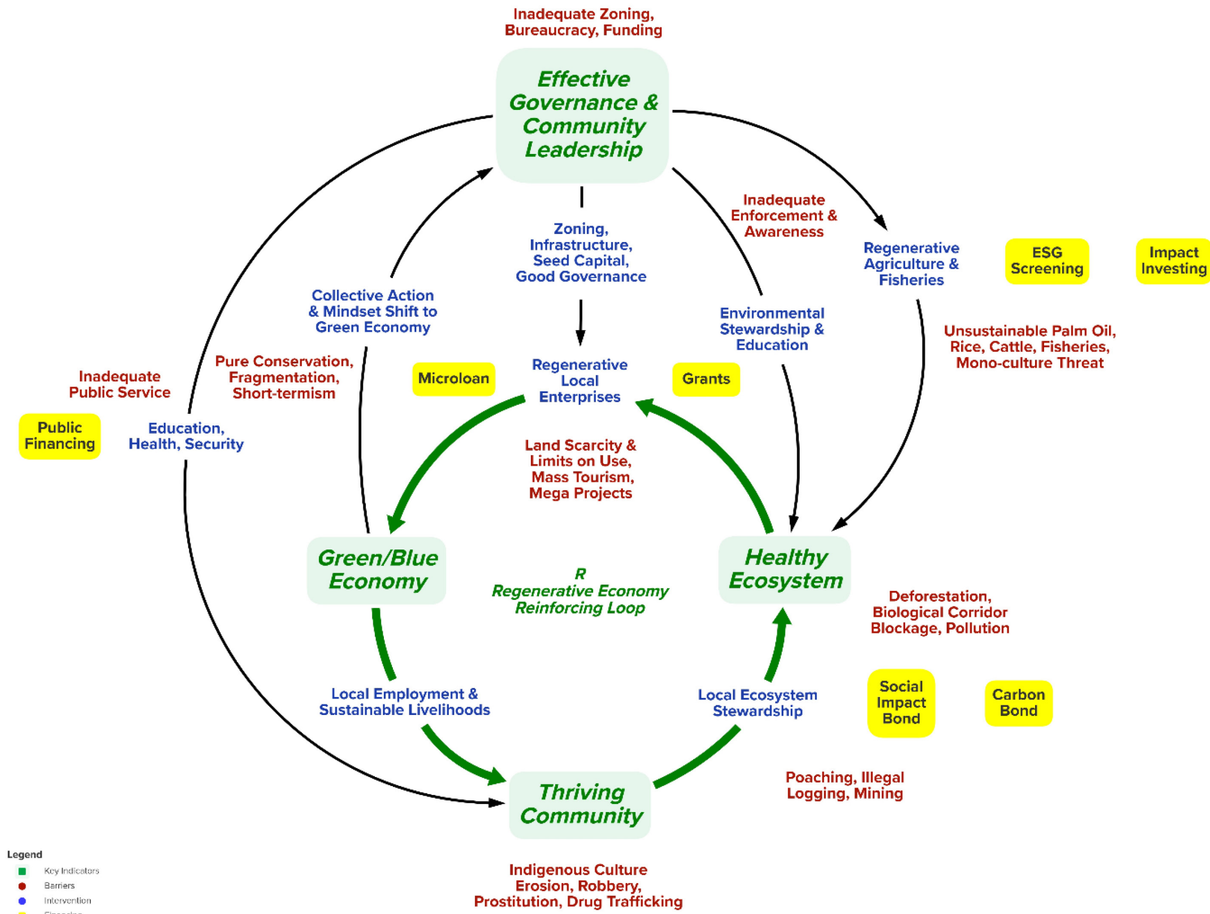


Figure 5. The OSA Golfito Systems Map developed by Joe Hsueh et al. (Note that this is a simplified version to highlight the key feedback loops, not the full map)[9]

[9] For a detailed walkthrough of the full system map, see https://kumu.io/simfo/systems-map-for-a-regenerative-rainforest-economy-in-the-osa-peninsula-costa-rica#systems-management-map

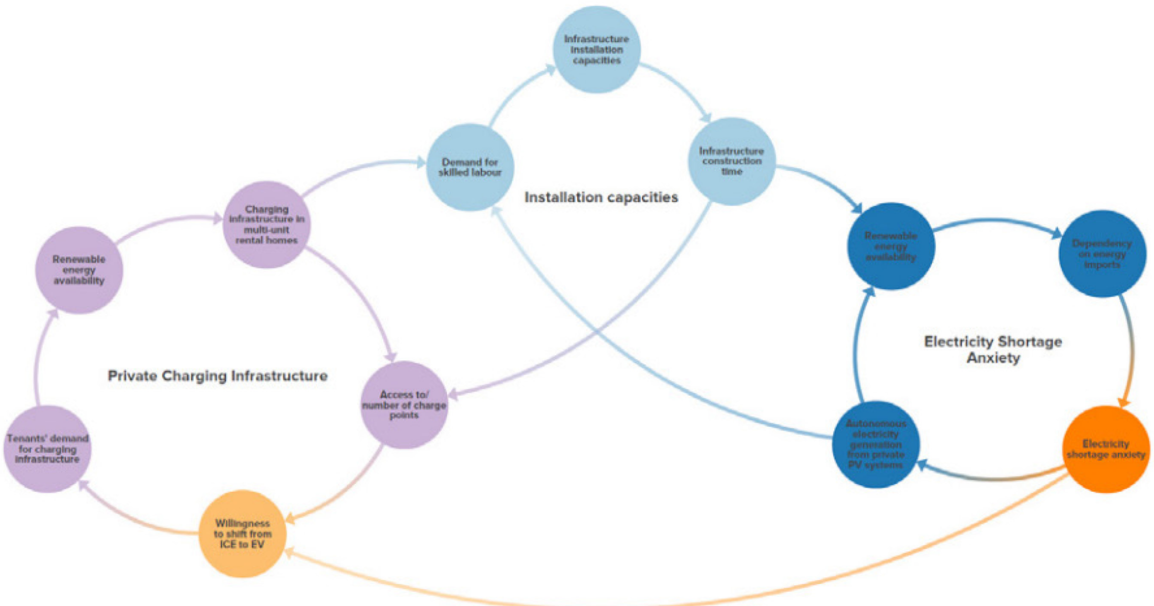


Figure 6. The Net-Zero Mobility Switzerland Systems Map developed by the TransCap Initiative (Note that this is a partial view to highlight the key feedback loops, not the full map)[10]

Stakeholder Relationships

Another important system intelligence investors find useful is stakeholder relationships. To identify how to engage with the existing networks relevant to their goals, investors need to understand "who is doing what" in the system and how they connect with each other. By mapping specific actors (elements), resources & needs of actors (attributes of elements), and actor relationships (links between elements), investors can identify the key players who share similar objectives or approaches, have significant influence, or control important resources or information. This can help investors find the right partnership in the space they are interested in; for instance, funders can explore the landscape of multi-stakeholder initiatives in the food system using The Global Food Systems Network Map (Figure 7) created by Meridian Institute. On the other hand, investors might also find the lack of relationship and trust among important stakeholders problematic. For instance, Regen Melbourne, an urban Doughnut Economics initiative in Melbourne, Australia, initiated their work on community activation and network facilitation after realizing that relevant stakeholders in the system do not have the necessary relationships to

[10] For a detailed analysis of this map, see https://transformation.capital/assets/uploads/The-TransCap-Initiative_Toward-a-System-Transformation-Strategy.pdf

enable change.[11] A better understanding of system stakeholder relationships also allows them to avoid conflict and duplication of efforts.

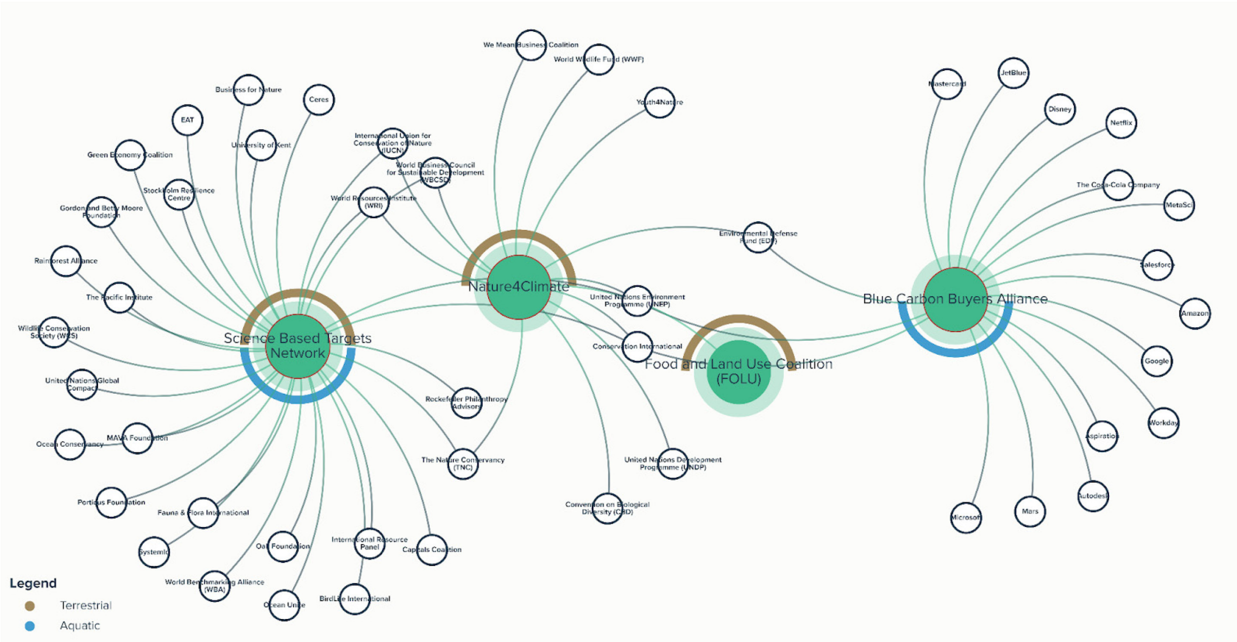


Figure 7. The Global Food Systems Network Map developed by Meridian Institute (Note that this is a partial view for demonstration, not the full map)[12]

Paradigms & Values

Many thought leaders in systems thinking believe that systems won't change without the shift of value and paradigm that created our current system in the first place (Meadows 2008; Scharmer 2016). Investors influenced by this school of thought are often convinced that new fixes might solve the problem in the short term until the pushback from the existing system entrenched in the old paradigm and the problem reemerges. Therefore, understanding the dominant mindsets and rules that guide current stakeholders' actions is critical for the change to last long-term. Many cases dedicate effort to discovering and shifting these problematic mindsets in their particular systems, such as "the elderly are the ones who need to be taken care of, not the ones who can contribute to the economy" or "impact is a drag on return instead of a source of value."

When utilized as investors' internal intelligence, these system understandings might help investors discover more impactful action areas to enable systems change. When

[11] For more detail about the community activation process, see https://www.regen.melbourne/news/towardsregenmelbreport
[12] For a detailed exploration of the map, see https://foodsystemsmap.merid.org/

the system inquiry process involves stakeholder participation, the system understanding can support the shared capacity to facilitate collective action and continuous learning. On this collective level, having “boundary objects” is important to help collaborate between different social groups, particularly when they have different perspectives, knowledge, or needs. A "boundary object," such as a tool, document, or even a physical artifact, is a concept from the field of sociology formed to help bridge the gap between diverse communities, allowing them to work together, share information, and achieve common goals while interpreting the object in ways relevant to their specific contexts (Star 2010, Star and Griesemer 1989). Using the impact investing industry, for instance, the five dimensions of the Impact Management Project (IMP) framework[13] can be seen as a boundary object. It was designed to be a shared logic for managing an organization’s impact, helping managers, investors, evaluators, and wider stakeholders communicate and collaborate to improve its impact effort. When it comes to investing for systems change, boundary objects can be in diverse forms that serve different functions. For instance, an ecosystem map can be utilized to illustrate connections between the activities of different stakeholders contributing to systems change, a causal loop diagram can be utilized to facilitate collective capital allocation to shift key dynamics, and a shared measurement dashboard can be utilized to help adaptive learning from the field and support bottom-up decision making.

3.2.2.2 Capital Deployment Method

Regarding capital deployment, we looked at two dimensions in investors’ practice. Firstly, do investors focus on one asset type or work across asset classes, including philanthropy? Secondly, how are the investment decisions made? Is it solely decided by the capital owner, decided by the capital owner but involving consultation with stakeholders, or decided by stakeholders?

Figure 8 shows the percentage of case studies categorized by these two dimensions. Two dominant deployment styles emerge from the sample. It seems that decision power held by capital owners tends to be combined with single asset class intervention. On the contrary, when investors deploy multiple asset classes, stakeholder consultation is more common in investment decision-making. These consultation processes range from soliciting deal input to engaging stakeholders to co-create intervention strategies. For instance, use the BreakFreeFromPlastic case study to demonstrate such consultation. This global systems change initiative began in 2016 to “transform a world where the land, sky, oceans, and water are home to an abundance of life, not an abundance of plastic.” The Oak Foundation funded the

[13] https://impactfrontiers.org/norms/

initial 18-month relationship-building, alignment, and strategy development phase, which included listening tours, convenings, coordination, and facilitation that brought global north and south together. A resulting pooled fund, The Plastic Solutions Fund, was launched based on the joint strategy proposed by the civil society core groups.

Letting stakeholders make the investment decision is rarer, with only one case study in single or cross-asset deployment. Investment decisions made by stakeholders require a more formal structure, allowing them to have seats in the investment committee. Use Hawaii Investment Ready (HIR)'s Hawai'i Food Systems Accelerator program for instance. This accelerator program aims to build a viable and resilient local food system in Hawaii. Stakeholder engagement was core from the beginning of the program, as most food actors were working in silos without talking to each other. HIR helped build trust among the stakeholders and brought them together to work in concert (the program now comprises the Enterprise Cohort and the Funder Cohort, two key stakeholders with the same objective). An Alternative Finance Debt Fund was set up to provide gap financing and technical assistance for enterprises underserved by the traditional capital market. Most importantly, every investment recommendation proposed by HIR is shared with the investment committee of food system stakeholders to finalize the investment decision.

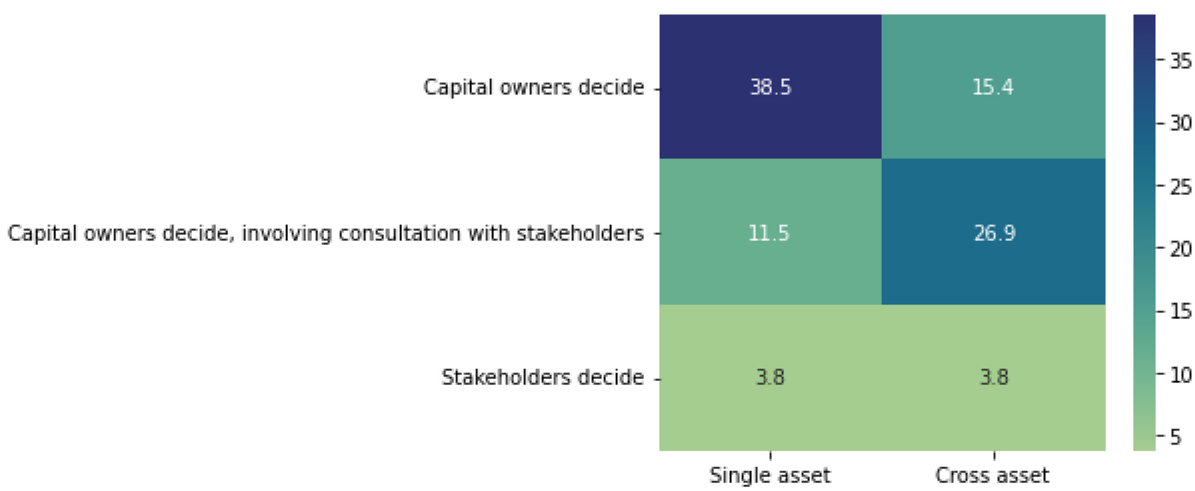


Figure 8. Investor's capital deployment method

3.2.2.3 Levers of Change

System understanding informs investors about the places in the system, or the levers, where investors can allocate their capital and effort to enable change. Our list of investor levers, derived from the case studies, is not necessarily exhaustive of ways to shift a system. Still, it does appear to be aligned with the existing literature (Burckart and Lydenberg 2021; Geels et al. 2017). The nine levers of change (summarized in Table 5) are discussed below, with examples from the case studies to illustrate how investors give life to these levers. Within each lever, investors can have different levels of involvement (Table 5, the third column), ranging from not involved to owned by investors.

Table 5. Investor's Levers of Change

<table>
<tr><th>Levers of Change</th><th>Brief Description</th><th>Investor's level of involvement</th></tr>
<tr><td>Solution Experimentation</td><td>Help to experiment and test the immature solutions that can directly prevent/address the challenge defined by investor</td><td rowspan="9">4 - Owned by investor
3 - Funded by investor, with extra investor contribution
2 - Funded by investor
1 - Engaged through partnership with others
0 - Not involved</td></tr>
<tr><td>Solution Scaling</td><td>Help to scale the proven solutions that can directly prevent/address the challenge defined by investor</td></tr>
<tr><td>Orchestration & Network</td><td>Foster collaboration and network of actors in the field that can potentially accelerate the solution development</td></tr>
<tr><td>Data & Knowledge</td><td>Generate knowledge or data that are important for the field to address the challenge</td></tr>
<tr><td>Human Capitals</td><td>Build human capitals (professionals/leaders) to advance the field</td></tr>
<tr><td>Physical Infrastructure</td><td>Build shared physical infrastructures that are critical for solution to function properly</td></tr>
<tr><td>Established Company Behavior</td><td>Change the established companies' behavior to facilitate solution development or directly prevent/address the challenge defined by investor</td></tr>
<tr><td>Social Norm & Public Awareness</td><td>Shift social norms and public awareness of the challenge</td></tr>
<tr><td>Policy & Regulation</td><td>Influence the policy, regulation, and standards that are critical to address the challenge</td></tr>
</table>

Solution Experimentation

Contributing to solutions in the system is the most natural avenue investors find themselves in. The solution defined here is any social or technological innovation in the form of products, services, business, and/or service delivery models that directly address or prevent the issues specified by investors, such as electric vehicles for the climate change issue or imperfect food channels for the food waste issue. Solution experimentation is a common lever in the impact investing industry, where angel investors, venture capitalists, or foundations provide equity investments, loans, or grants to organizations to test innovative but immature solutions. The uncertainties embedded in this stage of innovation development usually create a funding gap, and the emerging field of catalytic capital has been critical in trying to fill that gap. Some investors using this lever contribute extra through venture-building service, with general entrepreneurial knowledge and specific system understanding.

Solution Scaling

Another common lever for most impact investors is to scale the proven solutions existing in the system. This means providing growth capital to increase the magnitude of a proven or promising solution's quantity and quality to help create a larger impact. Investors can also provide technical assistance to the solution providers to increase capital efficiency and maintain mission lock at the stage when social enterprises pursue growth.

Orchestration & Network

Many investors initiate coalition building to create momentum and drive collective action. Some practitioners leverage the system mapping exercise not just for their own system understanding but also as part of a container-building process. The intention is to facilitate multi-stakeholder dialogue and create trust and alignment inside the network. Investors can also support dedicated multi-year staffing or a backbone organization to coordinate aligned action in the network, keep momentum, and accumulate collective learning. For instance, Regen Melbourne is an alliance of more than 180 organizations with a mission to co-create a thriving Melbourne within planetary boundaries. Initially, they are supported by 12 different funders who are deeply connected to Melbourne and want to invest in the collaboration they would like to see, not just single projects working in silos. Regen Melbourne thus became a platform for “deep collaboration, providing backbone functions for ambitious demonstration projects with moonshot goals that are not achievable by any single actor.” In these projects, Regen Melbourne catalyzes collective innovation, conducts collective measurement, and ensures activities by different stakeholders in the alliance are coherent.

Data & Knowledge

Data and knowledge infrastructure support all stakeholders in understanding the current state and trend of the system, learning how they might contribute, and making decisions based on evidence. In many cases, investors support creating the database and establishing a baseline of the issue to motivate impact-oriented actors and prove the market. The information serves as the basis for investment decision-making and helps mobilize more diverse capital to the system. Some partner with research institutions to develop issue-specific insights, open-source resources, toolkits, and frameworks to make the necessary information accessible for other stakeholders to take more effective actions. Take ReFED, an initiative fighting the food waste challenge in the United States. A group of investors behind ReFED helped support the launch of the "Insights Engine," an open-sourced interactive online data center, including solution impact and financial analysis, empowering stakeholders to make informed decisions based on quantitative analysis. With over 60,000 users and thousands of use cases, this platform allowed stakeholders, including large food companies, state governments, and startups, to delve into nuanced solutions tailored to specific challenges. Besides data, ReFED also generated original insights through extensive subject matter expert interviews and pilot initiatives involving distinct food companies. These interventions have gradually transformed the sector from acting on instinct to data and insight-driven decisions.

Human Capital

Human capital refers to individuals' knowledge, capabilities, and other attributes that contribute to their productive capacity to drive change. This is not only about entrepreneurs who create the solutions but also other stakeholders in the system, including people in the existing non/for profit organization, government officers, students, and new kinds of talent. Investors can invest in education organizations that train the technicians needed to transition to new technology or courses that develop new leadership in existing businesses. For instance, in an initiative to build a Regenerative Alpine Economy, the investor found the regional players to lack basic knowledge with respect to impact and regeneration and decided that strong education is needed. An 'Impact Academy' was established to educate all supporters, mentors, partners, investors, and co-creators. The investor even planned to expand the education to influence talents within the industry titans.

Physical Infrastructure

Besides serving as an enablement of operations, physical infrastructure often brings the connectivity for collaboration and potential for further investments. For many socio-technical systems, it becomes challenging, if not impossible, to implement and sustain the delivery of the solutions without adequate infrastructure. Businesses and investors are more likely to invest in regions or sectors with robust infrastructure, as it reduces operational risks and enhances market accessibility. It's worth noting that infrastructure investments are often made through project finance and debt-based mechanisms, which tend to be risk-averse especially when the infrastructure is related to cutting-edge technologies. Investors can play a crucial role in overcoming these challenges. For instance, in TransCap Initiative's Net-Zero Mobility Prototype in Switzerland, one of the key strategies is supporting the build-up of photo-voltaic (PV) systems and charging infrastructure for electric vehicles (EVs). Particularly, an emphasis was put on supporting infrastructure build-up for the underserved areas (where the utilization rate is lower) to attract further operation and funding.

Established Company Behavior
The practice of established companies is an important target for systems change, not only due to their significant scale but also because they largely influence the window of opportunity for emerging solutions. As current key actors in the system, established companies can have a wide-reaching impact through their operations, supply chains, and customer base, and their decisions and actions send powerful signals to the market, influencing customer preferences, demand patterns, and industry norms. In TWIST case studies, investors demonstrate two primary ways to change established company behavior. The first way is through innovation collaboration by setting up a vertical hub where investors bring innovation to experiment and try to transform from the bottom up. For instance, to fight the food waste challenge in the US, ReFED advised one of the largest American retail companies, Kroger, to launch their innovation fund, which became a valuable avenue for waste prevention technology startups to test their solutions in large corporate pilots. The second way is playing the "inside game" through relationships and investor pressure to push from the top down, often known as "shareholder engagement." For instance, to improve access to equitable reproductive health for women in the US, the Tara Health Foundation convened other investors to join a shareholder coalition. With over $500B in assets under management, this coalition has filed investor letters in 30 public companies to influence their internal health policies.

Social Norm & Public Awareness
Social norms shape individual and collective behavior within a society. They represent shared beliefs, values, and expectations that guide people's actions, including funders. A shift in norms and awareness can create a movement in consumers and businesses, mobilize more resources, and generate the political will to trigger institutional change. Investors have been found investing in multi-channel campaigns, such as events, press and publications, movies, and documentaries, to change the norm. They often engage the pioneers in the system to articulate new narratives around the system. For instance, when the BreakFreeFromPlastic initiative

began, the dominant narrative of plastic pollution was that it was caused by individuals behaving badly and failing to take responsibility for their waste. Leveraging the pre-existing annual global beach cleanup, movement groups launched, and donors funded a “brand audit” campaign to collect plastic waste on beaches, count the FMCG brand markings, and reveal that the top plastic polluters are huge companies, not individuals. A report and video were produced to name and shame the worst polluters and highlight the responsibility of these big corporations. This effort successfully flipped the script in the local-to-global narrative and fundamentally changed the frame and level of ambition in international dialogues about how to solve plastic pollution.

Policy & Regulation

Policy and regulation are often considered the most powerful lever for systems change as they set up the rules of the game. They are, however, also one of the most difficult elements to change. Policy-making and government decision-making vary significantly worldwide, while in most democratic countries, this lever changes very slowly and is full of conflict of interest. Investors usually help support or partner with campaigns to advocate for the necessary regulation to set up the right incentive for certain aspects of the system. For instance, the Fair By Design in the UK couples a venture fund with an advocacy campaign aiming to shift the policy agenda to end the extra cost of being poor.

Figure 9 summarizes the popularity of each lever from our case studies sample. Most investors participate in solution experimentation and network orchestration, while physical infrastructure and established company behavior are the levers with the least investor involvement. Taking a closer look into investors' different involvement levels (Figure 10), the pattern suggests that when investors participate, they tend to take the highest ownership in orchestrating networks and changing social norms. They often contribute to solutions by providing funding but engage with policy change through partnering with others. At first glance, it might be interpreted that the more ownership investors take, the better and more impactful they are. However, it’s debatable whether investors should play the dominant role in every aspect if we value a just and inclusive system change. We need to confront the question of how legitimate investors are to determine the evolution trajectory of a system consisting of multiple stakeholders. For instance, some investors are more comfortable with being a helper instead of leading the direction:

> *"My philosophy is to let the founders do what they want and ask me for help if they want it. Otherwise, I just provide capital."*

"What do I know what the community needs? They might be more knowledgeable than we [investors] are...So I think we can focus on whether my capital is helpful for them to achieve their goal and not put our judgment on what is needed for this community."

This is an ongoing conversation in the investor community and should be considered when investors shape their intervention strategies. Some of the efforts in the TWIST working group are trying to enable systems change in the financial system that relates to investors themselves in the system and address issues with power balance. This specific type sectiof systems change (metasystem) belongs to the most general system boundary (geography global and issue general) characterized in Table 3 in Section 3.2.1.1.

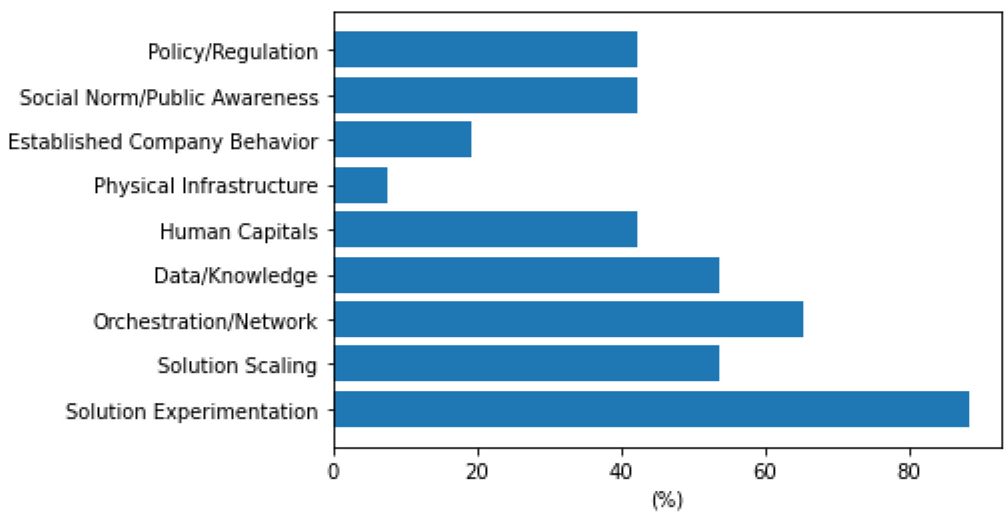


Figure 9. Investor's involvement in each lever of change

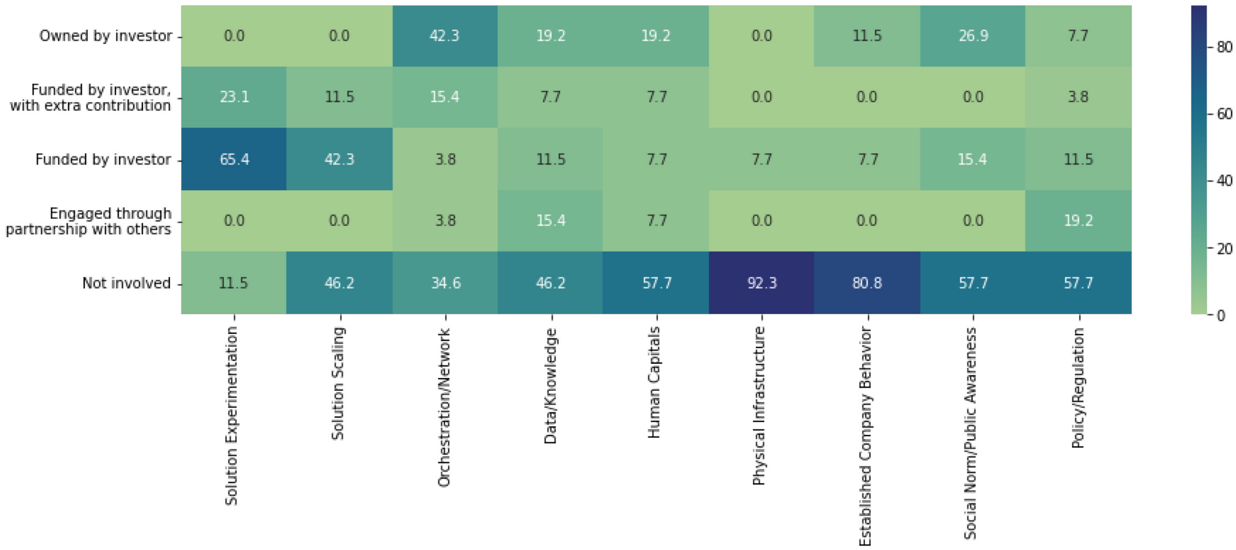


Figure 10. Investor's different involvement levels in each lever of change

So far, we discussed the nine levers of change in isolation as if they were independent of each other, like a list of checkboxes. However, investing for systems change is not merely a box-checking exercise. Instead, an investor chooses a set of interrelated efforts based on how she thinks the combination can create a route toward an endpoint. Thus, it's important to analyze the route: the investors' theory of how chosen levers lead the current system to change as they desire. We examine these process theories in the next section.

3.3 Analyzing investors' theories of systems change

Based on the pattern of the investor's involvement level in various levers of change, we clustered the case studies into emerging archetypes of practice combination. Specifically, we constructed a 9-dimensional space to represent the cases (each lever is one dimension with a value from 0 to 4, depending on the involvement level) and used the k-means method to cluster cases to a few cluster centroids (nearest mean value) that minimize within-cluster variance. The number of clusters is chosen to balance between optimizing the Sum of Squares Error (SSE) and the meaningfulness of clusters (for instance, it's meaningless if we have 26 clusters for 26 case studies). In our case, four clusters, each consisting of five to nine cases, turned out to be the sweet spot. Each cluster is defined as an archetype, representing a unique view of how investors believe systems change would occur; in other words, an investor's theory of systems change or theory of transformation. In this study, we aim to surface these mental models, recognize their existence in the investor community, and provoke reflexivity among investors who intend to change systems while leaving the judgment of plausibility and internal consistency of these theories to future research.

3.3.1 Emerging Archetypes of Investors' Theories of Systems Change

Four theory archetypes emerge through clustering case studies by the pattern of investors' involvement in each lever of change. The average behavior of each archetype is shown in Figure 11, with each color line representing one type of investor's theory of systems change. Within the same archetype group, while there are some variations among case studies, the investors appear to share the same core mental model of how these levers work in combination to change the system. Between the groups, investors have different prioritizations of levers and interpretations of their functions in the system. These four archetype theories are defined with these average investor behaviors and illustrated with specific case studies in our sample. To enhance the internal validity, the emerging archetypes are compared with existing literature (Eisenhardt 1989). Specifically, these archetypes of investors' mental models on system change are compared with the typology of socio-technical transition pathways (patterns synthesized from studies of the numerous historical transition trajectories) proposed by Geels and Schot (2007).

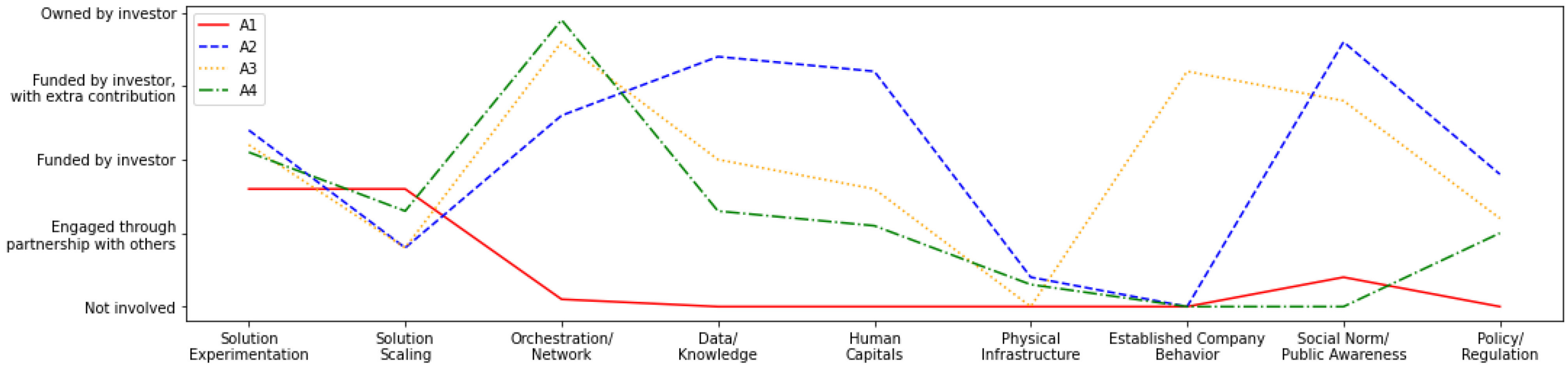


Figure 11. Four emerging mental model archetypes of investors for systems change

A1. Scale the superstar solution

This archetype is represented by the red solid line in Figure 11. Solution experimentation and scaling clearly stand out from all the other levers. Some variations exist among cases on social norms, but most investors (88%) in this archetype aren't involved in this lever. Our observation suggests that the investor focuses on experimenting and scaling a particular type of solution in this archetype. The investor believes the underlying enterprise has a high potential to fundamentally replace the current undesirable ways of delivering societal functions. Solutions are still emerging; the investor's role is to finance their development and help them reach a meaningful scale. The investor sees all other contextual factors as exogenous forces to create growth opportunities for the solution.

An example of this archetype is The Good Investors' effort to change Africa's charcoal cooking system. Charcoal, the primary cooking fuel in urban regions in Sub-Saharan Africa, is a major source of carbon emission, causes significant deforestation, and creates lethal health issues that affect millions of people. The Good Investors identified that liquid bioethanol is an emerging cleaner and safer solution and decided to invest in Koko Networks, a Kenya energy startup selling liquid bioethanol stoves and cooking fuel in replacement of charcoal. The decision was made because Koko Networks had the necessary infrastructure for last-mile delivery, had a replicable model to scale to other African countries, and could establish a long-lasting habit change attracting other players to come in. The Good Investors expect that by investing in Koko Network and helping scale the solution, a new sector will naturally form and ultimately replace the current charcoal cooking system, addressing the multifaceted challenge of environment and health. Additionally, the growing trend of the carbon credit market is also expected to generate more revenue for the solution and help to grow Koko Network even faster.

This theory archetype resembles the “Technology Substitution” pathway, one of the four socio-technical transition pathways from a framework commonly cited in the system transition and change community (Geels and Schot 2007). In this pathway, the “socio-technical regime” (a combination of incumbent industry, technology, policy, culture, science, market, and user practice) remains dynamically stable and entrenched even with the existence of developed “niches” (micro-level novelties that are initially unstable but have potential to break through radically) because of the strong mutually reinforcing relationship between incumbent actors. The transition becomes possible when outside shock and the “socio-technical landscape” (the exogenous, gradually changing environment beyond the influence of niche or regime actors) exert pressure on the regime, creating a window of opportunity for niche innovations. Because the niches have been developed and accumulated momentum, they diffuse into the mainstream market and compete with the incumbent. Geels and Schot (2007) noted in the original pathway description, "If the innovation replaces the old technology, this leads to knock-on effects and wider regime changes. Hence, this pathway has a technology-push character, where wider co-evolution processes *follow* substitution." This reflects the mental model of investors in this archetype: the technology solution will *lead* the broader change process. So, an investor's job is to correctly identify the landscape pressure (in Koko's case, it's the growing concern on climate and human rights and the emerging carbon market) and finance the scalable niche solution that is essential, as investors believe, to the change they envision. The rest would evolve spontaneously to change the system.

This mental model is illustrated by another investor in this archetype who invested in technology to address the exploitative business model of the biggest technology monoliths, who make their users the product:

> *"If hundreds of millions of people use this technology, then value and impact will be created by the people and for the people - with real-time social intelligence of the people ... thus unlocking opportunities for impact rating, analyzing beneficiary behavior, moving from shareholder value to stakeholder value, and enabling massive democratization of active participation in value and impact creation."*

A2. Create evidence to challenge the rules

This archetype is represented by the blue dashed line in Figure 11. High involvement in levers of data/knowledge, human capital, and social norms is the fingerprint of this archetype, with 80% of investors in this group either taking ownership of or having an extra contribution to at least two of the three levers simultaneously. Our observation suggests that in this archetype, the investor focuses on challenging the social norms and policies that hold the current system in place. The investor believes new knowledge is essential and can be utilized for narrative building and new talent training, ultimately supporting societal rule changes. Thus, the investor prioritizes collecting or creating supportive data and knowledge by funding a few innovative projects that align with the new paradigm and value.

An effort to challenge systemic ageism in Colombia by FAES (Fundación Arturo & Enrica Sesana) demonstrates a good example of this archetype. Ageism typically involves negative attitudes, stereotyping, or discrimination towards older people and is particularly concerning in Latin America and the Caribbean because of the aging population and insufficient retirement scheme. The dominant social norm considered the elderly as the ones who need to be taken care of instead of the ones who can contribute to the economy, and the resources available for older individuals were guided by welfare-like standards, reinforcing this stereotype. FAES has supported the data collection of public perception of the elderly and created diverse knowledge on aging in Colombia to advance the advocacy capacity of other stakeholders. They partnered with more than 10 organizations, including foundations, academia, the public sector, and others, to create an impact investment fund dedicated to financing businesses led by senior citizens through a hybrid of debt and grant seed funding, along with non-financial support. This intervention has empowered the elderly to view their age positively, and the resulting successful stories were utilized as evidence to prove to banks and traditional investors that investing in the elderly is attractive. FAES further crafted the narrative, from welfare and care to work and productive inclusion, and spread among specific actors to redirect their norms, routines, and public policies. For instance, they lobbied the Inter-American Convention on human rights for senior citizens and moved the government agency responsible for entrepreneurship programs to create public funds for the elderly.

This theory archetype resembles the “Transformation” pathway in the socio-technical transition pathways typology (Geels and Schot 2007). In this pathway, the niche innovations are not mature enough to challenge the regime when the landscape change arrives. Therefore, unlike the technology substitution pathway, no direct competition happens, but pressure could form out of the misalignment of the emerging change and the existing practice. The pressure creates tensions, conflicts, or power struggles, gradually reorienting regime actors. The bottom-up actor adaptation (evolutionary dynamics) and top-down policy and rule change (social-institutional dynamics) interact and transform the regime from within. However, the regime actors do not necessarily perceive the initial landscape changes as pressure. Stakeholders such as societal pressure groups, professional scientists, outside firms, and entrepreneurs are important in mobilizing the public's social movements and drawing the regime’s attention. As Geels and Schot (2007) elaborated, “Demonstration of viable alternatives may change perceptions of regime insiders and lead to reorientations of activities…Dedicated translation activities are important in such niche-regime interactions.” Investors in this archetype see solution investment not so much as a direct replacement of the old but as an inspiration, integrated with dedicated translation through other levers, such as building knowledge and human capital, to push adjustment of regime rules.

Another investor in this archetype shared the mental models behind investing in a fund for gender financial inclusion in low-income countries:

> *"The fund makes venture investments in early-stage inclusive financial institutions, including fintech. The GP, a global non-profit with decades of expertise advising on financial inclusion in emerging markets, assists its portfolio companies in implementing gender inclusion practices. The goal is to demonstrate that these practices can help companies achieve faster growth and higher valuation due to higher market share and higher margins, as women tend to be lower-risk customers…They also have done a lot in culture and communication, working on providing courses on gender inclusion for banks and regulators…the hope is to generate reinforcing loops in two ways. One is that other financial service providers will copy the success driven by gender-smart practices. Another is pushing institutional LPs in emerging markets to allocate more resources to products that seek to support gender diversity as they demonstrate the potential for superior returns."*

A3. Build an inclusive stakeholder ecosystem

This archetype is represented by the yellow dotted line in Figure 11. Involved across many levers, investors in this archetype are particularly characterized by their dedication to building networks and engaging established companies. All investors in this group either take ownership of or have an extra contribution to orchestration and at least funding activities to influence existing companies' behaviors. Our observation suggests that in this archetype, the investor focuses on creating a symbiotic environment for emerging solutions and incumbents around a societal problem. The investor believes an inclusive ecosystem that works with the established players is needed for changes to occur, and investors play a role in its development. The investor thus puts significant effort into orchestrating networks of stakeholders, including other investors and incumbent firms. The investor uses solution implementation for demonstration projects that prime the pump of the sector. This also requires investing in data, knowledge, and public awareness to make the case for why these actors should join the new ecosystem.

An example of this archetype is an effort to end food waste across the food system in the United States by The Betsy and Jesse Fink Family Foundation and ReFED. Every year in the US, one-third of food produced ends up in landfills or incineration, responsible for about 6% of US Greenhouse Gas (GHG) emissions and 22% of water usage. At the same time, one-tenth of Americans are food insecure despite a huge food surplus. However, the problem did not attract much attention before the 2010s. The Betsy and Jesse Fink Family Foundation initiated a country-wide multi-stakeholder engagement, co-created a national roadmap to eliminate food waste, and established a backbone organization, ReFED, to build the food waste reduction ecosystem. ReFED used its limited resources on three things. First, they built a data infrastructure to provide insights into food waste problems and solution landscapes that empower others to take action. Second, they catalyzed more capital into the space by initiating funds to provide catalytic capital for the early-stage solution experiments and organizing a funder circle to educate other investors. Third, they convened a network across private and public sectors and mobilized the whole food supply chain by helping them see food waste as an opportunity to reduce the bottom line and contribute to corporate sustainability. In addition, the Betsy and Jesse Fink Family Foundation also emphasized cultivating human capital, both professionals and students, in the food waste reduction ecosystem through informal mentorships and formal fellowship programs. All these efforts created momentum in this new field. Investable and grantable solutions across different areas emerged, capital flowing into the food waste space grew significantly over the years, and more food industry players committed to sharing private data on food waste and collaborating to change. This particular story is detailed in Section 4.2 *Deep Dive into a Case Study: US Food Waste Challenge.*[14]

This theory archetype resembles the "Reconfiguration" pathway in the socio-technical transition pathways typology (Geels and Schot 2007). The niches are developed in this pathway and have a symbiotic relationship with the regime actors. When the landscape pressures the regime, the latter adopts niche innovations as component replacements to solve local problems. When multiple component innovations combine and substantially change the basic architecture of the regime, the system undergoes a reconfiguration transition. Geels and Schot (2007) emphasize the importance of multiple-component change by pointing out that "The reconfiguration pathway is especially relevant for distributed sociotechnical systems that function through the interplay of multiple technologies (agriculture, hospitals, retailing). In these distributed systems, transitions are not caused by the breakthrough of one technology, but by sequences of multiple component innovations." This is reflected in the two aspects of the systemic practice by investors in this archetype. On the one hand, solution development, orchestration, new knowledge, and human capital are prioritized to ensure the development of multiple niche innovations across the value chain. On the other hand, data, public awareness, and established company engagement are combined to ensure the landscape

[14] This case study is separately published by the author on SSRN: http://dx.doi.org/10.2139/ssrn.4615351

pressures are seized and amplified so that the regime continuously adopts niche innovations.

Another investor in this archetype focuses on improving access to equitable reproductive health for women in the US and illustrates this mental model:

> *"With our grant funding of approximately $1.5M, we helped build the infrastructure at Rhia Ventures and then investing with $5M as an anchor LP, we have been able to catalyze $38M toward developing new reproductive health technologies spanning from improving quality of care in maternal health to innovative hormone-free contraceptive...Rhia Ventures also builds business cases and publishes white papers to support why quality reproductive health is a business imperative for companies. We help build a coalition with AUM of over $500B and file investor letters in 30 public companies on the quality of reproductive health coverage for their employees, with proxy votes up to 46%."*

A4. Organize a disruptor club

This archetype is represented by the green dashdot line in Figure 11. This archetype is very similar to A3 in most levers, specifically on network building, as all investors in this group also either take ownership of or make an extra contribution to orchestration. The feature that sets A4 and A3 apart is that none of the investors in this archetype is involved in changing established company behavior or social norms. Our observation suggests that in this archetype, the investor focuses on orchestrating a group of innovators and potentially other investors who cover the value chain of the disruptive niche. The investor believes it takes healthy soil to successfully grow a disruptive solution and push it across the tipping point to challenge and ultimately replace the incumbent firms. Therefore, if the disruptive solutions need specific knowledge, talents, and physical infrastructures to grow, investors play a role, among others, in building this necessary soil.

An effort by the TransCap Initiative to build a net-zero mobility system in Switzerland demonstrates a good example of this archetype. The mobility sector accounts for the highest sectoral Greenhouse Gas (GHG) emission in Switzerland, where privately owned internal combustion engine (ICE) cars are pervasive. Electric vehicles (EVs) emerged as a disruptive solution but were still far from reaching the critical mass to transform the sector. The TransCap Initiative engaged with stakeholders across the EV value chain and mobility experts to prioritize key interventions for accelerating transportation electrification in the country. Their investment strategy first focused on both the EV charging infrastructure and clean energy infrastructure built-up, including in the underserved areas, to ensure the attractiveness of EV solutions. They also recognized the importance of human capital needed to install those infrastructures and prioritized boosting the installation capacity in the industry. Not only did they want to promote a transition from ICE to EV, but they also strived to incentivize people to adopt alternatives to car ownership that can further decrease the number of cars on the road. Therefore, another strategic priority was to popularize mobility as a service in Switzerland and partner with others to shift the government's urban planning to become less car-centered. The TransCap Initiative played a role in orchestrating the actors and hoped to bring synergy into the effort.

This archetype doesn't map well directly to any specific socio-technical transition but shares important features with the "Technology Substitution" pathways (Geels and Schot 2007). Similar to A1, the ultimate goal of this pathway is to substitute the current dominant technology or practice held by incumbents. This competitive rather than symbiotic relationship with the regime is the key differentiator for A4 and A3. While investors in both archetypes emphasize ecosystem orchestration, A4 investors focus a lot more on the "niche innovation" value chain, excluding the incumbent. Although A1 and A4 investors share the same goal on technology substitution, they disagree on the process to reach the goal. Investors in the A4 archetype see the wider co-evolution process happen simultaneously with the solution development and require careful coordination. In contrast, A1 investors believe the broader change would follow the technology substitution. This makes A4 different from the previous three and should be considered a unique archetype.

One investor in this archetype articulates their strategies that perfectly reflect this mental model:

> *"We want to transform Hawai'i's current extractive and fragile economy, heavily tied to American capitalism, by accelerating the coordination and collaboration of capital to seed and scale local systemic solutions...the strategies over the next 3 to 5 years are focused on our soil-building work: capacity building, demonstrating capital navigation and deployment, consulting and partner support, research and data, and growing ourselves to be a stronger container for this work. These work us toward cultivating the following conditions: the enterprises are fully supported and have what they need to succeed, the wealth holders are collaborating to invest, and the capital infrastructures are in place to support the capital flows that create additional values."*

These four mental model archetypes observed in our sample (*A1. Scale the superstar solution, A2. Create evidence to challenge the rules, A3. Build an inclusive stakeholder ecosystem, A4. Organize a disruptor club*) are not exhaustive to represent all the efforts in the larger community of investors who aim to change systems, where more nuanced ideas are continuing to emerge. We also don't exclude the possibility of investors switching between mental models when the context of a system shifts. They are simply a starting point for us to understand the investors' behaviors in this emerging field and for investors to reflect on how they prioritize efforts. In the next section, we use these four archetypes as a basis to differentiate case studies and analyze how they correlate with the investors' other practices.

3.3.2 Analysis of Archetypes

How do investors in these emerging archetypes differ along other key dimensions of their behavior? We found that system sensemaking and capital deployment methods appear to align with these archetypes, converging to similar patterns within each archetype and differing across archetypes. We were surprised to find that intentionality for systems change does not align, varying within archetypes without converging.

3.3.2.1 System Understandings Align with Behavioral Archetypes

We observe heterogeneity in investors' system understanding (as defined in section 3.2.2.1) across archetype groups, as shown in Figure 12: investors in each archetype seem to prioritize four system understandings very differently.

Investors in Archetype A1 (Scale the superstar solution) put more emphasis on understanding the system's *value chain and functional process*. Their investment thesis is often formed through a thinking process described by an investor in this group as "XXX *is the single largest cause of the problem, and we need to identify what the main blockages are in the value chain and where our ability as a family can make a difference*..." In the aggregate, however, this archetype group tends to rely less on systems understanding than the average among all case studies.

Archetype A2 (Create evidence to challenge the rules) shows a different pattern. All investors in this group have an understanding of the underlying *paradigm* they want to change in their systems. Investors would say, for instance, "*We are pushing corporations to switch to steward ownership from the current dominant paradigm of shareholder ownership of companies...we define our success as the dynamic change within the relationship between investors and companies in the market.*"

Investors in Archetype A3 (Build an inclusive stakeholder ecosystem) heavily adopt the understanding of the value chain and stakeholder relationships in the form of different ecosystem maps. The understanding usually helps investors to come to a deeper realization of the problem they are tackling, illustrated by one of the investors in this group, "*...you start to realize that if you are trying to solve a systems-level problem using a variety of bespoke approaches, you could be creating negative consequences or shifting problems to other areas of the supply chain.*"

Finally, investors in archetype A4 (Organize a disruptor club) pay much more attention to the causal mechanisms than the other three and often couple it with an understanding of the system's value chain. Investors armed with these two understandings seek high-leverage interventions to build a new system to challenge the incumbents. For instance, investors in this group would create investment strategies by *"mapping the system and identifying investable interventions to activate leverage points. Those leverage points, targeted by a strategic portfolio of multi-asset class investments and nested within a broader system intervention approach, are to unlock combinatorial effects and trigger a transition in..."*

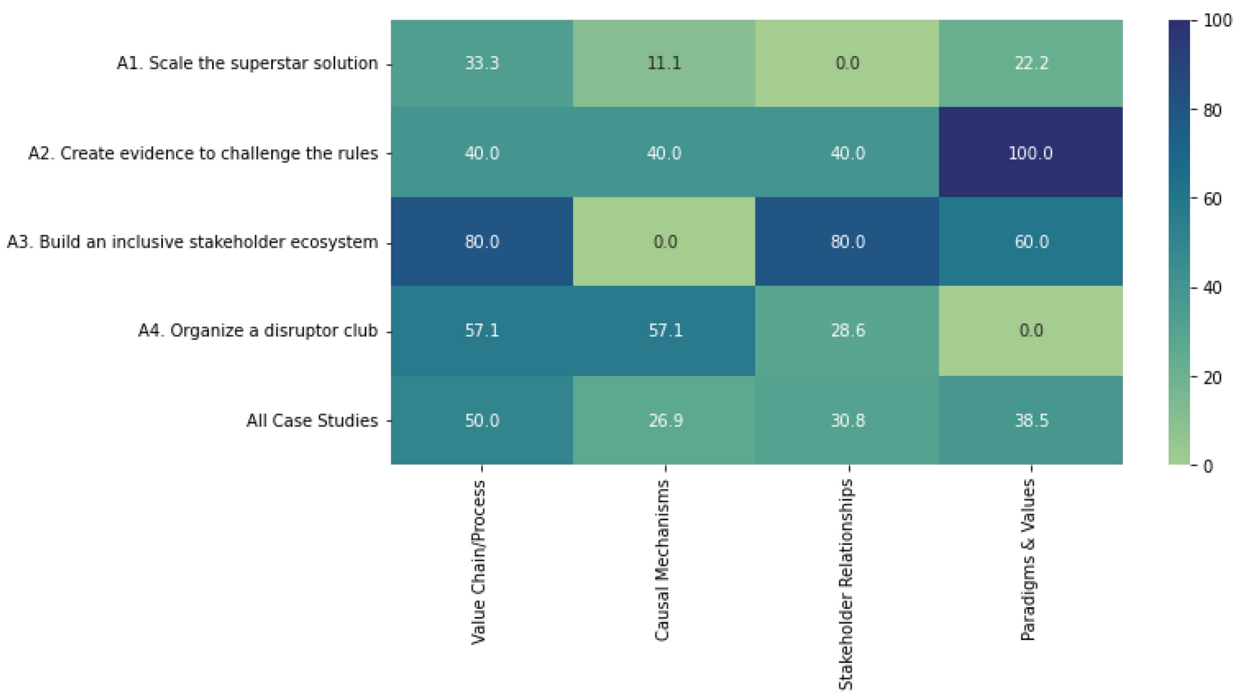


Figure 12. Investors' System Understandings in each Archetype

3.3.2.2 Capital Deployment Methods Align with Behavioral Archetypes

Investors in different archetypes also show slightly different patterns in capital deployment methods (Figure 13). None of the investors in A1 deploy cross-assets to intervene. On the contrary, at least 60% of the investors in the other three archetypes do. Using archetype A3, for instance, one of the investors in this group emphasized the need for a cross-asset class and blended capital approach to building the ecosystem:

> *"Many of these systemic change efforts need a substantial amount of philanthropic capital to get going with follow-up investments using subsidized debt, commercial debt, and equity capital structures. In regions where the players lack basic impact knowledge, education and field-building needs to be funded philanthropically…which then creates follow-up opportunities for using blended capital structures, like for impact accelerators."*

Stakeholder participation in the capital allocation process also differs, as investors in archetypes A1 and A2 seem to involve stakeholders less, while those in A3 and A4 tend to either consult or empower stakeholders in the decision-making. One potential explanation is that orchestration is essential in archetypes A3 and A4, and it requires some stakeholder involvement in capital deployment so that the orchestration effort won't be undermined. A more detailed analysis of how different investors operationalize the stakeholder voices is needed in future studies.

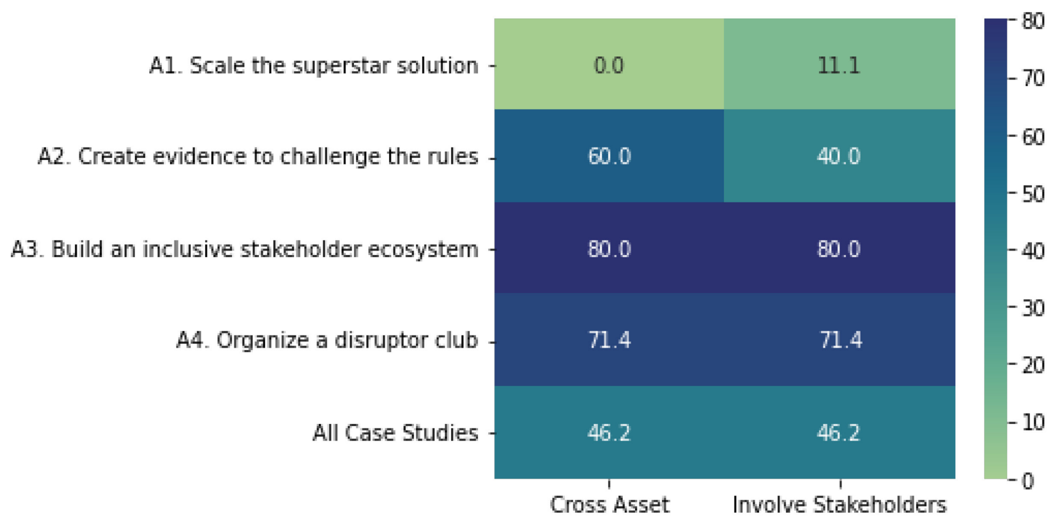


Figure 13. Investors' Capital Deployment Method in each Archetype

3.3.2.3 Investor Intentionality Varies within Behavioral Archetypes

To our surprise, investors' intentionality (system boundary and change goal) doesn't show any similar pattern within archetypes and has no significant difference across archetypes. For instance, the change goals of "partial system redesign" (n = 14) and "system transformation" (n = 12) are evenly split among almost every archetype group[15]. Therefore, investors' "ambition level" of the systems change effort doesn't correlate strongly with their mental model on the "process" of systems change; namely, investors might choose different routes to achieve a similar goal. This doesn't mean that intentionality and practice have no correlation at all because investors' participation level in individual levers might still vary within the archetype group (that highlights only the most prioritized levers).

If we aggregate all cases, no matter what archetype investors are in, Figure 14 shows the difference in investors' participation in various levers of change when they articulate their intentionality as "partial system redesign" or "system transformation." While scaling proven solutions prevails in partial redesign efforts, it's less so in transformation efforts. Some investors, including the one quoted in the previous paragraph on the need for a cross-asset approach, expressed the difficulty of finding existing solutions that meet their aspirations when they have transformative ambitions. Other differences between investors aiming for partial redesign and transformation lie in the involvement in orchestration and human capital. One of the common themes of system transformation efforts that appeared in investors' presentations is the limitation of silo actions in changing a combination of technology, user practice, and industry structure. This often requires investors to orchestrate an expanded network, sometimes including incumbents, to transform collaboratively. One investor focusing on system transformation illustrates this well:

> "*I was the first convener and put together the first core team…and now we're a concentric circle about 30 to 40 people that actually have a stake in what we do in the outcome…so now the question is how we get to the next concentric circle, to get to people who we want to activate to make a difference in their networks and give them a tool to do that.*"

Another recurring pattern in system transformation efforts is that investors often build their own "academy" for capacity building as transformation requires totally new skill sets and mindsets. This might partially explain the higher involvement in the human capital dimension in system transformation.

[15] Specifically, the proportion of "partial system redesign" is 56% in T1, 60% in T2, 40% in T3, and 57% in T4.

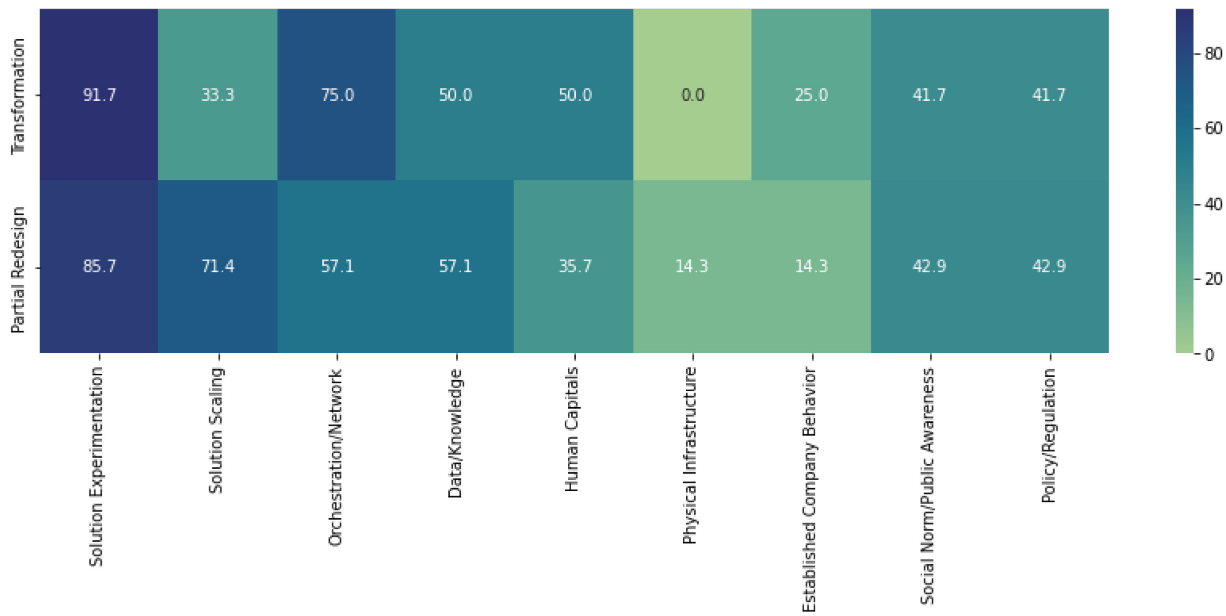


Figure 14. Investors' participation in levers of change varies with their change goal

To summarize, although investors' intentionality might have some influence on their involvement in individual levers of change, the prioritized levers and how investors see their role in the change process seem to be independent of the system boundary and change goal investors choose. In other words, investors have different mental models on how to enable systems change even when they have similar intentionality. Emerging from our sample are the four mental model archetypes of investing for systems change (summarized in Table 6), each representing a unique view of the investor's role in the process, relationship with incumbents, required system understandings, and prioritized levers of change.

Table 6. Four emerging mental model archetypes of investing for systems change

Archetypes	Investor's Main Role	View on Incumbents	Prioritized System Understandings	Prioritized Levers of change	Fit with Transition Pathway Typology
A1 Scale the superstar solution	Identify the landscape pressure/ opportunities and finance scalable solutions to replace the current regime.	Competition	1. Value Chain/ Process	1. Solution Experimentation 2. Solution Scaling	Substitution Pathway
A2 Create evidence to challenge the rules	Support innovations with similar values as a source of inspiration for others, educating the market and building new norms and narratives alongside concrete solutions.	Symbiosis	1. Paradigms & Values	1. Solution Experimentation 2. Data/Knowledge 3. Human Capital 4. Social Norm/Public Awareness (Vary across cases: Orchestration/Network, Policy & Regulation)	Transformation Pathway
A3 Build an inclusive stakeholder ecosystem	Support multiple niche innovations across the value chain and build a network that amplifies pressure and increases innovation adoption in the current regime.	Symbiosis	1. Value Chain/ Process 2. Stakeholder Relationships	1. Solution Experimentation 2. Orchestration/Network 3. Established Company Behavior 4. Social Norm/Public Awareness (Vary across cases: Data/Knowledge, Human Capital)	Reconfiguration Pathway
A4 Organize a disruptor club	Build enabling conditions for disruptive niche solutions and push them across the tipping point to replace the current regime.	Competition	1. Value Chain/ Process 2. Causal Mechanisms	1. Solution Experimentation 2. Solution Scaling 3. Orchestration/ Network (Vary across cases: Data/Knowledge, Human Capital)	Substitution Pathway

3.4 Discussion

Returning to our empirical question, how do impact investors behave when "investing for systems change"? In contrast to normal impact investing, investors aiming for systems change behave differently both in their intentionality and practice. They define their intentionality not in terms of isolated impact but a structural change (i.e., partial system redesign or transformation) in a specified system boundary (regarding geography, issue, and socio-technical system or natural ecosystem). Based on their mental models of how systems change occurs (the four archetypes), they identify the types of system understandings (value chains, causal mechanisms, stakeholder relationships, and underlying paradigms) that are valuable for their purpose and then use these understandings to operationalize specific levers of change for investors to take action—specific interventions and involvement level. They often use multiple types of capital to intervene across levers and involve strategic orchestration through a systems lens. Many of them involve stakeholders in the system understanding process (with boundary objects) and capital decision-making process (consultation or formal investment committee), decentralizing the investor's role.

The analysis also shows that investors might behave very differently when they have the same claim to "invest for systems change" - they can still differ in the scale of system boundaries, their ambition level of change goals, and their mental models of how system change evolves. We especially emphasize the importance of understanding investors' mental models of systems change. As shown in Section 3.3.2, even when investors have similar intentionality (system boundary and change goals), they can have different ways to operationalize systems theories, deploy capital, and prioritize levers of change. The four emerging archetypes presented in this paper provide a way to make sense of these differences and build the foundation for further investigation. The suitability of each archetype might depend on different factors in the problem landscape and solution landscape of the system investors aim to change, as well as investors' backgrounds and capabilities. Future work can analyze the real driver of the difference and help understand what type of mental model is more useful and when.

We recognize the limitations of this study (detailed in section 3.1.3). The sample used in this study is small (N=26) and biased on private wealth impact investors in the TWIST working group. In addition, the archetypes analyzed in this study are primarily based on self-reported data, as the empirical evidence and data about these approaches are too scarce. The archetypes should be evaluated as the field grows and more third-party data becomes available. In addition, although our initial analysis of investor behavior helps clarify some aspects of what “investing for system change” might mean and could look like, many important conceptual and operational puzzles remain unexplored. In the next chapter, the operational question of intervention strategy is explored.

Chapter 4

Theory Building through a Simulation Model Grounded in Single Case Study—Strategic Portfolios in Systemic Investing

This chapter explores investors' systemic practice, especially their decision-making on where to intervene in the system and the construction of strategic portfolios. Chapter 3 shows that many investors adopt a multi-pronged approach in their intervention. One might wonder, is the ultimate systemic investing strategy to influence "everything everywhere all at once"? This chapter argues this is not the case. Given the resource constraints investors have, there are choices to be made—capital and effort allocation among a few selected levers at different times. This strategic portfolio construction requires a more complex understanding of the interdependent choices in the intervention strategy. A more in-depth case study and a simulation model can help develop such an understanding. This chapter documents a narrative case study on how systemic investors conceptualize their intervention strategy and how it influences the system over time. Using this grounded empirical study, this chapter also constructs a simulation model to capture the system's key interdependencies, inertia, and feedback loops to provide a more nuanced view of systemic investing practice.

4.1 Methodology

4.1.1 Introduction

To answer the design question—How might we support investors' systemic practice and intervention strategy to enable systems change? —the objectives of this research are:

1. Identify practical choices and make them explicit in systemic investors' intervention strategy.
2. Investigate the assumptions and system context that might influence the outcome of systemic investors' intervention strategy.

In the next section, we outline the research methodology used in this study to explore these two objectives and to build general strategy intuitions for systemic investors.

4.1.2 The Research Design

In sustainability transition studies, three main approaches are generally adopted—with different perspectives and strengths—to analyze systems change: (a) initiative-based learning, (b) socio-technical analysis, and (c) quantitative system modeling (Turnheim et al. 2015). Trade-offs exist in individual approaches; for example, one needs to prioritize generalizability (e.g., building a generic transition model) or accuracy (e.g., developing a narrative case study). This research employs an approach to combine a narrative case study of a systemic investing initiative—to identify practical choices in its intervention strategy—and use the empirical context of the case study to ground a simulation model—to explore the dynamics of different intervention strategies. It follows the suggestion made by Papachristos (2014):

> "...An alternative approach would be to build middle-range models based on narratives developed from case study analysis. The combination of narratives and a rigorous modeling and simulation methodology with due attention to the richness of data would increase the coherency and confidence in the transition narratives...Good modeling practice compels the researcher to specify the relationships between system elements and thus to construct transparent, parsimonious transition narratives."

In this study, we chose the US food waste systemic challenge as our empirical context because (a) we were aware of the systemic approaches investors took to tackle this particular problem, (b) the challenge has a reasonable geography and issue specificity which make it tractable, and (c) food waste is a contemporary case that resonates with people and has attracted many studies in recent years, offering rich empirical information.

Our case study was conducted partnering with ReFED, a non-profit organization dedicated to solving the food waste problem in the US.[16] The qualitative data collection method was a series of semi-structured video interviews coupled with an online visual collaboration platform for facilitating interviewees' elaboration of

[16] https://refed.org/

complex relationships (see Figure 15 for example). Interviewee's responses are captured in real-time and visualized on the shared board. This process allows quick correction and deep reflection by interviewees. The stakeholders interviewed in this study all work in the US food waste reduction ecosystem, including funders/investors, for-profit & non-profit food waste reduction solution providers, conveners, and food producers/service providers. The sampling strategy was pursued to balance the investors' perspective and the broader ecosystem. In total, we conducted 13 recorded and transcribed interviews (see summary Table 7), in which we focused on understanding (a) the interconnections among system components from the interviewee's experience and (b) concrete examples of their behavior pattern and decision rules. For example, for investors or funders, we seek to understand their intervention strategies in food waste reduction and investment rationales. An example of a semi-structured interview protocol is provided in Table 8.

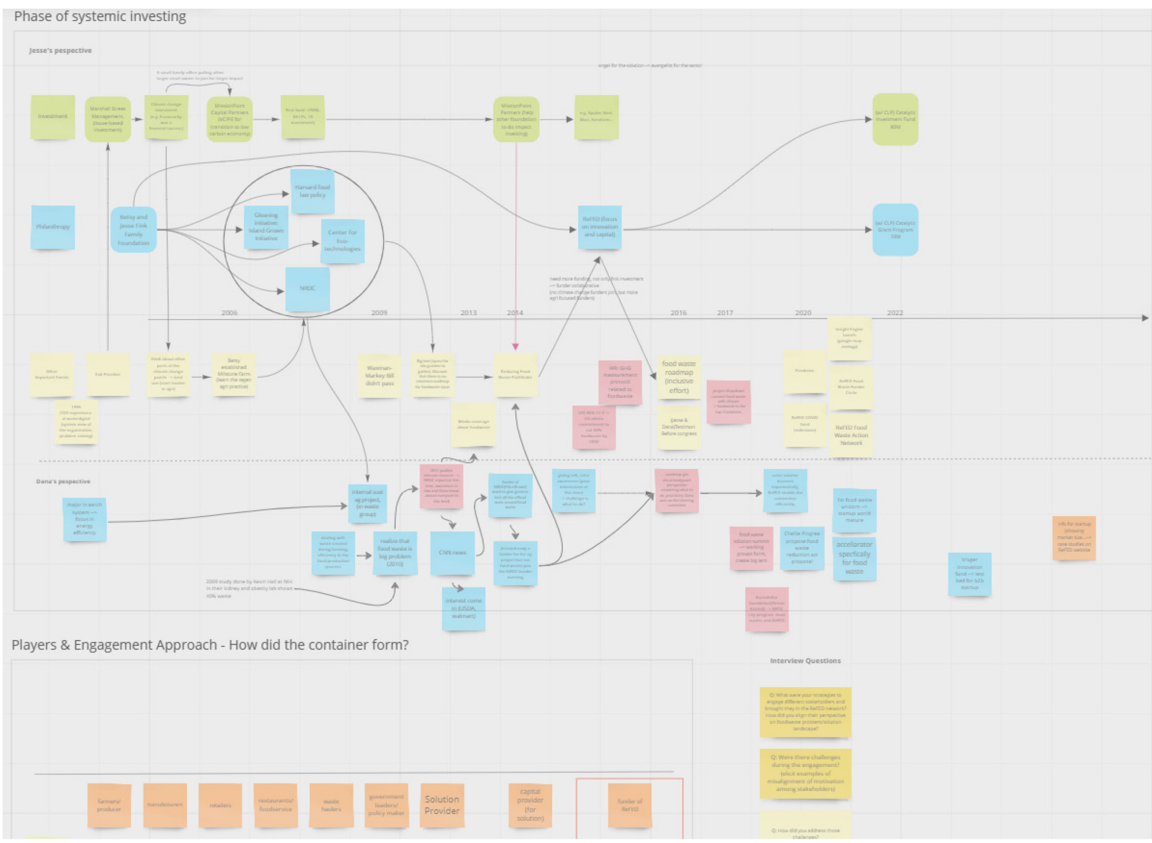


Figure 15, An example of using an online visual collaboration platform for facilitating interviewees' elaboration of complex relationships.

To further formalize the narrative of the connection between intervention strategy and actual change for exploring its underlying logic and assumptions, we rely on a simulation-based approach, constructing computer models with case study data from literature and interviews (Davis, Eisenhardt, and Bingham 2007; Repenning 2002). This is particularly suitable for our research questions because the case study offers concrete examples to illustrate the relevant interrelationships among components in the socio-technical system and plausible ranges for model parameters. The resulting simulation model allows us to explore the implication of different resource allocation scenarios and the preferred strategies under various conditions (Rahmandad 2012). Given that real-world system transitions can take decades, this approach helps extend the existing but underdeveloped theory through exploration experiments and robustness testing.

Specifically, we used differential equations and a continuous time simulation model (a standard system dynamics modeling approach) because it’s particularly suitable for modeling non-linear behavior and capturing dynamics and feedback between different levels (Papachristos and Struben 2019; Köhler et al. 2018). It has also been widely applied to several studies for understanding the complex phenomenon that couples human behavior and the “physics” of socio-technical systems within sustainability issues (Meadows et al. 1972; Sterman et al. 2012; Moallemi et al. 2021). Because of the focus of this study, we centered the model on the interaction among the food waste sociotechnical system components to construct a realistic mapping between investors’ managerial choices and real-world outcomes. However, as the model was designed to build general strategy intuitions for systemic investors without being too narrow on food waste, the granularity of the model is kept at a reasonable level to avoid the detailed complexity that can distract the readers.

Given the generic nature of the model, we did not pursue formal calibration. Still, we set the parameter range and tested the behavior of model output based on available data from ReFED’s Insight Engine to build confidence in the model. We followed a model validation process to test the model structures and robustness in extreme situations (Sterman 2000). Our data analysis primarily explored the transition dynamics under different parameter settings. We are particularly interested in the outcomes of different interventions and the impact of different system contexts and boundaries on those outcomes. Our sensitivity analysis examined the uncertainties of the results from our data analysis.

4.1.3 The Methodological Limitations

Although we tried to balance perspectives when sampling interviewees, as the study is framed as systems change, it created a bias on the change side. More data on the niche actors/funders was collected through interviews, while more data on the incumbent actors came from second-hand sources. The impact of this limitation was minimized through the creation of flexibilities in the model that allowed us to conduct sensitivity analysis on different regime actors' characteristics.

In addition, the model choice of being generic and focusing on financial capital poses some inherent limitations to this study. First, we aggregate solutions by their reactive or preventive nature but didn't distinguish specific solutions under those categories. For instance, choosing from various food waste prevention solutions, such as imperfect produce channels or upcycling technologies, might be an important investment decision. This was a trade-off we made to prioritize studying general insights to help build the field of systemic investing instead of recommending food waste reduction investments. Second, as the model is not formally calibrated, this study should be considered theory building and extension instead of testing. This also suggests that the numerical results of this study are only illustrative for comparison between scenarios and should not be interpreted as empirically reliable. Third, the current study disproportionately examines the role and impact of investors, while system change requires many more stakeholders. Future studies should incorporate more balanced model construction to reflect real-world stakeholder participation. However, given that research on the impact of financial capital on socio-technical transition is the most understudied area compared to policy and technology, we focused our research on filling the gap. We hope to set the foundation for systemic investors to understand the implications of their intervention strategy and their interdependence on other stakeholders' behaviors.

Table 7. Overview of interviewees

Ref.	Stakeholder Type	Interview Focus	Length (mins)
01	Funders/investors	Intervention strategies in food waste reduction, investment rationales, and observation the food waste ecosystem	78
02	Conveners, interfacing food producers/service providers	Experience of interacting with the food providers and observation the food waste ecosystem	94
03	Conveners, interfacing investors	Intervention strategies of engaging investors and observation of the food waste reduction investor community	88
04	Conveners	Observation the food waste ecosystem	82
05	For-profit food reduction solution provider	Solution development and experience of interacting with the food providers	57
06	Non-profit food reduction solution provider	Solution development and experience of interacting with the food providers	40
07	Funders/investors	Intervention strategies in food waste reduction and investment rationales	55
08	Funders/investors	Intervention strategies in food waste reduction and investment rationales	30
09	Food producers/ service providers	Experience of eliminating food surplus and transition	41
10	Food producers/ service providers	Experience of eliminating food surplus and transition	34
11	Conveners, interfacing food producers/service providers	Experience of interacting with the food providers and observation the food waste ecosystem	25
12	Funders/investors	Intervention strategies in food waste reduction and investment rationales	35
13	For-profit food reduction solution provider	Solution development and experience of interacting with the food providers	51

Table 8. Example of a semi-structured interview protocol for a for-profit solution provider

Interview purpose	Prompts
1. Introduction and research motivation	This research aims to understand how investing for systems change differs from normal impact investing and how this difference influences investor strategies and capital allocations. The US food waste challenge is our first case study. One of the key things we captured is that to enable systems change, investors invest in not only solutions development (such as investing in your company) but also in enabling conditions (such as data infrastructure, human capital, network building, and policy change), and these two things interact with each other. So, today's focus we are trying to learn from your experience in this interaction.
2. Inquiry on background story	Let’s start with a little bit of your background story. What's your first encounter with the food waste problem?
	What do you consider to be milestones of your solution development? Why are they important?
3. Inquiry on the relationship between solutions and enabling conditions	How did the other enabling conditions in the system affect your company’s ● Solution development efficiency ● Solution adoption ● Solution effectiveness
	Are there missing factors in the ecosystem that are important for your solution? In your opinion, why do such gaps exist?
	How did your success influence the ecosystem other than reducing the food waste itself?
4. Inquiry on behavior routines	What are the impact indicators you track or your stakeholders want you to track? How did they influence your practice?
	How did you decide where to prioritize your limited resources? Does the prioritization change in different stages of your company?

4.2 Deep Dive into a Case Study: The Fink Family and the US Food Waste Challenge[17]

In the United States, approximately 40 percent of all food produced is wasted (Gunders and Bloom, 2017). This challenge spans the entire supply chain, from farms to supermarkets to our kitchens, resulting in millions of tons of discarded food each year. The environmental toll is significant, as the effort to produce and transport this discarded food contributes to greenhouse gas emissions and other environmental burdens of farming. Astonishingly, this excess coexists with widespread food insecurity, highlighting the paradox of the issue. The food waste problem has persisted for decades, and the causes are multifaceted, encompassing inefficient supply chain practices, consumer behaviors, and a lack of standardized policies and incentives for waste reduction. This challenge is thus systemic at its root and involves multiple stakeholders with different views on the problem.

Betsy and Jesse Fink first encountered this challenge at Millstone Farm, which they established in 2005 after Jesse's successful exit as the founding COO of Priceline. The two were frustrated to see how much fresh produce would get discarded out the back door of local markets and decided to investigate further. Little did they know their curiosity would lead to a major effort of philanthropy, capital investment, and network building—a program of systemic investing with ripple effects far beyond their farm.

The Finks' Journey from Tech to Climate Change to Food Waste

In the late 1990s, during the pivotal transition from analog to digital, Jesse Fink was COO at Walker Digital, an intellectual property think tank. When Walker Digital decided to spin out international travel site Priceline, Jesse jumped on board as the Founding Chief Operating Officer. The role made him intimately familiar with the complexities of driving innovation and solidified his belief that successful solutions required the integration of diverse elements into a cohesive whole.

In 1999, Jesse's decision to exit Priceline brought him good fortune and marked a turning point. Jesse and his wife Betsy, whom he met while they were studying at SUNY College of Environmental Science and Forestry (ESF) and who worked with him at Priceline, shared a passion for the environment. With a clear vision and a desire to channel their resources toward a meaningful cause, the Finks set up Marshall Street Management as a family office and established the Betsy and Jesse Fink Foundation.

[17] This case study is separately published by the author on SSRN: http://dx.doi.org/10.2139/ssrn.4615351

Collaborating with the Finks' professional investment manager, Mark Cirilli, they meticulously charted various global challenges on a whiteboard. Climate change captured their attention, aligning with their desire to foster a sustainable future. With this grand challenge in mind, the Finks were unsatisfied with the conventional foundation approach:

> *"We were new to wealth management. We realized that in the foundation world, typically 100% of a foundation's endowment is invested in traditional investments, and only 5% goes to fund organizations and people in the sector, such as the environment, that align with the specific mission of the foundation. So, our whole quest was not to focus on diverting incremental amounts of the 5% to the causes we cared most about but to be a catalyst on the investment side, which could have a much greater impact. We thus embarked on a journey that continues today to find investments that can be aligned with the issues to which our philanthropic grants are allocated, and we called it issue-based investing."*

This led to their pioneering exploration of a new way of investing in 2002. Their climate-related investments mostly focused on clean technology infrastructures and environmental finance sectors, which yielded financial success and demonstrated the positive impact investment could have when the field of impact investing was still emerging. Core to the Finks' strategy, their impact investment approach incorporated five forms of capital: financial, intellectual, human, social, and spiritual. In all their endeavors, they utilized these five forms of capital to maximize the impact and results.

Driven by a desire to amplify their impact, Jesse established MissionPoint Capital Partners in 2006. Under the leadership of Mark Cirilli, Jesse Fink, and another professional partner, Mark Schwartz, they launched a venture fund, MissionPoint Capital Partners Fund I, aiming to steer the global economy toward a low-carbon trajectory. Unlike today, when the public generally considers climate change as an urgent issue, investors in 2006 hardly knew there was carbon in the economy. Thus, the team had to make an educational effort to get investors on board. The Fund successfully raised $335 million from a diverse array of limited partners (LPs), including family offices, college endowments, and even some hedge funds, among others. The Fund invested in clean technology and energy companies with some meaningful, successful results. Subsequent to the Fund, the Finks created MissionPoint Partners to make direct investments within a syndicate model and advise other families and foundations who want to do a better job in impact investing.

Whenever a family was interested in a specific topic, the MissionPoint Partners team created a "Pathfinder," a research document embedded with systems-integrated thinking that would dive deep into various aspects of the topic and ways to address them. Over fifty Pathfinders were created for different clients, and this model helped the Finks to scale their impact beyond what their resources could have had. Jesse made an analogy on this strategy, "*I felt like we were a tugboat, a small family office that got out and pulled larger family offices and larger asset holders into whatever we were doing once we had assessed and de-risked each opportunity to some extent. That has been a mantra for us from the beginning.*"

During the same period, the Finks' exploration of climate change led them to consider the broader puzzle, such as the critical role of land use in the climate equation. Betsy Fink's involvement on the boards of the American Farmland Trust and Wholesome Wave Foundation deepened her engagement in the agricultural realm. This exposure ignited a profound understanding of the complexities surrounding sustainable and regenerative agriculture. In 2005, the Finks established Millstone Farm in Connecticut, a real-world laboratory for them to learn and practice sustainable agriculture principles. Betsy created and managed the farm and immersed herself in the practicalities, developing an acute awareness of the challenges of growing and distributing organic, nutrient-dense crops. In an interview with Food Tank, Betsy shared her experience:

> *"I was seeing first-hand a tremendous amount of food left in the fields of some of our sister farms in Connecticut. As we know, at some point, the labor costs are too high or market demands are too low for farmers to harvest the full field of crops or produce the retailers might consider "seconds." ... When I would do deliveries for the farm, I also saw how much food and fresh produce was being discarded in the back of our local markets. This made me think there was something more systemic about the problem—how large is the problem and what could we learn to drive solutions?"*[18]

Through this realization at the farm, the Finks extended their impact to the realm of food waste by providing grants to nonprofits addressing the issue. Natural Resources Defense Council (NRDC), Harvard Food Law and Policy Clinic, Center for EcoTechnology (CET), Island Grown Initiative, and several local food banks received their support. They also emphasized the importance of human capital and invested in interns and fellows in these organizations. Jesse recalled an early observation from

[18] https://foodtank.com/news/2016/12/engaging-restaurants-and-markets-to-rebuild-a-regional-food-system/

their initial foray into the food waste issue, *"...we probably had a portfolio of ten nonprofits related to food waste, but they were each in their own silo, yet solutions in one area impacted initiatives elsewhere."* The Finks recognized that the effort needed some extra interventions to be effective. Strong believers in "ground truthing," where top-down ideas can be tested and validated at the local level, and where great ideas at the local level can be replicated or scaled, the Finks are convinced that the success of a systems approach to impact investing relies on the vertical integration of ideas.

The Finks harnessed an unexpected resource at the Millstone Farm: the expansive tents leftover from hosting wedding celebrations. Betsy and Jesse gathered their grantees and relevant stakeholders at the farm under the big tents to engage in a meaningful discussion of the food waste issue. This unconventional setting became the backdrop for multi-stakeholder dialogues that transcended traditional boundaries. The Finks orchestrated facilitated interactions, inviting stakeholders from diverse sectors— from Harvard policy experts to grassroots farmers—to share their perspectives and insights. Jesse was amazed by the conversations in this setting:

> *"You could hear farmers talking to funders who thought they had the right idea of regenerative agriculture and the right technology. The farmer responded that their problem was actually a lack of labor due to immigration issues. The power of these discussions lies in their ability to bridge gaps and dissolve preconceived notions, sparking novel approaches to complex problems."*

Emerging from the dialogue was the need for a roadmap that aligns every stakeholder's effort and breaks the silos.

Putting their climate hats on, the Finks realized that most food waste goes to landfills, creating methane and exacerbating climate change. Food waste is also the cause of other environmental issues, such as resource overuse (especially water and other inputs) and pollution from pesticides and other chemicals used in food production. They started looking for ventures diverting food waste from the landfills, but the field was far from established.

To help clarify the opportunity, MissionPoint Partners team members Sarah Vared and Adam Rein led a six-month research project in 2014 to create the food waste Pathfinder and laid the groundwork for a systemic investing approach: one that would integrate philanthropy (for consumer awareness and policy) and investment (for technology and infrastructure) to combat food waste across the value chain. One of the recommendations from the Pathfinder was a public-facing guide calling for collective action, something Adam emphasized as he recalled the challenge they faced in the early days:

> *"Jesse and Betsy asked us to identify a set of catalytic investments around food waste. But looking around, there was limited data on where to find the companies with the best economics or most impact, as the "food waste" sector was very fragmented across farms, manufacturers, grocery stores, restaurants, homes, composters, and anaerobic digestion. So, we ultimately decided that the most catalytic thing to do before making investments would be a philanthropic initiative to rally leading stakeholders to build a Roadmap so that we and all capital providers could have the data to learn the most effective solutions."*

As a result, the seeds were sown for a national stakeholder engagement to create a food waste reduction roadmap that eventually led to the important foundation for change.

Building a Foundation for Change in the Food Waste Sector

The early 2000s marked a time when food waste was neither a prominent public concern nor an established investment category. The scarcity of data on the issue compounded its obscurity, making it challenging to grasp the magnitude of the problem. The revelation that the United States wasted approximately 40% of food was a wake-up call. This staggering statistic first appeared in a 2009 study conducted by the National Institutes of Health (NIH), which revealed a 40% discrepancy between the caloric content of the food system and people's caloric intake (Hall et al. 2009).

Dana Gunders emerged as a critical figure in the unfolding story of food waste. Armed with a background in earth systems with an emphasis on energy efficiency from Stanford University, Gunders pivoted to food waste in 2010 as a Senior Scientist at the NRDC, recognizing that energy efficiency principles could be applied to food efficiency. Gunders researched the issue, culminating in a public report released in August 2012. Titled "Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill," the report covered the efficiency losses in the whole value chain, and its profound impact resonated well beyond expectations (Gunders 2012). The report garnered widespread media coverage, landing Gunders on major news outlets and propelling her into the center of the food waste dialogue.

As the report spread, stakeholders from unexpected quarters took notice. The U.S. Department of Agriculture (USDA) and Walmart, among others, expressed interest in the findings. The report's impact was further magnified when a donor reached out to NRDC, demonstrating their support through a grant, which enabled Gunders to continue her focused work on the food waste issue. Following the report's success, NRDC convened a meeting in 2013 in New York, bringing together a diverse array of funders and stakeholders connected to the food waste challenge. It was here that Dana Gunders encountered Jesse Fink. The meeting served as a seed for their collaboration.

The United Nations Sustainable Development Goals (SDGs) creation in 2015 further galvanized efforts to address food waste. SDG 12.3, aimed at cutting food loss and waste in half by 2030, provided a global target that resonated deeply with those committed to driving change. The commitment extended beyond international aspirations; the U.S. administration pledged to halve food waste by 2030. However, Dana saw the gap between awareness and action, and the question of "how" started to emerge on the table:

> *"In the early days, it was a lot of me shouting from mountain tops, giving talks, and presenting this problem to people. But what I found was that it was not hard to convince people that there was a problem as the numbers around food waste were pretty compelling. What was challenging was that they didn't know what to do...People talk about food waste as if it's one thing, but tomatoes not being harvested on the farm are very different from sandwiches not being finished at the Deli. There are so many different aspects of it, and people become paralyzed."*

Amid the prevailing uncertainty in 2015, the Finks decided to realize the idea of a national food waste reduction roadmap focusing on solutions and opportunities, building on the Pathfinder analysis Sarah and Adam at MissionPoint Partners had done. Sarah Vared first encountered Jesse through participating in the Finks-funded internship program while studying her Sustainability MBA at the Presidio Graduate School. She then secured a full-time position at MissionPoint Partners and took the lead in organizing the roadmap team. In line with their strategy of employing the five forms of capital in their journey to impact, the Finks recognized the need for social capital to catalyze the movement. The journey started with fundraising, not for the money itself, but for amassing support, credibility, knowledge, and convening power from these funders. The process, however, was not as smooth as Jesse initially expected:

"We approached climate funders and said, "Hey, we have discovered that food waste is a huge contributor to climate change. You're interested in climate change. Would you fund this report?" And almost all of them said, "Well, that's great! When the report is done, will you share it with us?" They were stuck in their silos and more interested in energy and renewables than food-related solutions to climate change. We were lucky to eventually get a handful of prominent national foundations to participate and coupled that with support from smaller foundations that were regional-based and focused on sustainable agriculture. Ultimately, we ended up with a terrific group of founding funders around the table, which provided the credibility, insights, and resources needed for a successful initiative."

The roadmap team engaged various stakeholders, surveying diverse solutions in food waste prevention, recovery, and recycling solutions and assessing suitable financing mechanisms for each. Innovations in technology include, for instance, converting food byproducts into new ingredients through value-added processing and extending the shelf life of fresh food by applying natural barriers to prevent chemical reactions between food and the environment. Business model innovation also has a huge role in reducing food waste, for instance, through creating new channels for distributing surplus, off-grade, near-expiration, or imperfect produce that would otherwise be wasted.

Deloitte's involvement lent credibility to the data-driven approach, in which they created the cost curve to reduce food waste (see Figure 16) to help prioritize actions (borrowing the idea from the McKinsey cost curve for GHG abatement. [19]) Composting technology, for instance, has the highest food waste diversion potential but very little economic value per ton of food waste diverted because of its capital expenditure. On the other hand, redesigning packages or standardizing date labeling are low-hanging fruits that can cost-effectively reduce smaller amounts of food waste.

Furthermore, the Finks' emphasis on ensuring broad stakeholder input, including the incumbent food companies, was crucial. The roadmap team played a unique role in being a neutral group that could convene big food companies (e.g., Walmart, Sodexo), big NGOs (e.g., NRDC, WRI), and big government agencies (e.g., EPA, USDA), along with the innovators and capital providers. These organizations contributed their data and validated that the ReFED roadmap was the best available data source at the time,

[19] https://www.mckinsey.com/capabilities/sustainability/our-insights/a-cost-curve-for-greenhouse-gas-reduction

a key to getting buy-in. This process took much more effort than Sarah originally thought:

> *"When we started, I thought it would be 10 hours per week of my time because I was also working on other investment research and pathfinders in the MissionPoint Partner team. And very quickly, it became 100% of my time for the year and a half...When we started building out the Advisory Council of the roadmap, we were essentially nobody in the food waste world. It took tremendous time to establish relationships, get the first people involved, bring different perspectives to the table, and build a community. The systemic problem was also more nuanced than we initially thought; we wanted to be rigorous and review all the underlying assumptions. "*

In addition to the intensive stakeholder engagement and rigorous data collection, the team ensured the roadmap was not just another academic report but something with actionable insights, beautiful charts, and eye-popping statistics. The final customized recommendations spoke vividly to all stakeholders, including producers, manufacturers, retailers, restaurants and food services, policymakers, and capital providers.

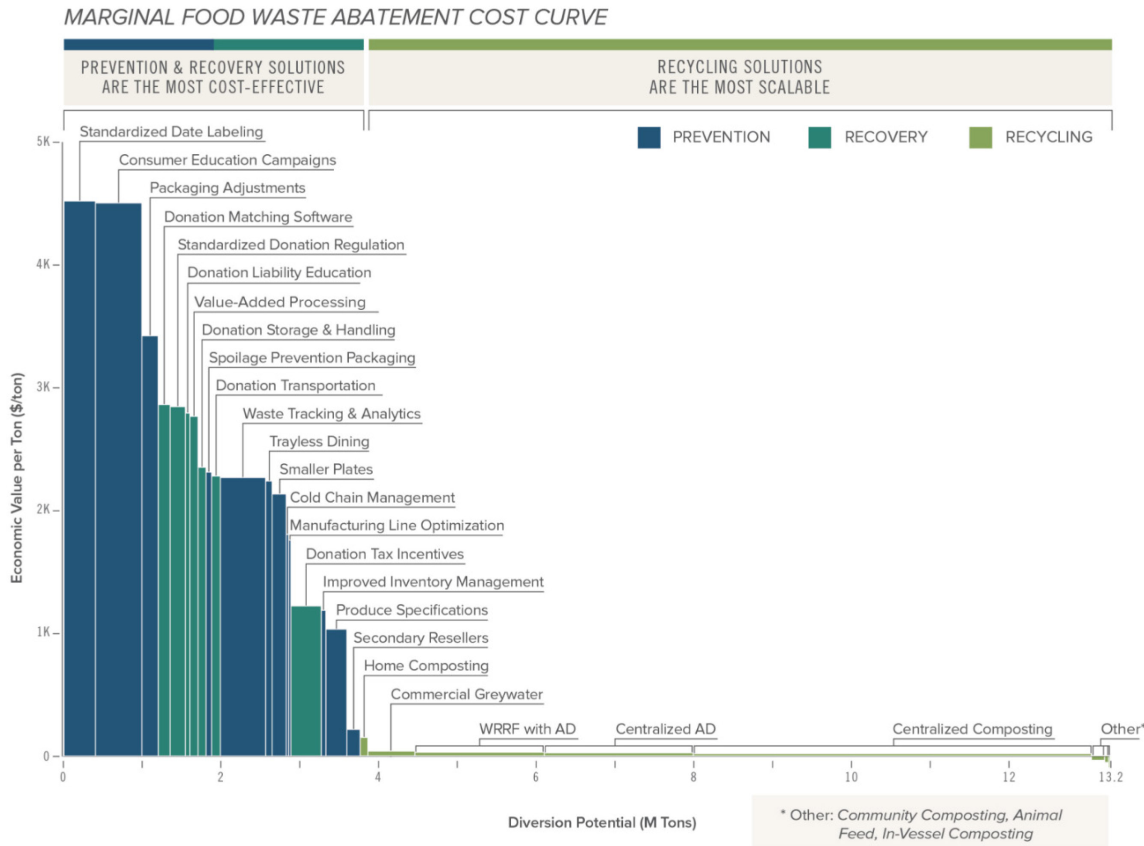


Figure 16. Marginal Food Waste Abatement Cost Curve in ReFED's 2016 Roadmap
(Source: ReFED. Note that data has been improved since then.)

The culmination of these efforts led to the launch of the roadmap under the ReFED (Rethink Food waste through Economics and Data) initiative in 2016 at the Stanford campus ("A Roadmap to Reduce US Food Waste by 20 Percent" 2016). The roadmap suggested that the United States wasted more than $200 billion in food and showed an achievable path to a 20% reduction of food waste in the coming decade that can avoid nearly 18 million tons of greenhouse gas emissions annually. The release of the roadmap sparked tremendous media attention and dialogue.[20]

The initiative's impact transcended a mere roadmap, however; it marked the inception of a freestanding organization as ReFED spun off into a fiscally sponsored 501(c)(3) nonprofit, with Jesse as the inaugural board chair and Sarah as the interim executive director. Alongside Jesse and Sarah were two key members of the founding team. Joan Briggs, Executive Director of The Fink Family Foundation, was responsible

[20] See, for example, NPR – "These 27 Solutions Could Help The U.S. Slash Food Waste" (https://www.npr.org/sections/thesalt/2016/03/15/470434247/these-27-solutions-could-help-the-u-s-slash-food-waste) and Food Tank – "ReFED Roadmap Creates "Actionable Paths" Towards Food Waste Reduction" (https://foodtank.com/news/2016/03/refed-roadmap-creates-actionable-paths-towards-food-waste-reduction/)

for sharing the message of ReFED with the philanthropic world. Eva Goulbourne was ReFED's first employee, coming from the World Economic Forum's food and agriculture team. Eva is credited with achieving wide distribution of the original ReFED Roadmap. Recognizing the need for focused action, ReFED adopted a unique strategy. The organization chose not to prioritize policy advocacy, nor did it take on the heavy lift of consumer education at first. Instead, ReFED positioned itself as a market maker, fostering a high tide that would lift all boats by focusing on capital and innovation. By identifying thought and market leaders in different opportunities in the roadmap, ReFED aimed to showcase the viability of a full spectrum of solutions. Avoiding being pigeonholed as an environmental nonprofit allowed ReFED to appeal to broader stakeholders. This was demonstrated in Jesse Fink's testimony before the House Committee on Agriculture hearing on food waste.[21] He embodied the voice of funders and businesses invested in food waste reduction alongside Dana Gunders from NRDC, Emily Broad Leib from the Harvard Food Law and Policy Clinic, and other stakeholders.

The testimony was a bonding moment for Jesse and Dana, as it fostered mutual respect, mentorship, and collaboration. Dana was on the steering committee of ReFED and then joined the board. When the first executive director of ReFED, Chris Cochran, left, Dana stepped in to lead the organization to overcome the challenges ahead. Jesse and Dana's own journeys intersected at a critical juncture, forging a partnership that united philanthropy, investment, and advocacy to combat food waste. As the national engagement process has built the foundation for a data infrastructure and a practitioner's network consisting of government agencies, large food companies, solution providers, farmers, and nonprofits, ReFED's effort laid the groundwork for system change to emerge.

Facilitating the Growing Momentum

A pivotal early supporter in this domain was The Rockefeller Foundation, which stepped forward around 2015 with a substantial commitment spanning seven years to address the issue of food waste. This commitment encompassed financial support for various initiatives, including NRDC's "Food Matters" program, the production of the documentary "Wasted," and ReFED in its early days. The Finks also provided catalytic capital to ventures including Spoiler Alert, Divert, and Mori and brought other funders in through MissionPoint Partners. In addition, Project Drawdown's

[21] https://www.c-span.org/video/?c4599293/user-clip-jesse-fink-testiomny

recognition of reducing food waste as a top climate change solution in 2017 garnered more attention and engagement, prompting new actors to join the conversation.

Nonetheless, despite the promising strides made by pioneering organizations and funders, investment in food waste solutions didn't gain the desired momentum. In the roadmap, ReFED estimated that it would require roughly $2 billion per year over the next decade to achieve a 20% waste reduction, while only about $200M was invested in food waste solutions in 2016. Innovative approaches by ventures, while holding transformative potential, had encountered challenges garnering the necessary attention and support. This underscored the pressing need for concerted efforts to further cultivate and facilitate the sector's burgeoning interest. ReFED continued its efforts on three key pillars they identified as leverage points in its Theory of Change (see Figure 17): data and insights, stakeholder engagement, and capital and innovation.

Figure 17. ReFED's Theory of Change in reducing food waste in the US (Source: ReFED)

Data & Insights One of the critical challenges in the food waste field was the absence of comprehensive data on both the problem and solution landscape. Through ongoing efforts to update, upgrade, and generate more granular data and insights, ReFED empowered stakeholders to make informed decisions based on quantitative analysis. The "Insights Engine"[22] launch in 2021, turning the static roadmap into an interactive data center, marked a significant leap. The food system is complex, adaptive, and embedded with uncertainties in technology evolution and human behavior, so the data and insights printed in the 2016 roadmap wouldn't be valuable to inform ongoing decisions as context changes. A more dynamic online interface allowed ReFED to continuously iterate the guidance when new evidence became available. In Dana's own words, it was analogous to the transition "from paper maps to Google Maps."

With over 60,000 users and thousands of use cases, this new platform allowed stakeholders to delve into nuanced solutions tailored to specific challenges. Leading retail giants, such as Amazon, Kroger, and Aldi, have harnessed ReFED's data to guide their explorations of innovative solutions that can tangibly enhance their financial performance by curbing food waste. The states of Washington and Oregon have used the Insights Engine in developing their state plan. Numerous publications have cited ReFED, underscoring its role as an authoritative source in the discourse on food waste. Startups also expressed that the insights provided by ReFED's data have proven immensely valuable in substantiating the existence of a viable market. Ricky Ashenfelter, founder of the food waste prevention technology company Spoiler Alert, commented on ReFED's influence on his company:

> *"In the early days, we relied heavily on the ReFED roadmap and resources for market sizing. At that time, our investors spanned three distinct categories: impact and sustainability, food and ag tech, and traditional software. Consequently, educating these investors on the market opportunity surrounding food waste was a big component of fundraising, and the ReFED resources proved instrumental in quantifying a compelling total addressable market."*

Besides data, ReFED generated original insights and publicly shared them. Through extensive interviews with subject matter experts within the food system and executing pilot initiatives involving distinct food companies, the valuable learning was meticulously synthesized and consolidated into comprehensive reports. The insights can range from industry best practices to a landscape assessment of the connection between food waste and diversity, equity, inclusion, and justice (DEIJ). ReFED aimed to transform the sector from acting on instinct to data and insight-driven decisions with this endeavor.

[22] https://insights.refed.org/

Stakeholder Engagement ReFED recognized that achieving systemic change in addressing food waste required collaboration across the entire food value chain, the "big tent" mantra they established at Millstone Farm. Through industry partnerships, advisory, programming, and networking events, ReFED fostered connections and cross-sector dialogue, such as the Pacific Coast Food Waste Commitment (PCFWC), the largest public-private partnership dedicated to food waste reduction. To help motivated companies advance their food waste reduction strategy efficiently, ReFED partnered with the Environmental Defense Fund (EDF) to launch a Climate Corps Food Waste Fellowship, training students to provide corporations with dedicated assistance. The program had deployed top-tier graduate students into more than 20 food brands, investment firms, and government agencies (such as Albertsons, Sodexo, Closed Loop Partners, and the New York City Housing Authority), helping solve the sector's growing capacity-building need with expert human capital. Furthermore, formal partnerships were established with federal agencies like the U.S. Environmental Protection Agency (EPA), the U.S. Food and Drug Administration (FDA), and the U.S. Department of Agriculture (USDA), solidifying ReFED's role as a trusted intermediary for collaboration and coordination. Their annual Food Waste Summit served as a focal point for these multi-stakeholder collaborative efforts.

Engagement with the incumbent was particularly crucial. Jesse's earlier experiences in renewable energy investing taught him that transformative change inevitably encounters resistance from established players:

> *"Prior to our deep dive into the food waste sector, I witnessed first-hand how long it took for renewable energy solutions to gain traction. A big reason it took so long was that the incumbents were so powerful and fought changes they found threatening. I wanted to make sure we avoided the same situation with food waste solutions so that we could expedite the timeframe for widespread adoption from fifteen years or more to five years."*

To achieve this, ReFED dedicated extensive efforts to secure the involvement and support of major food industry entities like Walmart, General Mills, and Kroger, who have all become staunch advocates of ReFED's mission. Nevertheless, the challenge remained that the food system, deeply entrenched in tradition, presents formidable barriers to entry due to its longstanding practices.

A notable endeavor ReFED started exploring involves the concept of a "Customized Roadmap." In this initiative, ReFED utilized its database to develop a customized list of optimal solutions tailored to food companies who collaborate by sharing their private data. This comprehensive roadmap could include insights into the projected costs, food waste reduction, revenue generation, and greenhouse gas savings associated with implementing these solutions. This effort aimed to empower internal champions within food companies to secure leadership buy-in for implementing recommended solutions by equipping them with an analytical understanding of the suitable solutions. Furthermore, ReFED's involvement facilitated connections between these companies and the solution providers that can help turn these strategies into actionable results.

Capital & Innovation Innovative solutions in food waste require financial support to overcome barriers and achieve scalability. ReFED convened and educated funders about emerging investment opportunities in the sector to bridge this gap and helped large food companies host open challenges to stimulate innovation. On the solution provider side, ReFED aimed to empower innovators to scale their solutions through capacity-building initiatives like accelerators and networking opportunities with potential funders.

One achievement was the establishment of the Food Waste Funder Circle (FWFC),[23] which evolved from ReFED's early one-on-one funder advisory interactions. Growing to involve over 160 members, the funder circle had the potential to catalyze more than $300 million of capital into the food waste sector. This collaborative platform provided funders with subject matter expertise, resources, and specific investment opportunities. The funder circle also enabled social learning and a supportive community, where investors learn from each other, collaborate on deal-sourcing and co-investing, and cultivate a feeling of being part of something bigger than themselves. Pete Oberle and Tripp Wall, Managing Partners at Trailhead Capital and members from the circle, shared the value this initiative brought to them ("ReFED 2022 Annual Report," 2022.):

> *"Trailhead Capital is excited to be both a member and ambassador of the FWFC, gaining access to an extensive network of partners and collaborators who are equally dedicated to targeting food waste challenges by working together to share and produce ideas and solutions... The deal flow reports, newsletters, and sponsored events help us aggregate this information in a substantive way, creating the network effect needed to deliver and capitalize on this catalytic opportunity."*

[23] https://refed.org/engage/food-waste-funder-circle/

In 2020, ReFED piloted a set of grants to 10 organizations selected to participate in its Nonprofit Food Recovery Accelerator program in partnership with Walmart.org, +Acumen, IDEO, and Feeding America. ReFED then ventured further into direct funding through a pooled fund approach, initially as a response to the emergency stemming from the COVID-19 pandemic. Amidst the onset of the pandemic, an urgent need emerged on the ground, prompting funders to seek ways to provide adequate support. Recognizing this need, ReFED took proactive steps by establishing a COVID fund that attracted a significant influx of new investors to the food waste sector and served as a means to regrant philanthropic capital to selected organizations ("The ReFED COVID-19 Food Waste Solutions Fund" 2020). The result was more than $3.5 million raised and regranted to 37 for-profit and nonprofit organizations across the US, who in six months were able to prevent or rescue more than 90 million lbs. of otherwise wasted food. Additionally, the fund helped catalyze more than 13x the original amount invested into the portfolio's grantees, of which 92% served BIPOC communities and 95% were led by diverse teams. The Finks played a pivotal role in this endeavor by contributing a grant to cover 100% of the administrative costs, allowing ReFED to assure donors that their contribution would be fully regranted to the intended recipients.

Building upon this learning experience, ReFED established a Catalytic Grant Fund to explore its unique position as a resource allocator by leveraging its data, insights, and network to identify crucial areas where catalytic change is most needed. Through its investments to date (September 2023), ReFED has grown to become one of the top five philanthropic funders of direct food waste work in the sector.

In 2023, the US food systems change was still an ongoing journey, not a finished job. But with this collective effort, the landscape of the food waste sector had been changed with emerging signs:

Startups in the sector, such as Apeel Sciences and Imperfect Foods (now acquired by Misfits Market), had gained traction, achieved significant valuations, and some already exited, underscoring the growing maturity of the field. Accelerator programs dedicated to food waste also emerged. The influx of investment in the food waste space had grown significantly over the years, over $1 billion in both 2021 and 2022, as more impact investors recognized food waste solutions as a way to achieve their impact goals. Some prominent Silicon Valley technology investors who don't consider social or environmental impact in their investment decisions have also come to the table because the market demonstrated huge potential.

More than 50% of the market share of the Pacific Coast's food retailers had committed to sharing private data on food waste and collaborating to change, and the three largest food service companies and some upstream companies had joined the effort as well. Several large companies have reduced significant amounts of food waste compared with their baselines (for instance, 42% for Kellogg's, 36% for Campbell Soup Company, and 12% for Walmart, "2023 Champions Progress Report" 2023) As the largest American retail company, Kroger, via its Zero Hunger Zero Waste commitment, shined a spotlight on the food waste issue. This commitment was followed by the launch of their innovation fund, a valuable avenue for startups to test their solutions in larger corporate pilots. Additionally, The Wonderful Company, a major agricultural producer, allocated $1 million for a global open call to address their waste challenges in 2020. This initiative received 385 applications and ultimately funded two promising solutions, showcasing the growing appetite for food incumbent companies to change.

The food waste policy landscape has also undergone significant shifts across government levels. Notably, the bipartisan passage of the Food Donation Improvement Act in late 2022 was a milestone achievement. A remarkable surge of over 75 state-level food waste-related policies was introduced in 2022, demonstrating the growing recognition of food waste as a vital issue. Although not all proposed bills came to fruition, the mere inclusion of food waste in legislative dialogues signals progress. In January 2023, Representative Julia Brownley introduced the Zero Food Waste Act, which proposed grants for food waste prevention, rescue, and recycling projects at all levels and was under congressional consideration. In September 2023, another bipartisan bill, the No Time to Waste Act (New Opportunities for Technological Innovation, Mitigation, and Education To Overcome Waste), was also introduced to Congress and had the potential to provide the much-needed resources.

From Dana Gunders' perspective, the evolution of the food waste sector was evident in the sheer growth of organizations and actors involved. The sector, for which she could once remember every contact individually, had grown into a complex ecosystem of over 1,800 organizations and initiatives. Although it was difficult to attribute any of the changes above directly to the Finks, Dana, or ReFED because a lot of people worked hard to realize it, they had acted as a backbone and a catalyst for the movement. Their multifaceted efforts certainly contributed to the enablement and facilitation of stakeholders to take meaningful action in the fight against food waste and changed the system's dynamics.

Zoominginto Investor Levers: The Systemic Investing Play

> *"When you interact with a multitude of investors on a one-on-one basis, you start to realize that if you are trying to solve a systems-level problem using a variety of bespoke approaches, you could be creating negative consequences or shifting problems to other areas of the supply chain...Our job should be thinking holistically, figuring out how to put money to work on this problem through a systems lens, and even pushing beyond just capital to incorporate the non-financial support needed to make investments truly catalytic and impactful."*

—Alexandria Coari, Vice President of Capital, Innovation & Engagement at ReFED

The systemic investing play can be seen in two parts in the US food waste challenge: the Finks' systemic efforts in the early days and ReFED's programmatic work in facilitating the system's capital flow, spearheaded by one of the organization's first full-time hires, Alexandria Coari, VP of Capital, Innovation & Engagement, and her team.

A brief review of what the Finks have done in addressing the food waste challenge with limited resources in a small family office and foundation (see Figure 18 and Appendix 1 for more information on financial investments): The Finks' capital allocation began with establishing Millstone Farm, where they experienced the issue first-hand and later became the essential space for multi-stakeholder dialogue. Their exploration then took shape through modest grants to various nonprofits, furnishing them with diverse perspectives on the issue—encompassing policy dynamics, pertinent data, potential solutions, and essential human resources. Embarking on early private investments, ranging from $50k to $250k each, in food waste reduction ventures aimed to experiment with for-profit solutions and showcase sector viability. These endeavors laid the groundwork for the Finks to discern emerging trends, bottlenecks, and sources of energy. The learning was solidified in the Finks' investment in Pathfinder research and the roadmap, which infused the field with crucial data and a network for collective action. Building upon this momentum, the Finks helped establish ReFED as a recognized food waste expert with robust data infrastructure, a strategic investment allowing the organization to effectively pursue its other two priorities: mobilizing stakeholders and capital. The incumbent companies came to ReFED due to its powerful insight, fostering a trust-based environment conducive to gathering more granular information and reinforcing ReFED's data and insight generation. These nuanced insights and the success stories of food waste ventures proved pivotal in attracting further funders. The Finks continue to play a catalytic role in funding ReFED experiments with new, emergent functions the field needs, such as the pooled fund and Climate Corps Food Waste Fellowship program.

Figure 18. The Finks' Strategy to Tackle Food Waste (Source: Jesse Fink)

The Finks could have focused their limited resources only on their private investment in food waste reduction ventures and giving grants to environmental nonprofits like many small family offices engaged in impact investing and grant-making. The concentrated capital might have a higher chance to build up a unicorn of a food waste prevention solution and change the US food system, but this would have assumed that:

- Incumbent food companies would adopt this particular solution.
- The policy would support the solution development.
- The startup could attract enough follow-on funding and human resources to scale to the whole U.S.
- The solution would be technically feasible and commercially viable to expand to cover the food waste generated in the whole supply chain.
- It would continue to be effective on a larger scale and in a changing consumer environment.

- Once the success is obvious in the market, competition between ventures would be beneficial rather than destructive, and the unicorn would maintain its impact mission.

If an impact investor only cares about isolated outcomes, for instance, the food waste diversion in a particular stage, these assumptions might be less critical. Therefore, concentrating on venture capital investment seems rational. When an investor intends to change the system's structure as a whole, though, this single-asset investing paradigm becomes questionable. The Finks chose to use their resources differently, acknowledging that those assumptions were not likely to hold given their observation of the space. Instead, they sequentially invested in building steppingstones that enable future possibilities, understand the system holistically, and nested solution investments with sector-wise interventions such as human capital, data and knowledge, network orchestration, and established company engagement. These efforts eventually reinforced each other to form an ecosystem that helped change the sector's trajectory. Jesse commented on his philosophy of facilitating systems change, not aiming narrowly at the tons of food waste reduced but more broadly at the overall dynamics of the system:

> *"I was trying to prime the pump, getting more people to participate and more funders to make investments. As some of the first wave of start-ups in a space succeed, more and more entrepreneurs enter the fray. Stanford or MIT undergrads begin saying, "Hey, forget about Facebook. I want to work on food waste technologies." And business schools begin to say, "Hey, we should be really looking at food waste as something going on there." So, I'm really a momentum player. If you manage to get smart people and smart money coming into a new space like food waste, you end up with an innovation ecosystem that's going to feed on itself."*

On the other hand, ReFED, functioning as an intermediary entity, has played a crucial role in helping the system allocate its resources more effectively across the solution landscape. At its most passive, the interactive Insight Engine empowers resource owners to prioritize cost-effective solutions without direct ReFED involvement. An illustrative example is the U.S. Department of Agriculture, which employed Insights Engine data in its 2022 $90 million funding announcement for food waste to shape fund allocation decisions. Being more proactive, Alexandria established ReFED's Food Waste Funder Circle to influence investors more directly. ReFED provided more up-to-date insights and sector trends through webinars and monthly ecosystem reports to educate investors in the network. The spotlight was cast on members' success stories, leveraging the platform for shared learning and encouraging collaboration in deal sourcing and co-investing. They bridged the capital demand and supply through deal flow reports (with more than $1 billion shovel-ready investment opportunities tracked), pitch days, speed dating events, and field trips for funders to experience tangible impacts. By posing critical questions to investors, ReFED promoted consideration of investments' upstream and downstream effects, avoiding waste of capital to shift the food waste from one place to another. They facilitated synergy, recognizing that food companies prefer streamlined solutions for issues across different stages rather than separate providers. Thus, integrating interoperability into an investor's multifaceted solution investments amplified overall adoption, generating more impactful outcomes than isolated endeavors.

Taking another stride forward, ReFED had advised more engaged funders to establish a more dedicated, customized, and systemic resource allocation approach to tackle the food waste challenge and achieve their unique goals. A prime example lay in ReFED's collaboration with The Kroger Co.'s Zero Hunger | Zero Waste Foundation, where they harnessed the Insights Engine to fashion a funding strategy for their innovation fund. This initiative catalyzed a substantial $10 million, bridging the philanthropic funding gap for food security and food waste solutions. The Posner Foundation of Pittsburgh, another strong advocate for addressing food waste as a critical issue, also benefited from ReFED's help. Ida Posner, a Strategic Advisor to the Foundation, shared her perspective:

> *"What drew me to ReFED was its systemic approach to the problem of wasted food, combined with an actionable plan to address it. We're a small foundation with just a few decision-makers, which allows us to be nimble and make decisions quickly. On the other hand, we don't have the capacity to do heavy diligence on the solution landscape or every project that may or may not bear fruit. So, it's been really helpful to have partners like ReFED that support our strategy development, help us to continuously learn, and facilitate relationships. "*

As a result of this intermediary support, the Foundation focused a significant portion of its $4 million funding on a cohort of organizations reshaping consumer environments, one of the top priorities ReFED advised them on. These initiatives span expertise in behavioral economics, exploring the intersection of criminal justice with nutrition and food waste in prison settings, and working within school cafeterias.

Engaging in their most intricate endeavor, ReFED delved into its second funding vehicle, an evergreen, pooled fund with an investment strategy developed using a data-driven approach informed by ReFED's own Insights Engine. While demanding more staff time and exerting influence on a more concentrated amount of capital than the Food Waste Funder Circle, this initiative grants ReFED greater control and certainty over the allocation of resources across the system. Extensive research enabled ReFED to establish a comprehensive framework detailing the required funding magnitude, solution impact potential, and appropriate matching between solutions and distinct types of capital.[24] For instance, enhanced demand planning software for retailers can be financed with venture capital, while buyer specification expansion solutions[25] might be more suitable for corporate finance and spending. Philanthropic grants are great for improving the distribution of food donations by increasing local transportation infrastructure or long-haul transport capabilities, and government project finance is needed for centralized composting facilities.

Additionally, the Food Waste Capital Tracker,[26] one of the databases in the Insight Engine, allowed ReFED and all investors to monitor the flow of capital within the sector, identifying areas of scarcity, high momentum, and opportunities to collaborate. These groundworks laid the foundation for the implementation of a pooled fund. The ReFED Catalytic Grant Fund,[27] the product of this endeavor, began dispersing both recoverable and non-recoverable grants in 2023 to for-profit companies and nonprofit organizations operating across the spectrum of food waste solutions while also covering emergent needs and providing support to "initiatives including but not limited to research, technology, general operations, capacity building, and pilots with food businesses." The first open call of the Catalytic Grant Fund, with $1.25M from Google (anchor with $1M), Fink, and Posner, received 280 applications worth $99M. An independent review committee was set up to incorporate external inputs to make funding decisions using insights from industry-leading subject matter experts across the food system. The evolution of ReFED into a resource allocator has had positive ripple effects. Beyond the demonstration effect of encouraging other funders to establish more capital dedicated to food waste solutions, this getting-hands-dirty approach has provided ReFED insights into the practical challenges, fostering a deeper understanding of the field's dynamics and struggles in capital allocation. This experiential learning, as ReFED's VP of Capital,

[24] https://refed.org/stakeholders/capital-providers/#capital-types

[25] According to ReFED's definition, a buyer specification expansion is the "Adjustment of purchasing specifications that allow for a greater variety of product grades into sales and recipes while still ensuring that specs do not lead to in-house waste."

[26] https://insights-engine.refed.org/capital-tracker/

[27] https://refed.org/our-work/initiatives/catalytic-grant-fund/

Innovation & Engagement Alexandria reflected, has equipped ReFED as a more effective enabler in facilitating the system's capital:

> *"We have gotten feedback as a systems-level organization that if you want credibility and drive influence, you can't just talk about data and theoretical strategies. You sometimes have to take the lead yourself. Being in the shoes of the investors we're trying to activate and sharing what we've learned has helped build trust, allowed us to reduce real and perceived risks felt by other asset owners, and driven new, additional funding into the sector…Something that would have been much more difficult to achieve if we were just a think tank."*

In contrast to normal thematic impact investing approaches, ReFED's systemic investing approach didn't just finance the technology or business model innovations in addressing the food waste challenge. They aligned the originally siloed actors with coherent system analysis, coordinated investments across asset classes to where the capital demand profile matched supply, and leveraged philanthropic capital to build critical public goods that create enabling conditions for solution providers and other actors. This fundamentally different resource allocation mindset shifted the investors' role from capturing value in innovation to facilitating socio-technical system transition.

In 2023, Jesse Fink, who still served as an active board member at ReFED, looked back on this fulfilling journey that no one had expected:

> *"Since we first engaged with the issue, we've invested millions of dollars, and now, collectively, over $10 billion has been invested by all types of funders of food waste solutions over the last decade. We helped launch dozens of new organizations and new initiatives at existing organizations, and now there are more than 1,800 organizations, big and small, leading efforts in the space. There are so many other people involved, and we don't know what would have happened if we hadn't shown up. But it's satisfying to think our limited resources might have contributed to a reinforcing cycle here. The sector has evolved from where the food waste issue was overlooked or unattractive to where it is widely recognized as a leading solution to climate change and worthy of considerable amounts of human and financial capital. I can't begin to express how excited and fulfilled I am to see large philanthropic funders, commercial investors, and other institutions and*

organizations engaging in food waste solutions. Really, we are going to need a bigger tent, and that's just great. "

Critical Questions Moving Forward

As the US food system change adventure continued with a growing ecosystem, some questions remained to be explored and critically examined.

Resource Usage The systemic investing approach involves allocating resources to a portfolio of interventions with suitable capital across the return spectrum. ReFED, as a backbone organization itself, is one of the interventions, thus also requires resources to keep the momentum going. The question about what kind of capital is most suitable to support ReFED started to cross Dana's mind:

> *"One key challenge we face is around earned income and whether that's something we should pursue. The puzzle is that either we can continue to make everything open source and free and be entirely grant-funded, or we can charge for some of the services we provide and not rely on grant funding. Some people look at us and say, "Oh, my gosh! You're sitting on tons of data, other people would have charged a ton of money for that!". We also do a lot of advisory work, and it's something a big consulting firm could make significant money from. However, charging for services creates a barrier for organizations to engage with us. We don't have a right answer for this. Our board has been really clear that we're mission first, so we don't want the goal of earning money to take over what our actual mission is. We're trying to be really careful about that."*

The use of philanthropic funding in systemic investing should also be taken cautiously, as organizations that allocate money for charitable purposes with tax-exempt benefits undergo increased scrutiny regarding the utilization of their financial resources. Private foundations and 501(c)(3) nonprofits would have to make sure the funding can't directly or indirectly benefit a "disqualified person" (who has substantial influence over the organization) to prevent the act of "self-dealing."[28] Some exceptions include "if the same goods, services, or facilities provided are made available to the general public on at least as favorable a basis," and can be seen in Dana's comment:

[28] For more detail, see IRC 4941 - THE NATURE OF SELF-DEALING (www.irs.gov/pub/irs-tege/eotopicq85.pdf)

> *"… the private foundations from the food industry have played a role in funding ReFED. Because of the self-dealing rule, their giving can't be directly tied to something they get in return, so they like the fact that we are serving the larger food industry."*

Stakeholder Conflict The systemic effort focused on reconfiguring the current demand-driven food system to reduce food waste by, for instance, optimizing harvest, maximizing product utilization, reshaping the consumer environment, and strengthening food rescue. One of the key goals was to push the current food companies to change operational practices, as illustrated by Ricky at Spoiler Alert:

> *"We spent the first few years of our business talking almost exclusively to individuals with Sustainability in their titles about food waste initiatives at major corporations. While those individuals offered helpful perspectives for us, the real inflection point for us came when we shifted our go-to-market motion and focused on engaging Supply Chain, Sales, and Finance operators instead. In our journey, those functions have had significantly more influence and budget to procure, implement, and finance emerging solutions like ours. Ultimately, my bias is that the industry needs functional leads outside of Sustainability to get more engaged in adopting innovative solutions, and climate-motivated entrepreneurs need to tailor their narrative accordingly for these audiences."*

On the other hand, some more radical food system transformation advocates argued that a bottom-up transition to agroecology or a model that aligns demand *to* seasonal and local supply is required, and the food challenge can't be solved by top-down solutions led by large corporations or institutional actors who are more likely to maintain, consciously or unconsciously, the status quo of exploitative capitalism (see Nobari 2021, for example). This perspective was different from the "big tent" philosophy the Finks and ReFED had adopted to include anyone motivated to reduce food waste, regardless of the perspective from the bottom-up or the top-down. The critical question is about what role systemic investors choose to play: When the goals of different stakeholders conflict, should systemic investors be neutral and promote all while bearing the risk of dissipating resources and energy in different directions, or should they pick a stance and align the resource toward one direction while unavoidably disregarding the voice from some? Or, to avoid the dichotomy, is there a way to sit in between?

Impact Measurement ReFED has been helping stakeholders understand their impact through the Insight Engine, and the team has also paid a lot of attention to understanding their own impact. Beyond the quantity of capital or people flowing into the food waste sector described earlier, ReFED is also dedicated to measuring the quality of those numbers, such as the engagement level of the funder network or connections enabled by ReFED that lead to real investments. However, as a system-level organization, most of ReFED's effort is not directly "contributing to solutions" but "creating enabling conditions," which only indirectly influences the ultimate outcomes as measured in tons of food waste reduced or greenhouse gas avoided. It is difficult, if not impossible, to attribute change in outcome to an indirect intervention with high confidence in a complex adaptive system. This challenge to demonstrate impact demands different accountability frameworks in the systems change work: how can we best conceptualize the contribution of systemic investors, and how might we measure them?

These questions will continue to shape the evolution of ReFED's pioneering work as they work to drive innovation and impact in the relentless fight against food waste. They will fuel the ongoing inquiry of those directly involved in this transformative journey, those keenly observing the trajectory of ReFED, and the broader field of systemic investing.

4.3 A System Dynamics Model of the US Food Waste Challenge

To examine the assumptions and dynamics of the narrative-based case study presented in Section 4.2, a stylized simulation model was constructed to capture the system structure and interdependencies underlying the US food waste challenge. This section documents the important structures and mechanisms in the model and provides rationales behind key model equations and parameter assumptions. Major constructs are first described, including food waste generation, food system actors, potential solutions, actor transitions, and the interactions among these constructs. A baseline simulation is then presented to build intuitions about the connection between system structure and system dynamics. The next section explores the impact of various investor interventions on system dynamics, expands the model boundary, and provides sensitivity analysis. Full model documentation can be found in Appendix 2. It should be noted that the purpose of this model is not to make predictions about how the food waste sector will evolve in the US but rather to make underlying assumptions explicit, and to leverage computing power to enhance our understanding of the dynamic complexity involved in the systemic investors' portfolio construction.

4.3.1 Food Waste Generation & Food System Actors

Food waste—as defined by ReFED as the amount of food that ends up in "landfill, incineration, or down the drain, or is simply left in the fields to rot"—is generated throughout the whole supply chain. Operationally, when food is produced in the system and goes unsold or uneaten, it becomes "surplus food." Surplus food becomes food waste if not recovered by other usages such as feeding the poor or fuel conversion.

According to an estimated breakdown of food waste generation by supply chain stage in ReFED's 2016 report, households account for 43% of the waste while food providers, including farms, manufacturers, grocery, and food services are responsible for the other 57% ("A Roadmap to Reduce US Food Waste by 20 Percent" 2016). However, several studies suggest that a notable portion of household waste is directly related to upstream practices such as food promotion, portion size, packaging, and processing, shifting the view away from blaming consumer's deliberate choices and habits to treating them as agents interacting with an environment created by food providers (Evans 2021; Göbel et al. 2015; Mylan, Holmes, and Paddock 2016). For simplicity, the base model only includes food providers' behavior while implicitly assuming that waste generated in households can be partly prevented by food providers' innovations and choices. This simplifying assumption implies that simulation results might be slightly more optimistic than reality.

All farms, manufacturers, grocery, and food services are aggregated into a single construct as food providers and are categorized into "Regime Incumbent Food Providers (*R*)" or "Innovative Food Providers (*I*)." Here, the word "innovative" is used narrowly in the context of surplus food reduction. "Innovative Food Providers (*I*)" are committed to eliminating surplus food wherever possible, such as innovating new production models, adopting better inventory management practices, or reshaping consumer-facing environments. For instance, Imperfect Foods is a grocery delivery service startup that enables customers to buy " imperfect " groceries that would have become surplus food in the traditional market standard. Albertsons Companies (a US grocery giant with over 2,200 stores) rolled out a program to redesign their operating system using artificial intelligence to reduce unsold food from farm to retail across the supply chain ("U.S. Food Loss & Waste 2030 Champions Milestones Report" 2022). Another US supermarket chain, Hannaford, adopted a solution from

Apeel (providing an edible coating to keep produce fresher longer) for their fresh items, offering an example of innovation by food providers that potentially reduce household food waste ("U.S. Food Loss & Waste 2030 Champions Milestones Report" 2022). Conversely, "Regime Incumbent Food Providers (*R*)" continually use long-lasting practices without eliminating surplus generation. These two system actors collectively supply the food the US people need yearly and generate a certain amount of surplus food that eventually becomes food waste. Figure 19 shows a simplified causal loop diagram (which will be expanded as additional concepts are introduced in the following sections) visualizing this basic structure.

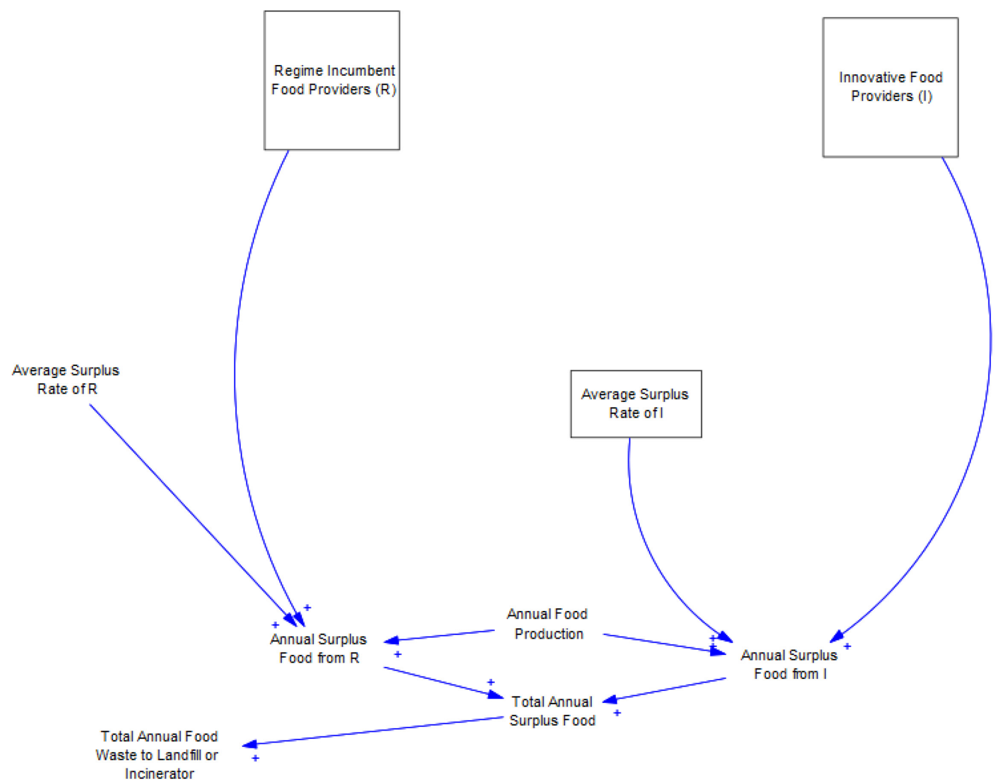


Figure 19. Overview of the model structure in Food Waste Generation & Food System Actors (Note that stock/state variables are depicted in rectangles.)

In the base model "Regime Incumbent Food Providers (*R*)" and "Innovative Food Providers (*I*)" are assumed to operate at a similar scale with no significant difference in attractiveness to consumers. Therefore, the market share of *R* and *I* simply scales with the number of actors in each construct. A key equation in this part is the "Annual Surplus Food" calculation:

$$S_I = f \cdot \frac{I}{(R+I)} \cdot L_I \quad (1)$$

where S_I is the annual surplus food from *I*, f is the annual food production, I is the number of innovative food providers, R is the number of regime incumbent food providers, and L_I is the average surplus rate of *I* (measured in percentage). Throughout this section, variables that change over time are in ***upper case***, and constants are in *lower case* or *Greek letters*. Annual surplus food from *R* is calculated similarly with a different average surplus rate l_R (which is a constant since *R* doesn't attempt to eliminate surplus).

4.3.2 Reactive Solutions and Surplus Elimination

To guide food waste reduction, the US Environmental Protection Agency (EPA) established a Food Recovery Hierarchy, starting from the more preferred Source Reduction and Feed Hungry People to less preferred Feed Animals, Industrial Uses, and Composting. For simplicity, all solutions that deal with food waste after the surplus food has already been generated are aggregated into a single construct, "Reactive Solutions Capacity (RS)." This includes donation programs at food banks or shelters, energy recovery facilities, centralized anaerobic digesters, and community composting sites, to name just a few. As the name suggests, these solutions react to surplus food and thus are modeled as ad-hoc food waste subtraction from the surplus generated by food providers. The capacity normally stays in the system for a while but eventually becomes outdated, unable to function as needed, and requires renewal. It's important to note that not all available RS capacity is utilized to reduce food waste. For instance, according to an anaerobic digestion facilities survey conducted by the U.S. EPA in 2021, the reported processing capacity in 2019 was approximately 42.7 million tons while the actual food waste processed in the same year was only 17.6 million tons, resulting in 41% utilization rate ("Anaerobic Digestion Facilities Processing Food Waste in the United States 2019" 2019). When food providers don't pursue reducing food waste, for reasons such as liability concerns in the case of donations or low landfill disposal cost, there will be no desire to utilize available RS capacity. Therefore, the utilization rate is a function of the amount of surplus food and the food waste reduction target of food providers. This applies to incumbent and innovative food providers, as incumbent actors also make small adjustments in routines to make incremental improvements, in this case, to adopt reactive solutions under external pressures (Messner, Richards, and Johnson 2020; Warshawsky 2016). This aligns with the idea of "local search" in incumbent reorientation rooted in transition studies (Geels 2014).

Being more aggressive, innovative food providers don't just adopt reactive solutions but also eliminate surplus food in the first place, the most preferred strategy in the Food Recovery Hierarchy mentioned above. The surplus elimination potential ranges widely across different prevention strategies, from reducing about 3.8% (accepting partial order instead of complete rejection if sampling results are not meeting standards) to 35% (establishing new channels and business models for imperfect food). Advancing the technologies or supply models can help push the "Feasible Minimum Surplus Rate" further down to closer to 0%, although it's recognized that certain cultural and behavioral norms shift (from expecting cheap and abundant food) is required to really reach that ideal rate (Messner, Richards, and Johnson 2020; Thyberg and Tonjes 2016).

Some prevention solutions are well-established to lower the "Feasible Minimum Surplus Rate" below innovative food providers' current average surplus rate and target rate. The surplus elimination process, however, takes time. The "improvement half-life," defined as the time required to reduce the surplus rate by 50% from its original level, varies depending on the complexity of the process or innovation adopted. Schneiderman (2005) conceptualized the complexity of improvement with two dimensions: technical complexity and organizational complexity. Technical complexity declines as the maturity of the technology increases. Organizational complexity captures the number of different goals, objectives, and cultures of various stakeholders involved in the process, ranging from uni-functional, cross-functional, to cross-organizational. Schneiderman (2005) summarized his findings in the half-life matrix (Figure 20) and noted that "increasing organizational complexity has about three times the slowing effect of increased technological complexity." As surplus elimination often involves cross-industry collaboration in the supply chain or at least many departments within an organization, the half-life of these meaningful improvements should be considered in the range of 11 to 22 months with medium to high organizational complexity.

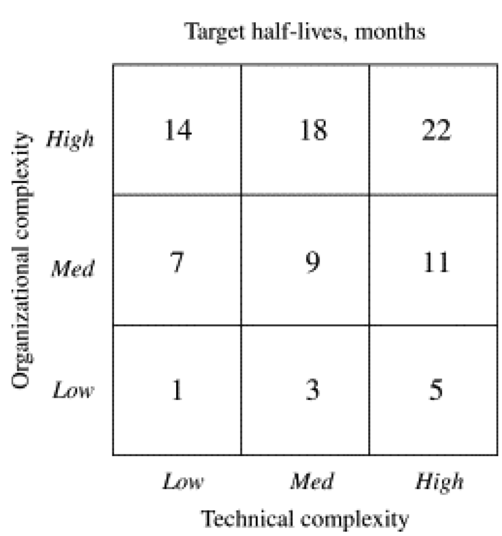


Figure 20. Half-life matrix (Source: Schneiderman 2005)

The various food waste reduction strategies described in this section are captured in the expanded causal loop diagram (Figure 21.) Potential investor leverage points are highlighted in red. To facilitate food waste reduction, an investor can choose to

(a) invest in building additional innovative food providers, replacing a certain fraction of food production from incumbent actors

(b) engage existing food providers (as shareholders of the companies or through funding third party organizations/campaigns) to set more ambitious food waste reduction targets, inducing higher reactive solution utilization rate or further lowering the surplus rate of *I* until it reaches the feasible minimum

(c) invest in building additional reactive solution capacities, diverting food surplus from landfill or incinerators

(d) invest in surplus prevention technology or model innovation to lower the feasible minimum of surplus rate, helping existing or future innovative food providers to lower their surplus rate.

Note that a basic balancing feedback loop exists in surplus elimination: When the surplus rate L_I is high, it's easier to find places to improve, and the progress is fast. When L_I is getting closer to the feasible minimum, the speed of surplus reduction goes down (B1: Low-hanging Fruits).

Following the empirical observation of the half-life system (Schneiderman 1988), innovators' surplus elimination rate (surplus percentage reduction per year) is proportional to the half-life of the process and is formalized as

$$\frac{dL_I}{dt} = -\phi(L_I - L_{min}) \tag{2}$$

where ϕ is the fractional rate of surplus reduction per year (so the half-life is $\frac{ln(2)}{\phi}$) and L_{min} is the larger number of either the feasible minimum surplus rate or *I*'s target rate (this ensures that *I*'s surplus rate would never go below the feasible minimum even when they target at a lower rate, and vice versa). Integrating equation (2) yields the evolution of I's surplus rate: $L_I(t) = L_{min} + (L_{I,t_0} - L_{min})\, exp(-\phi(t - t_0))$. The initial value of L_{I,t_0} is set to be equal to R's average surplus rate l_R as we assume there was no significant difference in surplus rate between R and I in 2010 (the simulation start time) when food waste was not a big concern yet according to case study described in section 4.2.

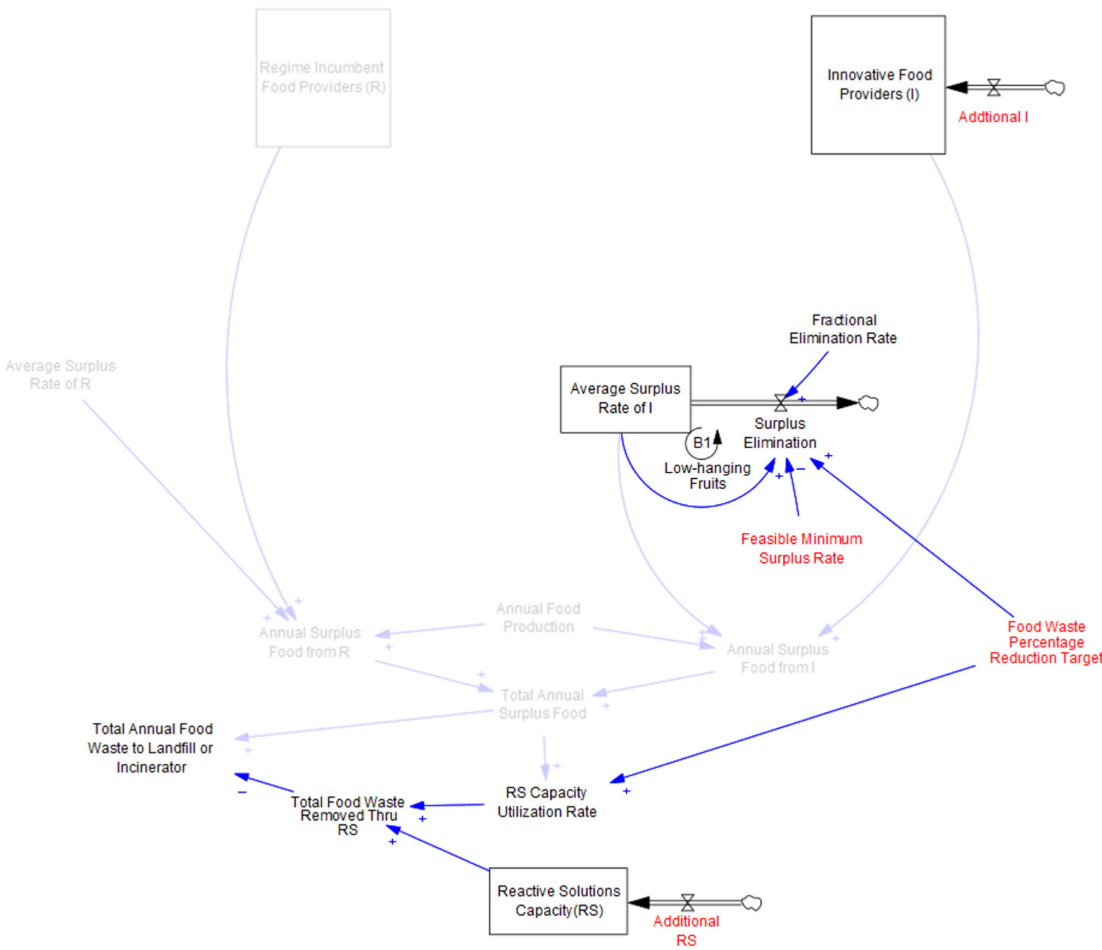


Figure 21. Overview of the model structure in Reactive Solutions and Surplus Elimination

4.3.3 Incumbent Transition Rate

Innovative food providers can emerge from niches built by newcomers (such as Imperfect Food mentioned above) and transition from the incumbent (such as Albertsons Companies and Hannaford mentioned above). The latter is akin to the "distant search" process, an exploration of alternative new technology, knowledge, and practice by regime actors (Geels 2014). The incumbent's exploration eventually leads to exposure to innovation, either from interaction with innovative food providers or marketing material of innovation. The exposure to innovation, however, is not always effective to end up with a transition decision. To formalize the effectiveness of innovation exposure on transition, the model should capture how incumbent actors make decisions as they are and not assume people are perfectly rational (Sterman 2000). Empirical evidence suggests that people are bounded rational, have psychological bias, and normally make decisions with imperfect information (Simon 1990; Conlisk 1996; Ehrlinger, Readinger, and Kim 2016; Johnson 2021). The interviews done in this case study and literature on food systems suggest that, although the initial search might be induced by environmental concerns or other pressures, the final innovation adoption and transition decision is largely determined by (a) economic incentive (Aramyan et al. 2020; Warshawsky 2016), (b) risk perception of the innovation (Marra, Pannell, and Abadi Ghadim 2003), and (c) skill fit of the available workforce (Avermaete et al. 2004; Triguero, Córcoles, and Cuerva 2013).

The economic incentive comes from improving the bottom line, as surplus food implies production and disposal costs. When incumbent food providers perceive innovative food providers create far less surplus, the transition becomes a potential saving opportunity. However, there is a discrepancy between *I*'s actual surplus rate and *R*'s perception of it. It takes significant time for *I* to measure its updated surplus rate, spread the latest information, and for *R* to recognize the information and decide to believe it. In the absence of good data and communication combined with a low willingness to listen and bias toward the status quo, the perception can persist for a long time. Even when the perceived surplus is favorable, it's still not a free lunch. Surplus elimination also incurs switching costs such as the upfront cost of the facility, technology, staff retraining, and operational costs. Although net present value (NPV) analysis can inform more accurate financial decision-making, the payback period has been found to be popular as a simple heuristic for management to make decisions, especially when the project is risky (Mukherjee and Henderson 1987; Kengatharan 2016). In practice, the decision rule involves setting up a maximum payback period acceptable to management. Lacking strong empirical evidence in the food system against this simple heuristic, the model employs the payback period decision rule to formalize the effect of economic incentives on transition decisions.

Risk aversion is a well-known psychological bias in human decision-making (Kahneman and Tversky 1979). When surplus innovation is perceived as risky, the adoption can be low even when there are obvious economic incentives. One of the interviewees in this case study illustrates this well when describing the difficulty of convincing management in transition:

> *"We need to demonstrate to the management that there are savings, but it's not showing up as a line item on their P&L. Is it real? That's really hard. So, we had to do some pilots to show the cost-saving results before expanding to the whole organization."*

Risk perception can be reduced through the learning effect. As the innovation gains momentum and accumulates certain results, the perceived and actual risks gradually decrease due to skill improvement, technology maturation, and information generation (Marra, Pannell, and Abadi Ghadim 2003). This can be generally characterized by a learning curve where the risk perception is assumed to be reduced by a certain fraction per doubling of accumulated innovation production.

Finally, as emphasized in the section 4.2 case study, it is considered essential to have enough innovative human capital for food incumbents to reduce surplus and successfully transition. The impact of workforce skills on other innovation activities in food companies is also characterized by Avermaete et al. (2004). This phenomenon is captured by conceptualizing that the transition decision is impacted by the "innovative human capital density" in the food system. When the density is high, the required skill is either within the organization or easily accessible from the talent market, facilitating a higher chance to make transition decisions. The innovative human capital, however, won't be attracted, hired, and trained if there are not enough innovative food providers in the industry. This creates a chicken-and-egg problem where innovative food providers and human capital coevolve from an undesirable equilibrium. With low innovative human capital density, incumbents hesitate to transition even when the economic and risk perception is favorable. In return, the small number of innovative food providers have very limited capacity to employ and attract innovative human capital, resulting in a vicious cycle and regime talent lock-in.

When an incumbent goes through the above decision-making process and ends up transitioning into *I*, it is worth noting that this new innovative food provider won't magically change its surplus rate to the current average of other *I*. Instead, it takes time for this new *I* to eliminate its own surplus rate. Therefore, when the transition happens, this new member introduces a higher surplus rate to the club, bringing the average surplus rate of *I* up from its current value. This mechanism is important because, for instance, let's assume that there are now 100 innovative food providers with a lower surplus rate. If 10000 incumbents suddenly recognize the economic value of surplus reduction and transition to *I*, then in the following years an outsider can't really tell the difference between this group of innovative providers and the rest of the incumbents since their average surplus rate hasn't dropped too much. This dilution effect creates a balancing process where the transition rate declines due to decreased perceived economic incentives.

Figure 22. summarizes these additional interdependencies in the system, illustrating multiple feedback loops governing the transition process. Three reinforcing feedback loops favor the transition to I (R1: Innovation Exposure, R2: Actor Learning &

Innovation Derisking, R4: Innovative Talent Attraction) while two balancing loops and one reinforcing loop counter the transition process (B2: *R* Saturation, B3 Is It Really Working?, and R3: Regime Talent & Knowledge Lock-in).

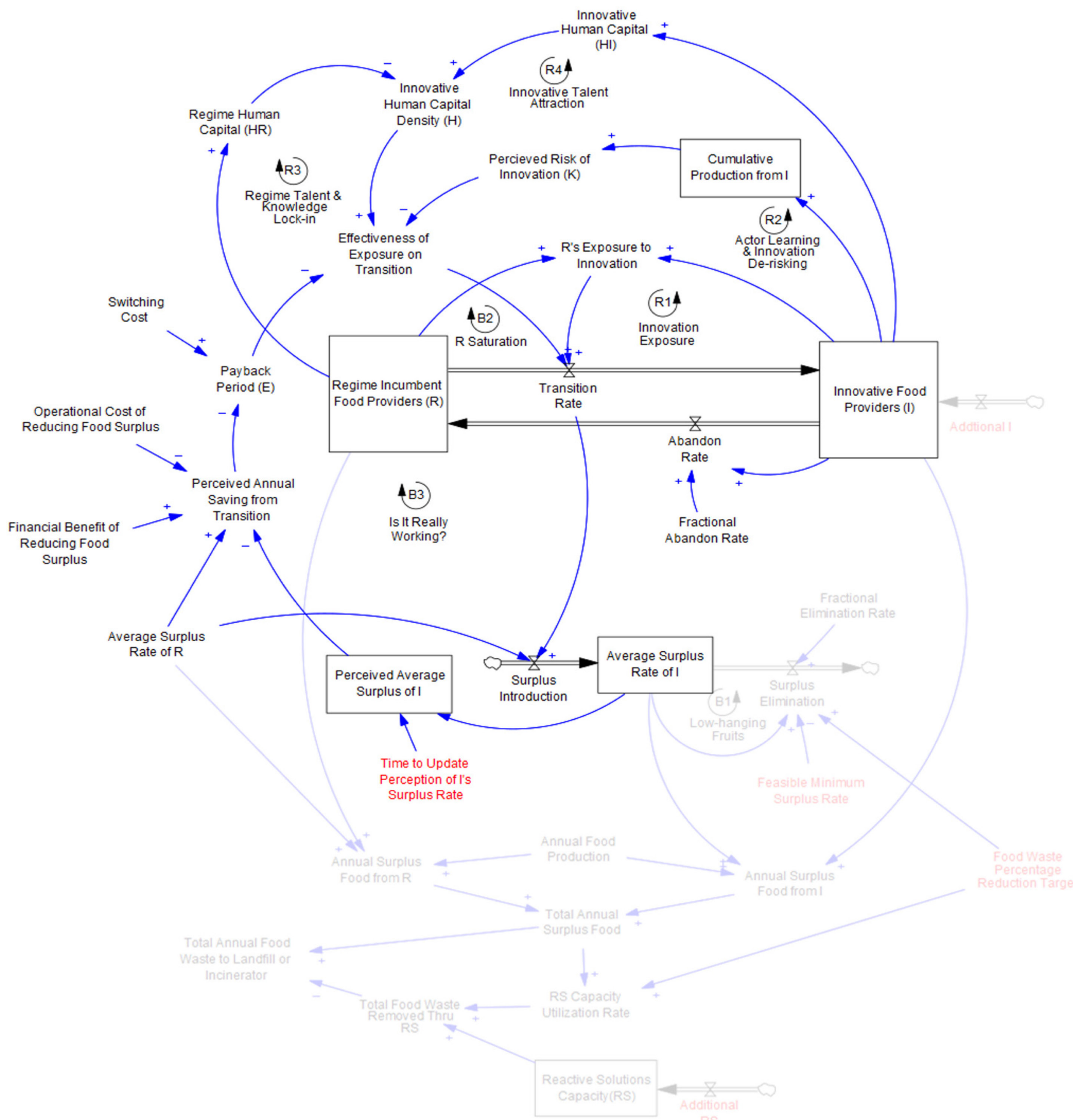


Figure 22. Overview of the model structure in Incumbent Transition Rate

In the base model, the total actors in the system stay constant with no net growth (given that the US food system is already a long-lasting industry.) The fraction of *I* (F_I) in the system is defined by $\frac{I}{R+I}$, and thus the fraction of *R* is $1 - F_I$. The model assumes *R*'s annual exposure to innovation marketing material (*p*) and *R*'s annual interaction with other food providers (*q*) as two constant parameters. Therefore, *R*'s annual total exposure to innovation is $(1 - F_I) \cdot (p + q \cdot F_I)$ where the second term $q \cdot F_I$ turns *R*'s annual total interaction into those interactions with *I* (that is, when *R* interact with another *R*, there is no innovation exposure for them). Adapting from the basic structure of the innovation-diffusion models (Bass 1969), the net change rate of F_I grows with the total innovation exposure and the effectiveness of those exposures on transition and decays when *I* abandon the commitment of eliminating surplus and switch back to *R*:

$$\frac{dF_I}{dt} = (1 - F_I) \cdot (p + q \cdot F_I) \cdot V - F_I \cdot \theta \qquad (3)$$

where *V* is the effectiveness of exposure on transition and θ is the constant fractional abandon rate (fraction of I abandon per year). As discussed above, *V* is a non-linear function of economic incentive (*E*), risk perception (*K*), and innovative human capital density (*H*). Below, *E* is used to illustrate such non-linear relationships.

Economic incentive *E* is formally defined by the payback period (*P*) and the maximum acceptable payback period (p_{max}):

$$E = Max(0,1 - (\frac{P}{p_{max}})) \qquad (4)$$

P is calculated by dividing switching cost (*s*) and perceived annual saving by eliminating the surplus (*A*):

$$P = \frac{s}{A} \qquad (5)$$

where *A* is a function of the perceived surplus rate of *I*, operational cost and financial benefit of reducing surplus. Note that the perceived surplus rate of *I* is modeled as a first-order information delay of *I*'s actual surplus rate L_I defined in Equation (2).

When *P* is larger than p_{max}, there is no economic incentive, and thus, *E* equals 0. As L_I goes down due to the elimination process, *A* increases (with a perception delay) and shortens *P*, increasing *E* once *P* is smaller than p_{max}.

Finally, the effect of E on V is formulated as

$$Effect\ of\ E\ on\ V \quad = E^{\gamma} \tag{6}$$

where γ is the sensitivity of transition to economic incentive. Figure 23 visualizes the effect of the payback period on V to build intuition about how γ influences the relationship. The effect is bounded between 0 and 1; that is, there is no transition if P is larger than p_{max} (effect = 0) and all exposure to innovation converts to transition if P is 0 (it's a no-brainer to adopt the innovation, so effect = 1). When γ is 1 (blue line), the effectiveness of exposure on transition linearly decreases as the payback period increases. The larger the γ, the more sensitive the transition is to the payback period, i.e., a small increase in P causes transition to drop significantly (green line). In the base model, γ is set to be 3.3 by assuming that 10% of the exposure effectively ends up transitioning when the payback period is half of the acceptable maximum value. The impact of this assumption is explored in the sensitivity analysis in section 4.4.

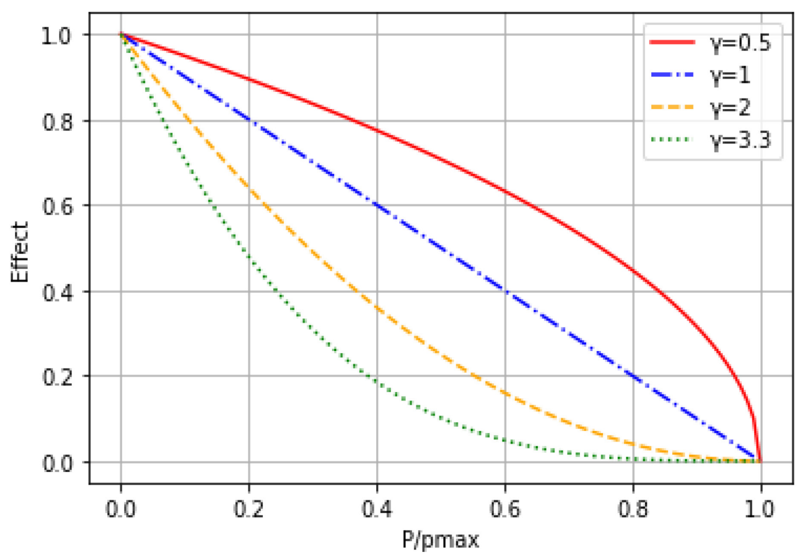


Figure 23. Effect of the Payback Period on V

Similar concepts apply to risk perception (K) and innovative human capital density (H). However, the shape and curvature of the non-linear function can be different. K is a function of cumulative food production from I and follows a standard learning curve function. The effect of K on V looks similar to Figure 23 and is governed by the parameter "strength of risk aversion (β)." H is defined by the quantity of innovative human capital (HI) and the quantity of regimes human capital (HR) as

$$H = \frac{HI}{HI+HR} \quad (7)$$

and the effect of *H* on *V* is governed by the parameter "Importance of Human Capital on Transition (α). In the base model, *HI* and *HR* are assumed to simply scale with the corresponding food provider (they are attracted, hired, and trained by those actors),

$$HI = I \cdot d \quad (8)$$
$$HR = R \cdot d \quad (9)$$

where *d* is the adequate number of human capitals per organization. This simplifying assumption implies that each organization attracts and hires its desired amount of human capital and can always get it immediately with no delays. In section 4.4, this assumption is relaxed, and the model is expanded to include a more explicit human capital-building process.

4.3.4 Base-case simulation

In the base-case scenario, the simulation starts in 2010 when food waste was not yet a big public concern. This scenario assumes no intervention is done by the Finks or ReFED. The market is dominated by regime food providers, with only very few innovative food providers in 2010. Base-case parameters are provided in Table 9.

Table 9. Base-case parameters
(R: Regime food providers; I: Innovative food providers; dmnl: Dimensionless)

Parameter	Definition	Unit	Value	Note
Annual food production (f)	Annual food production in the US.	Tons/ year	235M	From ReFED insight engine.[29]
Average Surplus Rate of R (l_R)	The average surplus rate of all actor *R* in the industry.	dmnl	0.4	Approximate number calculated from ReFED insight engine and "2019 Wasted Food Report" by EPA
Fractional Elimination Rate (ϕ)	The fractional rate of surplus elimination per year.	$year^{-1}$	0.35	The value is calculated by assuming a 2-year half-life. See sensitivity analysis in section 4.4.4
Feasible Minimum Surplus Rate (L_{min})	The minimum surplus rate *I* can feasibly achieve given the current available technology and practice.	dmnl	0.35	This initial value is set to be the case in 2010 and is treated as an exogenous variable to vary in intervention testing.

[29] https://insights.refed.org/

Parameter	Definition	Unit	Value	Note
Time to Update Perception of I's Surplus Rate (t_u)	The time required for *R* to update its perception of the surplus rate generated by *I*. This includes the time for *I* to measure its updated surplus rate, spread the latest information, and for *R* to recognize the information and decide to update its perception.	year	10	This initial value is set to be the case in 2010 and is treated as an exogenous variable to vary in intervention testing.
Unit Switching Cost (s)	Average total switching cost per production capacity for *R* to transition to *I*. This can include the upfront cost of facility, technology, and staff retraining.	$/ (tons/ year)	278	Average over a range of prevention solutions documented in ReFED's insight engine solution database methodology.
Operational Cost per tons of Food Surplus Reduced	Average operational cost for *I* to reduce surplus.	$/tons	846	Average over a range of prevention solutions documented in ReFED's insight engine solution database methodology.
Financial Benefit per tons of Food Surplus Reduced	Average financial gain because of reduced surplus. This can include food cost savings and landfill tip fee savings.	$/tons	3569	Average over a range of prevention solutions documented in ReFED's insight engine solution database methodology.
Max Limit of Payback Period (p_{max})	The maximum payback period *R* would consider the transition. A payback period longer than this maximum would lead to a zero transition rate.	year	3	The average hurdle payback period is reported to be 2.91 year (Fotsch 1984), 2.83 year for conventional projects, and 3.11 years for new technology projects (Drury 1993)
Sensitivity of Transition to Economic Incentive (γ)	The responsiveness of *R*'s transition to the change of payback period. The higher the value, the faster the decay of the transition rate as the payback period increases. See Figure 23 for a visualization of this parameter's impact on the transition	dmnl	3.3	The value is calculated assuming that 10% of the exposure effectively results in transition when the payback period is half the maximum limit p_{max}. See sensitivity analysis in section 4.4.4
K Learning Curve Strength (κ)	Strength of a learning curve from accumulated food production by *I*. The learning includes reducing the perceived risk and actual physical risk such as technology or implementing surplus elimination practice/innovation.	dmnl	-0.32	This learning curve exponent is calculated from the assumed 20% fractional reduction in risk perception per doubling of accumulated food production by *I*.
Strength of Risk Aversion (β)	The degree of *R*'s transition decision is influenced by the perceived risk of surplus elimination practice/ innovation.	dmnl	2.3	The value is calculated by assuming that when the perceived risk is 0.5 (the probability of success is 50%), only about 20% of potential transitions incentivized by economic reasons actually results in transition. See sensitivity analysis in section 4.4.4

Parameter	Definition	Unit	Value	Note
Adequate Human Capital per Org (d)	The number of skilled human capital required for an organization to function well.	talent/ actor	30	Heuristic. See sensitivity analysis in section 4.4.4
Importance of Human Capital in Transition (α)	The degree of *R*'s transition decision is influenced by the industry's innovative human capital density. The higher the value, the lower the transition rate given the same human capital density.	dmnl	0.32	The value is calculated by assuming that when the innovative human capital is equal to regime human capital (density is 50%), 80% of potential transition incentivized by economic reason actually results in transition. See sensitivity analysis in section 4.4.4
Fractional Abandon Rate (θ)	The normal fraction of *I* abandon the commitment of eliminating surplus and switch back to *R* per year.	$year^{-1}$	0.01	Conservative heuristic, assuming only 1% of the companies gives up experimenting innovation per year.
External Exposure (p)	Fraction of *R* exposed to innovation from marketing material per year	$year^{-1}$	0.1	Conservative heuristic, assuming only 10% of the incumbent food provider engages with innovation marketing material per year.
Interaction Frequency with other Providers (q)	Number of *R*'s active interaction with other food providers per year	$year^{-1}$	10	Heuristic.
Average Time to Build RS Capacity	Average time required to build up reactive solution capacity, including recycling plant, donation sites, logistics and information system, etc.	year	2	Conservative heuristic—for instance, it takes about months to several years to build an Anaerobic Digestor "AgSTAR Project Development Handbook 3rd Edition," n.d.)
R's Food Waste Percentage Reduction Target	*R*'s food waste reduction target, in terms of percentage reduction from its 2010 food waste level.	dmnl	0	This initial value is set to be the case in 2010 and is treated as an exogenous variable to vary in intervention testing.
I's Food Waste Percentage Reduction Target	*I*'s food waste reduction target, in terms of percentage reduction from its 2010 food waste level.	dmnl	0.5	This initial value is set to be the case in 2010 and is treated as an exogenous variable to vary in intervention testing.
Average Lifetime of RS Capacity	Average time for the reactive capacity to be unable to function as needed and thus retire.	year	20	Conservative heuristic. Composting facility or Anaerobic Digestor can normally last over 30 years.

Figure 24 shows some results from the base run. The base case scenario is a boring world from the perspective of food waste reduction. Food waste and surplus levels remain at about 40% high. Innovative food providers eliminate their surplus, but the progress quickly slows down after 2020 when it approaches the feasible minimum, and R's perception of it lags behind until 2040. Therefore, there is no significant change in the composition of food providers; the food system is still dominated by regime incumbents and human capital. From 2010 to 2030, some fraction of I abandon the practice, while no R transition into I because it's too risky and there's no economic incentive yet. From 2030, some R starts to transition as the perception of I's surplus rate starts to make economic sense and risk perception is slightly lower due to learning. However, the economic incentive is too low to trigger further transition and talent remains locked-in, inhibiting faster transition from happening. This base run offers a counterfactual scenario for later intervention testing.

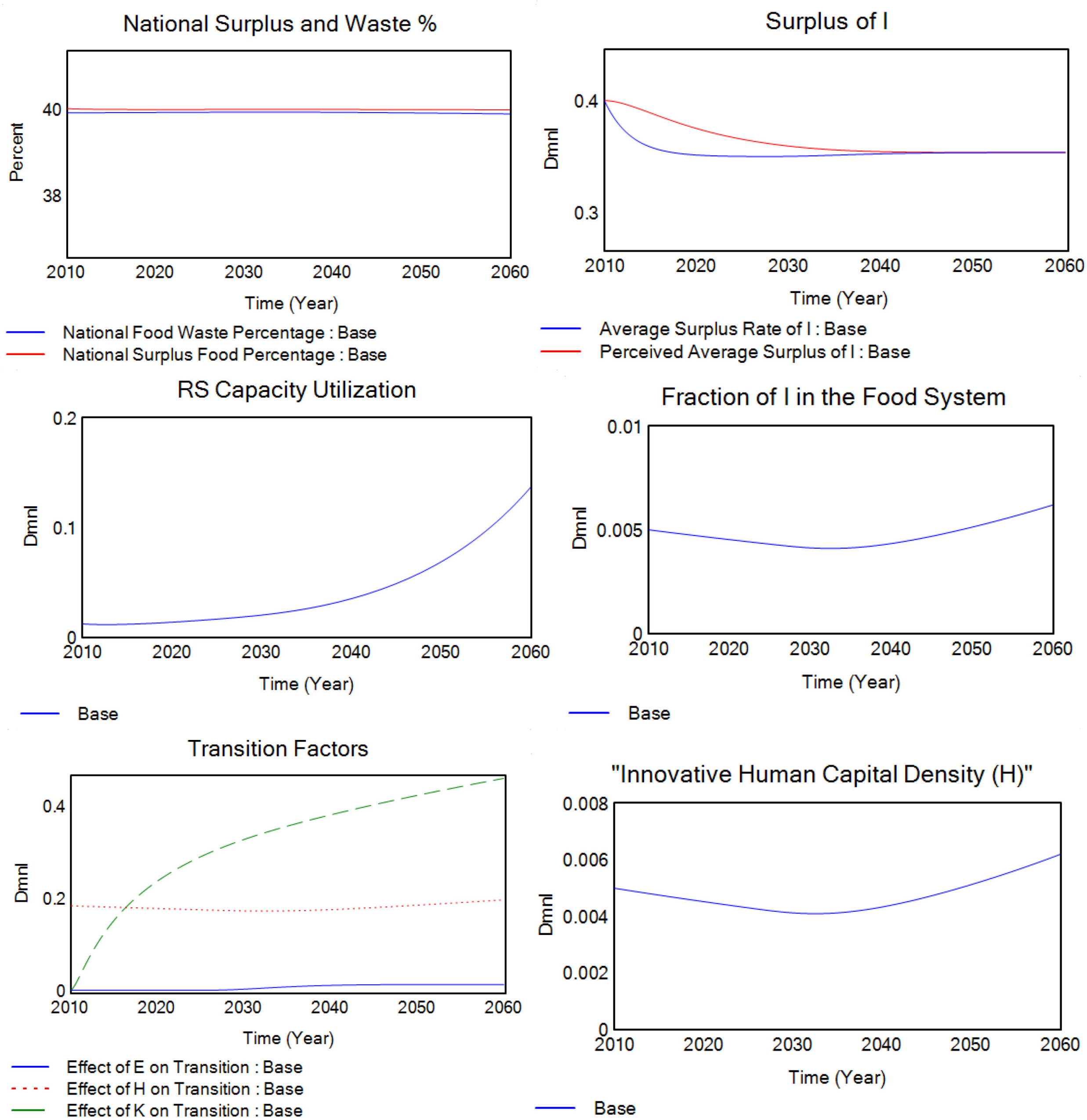


Figure 24. Base-case simulation results

4.4 Analysis of the System Model

Using the system model as a container of assumptions, including investors' mental model documented in the case study and the system context documented in the literature, the impact of various potential leverage points for investors is explored. Again, the purpose of this model is not to make predictions but to complement investors' current decision-making based on their mental models. Specifically, this section (a) introduces and analyzes five different investor interventions in isolation,

(b) explores the impact of combining interventions, (c) explores the impact of expanding the model boundary, (d) analyzes additional leverage points in the expanded model boundary, and (e) explores the impact of uncertainties embedded in the system with sensitivity analysis.

Before jumping into the analysis, it helps to imagine the situation faced by Jean, a hypothetical systemic investor in 2015 who wanted to enable a waste-free transition in the food system. With a budget of a few million dollars per year, Jean needed to figure out where to allocate the money to have the biggest impact. She understood that transitions are a long-term process, so she wanted to develop an investment thesis with a 20-year horizon. She has done the basic analysis and found three potential investment areas. She could invest in the reactive solution capacity in the system, new innovative food providers, or surplus prevention innovations. She also identified two more non-investable activities, engaging the incumbents and providing good data, which are potentially impactful and can be supported by her funding. Given the limited budget, she had to prioritize a few. The puzzle was, how should she think about the choices and under what conditions?

4.4.1 Five Potential Interventions

To test the five interventions in the model, they are operationalized as follows:

1. *Invest in more reactive solution capacity ("More RS")*

Based on ReFED's insight engine dataset, a 1-million-dollar investment can provide 5,000 to 10,000 tons of diversion potential on average. Assuming Jean invests 10 million annually starting in 2015 and continues for 20 years, the resulting test input in the model is shown in Figure 25.

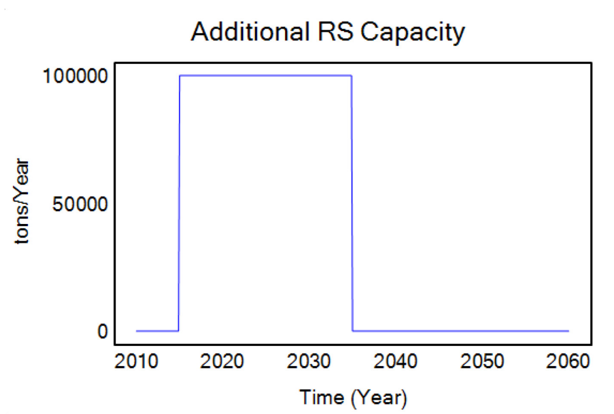


Figure 25. Test input for "More RS"

2. *Invest in new innovative food providers ("More I")*

Assuming an average of 500k funding for each new food provider, Jean can support 20 more actors per year with 10 million.[30] The test input in the model is shown in Figure 26.

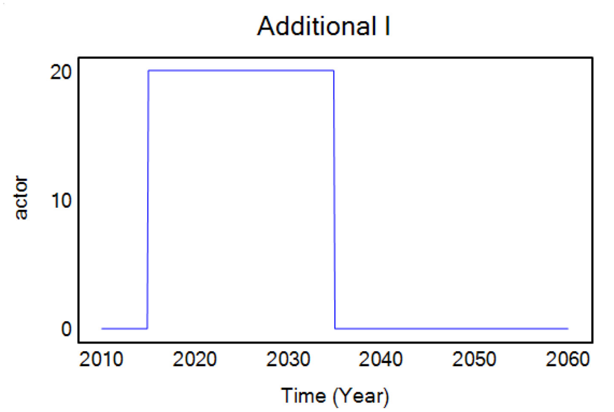


Figure 26. Test input for "More I"

3. *Invest in surplus prevention innovations ("Lower L_{min}")*

In the base model, the original industry average surplus rate is 0.4, and the feasible minimum surplus rate is set to be 0.35, a 12.5% prevention capability. Assuming an annual 10 million funding can further decrease 5% of this minimum over time, achieving 17.5% prevention (according to ReFED's insight engine dataset, the current solutions' average prevention potential is about 15% to 25% in 2023). Therefore, L_{min} decreased from its current rate of 0.35 to 0.33 over 20 years, resulting in the test input shown in Figure 27.

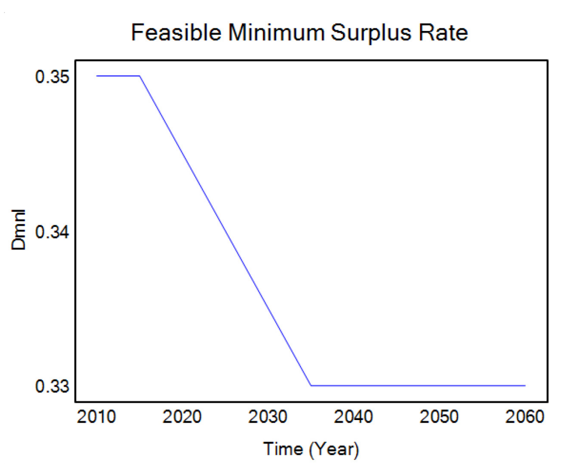


Figure 27. Test input for "Lower L_{min}"

[30] Note that in the base model, it takes on average 5 years for these additional I to reach the average scale of the industry and become a new I.

4. Engage the incumbents ("R20%Target")

In the base model, the incumbents take no action against food waste. An engagement activity can help them set food waste reduction targets. This activity is assumed to gradually increase *R*'s average reduction target from 0 to 20% over time. The test input in the model is shown in Figure 28.

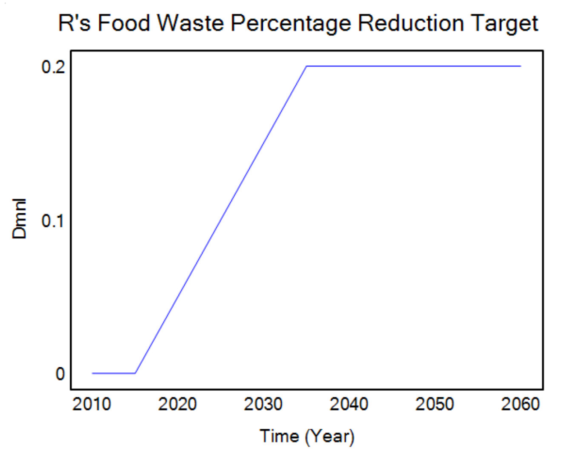


Figure 28. Test input for "R 20% Target"

5. Provide good data ("Less T_u")

In the base model, as in the case of 2010, the system lacks good data on food waste, measurement protocol, and general awareness. It takes on average 10 years for incumbents to update their perception of innovator's surplus rate and react to the innovation. Providing good data is assumed to accelerate the perception update process to 2 years on average. The effect ends when Jean's efforts cease in 2035, and the test input is shown in Figure 29.

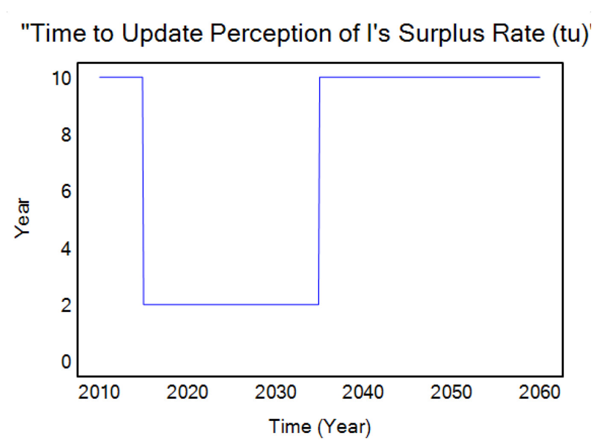


Figure 29. Test input for "Less T_u"

Figure 30 compares the impact on *I*'s market share by these five interventions and the base case. The "More RS" and "R20%Target" interventions do not impact the fraction of *I* since they focus on dealing with food waste after the surplus is generated. Intervention "More I," as the name suggests, directly impacts the fraction of *I* and thus shows immediate results in 2015. After the investment activity finishes in 2035, *I*'s fraction continues to grow at a faster rate than the base case in the same time period, a result of reinforcing feedback the early investment triggered (R1: Innovation Exposure, R2: Actor Learning & Innovation De-risking, R4: Innovative Talent Attraction). Intervention "Lower L_{min}" shows negligible impact until 2030, 15 years after the investment, and then grows significantly to outpace the intervention "More I." A lower L_{min} can greatly influence the economic incentive to transition, but the influence is delayed due to two system structures. For *I,* it takes time to adopt and implement the innovation, gradually eliminating the surplus and communicating the result. For *R*, it takes time to receive the information, give up bias, and then update their perception. But once the perception is updated, the economic incentive is a strong driver, coupling with the reinforcing loops triggered as the number of *I* grows. These temporal dynamics make decision-making difficult because the intervention might be seen as ineffective during the early days and abandoned before the effect takes off. Finally, the intervention "Less T_u" has a relatively fast result starting from 2020, but the growth rate is not too different from the base case in the long run.

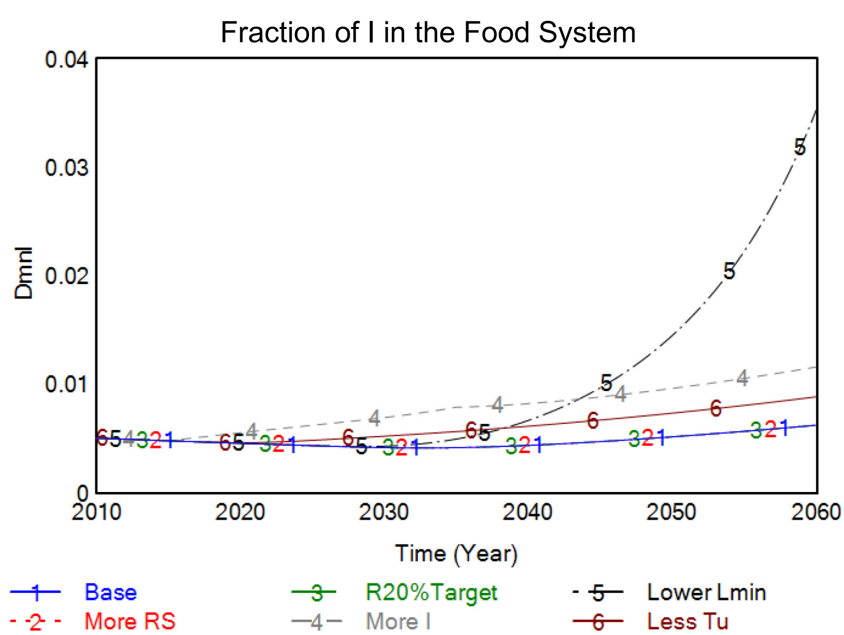


Figure 30. Impact of five interventions on I's market share in the food system

Because the fraction of *I* is so small (even in the best scenario it's still lower than 4% in 2060, the rest is less than 1%), most interventions' impact on the scale of national food waste problem is limited (Figure 31). The exception is "R20%Target", as the volume of food waste produced by R is significantly larger and the reduction target drives the utilization of reactive solutions (Figure 32). However, the impact diminishes after the utilization reaches full capacity and some available capacity gradually retires after certain years of operation. Without adding new capacity, the food waste percentage rebounds back.

On the other hand, "More RS" has limited impact in this scenario because, in the base case, utilization of current *RS* capacity is low due to low willingness to reduce food waste. Therefore, adding more capacity doesn't result in meaningful differences at the national scale. "More RS" only makes sense in the scenario that capacity becomes the constraint (like after the year 2025 in "R20%Target") or in the case where utilization is dependent on other factors not considered in this model (for example, when an actor has the willingness to donate extra food but face technical difficulties or geographical heterogeneity make the available capacity out of reach). Otherwise, additional reactive solutions might simply compete with existing reactive solutions when none is at full capacity. When done right, reactive solutions can significantly and immediately reduce food waste, plus other social impacts. However, the focus on the end-of-pipe problem ignores the impact surplus food has upstream and has no effect on the transition.

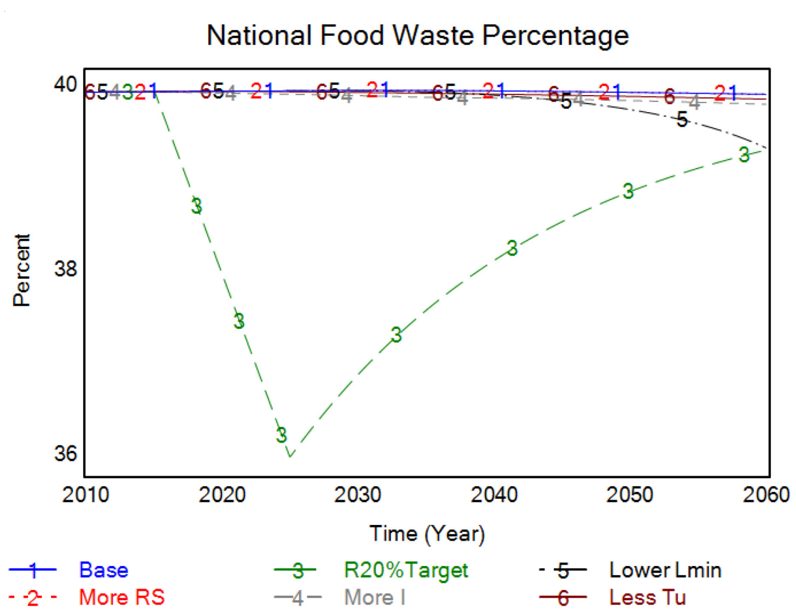


Figure 31. Impact of five interventions on the food waste percentage

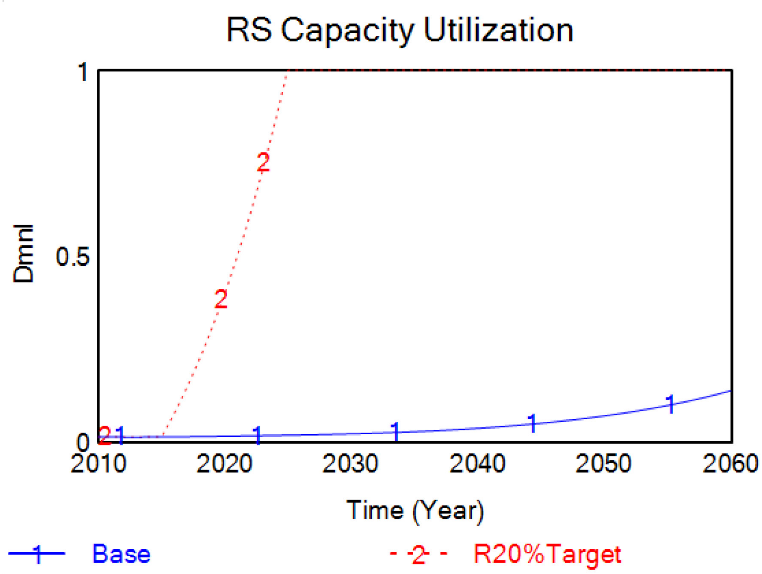


Figure 32. RS capacity utilization in the base case and scenario “R20%Target”

4.4.2 Combination of interventions

As an investor focusing on changing the systems, Jean wonders if it would be worth combining two different types of interventions if resources allow. If the combination's impact simply adds the two impacts, then having different interventions in the portfolio can potentially lose the benefit of specialization as investors might be better off putting all resources into one bucket with a higher impact. In this case, the only argument for combining is the diversification logic of reducing risk when investors are unsure which bucket has better results. If, however, the combination could have additional benefits that neither intervention has, it might be a good idea to pursue such combinations intentionally. Below, this combinatorial effect is explored.

Figure 33 compares the scenario of combining “Lower L_{min}” (invest in surplus prevention innovations) and “Less T_u” (provide good data) against their separate effects. “Less T_u” alone has a very limited impact on *I*’s fraction in 2060 (far less than 1% contribution.) However, when combined with “Lower L_{min},” it helps more than double the impact of “Lower L_{min}” alone. A partial view of the system model helps understand the structural reason behind the effect (Figure 34). In this combination, investing in surplus prevention innovations drives the main effect of transition, bringing down the actual surplus rate and creating economic incentives. However, significant system inertia (*R*’s perception bias) in this causal chain slows down the dynamics. Providing good data helps remove such inertia, realizing the full potential of surplus prevention innovations. In other words, "Lower L_{min}" determines the equilibrium value the system is moving toward, while "Less T_u" determines how fast the system moves there. In systems change, speed generally has two important benefits. First, it creates small and quick wins that can encourage the intervener to persist. Second, perhaps more importantly, in a system full of reinforcing feedback loops, the faster the system accumulates, the stronger the reinforcing effect is and further pushes the system forward.

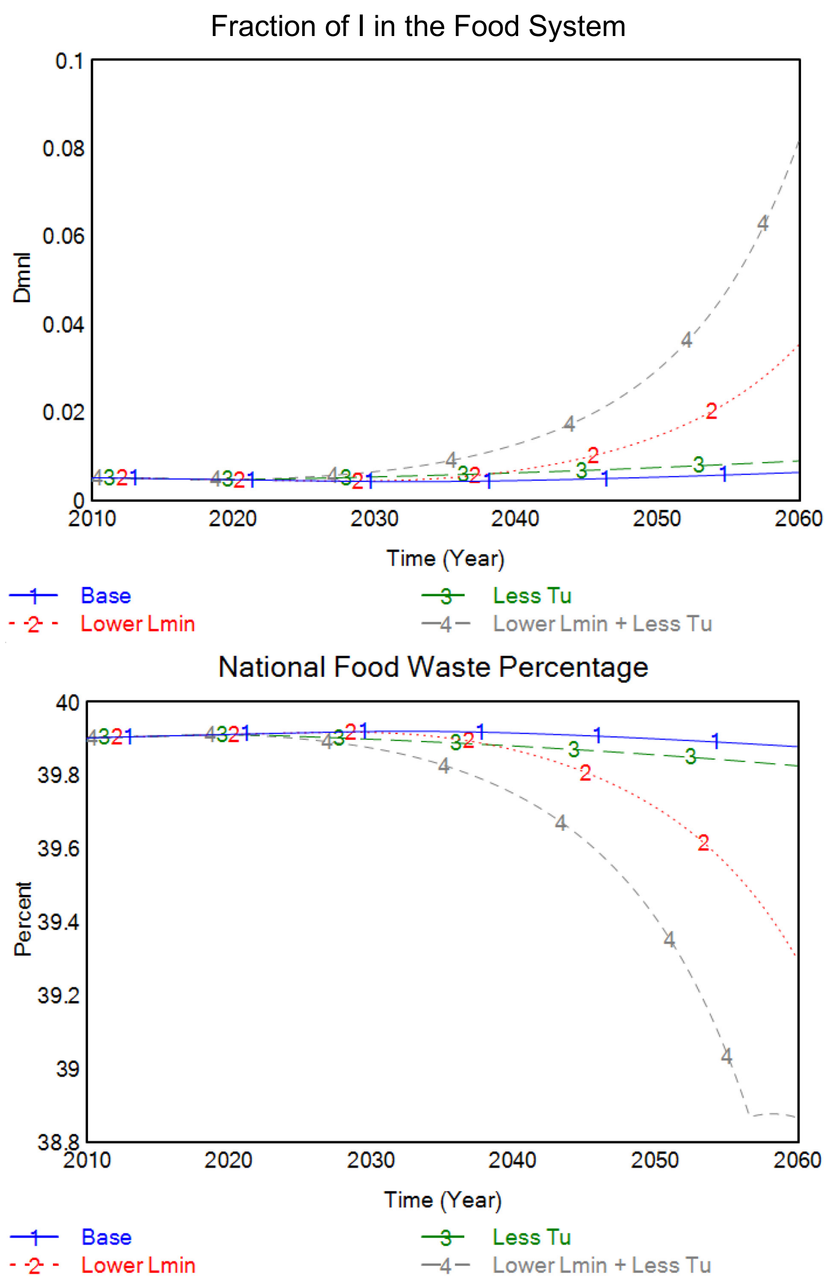


Figure 33. Combinatorial effect of "Lower L_{min}" and "Less T_u"

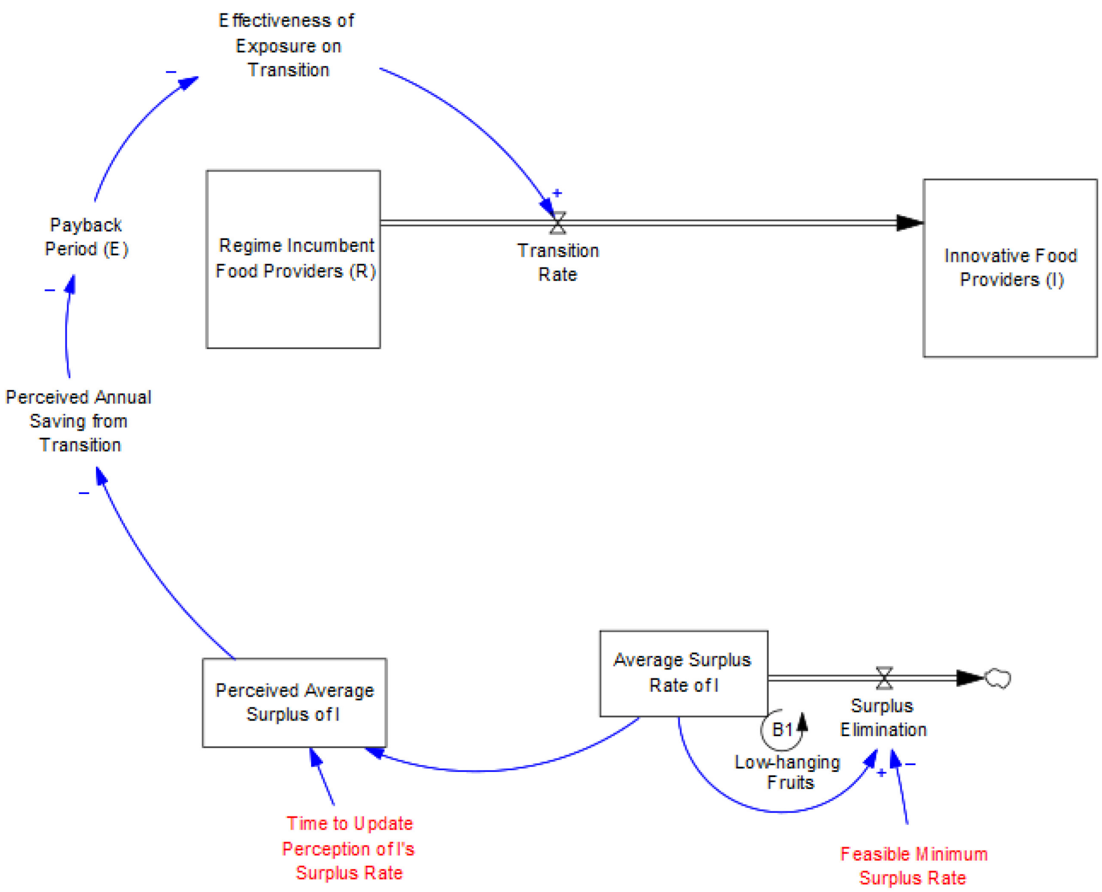


Figure 34. Partial view of system structure behind the combinatorial effect of "Lower L_{min}" and "Less T_u"

"Less T_u" (provide good data) doesn't incur too much more resource investment compared to "Lower L_{min}" (invest in surplus prevention innovations) so it's arguably feasible given the resource constraint faced by Jean. However, if Jean wants to further combine "More I" (Invest in new innovative food providers) into her portfolio of interventions, she would need to raise more funding. To cut the funding burden, "More I" needs to be shortened from a 20-year program to only 10 years, ending in 2025 instead of 2035. Is it worth it?

Figure 35 shows the effect of such a combination. Again, while investing in new innovative food providers alone contributes very little in the long run, adding a "lite" version upfront greatly impacts the existing portfolio. In this case, these additional innovative food providers help remove the inertia of regime talent lock-in. The effect of human capital on the transition from 2015 to 2030 is shown in Figure 36. It takes 15 years for the existing portfolio of "Less T_u" and "Lower L_{min}" to reach about 0.2 (i.e., only 20% of the potential transition incentivized by economic reason actually results in transition because of low innovative human capital density). The “lite” version of “More I” starting in 2015 attracts more human capital into the space and helps surpass the same value in 5 years. This results in more *R* transition into *I* and triggers further talent attraction, starting the virtuous cycle (Figure 37). Therefore, not only does the feedback mechanisms matter, but the sequence also plays a big role in driving the desired dynamics, especially when the resource is constrained.

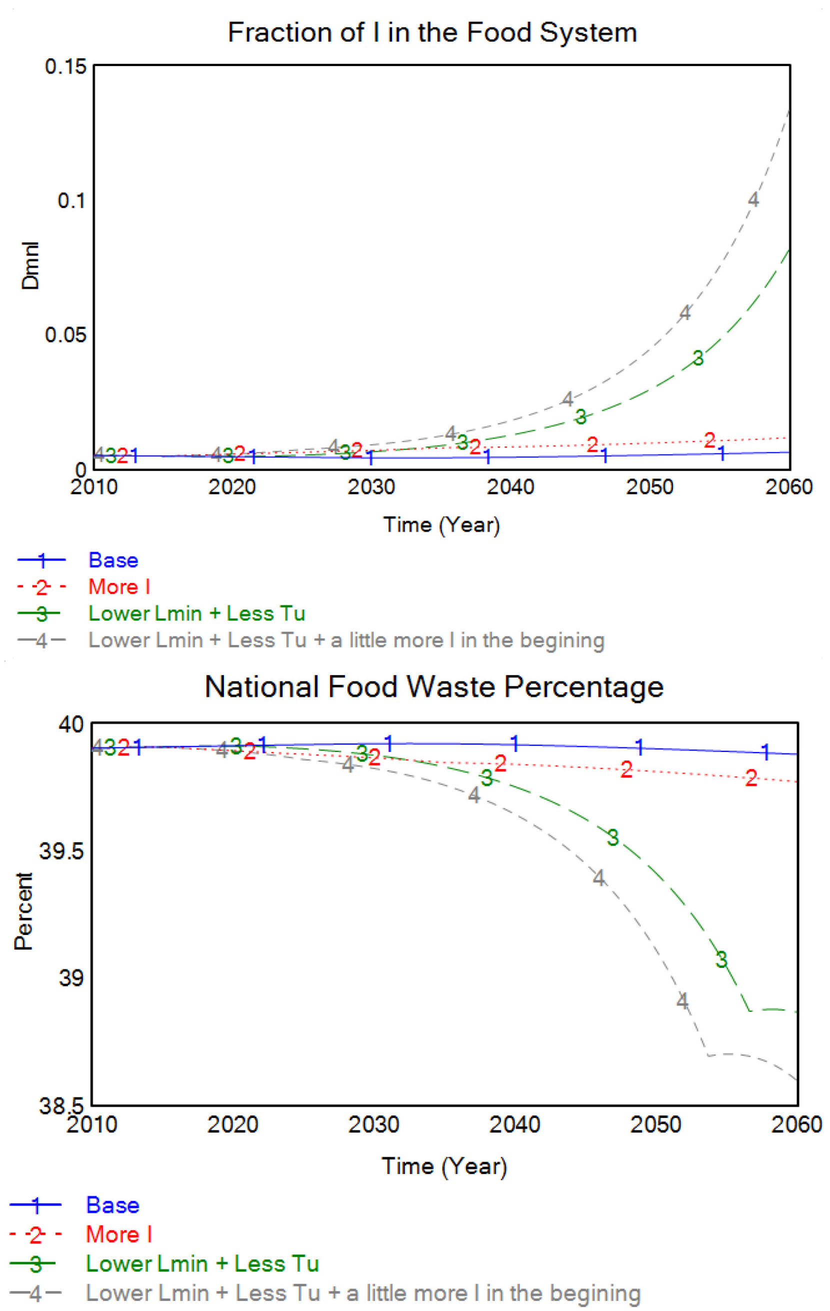


Figure 35. Combinatorial effect of “Lower L_{min}”, “Less T_u”, and “More I”

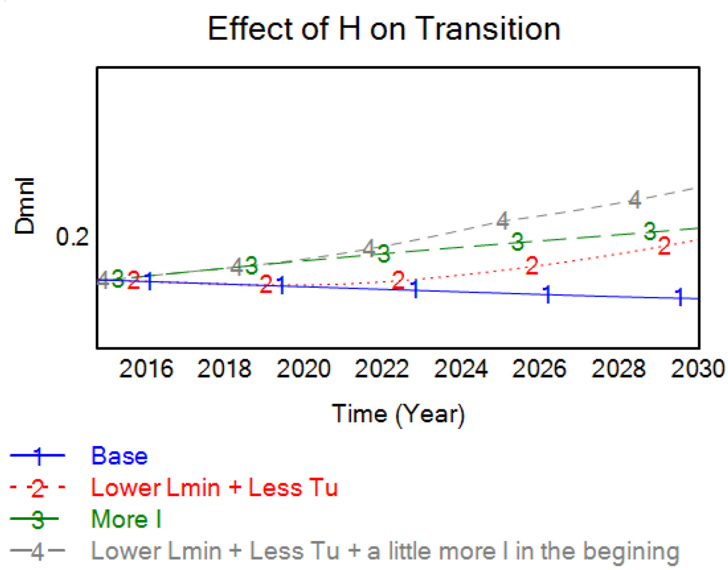


Figure 36. The effect of H on Transition in 2015-2030

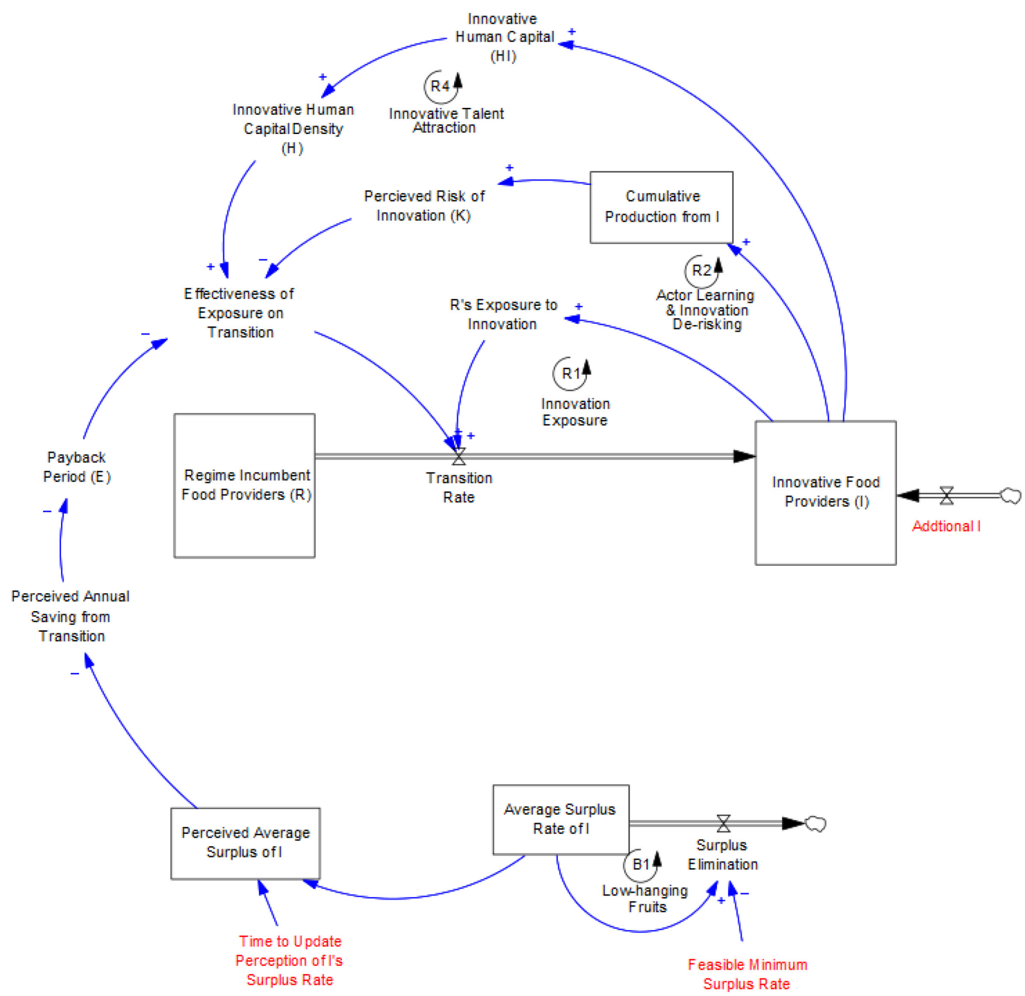


Figure 37. Partial view of system structure behind the combinatorial effect of “Lower Lmin,” “Less Tu,” and “More I”

4.4.3 Expanding the Model Boundary

So far, the model has assumed that talents scale with actors immediately (Equation (8) and (9)). In the argument made in the last paragraph, the intervention "More I" starting in 2015 attracts more human capital into the space and has an impact in 2015. It is important to critically evaluate how the result may vary when this structural assumption of the model is changed to include other important feedback mechanisms impacting the evolution of the food system.

Operationally, what actually scales with innovative food provider *I* is the "desired" *HI*, not the "current" *HI*. The "current" *HI* is what really has a physical impact on the world; the "desired" *HI*, on the other hand, is a piece of information in the system. This information can trigger *I* to hire or trigger potential talents to enter the space, gradually increase the current *HI,* and close the gap between the two. This process is not immediate; in fact, it can take years in a new space like the one being studied. Furthermore, no one is born to understand how to eliminate the surplus and can contribute to the process. If food waste reduction is not a public concern nor seen as a business opportunity, the normal education system won't help prepare students for the skills required to help food providers eliminate the surplus. Therefore, hiring can only bring inexperienced human capital to the system. After a few years of learning by doing, they become the experienced human capital. Suppose this inexperienced human capital has less effect on transition than experienced human capital. The "effective" *HI* is then different from the "current" *HI* which only counts the number without accounting for their effectiveness.

Now, consider the transition process. When incumbents decide to transition, their regime human capital doesn't just magically become innovative human capital. One of the interviewees in this case study shed some light on the impact of transition on human capital:

> "...We focused a lot on training our managers and chefs to work through the change cycle. When we hire them, we give them a job description and tell them not to deviate from this. So, we really had to rethink everything we were doing in our kitchens and reskill our employees for this [surplus elimination] program to succeed."

It is thus helpful to conceptualize an intermediate state as the "Human Capital in Transition." It increases with the actor transition rate and decreases after people successfully reskill themselves to become experienced, innovative human capital after an average reskilling time (and there is a fraction of them decide to quit during this period, which is also captured in the model). During the transition, they can also be less effective like the inexperienced, and are modeled as the same for simplicity.

Finally, since the “effective” *HI* differs from the “current” *HI* and “desired” *HI*, innovative food providers might experience periods of low talent adequacy. In the short term, this can impact the half-life of surplus elimination, as suggested by one of the interviewees in this case study:

> “When I moved to another position, we tried to find another champion, but we couldn't find anyone. Those were a tough couple of years and had a huge impact on surplus reduction rate because the sites that had launched the program couldn’t have the support they did before.”

In the long term, this can degrade the political will to keep the momentum and increase the abandonment rate of I. These two adverse effects driven by talent adequacy create two additional balancing feedback loops in the system (B4: Losing Political Will; B5: Diluted Implementation Capacity) shown in Figure 38.

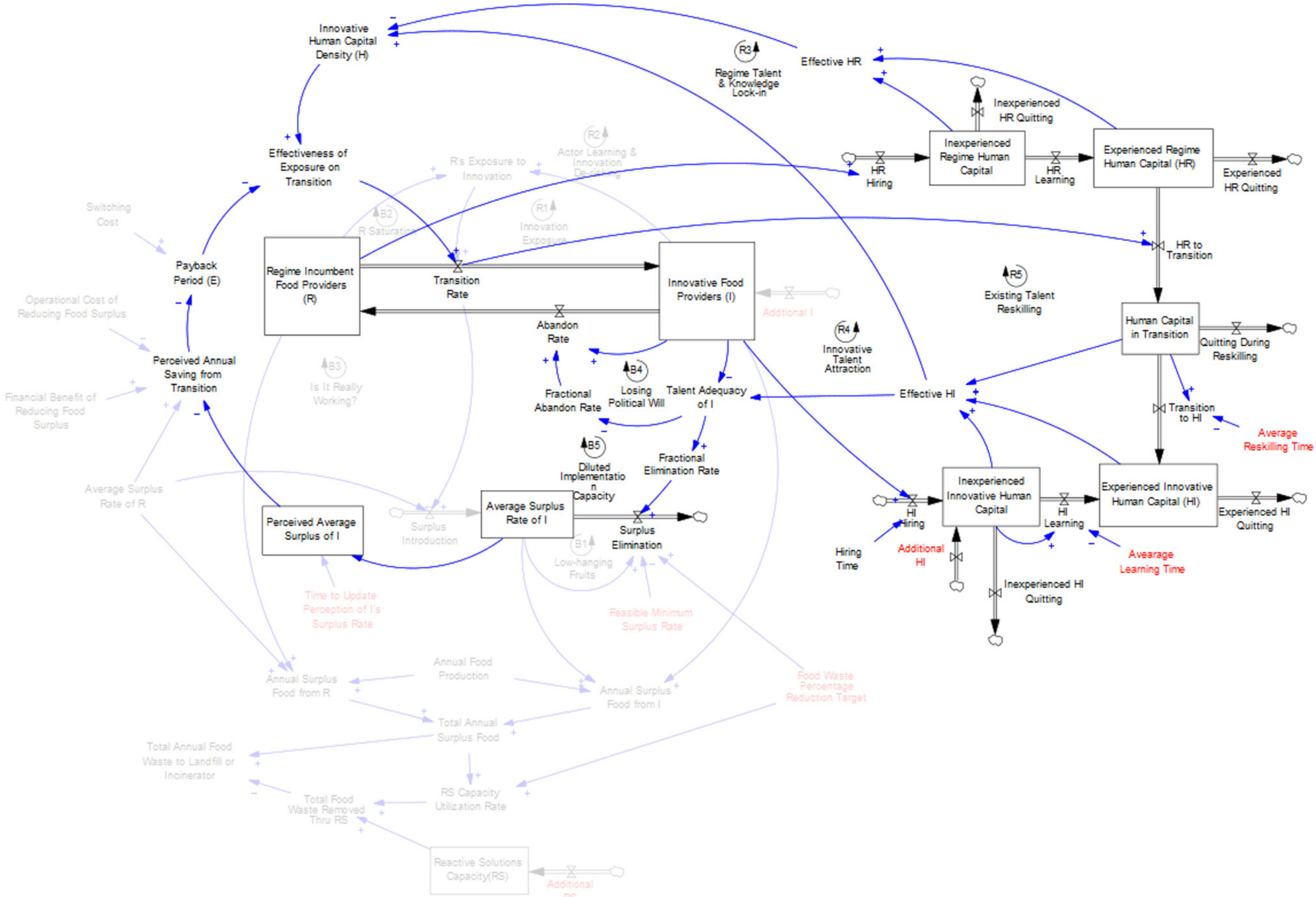


Figure 38. Overview of the model structure in Human Capital

In the expanded model, the innovative human capital density (*H*) is reformulated from Equation (7) into

$$H = \frac{HI_e}{HI_e + HR_e} \tag{10}$$

where HI_e is the effective *HI* and HR_e is the effective *HR*. HI_e is calculated by summing all the current *HI* (HI_c) while applying an effective ratio of inexperienced (λ) to those not yet experienced. Equations (8) and (9) are reformulated to capture the idea of "desired" human capital; for example, the desired *HI* (HI_d) is

$$HI_d = I \cdot d \tag{11}$$

The net change rate of inexperienced *HI* (HI_i) grows proportionally to the gap between current *HI* and desired *HI* and decay either through turnover or learning to become experienced:

$$\frac{dHI_i}{dt} = \frac{HI_d - HI_c}{t_h} - HI_i(\rho + \frac{1}{t_l}) \tag{12}$$

where t_h is the average hiring time, ρ is the fractional turnover rate of inexperienced, and t_l is the average learning time. The "experienced human capital" and "human capital in transition" have a similar structure and are detailed in full model documentation in Appendix 2.

Finally, the talent adequacy of *I* (T) is calculated by

$$T = \frac{HI_e}{HI_d} \tag{13}$$

T has two impacts in the system as mentioned above, one in the short term and one in the long term. Below, the short-term impact on the fractional surplus elimination rate is used to illustrate the relationship:

$$Effect\ of\ T\ on\ surplus\ elimination = T^{\mu} \tag{14}$$

where μ is the importance of talent on surplus elimination. μ capture how dependent the surplus elimination process is on effective human capital and is evaluated in the sensitivity analysis in section 4.4.4 due to its inherent uncertainty. Table 10 provides the additional parameters used in the expanded model.

Table 10. Additional parameters used for expanded model boundary

Parameter	Definition	Unit	Value	Note
Recruiting Time	Average time required for actors to recognize their need for new human capital, create vacancies, go through the hiring process, and eventually close the gap between their current and desired human capital.	year	2	Assume symmetric recruiting time for *R* and *I*. Note that this is a favorable assumption for *I* as it generally takes longer for new actors to recruit people than existing established actors.
Learning Time	Average time required for inexperienced human capital to acquire knowledge and practical skills to become as productive and effective as the experienced human capital.	year	3	Heuristic
Reskilling Time	Average time required for regime human capital to change their original practice, acquire new knowledge and practical skills in preventing food surplus, and eventually become more productive and effective in surplus prevention like the experienced human capital in I.	year	3	Heuristic
Importance of Talent in Surplus Elimination (μ)	The degree of I's surplus elimination rate depends on talent adequacy. The higher the value, the faster the decline of surplus elimination rate when talent adequacy is lower than 1.	dmnl	1	The value is assumed to make the relationship between talent adequacy and surplus elimination linear, i.e., a 20% drop in talent adequacy would result in a 20% drop in surplus elimination rate. The heuristic behind the assumption is that most surplus elimination practices/innovations are directly linked to people behind the process; thus, inadequate talent has an immediate and proportional impact on how fast the average surplus rate can be eliminated. See sensitivity analysis in section 4.4.4
Fractional Turnover Rate of Inexperienced	The normal fraction of the inexperienced human capital quitting and leaving the industry before becoming experienced per year.	$year^{-1}$	0.4	Conservative heuristic—the annual turnover rate reported by U.S. Bureau of Labor Statistics: -Food manufacturing 38%-48% -Retail trade 52%-56% -Food service 66%-81%
Fractional Turnover Rate of Experienced	The normal fraction of the experienced human capital quitting and leaving the industry per year.	$year^{-1}$	0.05	Heuristic—the value is assumed to be much lower than the inexperienced since people normally become more attached to their jobs and industry once they have developed their skills and networks.

Parameter	Definition	Unit	Value	Note
Sensitivity of Abandon to Talent	The responsiveness of I's fractional abandon rate to the change of talent adequacy for I. The higher the value, the larger the fraction of I would switch back to R when talent adequacy is lower than 1.	dmnl	1.4	The value is calculated by assuming that the fractional abandon rate doubles when talent adequacy is only 50% of its desired level.
Effectiveness Ratio of Inexperienced (λ)	The effectiveness ratio between the inexperienced and experienced human capital.	dmnl	0.5	Heuristic, for simplicity we aggregate the inexperienced into one construct regardless their tenure, although the relationship between experience and productivity /effectiveness is non-linear (see Gagliardi, Grinza, and Rycx 2023)

Does the effort to expand the model boundary change anything investors care about? After all, all models are abstractions from the real world and are only useful for the purpose of building them, in this case, informing allocation decisions. Figure 39 shows that the structural assumption significantly impacts the magnitude of the intervention results. The original superstar portfolio “More I,” “Lower L_{min},” and “Less T_u” in the expanded model is only as good as the portfolio “Lower L_{min}” and “Less T_u” in the base model. Figure 40 illustrates why. While the base model assumes food providers always have desired human capital, and thus, talent adequacy is always 1, it’s not the case in the expanded model. Transitions and interventions can all make the problem worse. For instance, while intervention “More I” is always good in the base model, there is an unintended consequence in the expanded model. By introducing more *I* into the space, the immediate effect is competing for talent and causing the talent adequacy per *I* to drop in the short term. Only after some time can the system bring the number back to the desired value through attracting, hiring, and training new people. During the period talent is inadequate, surplus elimination slows down, and a certain fraction of *I* decide to switch back to *R*, jeopardizing the transition.

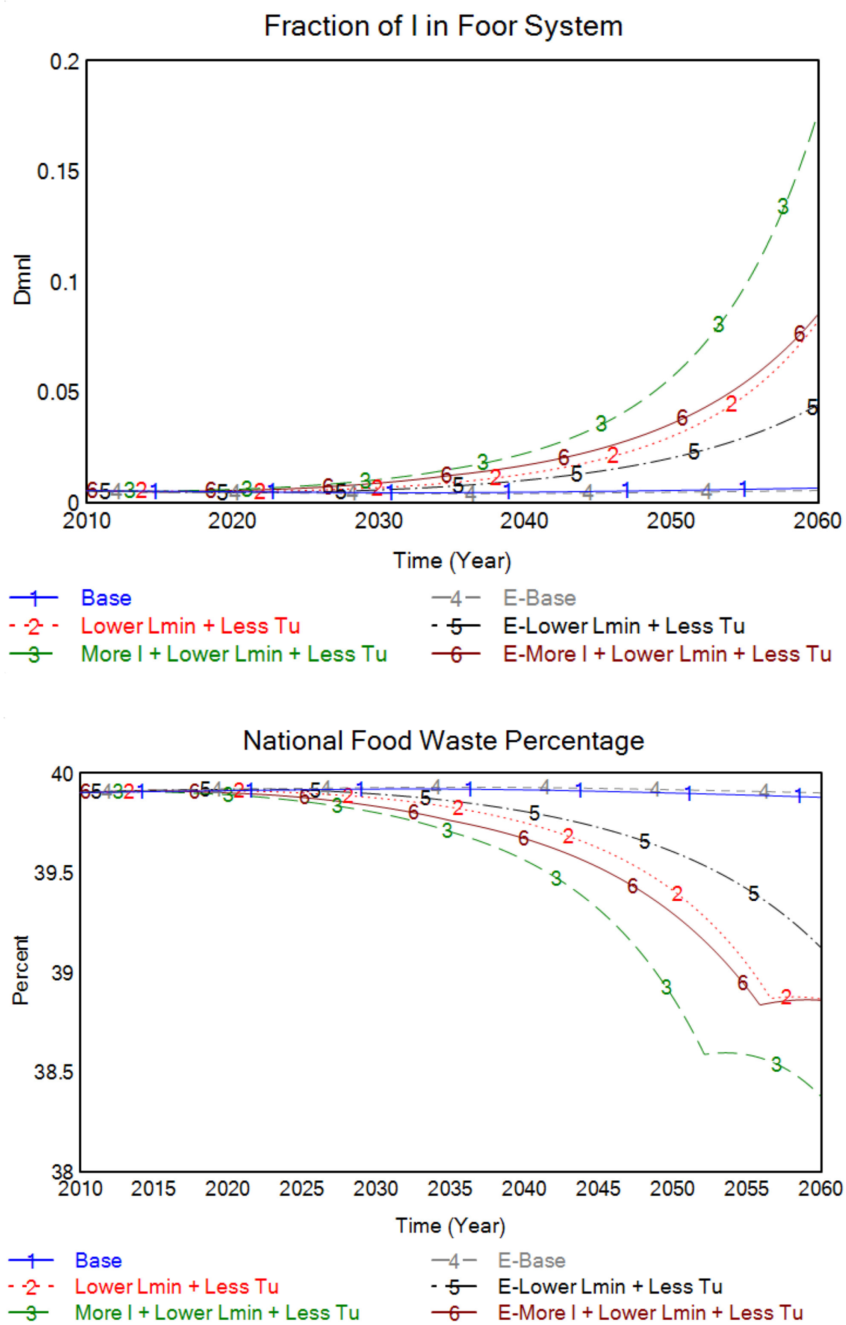


Figure 39. Comparison between the base model and expanded model (Scenario starting with E- represents expanded model)

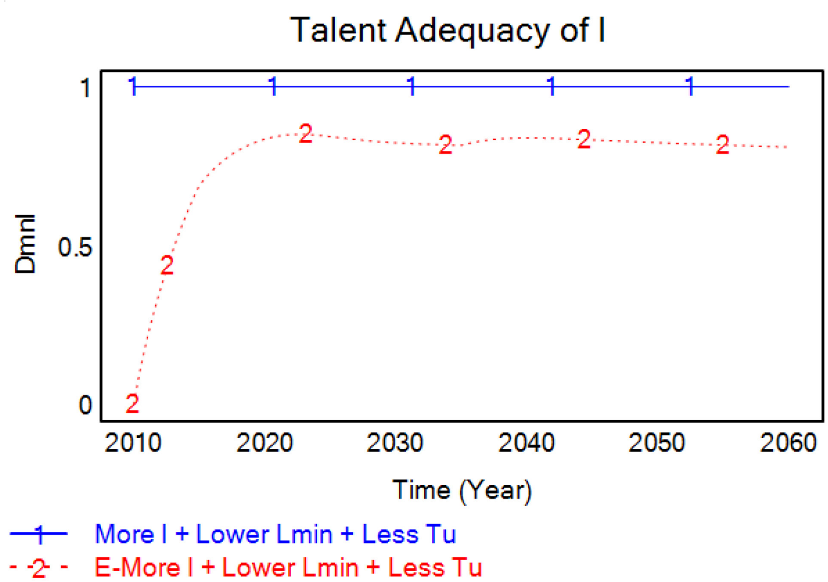


Figure 40. Talent Adequacy difference between the base model and expanded model

To compensate for the impact drop, additional interventions are needed. The expanded model boundary also expands the decision space of investor leverage points. For example, investors can help introduce additional inexperienced human capital to the space and shorten the average learning and reskilling times. How? The case study in section 4.2 provides a great operational choice:

> "To help motivated companies advance their food waste reduction strategy efficiently, ReFED partnered with the Environmental Defense Fund (EDF) to launch a Climate Corps Food Waste Fellowship, training students to provide corporations with dedicated assistance. The program had deployed top-tier graduate students into more than 20 food brands, investment firms, and government agencies (such as Albertsons, Sodexo, Closed Loop Partners, and the New York City Housing Authority), helping solve the sector's growing capacity-building need with expert human capital."

In the model, these three leverage points are tested with the inputs shown in Figure 41.

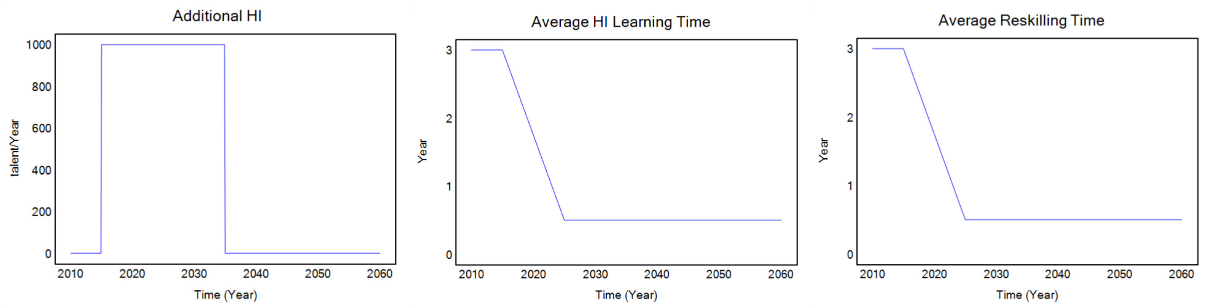
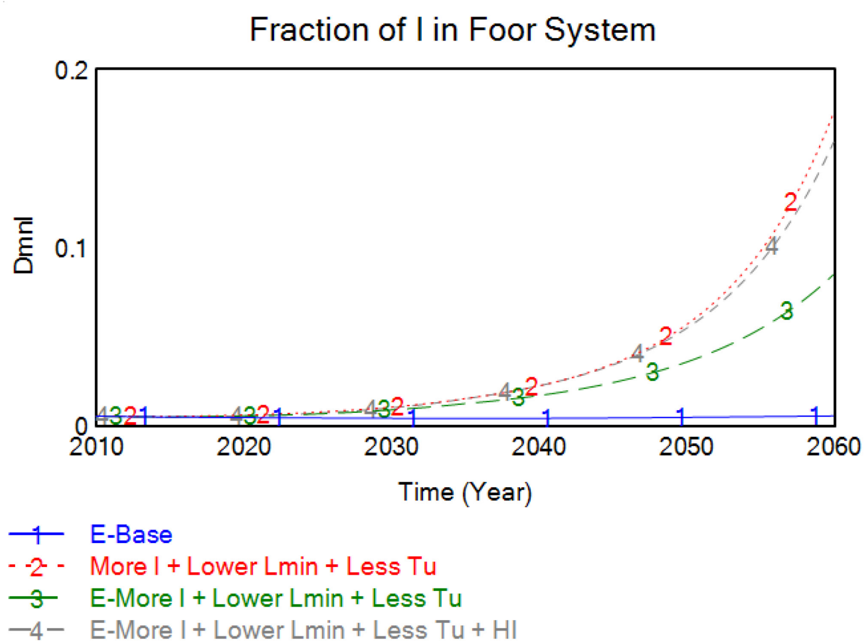


Figure 41. Test input for “HI”

The result of this new portfolio is shown in Figure 42. It successfully matches the impact to the level in the base model. A detailed look into the effect of *H* on transition shows why (Figure 43). Without the addition of intervention “HI” in the portfolio, the innovative human capital density is way below the case in the base model when there is abundant *HI* as desired. Adding “HI” to the portfolio helps to create “surplus human capital” (around 2020 to 2040) to compensate for the delay in the human capital building process and overcome the inertia it created in the system.



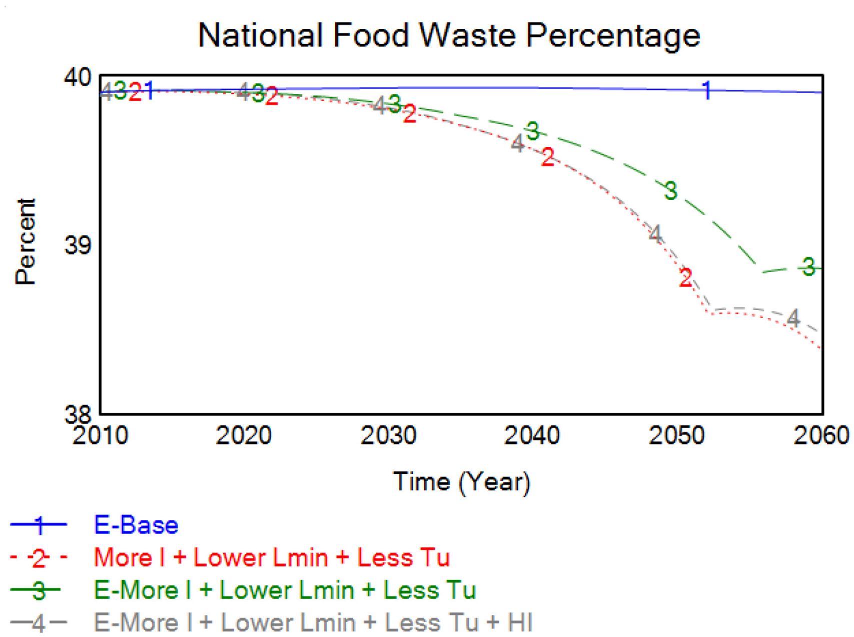


Figure 42. Result of the expanded portfolio in expanded model

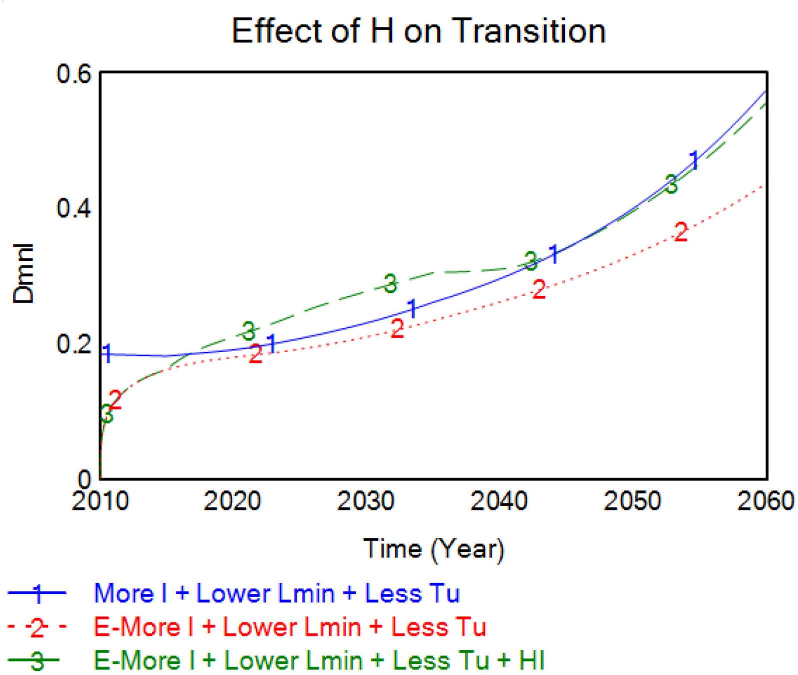


Figure 43. Effect on H on Transition for the base model and expanded model

4.4.4 Parameter Sensitivity Analysis

Transition in the food system is complex and adaptive, with inherent socio and technical uncertainties. Technical characteristics, such as the half-life of surplus elimination or feasible minimum surplus rate, are subject to unpredictability in technology advancement and policy environment. Social aspects are even more uncertain regarding human decision-making, such as the incumbent's strength of risk aversion or sensitivity to economic incentives. Examining how simulation results vary in response to the parameter change is essential to understanding the robustness of intervention strategy and building intuition of how the dynamics might evolve under different conditions.

First, consider the incumbent's transition decision-making. In the model, the main behavioral parameters (α for human capital, β for risk aversion, and γ for economic incentives) are estimated by qualitative argument since there is no established research on these values and they are hard to measure. We can't ignore them in the model since ignoring them assumes the effect is zero, which is the worst assumption to our best knowledge (e.g., assuming human capital has no impact on decision-making when the field study suggests strong evidence of its importance). Instead, the parameters are chosen to be the most likely value and varied in a wide plausible range to see how context influences the intervention's impact on the system. Take β (Strength of Risk Aversion) for instance. The base value 2.3 is calculated by assuming that when the perceived risk is 0.5 (the probability of success is 50%), only about 20% of potential transitions incentivized by economic reasons actually result in transition. If the agent is purely rational, i.e., making the decision by calculating the expected utility, then β should be 1 because a 50% chance of success would result in a 50% transition. The base value 2.3 is thus directionally aligned with the empirical study on risk aversion, where the utility drops significantly as risk increases from zero and diminishes. In the sensitivity analysis, β is varied from 1 (purely rational and risk-neutral) to 5.5 (highly risk averse, with only 2% of transitions happening when the perceived risk is 0.5) to understand a range of plausible scenarios.

Now, consider the technical assumption in the model. As shown in the intervention analysis in this section, the speed of surplus elimination greatly impacts the dynamics. The base value of the fractional elimination rate (ϕ) used in Equation (2) is 0.35, calculated by assuming a 2-year half-life, the higher extreme in the Half-life Matrix proposed by Schneiderman (2005). This assumption recognizes the technical and organizational complexity involved in food surplus elimination, where the emerging technologies and innovations are far from well-established and usually involve multiple stakeholders across the supply chain. In the sensitivity analysis, ϕ is varied from 0.17 (extremely complex innovation with a 4-year half-life) to 1.39 (extremely easy low-hanging fruit with a 0.5-year half-life).

Figure 44 shows how the interventions' impact varies with these and other parameters. The reference point shown in the figure is the simulation result in Figure 42 with the portfolio of "More I," "Lower L_{min}," "Less T_u," and "HI" in the expanded model. The "impact" of this portfolio in 2060 is calculated by comparing the difference in innovative food providers' market share (as a proxy) between scenarios with and without intervention (the delta). Under the system context characterized by the base parameters, this impact is about 15.4% delta in I's 2060 market share.

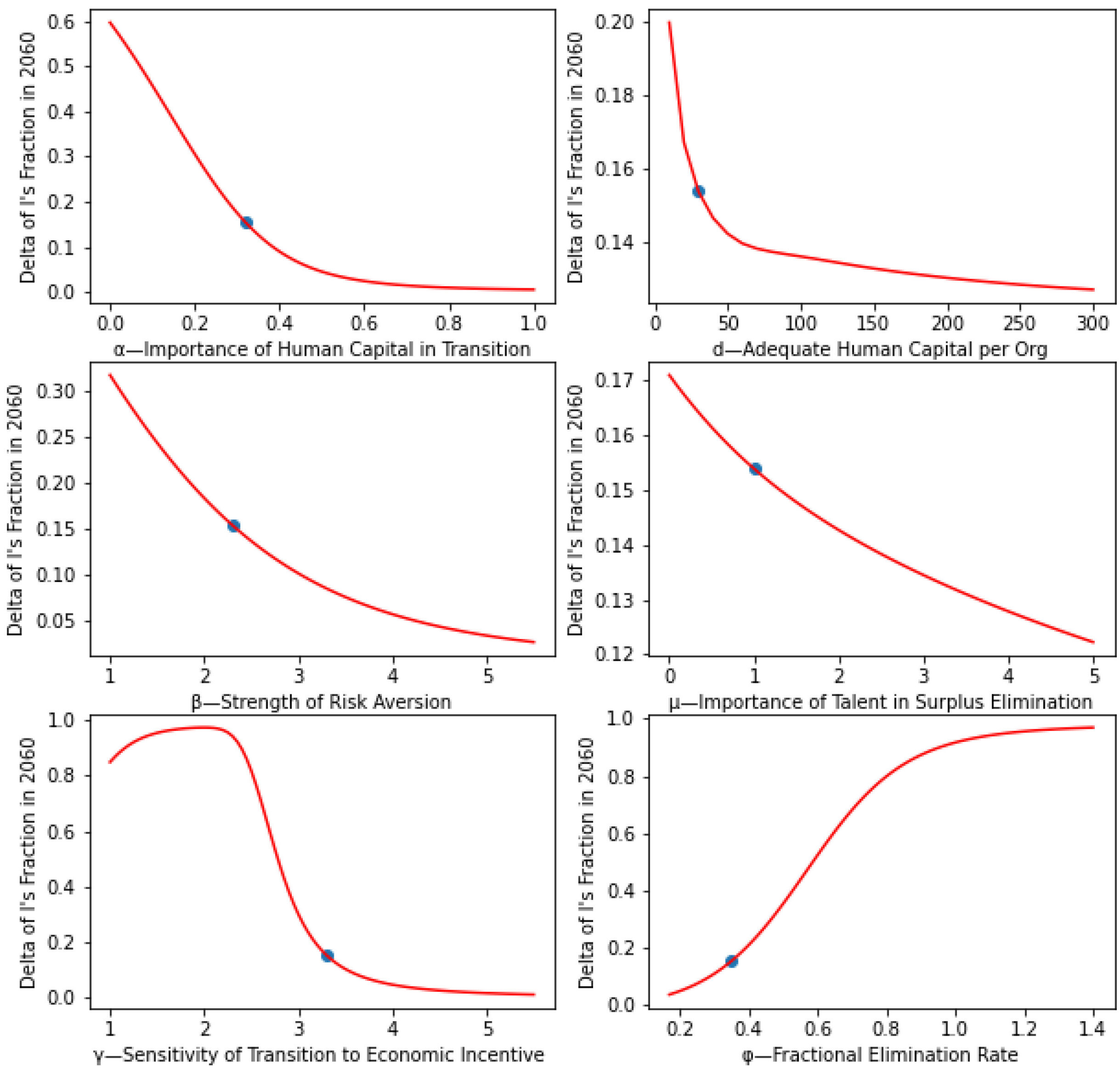


Figure 44. Sensitivity of intervention's impact on the market share of innovative food providers to key parameters. Each panel shows the difference in innovative food providers' market share in 2060 with and without intervention, namely, the delta between the intervention and base case scenarios. The reference points (dots for 15.4% market share) indicate the value in the scenario with the portfolio "More I," "Lower L_{min}," "Less T_u," and "HI" shown in Figure 42 number 4 run under the base parameter setting.

The left-hand side of Figure X shows the factors influencing the incumbent's transition decision-making. Consider first the importance of human capital in transition (α): the degree of R's transition decision is influenced by the industry's innovative human capital density. A zero value means human capital has no effect on the transition decisions, removing the regime talent lock-in feedback loop that counters the transition. In this extreme, the portfolio can have a much bigger impact to have a 60% delta on *I*'s market share. As human capital density becomes more important in the incumbent's transition decision, the portfolio's impact diminishes toward zero when α approaches 0.8. A similar trend is observed in β. As expected, higher risk aversion slows the transition, but the portfolio can still have a 5% impact even in the worst extreme. Finally, the transition is very sensitive to the assumption of the incumbent's responsiveness to economic incentives (γ). If the sensitivity is high, i.e., the payback period needs to be significantly smaller than the maximum acceptable payback period to trigger a larger transition, the portfolio can be entirely useless (at the extreme value when only 2% of *R* decides to transition when payback period is half of the maximum acceptable value). On the other hand, if the transition is less sensitive, the portfolio can have a huge impact, helping to push the system toward full transition to innovative food providers. A little drop in the impact when γ approaches the minimum value is because, in such an economically insensitive environment, the incumbent would have had a higher transition even without the intervention, diminishing the delta or usefulness of the portfolio. Note that the base parameters are all on the lower end of the potential impact concerning these socio-uncertainties, indicating that the portfolio analysis in the previous sections is under fairly conservative assumptions.

Parameters subject to uncertainties in the physical world are shown on the right-hand side of Figure X. Parameter *d* captures the skilled human capital required for an organization to function well, an assumption super relevant to the expanded model boundary. The higher the value of *d*, the longer it takes for food providers to achieve the desired and subject to a longer period of talent inadequacy, slowing the transition. However, sensitivity analysis shows this parameter's influence on the portfolio's impact is fairly limited, resulting in a range of 13%-20%. This means that the strategy is relatively robust with respect to this uncertainty. A similar trend is found in μ, a parameter capturing the degree of *I*'s surplus elimination rate depending on talent adequacy. The higher the dependency, the faster the decline of the surplus elimination rate when talent adequacy is lower than 1. However, the result also shows that the portfolio is robust with respect to this uncertainty. Finally, the portfolio impact is highly sensitive to the fractional surplus elimination rate. When the half-life approaches the extreme 4-year value, the portfolio has almost no impact on the transition. On the other hand, accelerating the elimination process can greatly drive the economic incentive quickly in the early years and trigger the reinforcing feedback loops, compounding the impact. However, the complexity of the surplus elimination innovation makes the short half-life unlikely. Additionally, the half-life and the feasible minimum surplus rate are not coupled in this model for simplicity. In the real world, however, the shorter half-life usually means an easier tweak of the existing practice or a small technological change, limiting the lower end of the feasible minimum. On the other hand, a more fundamental change in the architecture or behavioral norm can greatly reduce the feasible minimum surplus rate, yet the "half-life" in this case can be extremely long, sometimes more than decades.

The sensitivity analysis also shows how impactful it is when the incumbent's decision rules and mental model change. These parameters are treated as context during intervention design because of the difficulty for investors to change others' mental models. Still, these implicit conditions might also be treated as the highest leverage points, aligned with insights suggested in the literature (Meadows 2008, Kania, Kramer, and Senge 2018, Abson et al. 2017).

4.4.5 Potential Extensions

So far, this is an analysis of Jean's one-woman show without explicitly considering the other investors that might also invest in food waste reduction. Although Jean's portfolio achieves some progress, the impact is unsatisfying as the country will still waste more than 38% of its food in 2060 (Figure 42). However, as described in the case study, one important early focus of systemic investors is crowding in funding. The size of the problem and the market potential might initially attract investors to become interested in the sector. Still, other concerns and barriers may prevent an investor from actively investing in reducing food waste. ReFED's programs, such as building a funder circle or providing subject matter expertise to support the investment process, help convert some active investors and increase the annual investment in food waste reduction (Figure 45). More active investors can attract more investors through social learning and accumulated investment in the food waste sector also reduces the perceived investment risk (through demonstration effect, performance data generation, better and standardized due-diligence process in the sector, and established partner network, to name just a few), further converting even more investors. Visualization of such additional reinforcing loops is provided in Figure 46 as a potential extension of the model in future works to explicitly include financial capital growth that can then feed into all leverage points, accelerating the transition.

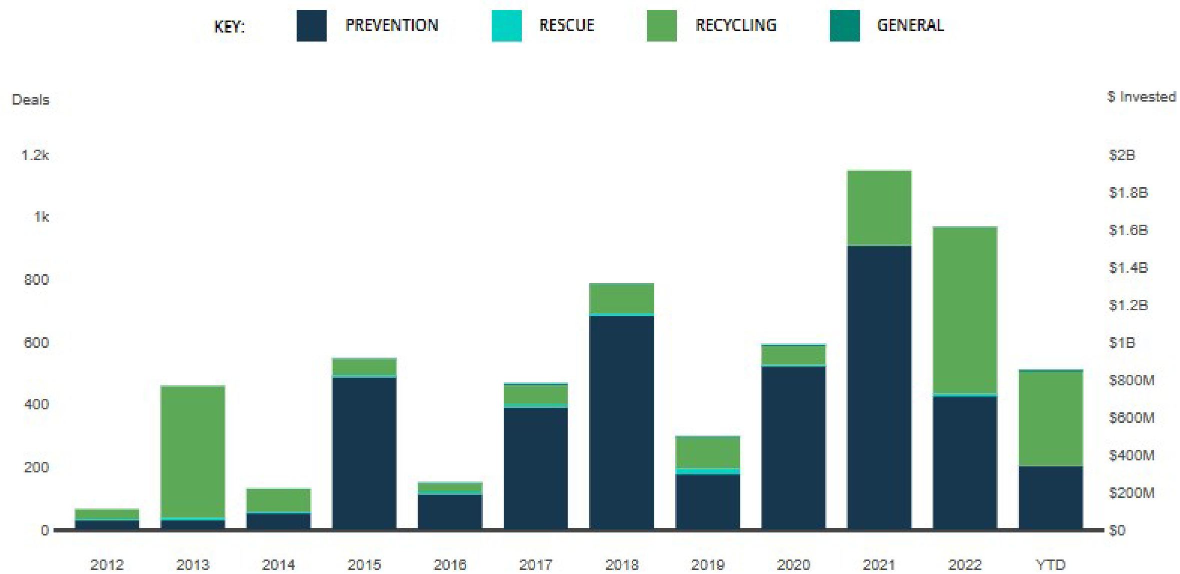


Figure 45. Annual investment in food waste reduction in the US (source: ReFED Insights Engine)[31]

This potential growth in financial capital means that the actual scale of intervention could be much greater than what has been analyzed here where the resource is assumed to be in the million-dollar range per year. Without explicitly modeling the annual investment endogenously change over time from the system structure hypothesized in Figure 46, let's do a quick and dirty thought experiment. Suppose Jean, like what the Finks and ReFED have done in the real world, orchestrates a network of investors and stakeholders to allocate more resources and scale the original portfolio (add 5x more I, add 2x more HI, push L_{min} further down to 0.31, and keep data infrastructure running until 2060, see Figure 47). In that case, they might successfully enable the food system to transition to 100% innovative food providers in 2060 (Figure 48). However, unless the half-life of surplus elimination can be greatly reduced, the food waste percentage will still take significant time to drop. Therefore, to achieve the goal of halving food waste by 2030, reactive solutions still play a role, but the utilization rate must first be greatly increased by additional interventions like engagement or policy suggested in the earlier analysis.

A few further extensions of the model are possible with the basic architecture presented here, including more explicit competition effect between and within R and I, or more explicit consumer feedback and behavior structure, depending on the granularity of information we have. One might ask, "why should I believe in THIS model to develop intervention strategy for systems change?" We want to argue that no model is perfect, requiring the users to challenge the underlying assumptions

[31] https://insights-engine.refed.org/capital-tracker

about boundary, structure, and parameters. The same person should also ask, “why should I believe in any other industry report, due diligence, expert opinion, or my own mental model to develop intervention strategy for systems change?” When an investor decides to invest in a food waste prevention technology company to enable systems change, the decision is based on some model, usually the investor’s mental model with a set of observations, interpretations, and assumptions. The point of a system model is not providing answers, but serving as a boundary object (discussed in section 3.2.2.1 System Understanding) to:

(a) make these assumptions explicit and discussable so we can leverage collective intelligence and promote collaboration (Holtz et al. 2015);
(b) facilitate systematic experiments with different interventions and identify transition pathways (Papachristos 2014; Holtz et al. 2015);
(c) enhance human cognitive limits to process complex nonlinear interdependencies, time delays, and feedback loops, and promote learning in such environments (e.g., Sterman 1994; Cronin, Gonzalez, and Sterman 2009; Sterman 1989).

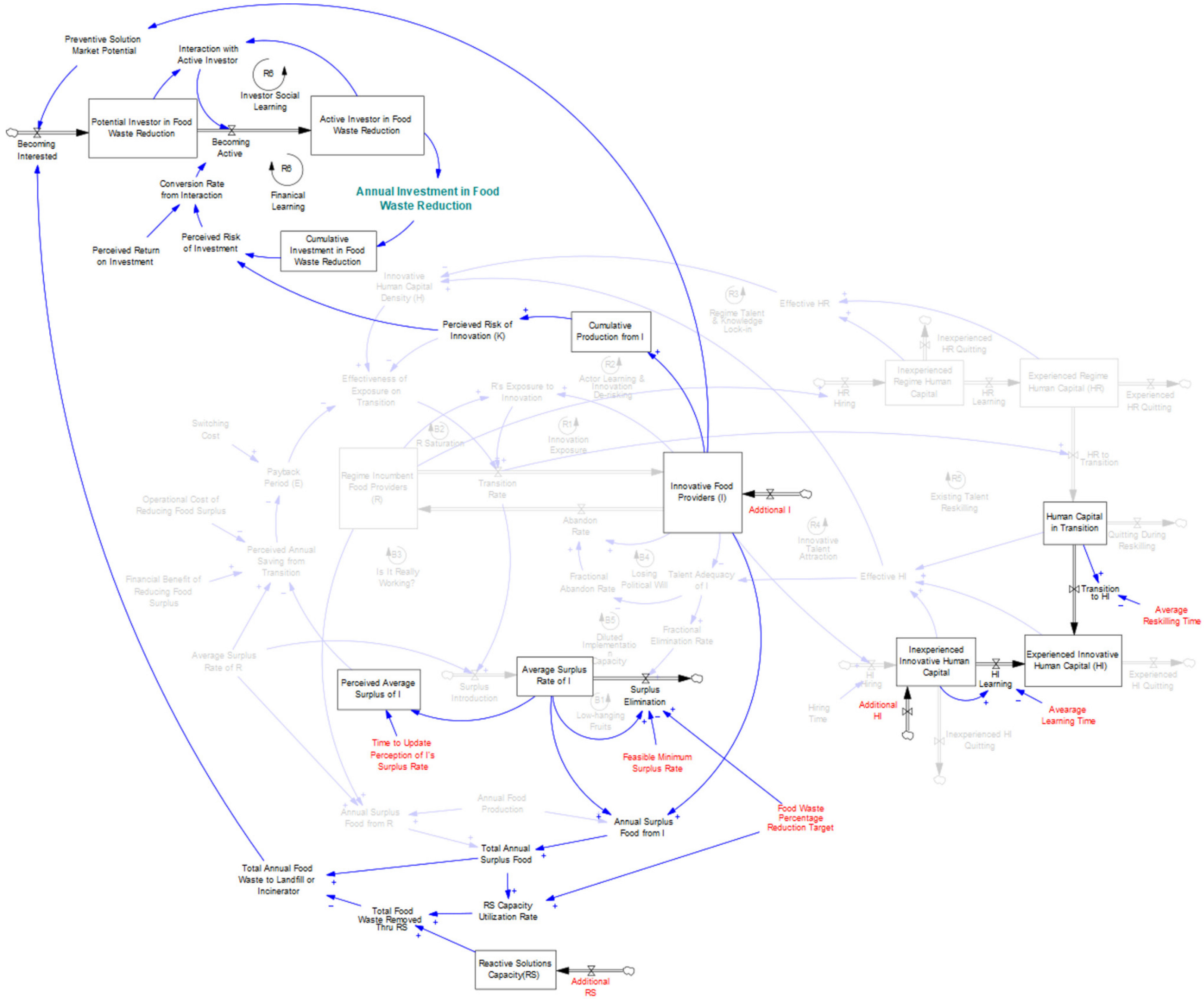


Figure 46. Overview of the potential model structure extension to explicitly include investors and financial capitals[32]

[32] An online, interactive version of this system map can be found at: https://kumu.io/Albanyau/systemic-investing-to-tackle-the-us-food-waste-challenge

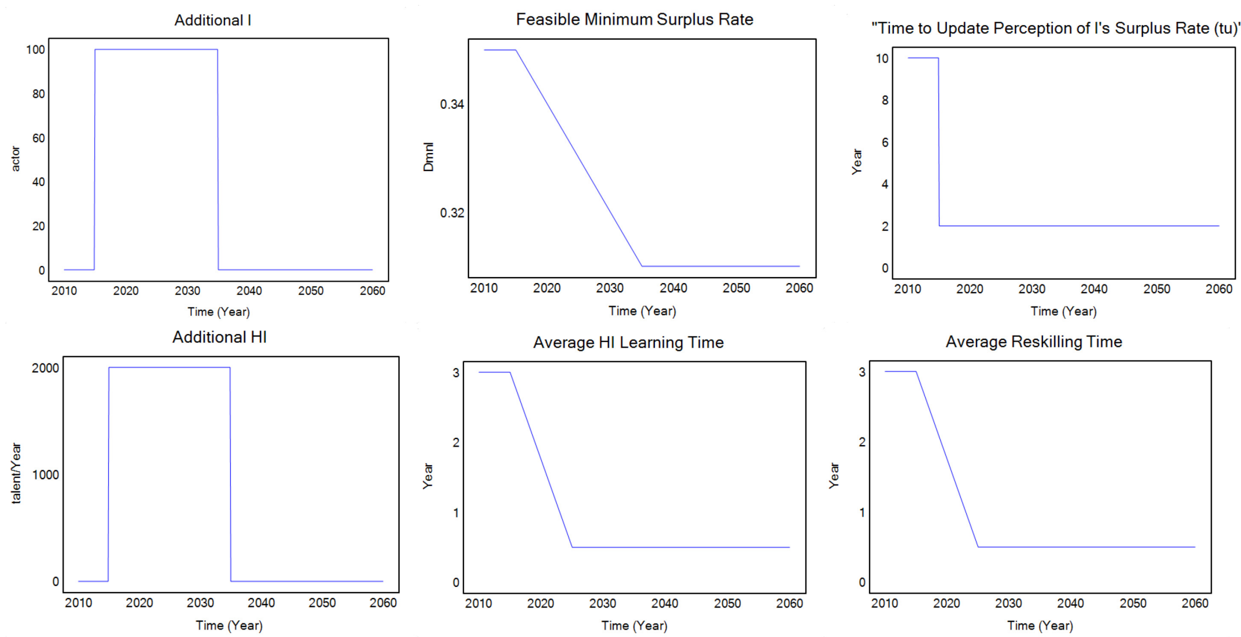


Figure 47. Test input of collective intervention

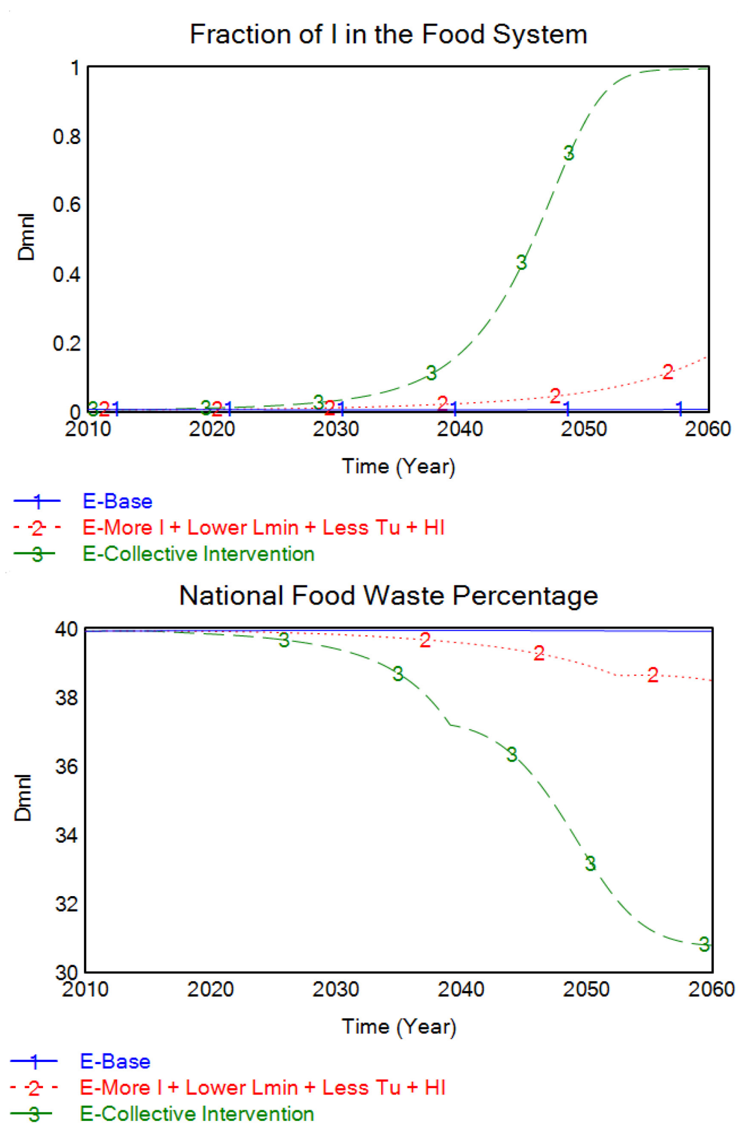


Figure 48. Result of the collective intervention

4.5 Discussion

Based on the literature review, systemic investors should have a higher chance of enabling systems change when they can identify high-leverage points and combine interventions into a strategic portfolio to shift implicit and explicit conditions. This chapter provides an empirical example of how systemic investors can operationalize these concepts in the real world. Complementing the narrative, the simulation model grounded in this empirical case study offers additional insights into the directional guidance on how such a portfolio construction process could work.

First, since the potential of the leverage point depends on the system structure, the important interdependency, feedback loops, and system inertia should be identified from archival data, existing literature, and stakeholder interviews. The causal relationship should be constructed based on "operational thinking" instead of "factors thinking" to minimize false interpretations (see Richmond 2016 and Olaya 2015). For instance, people using "factors thinking" might ask, "What factors influence the number of innovative food providers?" and discover a factor "perceived risk of innovation," resulting in a hypothesized causal relationship linking "perceived risk of innovation" directly to "innovative food providers." Conversely, people using "operational thinking" might ask, "How do incumbent food providers transition into innovative food providers? What happens in that process?". The difference in inquiry direction leads to a new understanding of the incumbent's distant search, exposure to innovation, and how effective the exposure is to transition, where "perceived risk of innovation" only influences the last concept. The implication is significant. The model constructed with factors thinking can overestimate the impact of decreasing the perceived risk of innovation. However, in a world where the incumbents don't interact with other food providers or look for alternatives (for instance, no awareness of the issue and no external interaction opportunities such as a food waste summit), there is no innovation exposure, and thus, no transition happens at all no matter how low the risk perception is.

Second, while the analysis helps identify potential leverage points, resource constraints force investors to decide which leverage point to target and when. The general insights from this study suggest that investors could consider

(a) **Feedback Loops**: prioritize interventions that can trigger desirable reinforcing feedback loops (e.g., investing in new innovative food providers can directly trigger R2: Actor Learning & Innovation De-risking and R4: Innovative Talent Attraction). Plan for the limits imposed by the balancing loops (e.g., shorten the average learning time for human capital to compensate for the limit by B5: Diluted Implementation Capacity).

(b) **System Inertia**: prioritize the impact-generating mechanisms with a shorter time constant or find ways to remove the inertia (e.g., providing good data to help remove the inertia of perception update). This inertia-removing strategy is similar to operation management's "theory of constraints" (Goldratt and Cox 1992).

(c) **Range of Impact**: even without a simulation model, the range of each leverage point's impact can still be estimated to understand the upper/lower bound (e.g., under the most optimistic scenario, investing in surplus prevention innovations can create an economic incentive that triggers roughly X% transition)

(d) **Combinatorial Effect**: combine interventions where (i) one intervention regulates the impact of the other (e.g., surplus prevention innovations' impact on transition is delayed by perception update and providing good data accelerates their impact realization) or (ii) interventions can reinforce each other's impact. For example, new innovative food providers benefit from a lower feasible surplus rate made possible by surplus prevention innovation, while surplus prevention innovation's impact on transition benefits from a higher density of innovative human capital driven by new innovative food providers. In combination, additional food waste reduction is realized.

(e) **Sequence**: consider (a) to (d) first and order investment to maximize each intervention's value on influencing system dynamics (e.g., investing in new innovative food providers is super impactful when human capital is scarce and constraining the transition at first but less so once the other loops are activated.)

Third, investors should consider expanding their (mental) model boundary to evaluate the strategic portfolio. Be aware of the structural assumptions made during the analysis and seek signals about when these assumptions may create misjudgment. Assuming that human capital scales with food providers immediately might be immaterial in a rather mature industry where the time delay is short compared to the time scale of the transition investors care about. When the assumptions cannot be justified, the (mental) model boundary and the leverage point decision space should be expanded.

Finally, investors should acknowledge and identify the technical and social uncertainties in the system. Hughes, Strachan, and Gross (2013) suggest that it is helpful to distinguish between actor-contingent uncertainties and non-actor-contingent uncertainties, depending on whether the uncertainties are within the power of system actors to influence. Non-actor-contingent uncertainties, such as the parameter "importance of talent in surplus elimination," require investors' "protective decision-making" to ensure the portfolio's robustness under various conditions (like the sensitivity analysis done in section 4.4.4). On the other hand, actor-contingent uncertainties, such as the parameter of the incumbent's responsiveness to economic incentives, suggest the potential for investors' "proactive decision-making" to influence such actors through additional interventions or consensus building.

Parameter uncertainties are, however, not the only uncertainties in the model. There might also be uncertainties in the (mental) model's causal structures that are not foreseeable, given the complex adaptive nature of the system. Continuous learning and planned adaptation are thus critical in systemic investing but require us to have a deeper understanding on what "learning" means. According to the Cynefin framework, the existing interventions in the portfolio are designed through "exploitation" of the current knowable cause and effect in the system and have limited effect on probing into the complex domain for unknown patterns to emerge (see Kurtz and Snowden 2003. Note that the word "exploitation" is narrowly used here following the literature and means utilizing knowable knowledge, not exploiting any people or the environment). The learnings that can be generated from this portfolio are mostly how effective each intervention is, informing the reallocation between the existing levers and optimization of resources. On the other hand, adding intentional "exploration" projects in the portfolio, while generating no meaningful impact now, enables probing into the complex domain to make the unforeseeable patterns more visible and increase the number of perspectives available for decision-makers. Learnings from these new perspectives and patterns can potentially help update the (mental) model structure and enable new intervention design, exploiting the emerging, additional knowable cause and effect. This is known as the exploration vs. exploitation tradeoff in the literature on complex adaptive systems (Holland 1975; March 1991). The puzzle for systemic investors is to find the right balance between exploiting the known model to maximize impact now (for instance, putting resources into prevention technology to lower the feasible minimum surplus rate) and exploring the uncertain system structure that might inform better intervention in the future. For instance, an investor could put resources into a consumer-facing pilot and observe the emergence of the potential “rebound effect”: is the impact of avoiding food surplus offset by increased consumption due to lower prices (see Hegwood et al. 2023)?

Below, we propose a research agenda on this emerging field to encourage further theoretical and practical discussions.

Analyzing the Relationship between Investors and Historical Socio-technical/ Socio-ecological Systems Transformation

An in-depth exploration of the financial aspects in historical case studies, where socio-technical or socio-ecological systems have undergone significant transformation, can offer insights into the role of investors in the process of systemic change. Some researchers have attempted to integrate finance into the multi-level perspective in socio-technical system transition research (see Geddes and Schmidt 2020, for example) and highlight the potential policy intervention on finance to accelerate the transition. By delving deeply into such cases, researchers can help uncover the resources needed and nuances of the financial mechanisms that underpin these transformations.

One can also center the analytical focus on the legitimacy of investors engaged in systems transformation and their connections with diverse stakeholders. Understanding how investors establish trust and build collaborative relationships with governments, non-governmental organizations, businesses, communities, and individuals is paramount. Researchers can investigate the dynamics of these relationships, considering aspects such as accountability and transparency. Such an inquiry enables a comprehensive assessment of the legitimacy of investors' efforts in driving meaningful change within systems.

Another vital research area in this line is the inner transformation of investors themselves. It seeks to understand how investors' personal and professional development impact their role in systems change. This includes exploring their motivations, ethical frameworks, personal journeys, and how their inner transformation aligns with their external investment strategies. It also includes exploring ego attachment to the outcomes of investing, given that systems change processes can involve decentering the investor and surrendering some degree of control to other stakeholders. Researchers can delve into the skills, knowledge, and spiritual capital that investors develop to navigate the complexities of systems change, shedding light on the capacity-building needs within the investor community. As the Inner Development Goals effort unfolds and develops measurement methodologies, it might be possible to gauge the relationship between inner development in systemic investing ensembles, their intentionality and practice, and the outcomes they enjoy.

Interrogating Assumptions and Implications of Investors' Different Mental Models on Systems Change

The investor mental model archetypes that emerged from this thesis are embedded with different assumptions about the world and, as a result, distinct implications of what follows their actions. It is unclear what type of mental model is more useful and when. Future research can aim to uncover and make explicit the hidden assumptions that underlie each mental model that investors adopt to guide their actions. By making these assumptions explicit, in line with the idea of “mechanism-based theorizing” encouraged by Davis and Marquis (2005) in organization science, researchers can critically evaluate them against empirical evidence within the system. This examination allows for a deeper understanding of the effectiveness and boundary conditions of each archetype's approach and provides a foundation for evidence-based decision-making in investing for systems change.

The comparison between investors' mental models and socio-technical transition pathways can also be further interrogated to understand the implications of different approaches. While pathway research has traditionally focused on identifying general patterns and directions of change, it has the potential to evolve into a more detailed exploration of the specific sequence of choices that either enable or constrain possibilities within systems change (Rosenbloom 2017). This interrogation can enhance investors' decision-making processes and give them a more nuanced understanding of how their interventions can be path-creation or path-dependence in transitions, offering opportunities for informed and targeted investments.

Understanding the implications of different mental models on systems change also helps inform impact measurement research in this field. Different mental models of systems change may lead to distinct trajectories of evolution, influencing different indicators on different time horizons under different risks (as shown in the food waste example, some strategies can have a large impact with a long delay and low sensitivity to assumptions). This fundamental uncertainty calls for different approaches to conceptualizing and measuring impact. Systemic efforts focusing on human capital and network orchestration may have different near-term/proximate measures than investment approaches focused on particular point solutions. Thus, the focus of measurement must reflect the underlying dynamics instead of a single metric. By examining these variations, future research can guide the development of impact measurement frameworks that align with the goals and strategies of investors for systems change, ultimately promoting more accurate and meaningful assessments of their efforts.

Exploring Key Operational Choices and Capital Allocation Decisions

The field requires more clarity on the systemic practices highlighted in this study to realize its full potential. Based on the findings in Chapter 4, the decision for systemic investors would at least include (a) what system boundary to draw, (b) which leverage points to push in the boundary (based on their system understanding), (c) which intervention/company/project to invest to push those leverage points most effectively, and (d) how much to put on systems change vs. other opportunities that can drift investor's focus away from (a)-(c). We can enable better and easier implementation by exploring existing or new tools and methods to formalize these decisions. For instance, the four system understandings characterized in section 3.2.1.1 can be further investigated and streamlined to establish a clear connection to investment decisions. The use of boundary objects (Star 2010) to facilitate multi-stakeholder actions and accumulate collective system understanding should also be explored in more detail, shedding light on the different “forms and functions” of these objects available for investors’ disposal.

The governance aspect of capital deployment also deserves critical examination. Working in complex adaptive systems with inherent uncertainty and unpredictability, the exploration vs. exploitation question and the planned adaptation strategy should be further explored. In such uncertain environments, the investment strategy will not be a static plan but a dynamic guide, which should specify the required capacity and decision rules for investors to probe and react to emerging signals.

Chapter 5

Conclusion

This thesis has explored two important questions—one empirical question and one design question—in the emerging field of investing with explicit consideration of system complexity and systems change. We found that impact investors have the great potential to make a big difference in complex challenges, especially when they don't just invest in single-point solutions seeking isolated impact. We have shown that the tension between the practicality of impact investing and the complexity of systems change can be balanced through operationalizing systems theories, building collectives with stakeholders, and developing a strategic portfolio to influence the system dynamics.

On the empirical front, a typology was developed through an abductive process, iterating between theories from literature and emerging patterns from the sample, to characterize 26 self-reported case studies of investing for systems change. Specifically, investors' intentionality (systems change) and practice (systemic approach) are differentiated. We found that intentionality and practices in "investing for systems change" can differ in several dimensions, such as system boundaries, tools to operationalize system theories, levers used to intervene in systems, and mental models on how systems change occurs. Emerging from the 26 cases are 4 mental model archetypes—Scale the Superstar Solution, Create Evidence to Challenge the Rules, Build an Inclusive Stakeholder Ecosystem, and Organize a Disruptor Club—representing investors' diverse views on the world and how change happens. These mental model archetypes provide a basis to understand pluralism in the emerging field and hopefully can provoke reflexivity among investors who intend to change systems.

To further advance the understanding of systemic practice in strategic portfolio construction to enable systems change, an in-depth empirical study was conducted to examine systemic investors' intervention strategy in tackling the US food waste challenge. The story of the Finks family and ReFED shed light on how expanding investors' mental model boundary—from isolated food waste prevention technology companies or non-profits to the whole food waste sector and food system—influences the decision space and intervention strategy. Grounded in this rich empirical case, a simulation model was constructed to provide insights into how practical choices made by investors—the leverage points chosen, the combination of intervention, and the sequence of intervention—influence the system's dynamics. These practical insights, which we intentionally abstract away from the food waste example, offer investors a way to operationalize systems theories in strategic portfolio construction, considering the system's key interdependencies, inertia, and feedback loops.

System scientist Meadows (1982) once pointed out, "The world is a complex, interconnected, finite, ecological–social–psychological–economic system. We treat it as if it were not, as if it were divisible, separable, simple, and infinite. Our persistent, intractable global problems arise directly from this mismatch." At the beginning of the thesis, we discussed the tension between the practicality of impact investing and the complexity of systems change. Meadows' view represents the extreme end of the complexity side, which might be seen as irrelevant to the impact investing industry. This thesis has shown that pragmatic approaches to systemic challenges are emerging, and, with the right mix of curiosity, courage, and critical thinking, impact investors can depart from the extreme end of practicality and play an essential role in the journey of systems change toward a more sustainable world. The first in-depth empirical case study of how it might look in operation presented in Chapter 4 is thus important to show the exciting possibility and spark imaginations of what can be done pragmatically while embracing the complexity. We hope that, by providing a window into the theory and practice of this emerging field, this thesis can contribute to the broader adoption of the investing paradigm that enables systems change.

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Appendices

Appendix 1. Finks' Select Financial Investments in Food Waste Through its Philanthropic Entities. (Source: Jesse Fink)

Recipient	Activities Funded
Ample Harvest	General Operating Support
Borderlands Food Bank	Nogales Produce Importation
Center for EcoTechnology	Fellows and Interns; General Operating Support
Common Ground - New Haven Ecology Project	Interns; Gleaning; Composting
CommonWealth Kitchen	Food Incubator
Community Food Bank of Southern Arizona	Nogales Produce Importation
Community Plates	Staffing and Interns
Conservation Law Foundation	Fellows
CT NOFA	Convening
Daily Table	General Operating Support
Divert	Direct Investment
Environmental Defense Fund	Food Waste Solutions
Feeding America	Food Waste Solutions
Food Corps	Fellows and Interns; Gleaning
Food Recovery Network	General Operating Support
Food Rescue US	Staffing and Interns; Food Recovery Efficiency
Food Tank	Convening; Food Waste Track
Harlem Grown	Fellow; Food Recovery and Food Access; Community Gardens
Harvard Food Law and Policy Clinic	Fellow; Regional Collaborative
Island Grown Initiative	Fellows and Interns; Gleaning; Year-Round Apprentices; Compost; General Operating Support; Consumer Awareness
Just Food	CSA; Food Education
Misfit Foods	Program Related Investment
Mission Investors Exchange	Convening; Fellows

Mori	Program Related Investment
National Council for Science and the Environment	Food Waste Forum
Natural Resources Defense Council	AdCouncil; Food Waste Law Fellow; Regional Collaborative
New Venture Fund	Initial Fiscal Sponsor for ReFED
OpenIDEO	Food Waste Solutions Challenge
Our Community Foundation	Regional Food Access
Presidio Graduate School	MBA Interns
Rachel's Network	Convening
Re-plate	General Operating Support
ReFED, Inc.	Initial Seed Funding and Ongoing Support
Rockefeller Philanthropy Advisors	Peer Outreach
Spoiler Alert	Program Related Investment
Stone Barns Center for Food and Agriculture	Convening
Sustainable Agriculture and Food Systems Funders (SAFSF)	Convening
Sustainable America	General Operating Support
University of Arizona	Nogales Produce Importation
Upcycled Food Association	Fellow; Grant; Program Related Investment
Warehouses4Good	Recoverable Grant
Wholesome Wave Foundation	General Operating Support
World Wildlife Fund	Food Waste Solutions
Yale University	Interns; Convening

Financial Capital Overview	**Amount**
Direct Investments / Program Related Investments	$1.6M
Grants	$3.8M
Total	$5.4M

Appendix 2. Ful Model Documentation
(All equations and parameters in the expanded model described in Chapter 4)

Abandon Rate=
"Innovative Food Providers (I)"*Fractional Abandon Rate
Units: actor/Year

Additional HI=
0
Units: talent/Year [0,5000]

Additional I=
0
Units: actor [0,1000,1]

Additional RS Capacity=
0
Units: tons/Year [0,5e+06,5000]

Adequate Human Capital per Org=
30
Units: talent/actor

Adjustment from HI Quitting=
DELAY1(Experienced HI Quitting+Inexperienced HI Quitting, HI Recruiting Time)
Units: talent/Year

Adjustment from HR Quitting=
DELAY1(Experienced HR Quitting+Inexperienced HR Quitting, HR Recruiting Time)
Units: talent/Year

Annual Food Production from I=
Total Annual Food Production*Fraction of I in the Food System
Units: tons/Year

Annual Food Production from R=
Total Annual Food Production*(1-Fraction of I in the Food System)
Units: tons/Year

Annual Food Waste to Landfill or Incinerator=
Total Annual Surplus-Food Waste Removed Thru RS
Units: tons/Year

Annual Surplus of I=
Annual Food Production from I*Average Surplus Rate of I
Units: tons/Year

Annual Surplus of R=
Annual Food Production from R*Average Surplus Rate of R
Units: tons/Year

Average Food Production=
Total Annual Food Production/Total Actors
Units: tons/Year/actor

Average HI Learning Time=
3
Units: Year [0,10]

Average HR Learning Time=
3
Units: Year

Average HR per R=
"Experienced Regime Human Capital (HR)"/"Regime Incumbent Food Providers (R)"
Units: talent/actor

Average Lifetime of RS Capacity=
20
Units: Year

Average Reskilling Time=
3
Units: Year [0,10]

Average Surplus Rate of I= INTEG (
Surplus Introduction-Surplus Elimination, Average Surplus Rate of R)
Units: Dmnl

Average Surplus Rate of R=
0.4
Units: Dmnl

Average Time to Build RS Capacity=
2
Units: Year

Average Time to Initiate New I=
5
Units: Year

Capacity Building=
Additional RS Capacity/Average Time to Build RS Capacity
Units: tons/Year/Year

Capacity Retirement=
SW for RS Retirement*"Reactive Solutions Capacity (RS)"/Average Lifetime of RS Capacity
Units: tons/(Year*Year)

Current Total HR=
Inexperienced Regime Human Capital+"Experienced Regime Human Capital (HR)"
Units: talent

Cumulative Production from I= INTEG (
Annual Food Production from I, Initial Production)
Units: tons

Current Total HI=
"Experienced Innovative Human Capital (HI)"+Human Capital in Transition+Inexperienced Innovative Human Capital
Units: talent

Desired RS Removal from I=
Annual Surplus of I-Target Food Waste Level of I
Units: tons/Year

Desired RS Removal from R=
Annual Surplus of R-Target Food Waste Level of R
Units: tons/Year

Desired Total HI=
Adequate Human Capital per Org*"Innovative Food Providers (I)"
Units: talent

Desired Total HR=
Adequate Human Capital per Org*"Regime Incumbent Food Providers (R)"
Units: talent

Desired Utilization=
ZIDZ(Desired RS Removal from I+Desired RS Removal from R, "Reactive Solutions Capacity (RS)")
Units: Dmnl

"Economic Incentive (E)"=
Max(0,(1-Payback Period/Max Limit of Payback Period))
Units: Dmnl

Effect of E on Transition=
"Economic Incentive (E)"^"Sensitivity of Transition to Economic Incentive (γ)"
Units: Dmnl

Effect of H on Transition=
"Innovative Human Capital Density (H)"^"Importance of Human Capital on Transition (α)"
Units: Dmnl

Effect of K on Transition=
(1-"Percieved Risk of Innovation (K)")^"Strength of Risk Aversion (β)"
Units: Dmnl

Effect of Talent on Abandon=
EXP(-Sensitivity of Abandon to Talent*(Talent Adequacy of I-1))
Units: Dmnl

Effect of Talent on Surplus Elimination=
Talent Adequacy of I^Importance of Talent on Surplus Elimination
Units: Dmnl

Effective HI=
"Experienced Innovative Human Capital (HI)"+(Inexperienced Innovative Human Capital
+Human Capital in Transition)*Effectiveness Ratio of Inexperienced
Units: talent

Effective HR=
"Experienced Regime Human Capital (HR)"+Inexperienced Regime Human Capital
*Effectiveness Ratio of Inexperienced
Units: talent

Effectiveness of Exposure on Transition=
Normal Effectiveness on Exposure*Effect of E on Transition*Effect of K on Transition
*Effect of H on Transition
Units: Dmnl

Effectiveness Ratio of Inexperienced=
0.5
Units: Dmnl

Experienced HI Quitting=
"Experienced Innovative Human Capital (HI)"*Fractional Turnover Rate of HI
Units: talent/Year

Experienced HR Quitting=
"Experienced Regime Human Capital (HR)"*Fractional Turnover Rate of HR
Units: talent/Year

"Experienced Innovative Human Capital (HI)"= INTEG (
HI Learning+Transition to HI-Experienced HI Quitting, 0)
Units: talent

"Experienced Regime Human Capital (HR)"= INTEG (
HR Learning-Experienced HR Quitting-HR to Transition, Desired Total HR)
Units: talent

External Exposure=
0.1
Units: 1/Year [0,0.1]

Feasible Minimum Surplus Rate=
0.35
Units: Dmnl [0,1,0.01]

Financial Benefit per tons of Food Surplus Reduced=
3569
Units: $/tons [0,?]

Food Waste Removed Thru RS=
RS Capacity Utilization*"Reactive Solutions Capacity (RS)"
Units: tons/Year

Fraction of I in the Food System=
"Innovative Food Providers (I)"/Total Actors
Units: Dmnl

Fractional Abandon Rate=
Normal Abandon Rate*Effect of Talent on Abandon
Units: 1/Year

Fractional Elimination Rate=
Effect of Talent on Surplus Elimination*Normal Fractional Elimination Rate
Units: 1/Year

Fractional Turnover Rate of HI=
0.05
Units: 1/Year

Fractional Turnover Rate of HR=
0.05
Units: 1/Year

Fractional Turnover Rate of Inexperienced HI=
0.4
Units: 1/Year

Fractional Turnover Rate of Inexperienced HR=
0.4
Units: 1/Year

Fractional Turnover Rate of Reskilling=
0.1
Units: 1/Year

HI Hiring=
Max(0,(Desired Total HI-Current Total HI)/HI Recruiting Time+Adjustment from HI Quitting)
Units: talent/Year

HI Learning=
Inexperienced Innovative Human Capital/Average HI Learning Time
Units: talent/Year

HI Recruiting Time=
2
Units: Year

HR Hiring=
Max(0,(Desired Total HR-Current Total HR)/HR Recruiting Time+Adjustment from HR Quitting)
Units: talent/Year

HR Learning=
Inexperienced Regime Human Capital/Average HR Learning Time
Units: talent/Year

HR Recruiting Time=
2
Units: Year

HR to Transition=
Transition Rate*Average HR per R
Units: talent/Year

Human Capital in Transition= INTEG (
HR to Transition-Quitting During Reskilling-Transition to HI, 0)
Units: talent

I's Food Waste Percentage Reduction Target=
0.5
Units: Dmnl [0,1,0.05]

"Importance of Human Capital on Transition (α)"=
0.32
Units: Dmnl [0,1,0.05]

Importance of Talent on Surplus Elimination=
1
Units: Dmnl [0,1,0.05]

Indicated Surplus Level Introduced by R=
(Average Surplus Rate of R*Transition Rate*"1 Year"+Average Surplus Rate of I
"Innovative Food Providers (I)")/(Transition Rate"1 Year"+"Innovative Food Providers (I)")
Units: Dmnl

Inexperienced HI Quitting=
Inexperienced Innovative Human Capital*Fractional Turnover Rate of Inxperienced HI
Units: talent/Year

Inexperienced HR Quitting=
Inexperienced Regime Human Capital*Fractional Turnover Rate of Inexperienced HR
Units: talent/Year

Inexperienced Innovative Human Capital= INTEG (
Additional HI+HI Hiring-HI Learning-Inexperienced HI Quitting, 0)
Units: talent

Inexperienced Regime Human Capital= INTEG (
HR Hiring-HR Learning-Inexperienced HR Quitting, 0)
Units: talent

Initial I=
100
Units: actor [0,?]

Initial Production= INITIAL(
"1 Year"*Average Food Production*Initial I)
Units: tons

Initial R=
20000
Units: actor
Initial Risk Perception=
0.99
Units: Dmnl

Initial RS=
2e+07
Units: tons/Year

Initiation Rate of I=
Additional I/Average Time to Initiate New I
Units: actor/Year

"Innovative Food Providers (I)"= INTEG (
Initiation Rate of I+Transition Rate-Abandon Rate, Initial I)
Units: actor

"Innovative Human Capital Density (H)"=
Effective HI/(Effective HI+Effective HR)
Units: Dmnl

Interaction Frequency with other Providers=
10
Units: 1/Year [0,100]

"K Learning Curve Strength (κ)"=
-0.32
Units: Dmnl [-1,0]

Max Limit of Payback Period=
3
Units: Year

National Food Waste Percentage=
Annual Food Waste to Landfill or Incinerator/Total Annual Food Production*
100
Units: Percent

National Surplus Food Percentage=
Total Annual Surplus/Total Annual Food Production*100
Units: Percent

Normal Abandon Rate=
0.01
Units: 1/Year

Normal Effectiveness on Exposure=
1
Units: Dmnl

Normal Fractional Elimination Rate=
0.35
Units: 1/Year

Operational Cost per tons of Food Surplus Reduced=
846
Units: $/tons

Payback Period=
XIDZ(Switching Cost, Perceived Annual Saving from Transition, Max Limit of Payback Period)
Units: Year

Perceived Annual Saving from Transition=
Max(0,Average Food Production*(Average Surplus Rate of R-Perceived Average Surplus of I)*(Financial Benefit per tons of Food Surplus Reduced-Operational Cost per tons of Food Surplus Reduced))
Units: $/Year/actor

Perceived Average Surplus of I= INTEG (
Update of Surplus Perception, Average Surplus Rate of R)
Units: Dmnl

"Perceived Risk of Innovation (K)"=
Initial Risk Perception*(Cumulative Production from I/Initial Production)^ "K Learning Curve Strength (κ)"
Units: Dmnl

Quitting During Reskilling=
Human Capital in Transition*Fractional Turnover Rate of Reskilling
Units: talent/Year

R's Exposure to Innovation=
"Regime Incumbent Food Providers (R)"*External Exposure+"Regime Incumbent Food Providers (R)" *Interaction Frequency with other Providers*Fraction of I in the Food System
Units: actor/Year

R's Food Waste Percentage Reduction Target=
0
Units: Dmnl [0,1,0.05]

"Reactive Solutions Capacity (RS)"= INTEG (
Capacity Building-Capacity Retirement,
Initial RS)
Units: tons/Year

"Regime Incumbent Food Providers (R)"= INTEG (
Abandon Rate-Transition Rate,
Initial R)
Units: actor

RS Capacity Utilization=
Min(1,Desired Utilization)
Units: Dmnl

Sensitivity of Abandon to Talent=
1.4
Units: Dmnl [0,5]

"Sensitivity of Transition to Economic Incentive (γ)"=
3.3
Units: Dmnl [0,10,0.01]

"Strength of Risk Aversion (β)"=
2.3
Units: Dmnl [0,10,0.1]

Surplus Elimination=
Fractional Elimination Rate*Min(Average Surplus Rate of I-Feasible Minimum Surplus Rate
,Average Surplus Rate of I-Target Surplus Rate)
Units: 1/Year

Surplus Introduction=
(Indicated Surplus Level Introduced by R-Average Surplus Rate of I)/"1 Year"
Units: 1/Year

SW for RS Retirement=
1
Units: Dmnl [0,1]

Switching Cost=
Average Food Production*Unit Switching Cost
Units: $/actor

Talent Adequacy of I=
Effective HI/Desired Total HI
Units: Dmnl

Target Food Waste Level of I=
Annual Food Production from I*Average Surplus Rate of R*(1-I's Food Waste Percentage Reduction Target)
Units: tons/Year

Target Food Waste Level of R=
Annual Food Production from R*Average Surplus Rate of R*(1-R's Food Waste Percentage Reduction Target)
Units: tons/Year

Target Surplus Rate=
Average Surplus Rate of R*(1-I's Food Waste Percentage Reduction Target)
Units: Dmnl

"Time to Update Perception of I's Surplus Rate (tu)"=
10
Units: Year [0,10,1]

Total Actors=
"Regime Incumbent Food Providers (R)"+"Innovative Food Providers (I)"
Units: actor

Total Annual Food Production=
2.35e+08
Units: tons/Year

Total Annual Surplus=
Annual Surplus of I+Annual Surplus of R
Units: tons/Year

Transition Rate=
R's Exposure to Innovation*Effectiveness of Exposure on Transition
Units: actor/Year

Transition to HI=
Human Capital in Transition/Average Reskilling Time
Units: talent/Year

Unit Switching Cost=
278
Units: $/(tons/Year)

Update of Surplus Perception=
(Average Surplus Rate of I-Perceived Average Surplus of I)/"Time to Update Perception of I's Surplus Rate (tu)"
Units: 1/Year