The End of Core: Should Disruptive Innovation in Telecommunication Invoke Discontinuous Regulation?

by
Chintan Vaishnav

Bachelor of Engineering, Electronics and Communications
Rastriya Vidyalaya College of Engineering, Bangalore University, India

Master of Science, Electrical Engineering
Colorado State University, USA

Master of Science, Technology and Policy Program
Massachusetts Institute of Technology, USA

Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Technology, Management, and Policy
at the
Massachusetts Institute of Technology
February 2010

Signature of Author…………………………..……………………………………………
Engineering Systems Division
October 16, 2009

Certified by……………………………….………………………………………………
Charles Fine
Chrysler LFM Professor of Management and Engineering Systems
Thesis Supervisor

Certified by……………………………….………………………………………………
David Clark
Senior Research Scientist, MIT Computer Science and Artificial Intelligence Laboratory
Thesis Committee Member

Certified by……………………………….………………………………………………
John Sterman
Jay W. Forrester Professor of Management and Engineering Systems
Thesis Committee Member

Certified
by……………………………………………………………………………………

Kenneth Oye
Professor of Political Science and Engineering Systems
Thesis Committee Member

Accepted by ……………………………………………………………………………….…

Yossi Sheffi
Professor of Civil and Environmental Engineering and Engineering Systems
Director, Engineering Systems Division

Blank

The End of Core: Should Disruptive Innovation in Telecommunications Invoke Discontinuous Regulation?

by
Chintan Vaishnav

Submitted to the Engineering Systems Division on October 6, 2009
in Partial Fulfillment of the Requirements for the Degree of Doctor
of Philosophy in Technology, Management, and Policy

Abstract

This research analyzes how a telecommunications regulator can balance regulation with innovation, at a reasonable cost. This question has gained critical importance for telecom regulators as the unregulated Internet technologies such as voice and video over Internet disrupt the regulated traditional technologies such as telephony and television and the historical paradigm of the regulator. The existing U.S. telecommunications regulations were created in the integral age. In that paradigm, functional components that constitute a service compliant with regulation resided inside the network core; each operator was vertically integrated and controlled the total functionality necessary to deliver a service; a few such operators controlled the industry; they faced low competition and were under limited pressure to adopt innovation; and consumers had limited choice. The Internet has introduced a polar opposite paradigm—the modular age. In this paradigm, functional components that constitute a service are dispersed across the network core and edges; each firm controls only a subset of the total functionality necessary to constitute a service; many modular firms interoperate to deliver a service; firms compete fiercely and are under great pressure to innovate; and consumers enjoy far greater choice due to the multi-modal competition among multiple technologies. Although transitioning from an integral to a modular age dramatically flips the environment, the current regulatory response to this dramatic shift has been hesitant to shift its intellectual roots. Consequently, this thesis describes and analyzes the new telecommunications paradigm and explores its implications for an appropriate regulatory paradigm. The research uses the regulation of voice communications in the United States as a representative case.

We analyze the new telecommunications paradigm as a dynamic complex system. Our research approach rests upon four principles of systems: two organizational principles (hierarchy and feedback) and two behavioral principles (emergent behavior and strategic and statistical behavior).The telecommunications system is viewed as one of the many subsystems that together fulfill the objectives of a society. The dynamics of the telecommunications system itself are conceptualized as those resulting from the interactions of four subsystems: regulatory dynamics, corporate strategy dynamics, consumer dynamics, and technology dynamics. The regulatory objectives to be fulfilled are conceived as an emergent property of such a system of systems.

To carry out this research, we have developed a system-level dynamic feedback model and two case studies. As modular entrants of Internet-based technology disrupt integrated incumbents of traditional technology, bewildering dynamic complexity complicates decision-making by policymakers, managers, consumers, and technologists alike. Our model makes understandable the emergent behavior amidst the uncertainty that surrounds such a disruption phenomenon. The model formulations are behavioral. They are derived from the existing theories of technology and industry disruption, where possible. Alternatively, where theories have a gap, the decision processes of stakeholders, gleaned from unstructured interviews, are mathematised as the basis for the model formulations. The resulting structure is a fully endogenous systems model of regulation, competition, and innovation in telecommunications.

In the first case study we analyze the regulatory environment of pre vs. post-Internet periods, both quantitatively and qualitatively. For the analysis, public comments in response to the Telecommunications Act of 1996 Notice for Proposed Rulemaking (NPRM) are compared with those in response to the IP-Enabled Services NPRM published in 2004. The analysis demonstrates how the differences in the integral and modular age are reflected in the regulatory record. The second case study analyzes how market, technology, organizational, and regulatory uncertainties affect technology and industry disruption. For this case, we use a combination of industrial statistics and content analysis of media publications. The analysis demonstrates the limits to technology and industry disruption. The case studies complement the model in two ways: first, they facilitate further refinement of the systems model; second, they empirically validate the arguments deduced from model analysis.

Through this research we answer three questions: (1) Can the regulatory structure designed in an integral age—in its objectives, obligations (requirements), and enforcement mechanisms—work for a modular age? (2) How can regulators and managers improve decision making amidst the uncertainty surrounding the disruption of an integrated technology and industry by a modular one? (3) What is the new role of the telecommunications regulator and how can it be fulfilled in the modular age of the Internet? Our analysis shows that the current regulatory structure is inadequate for responding to the challenges the modular age poses. Firstly, the current objectives are appropriate but cannot be met unless regulators discontinue the merely efficiency-centered thinking and begin to address objectives at the societal level. Secondly, the current obligations may attain short-term goals, but have undesirable long-term consequences. Devising obligations that are appropriate in the long-term requires regulators to discontinue myopic measures such as incremental regulation of new technologies. Finally, the current enforcement mechanisms are blunted by the dynamic complexity of the modular age. Enforcing regulations effectively in the modular age necessitates adding to the regulatory quiver new mechanisms that are more versatile than the merely adversarial command-and-control mechanisms.

Through model analysis, we demonstrate how a lack of understanding of the various uncertainties, and misperceptions of feedback in a complex system where regulators, firms, consumers, and technologists constantly interact, could lead to decisions that are

costly for regulators as well as managers. Yet, as we demonstrate, with better grasp of the dynamic complexity involved, they can significantly improve decision-making to meet the challenges of the modular age.

We argue that the most critical role for the telecommunications regulator in the new telecommunications paradigm is to sustain a balance between regulation and innovation, at a reasonable cost. Achieving such a balance in a modular structure is not trivial because of several natural tendencies. First, achieving high compliance at low cost is difficult because in highly modular architectures and industries, coordination costs, such as the time to build consensus, can be inordinately large. Second, keeping the innovation-level high is difficult because it requires fighting the natural tendency of modular firms to gain and abuse market power. We propose a combination of two policy levers—Limiting Significant Market Power (SMP) Accumulation and Building Broad-based Consensus around Regulatory Issues—that most effectively achieve the desired balance and remain inadequately explored in the United States. We contend that implementing these policy levers will require, first, a more broadly construed antitrust regulation in the United States that will ensure higher modularity, and, second, a telecommunications regulatory agency that is empowered and organized to pursue objectives at the societal level and to build broad-based consensus among divergent interests in a highly modular structure.

Thesis Supervisor: Charles Fine
Title: Chrysler LFM Professor of Management and Engineering Systems

To my maternal grandfather,
P. T. Chhaya,
who taught me the importance of childlike curiosity, relentless hard work, and living with higher ideals.

And
to my wife,
Hetal,
for her love, patience and encouragement, without which MIT would not have happened.

Acknowledgements

Most of the times, it is greatly difficult to understand which events ultimately lead to an outcome, and my journey through the PhD at MIT is no exception. Nonetheless, I must utilize this opportunity to acknowledge a few people who I believe have contributed to the successful completion of my PhD in various ways.

The idea that an engineer must get educated beyond mere technical knowhow had brewed in my mind over several years of long and contemplative walks. I had also realized that my previous engineering education had not afforded me the tools to think systematically beyond technology. Additionally, it was clear to me that thinking about how technology influences socio-economics (my interest at the time) and vice versa did not mean abandoning technological expertise. However, I had never imagined that MIT's engineering school would offer an opportunity for such broad-based inquiry, which I can blame on nothing but my ignorance. Once I learned that MIT and few other institutions (Carnegie Mellon being the other attractive contender) offer such an opportunity, I had set my mind on it. Yet, the push came to shove when one fine day Hetal, my wife, told me that the dream is worthless without action. My gratitude first goes to her, as I cannot imagine the experience of coming to and getting through MIT without Hetal's encouragement and unshakable faith in me.

Equally important is the contribution of my academic advisory committee: Charles Fine (Chair), David Clark, John Sterman, and Kenneth Oye. The credit for recognizing my potential early and steering my academic journey so ably goes squarely to Charlie. Charlie has also provided maximum input from the conceptualization to the final draft of this work. Without his astute judgment of where to go and what to avoid, it would have been easy to get lost in the process. I am deeply indebted to him for being such a kind and patient helmsman.

Before coming to MIT, David Clark was the one I had surely dreamt as being on my thesis committee. He was the only one I knew of whose interests were synergistic with mine. Moreover, being a network engineer, I had greatly admired his contributions as an Internet pioneer. I thank Dave for several invigorating conversations. As a domain expert, his criticism (through the process of this research) and consent (of this thesis) have greatly enhanced my confidence in the practical utility of this work. Dave has also graciously afforded me an office space in MIT's iconic Stata Center, which is a very creative work environment.

I got my early education in System Dynamics from Jim Hines. However, John Sterman is clearly responsible for introducing rigor to my System Dynamics. Once I decided to use System Dynamics as my research methodology, I opted to become John's teaching assistant for the introductory course in System Dynamics, which is Sloan's flagship course. Ever since, I have learned much from this incredibly gifted teacher. Together, Charlie, Dave, and John wrote a well-orchestrated set of questions for my PhD General Examination.

Kenneth Oye joined my committee after my general exam. We got to know each other better as I served as a teaching assistant for his Science, Technology and Public Policy class (STPP). Thanks to Ken's masterful craftsmanship, STPP remains the hardest and most valuable class a Technology and Policy graduate can take at MIT. Working with him, I learned how to assess student's true grasp of the subject, regardless of performance on assignments and examinations. Ken was also instrumental in securing me the National Science Foundation's IGERT Fellowship.

Several other teachers at MIT have enriched my intellectual journey. I owe intellectual debts to Daniel Whitney, Chris Mcgee, Joel Cutcher-Gershenfeld, Joel Moses, Kenneth Keniston, Merit Roe Smith, Larry McCray, Frank Field, Joseph Sussman, Kim Thompson, Joanne Yates, and Karen Sollins.

I am a product of many environments. Foremost among them is the emotionally and economically stable, loving environment that my parents – Dr. Uma and Dr. Harshad Vaishnav – created at home. My parents were (and are) a major pillar of support for the whole family, so our household always brimmed with people of all ages and persona, from whom I absorbed much. Being medical doctors, my parents also exuded a deep sense of service to the community at large, which, I believe, inculcated in me the sense of giving at a very young age. My father also gets credit for being my first investor. He paid a hefty sum to send me to an excellent engineering college for my undergraduate education. He was given the confidence that it will all be worth it by at least two others who always believed in me: Ravindra Vaishnav (his older brother) and B. J. Chhaya (my mother's uncle). Fortunately, all of my subsequent investors have been institutional. One last word of thank you that I cannot omit, my parents always supported me in all my endeavors so far, whether they agreed or disagreed with it. The payoffs have generally been positive.

I have also been blessed with mentors who greatly shaped my work ethic and the sense of what is worth pursuing. They are: P. T. Chhaya, my maternal grandfather; R. C. Pota, my maternal uncle; and J. J. Baxi, my paternal uncle; Prof. Anil Gupta of Indian Institute of Management, Ahmedabad (IIMA). I am thankful that I grew to maturity soon enough to begin to understand the illustrious life of my grandfather, the late Prof. Prataprai Tuljaprasad Chhaya. Before India's independence in 1947, grandfather had dedicated his life to the struggle for independence. When Mahatma Gandhi was arrested after the salt march in 1930, grandfather served as the personal messenger between the freedom fighters and the Mahatma. His life has taught me the importance of honest and relentless hard work, a child-like curiosity, and the courage to speak truth to power.

During my college years, I lived in Bangalore with my maternal uncle (RC) and aunt (Vishakha) Pota. When it came to motivating young people, the late R. C. Pota was a giant. I remember him as my first adult friend who always discussed difficult choices, questioned decisions, and invited thinking beyond the conventional. His model of nurturing fascinated me. I still miss him when making difficult choices.

Growing up, Rear Admiral J. J. Baxi was known to me as the highly-attained paternal uncle, but we came in closer contact only in Bangalore. More importantly, we spent time together when I was mature enough to recognize his formidable intellect and towering accomplishments. With his encyclopedic mind and vast exposure, he was clearly the one who could guide me on decisions such as coming to MIT. Adm. Baxi remains an important mentor for me.

My association with Prof. Anil Gupta began during a research internship at IIMA in 2005. His missionary zeal to make India more creative and innovative has been an abiding source of inspiration to me. Despite his extremely busy schedule, Prof. Gupta has always made himself available whenever necessary. I also credit him for teaching me how to liberate oneself by throwing away their old writings and embracing the new constructs by starting afresh.

Several other family members have burdened responsibilities from time to time that I ought to have shouldered, so as to keep me on track for my PhD. These include: my wife's family (Jagdishbhai-Nitaben, Mihir, Jalpa, Kruti-Rajan-Priyanka); my sister's family (Vibha, Vanashree, Divyeshbhai); my aunt's family (Jyoti-Deepak, Aditi, Heli, Chirayu). I thank them for their support and understanding. Two of my cousins – Nirjhari Chhaya and Shivangi Vachharajani-Vora – even attended my PhD Defense.

The concept of my thesis came to life during my research internship at the Federal Communications Commission (FCC) in the summer of 2004. It was Sharon Gillette (then MIT, now FCC) and David Clark's recommendation that had made this internship possible. At the FCC, I made many good friends, who remain enthusiastic about my work. I am indebted for their time, encouragement, and much needed criticism. I owe my confidence in the relevance of this thesis for a telecommunications regulator to the support of Mark Bykowsky, Bill Sharkey, Scott Marcus, Robert Pepper, Evan Kwerel, Chuck Needy, Barbara Cherry, Tom Spavins, Kenneth Carter, Jonathan Levy, and Sherille Ismail.

This thesis has four intellectual fathers: Herbert Simon, Jay Forrester, Norbert Wiener, and the scholarship at MIT's Engineering Systems Division (ESD). The thesis borrows two pages from Herbert Simon's work: his conception of hierarchy as a structural scheme to deal with the architecture of complexity and his notion of bounded rationality. One page from Jay Forrester's work: his conceptualization of feedback as the broad organizing principles of global systems. And one page from Norbert Wiener's work: his emphasis on uncertainty resulting from stochastic as well as strategic behaviors. The overall focus on emergent behavior of complex systems reflects the research philosophy central to the intellectual pursuit at ESD, MIT.

The support for my research, for the initial two years, came from the Communications Futures, Program (CFP) at MIT. The academics and industry sponsors involved in CFP have critiqued my work over last several years in very useful ways. I am very thankful for the longstanding enthusiasm and support for my work offered by Natalie Klym, Dirk Trossen, David Reed, Andy Lipman, Marie Jose Montpetit, Sylvie Bokshorn, and Steve

Whittaker. The second round of support for my work came from a fellowship offered by the National Science Foundation's Program for Emerging Technologies (PoET). Interactions with fellow PoETs have greatly broadened my inquiry. For this, I thank Matt Silver, Katherine Steel, Katherine Dykes, Greg Distelhorst, Rachel Wellhausen, Matthew Richards, Gautam Mukunda, Michael Paul Rossi, and Mary Beth Mills-Curran.

At least as important as the support of my teachers at MIT has been the camaraderie with my officemates at MIT. The whiteboard in our office never lacked interesting content we could fight over. My first officemate at MIT who taught me much was the versatile Carlos Osorio. Once I moved to Stata Center, I have enjoyed rich discussions with Steve Bauer, Peyman Faratin, Jesse Sowell, Dietrich Falkethal, Stephan Woodrow, Tony Greco-Smith, Nishanth Sastri, Hironorio Matsunaga, and Matthias Barwolff.

Special thanks must go to Jesse Sowell for his timely and able help in creating a software program to swipe thousands of public comments off the FCC database; to my wife, Hetal, for helping with the analysis and cataloging of hundreds of FCC comments; and to Arthur Burger (at CSAIL) for showing me the meaningful statistical analysis of those comments. I am also indebted to Bob Irwin and Marilyn Levine of MIT's Writing Center for their tireless guidance during my thesis and other writing pursuits. Finally, a big thank you for the great academic support to wonderful friends: Susan Perez, Rita Adom, Elizabeth Milnes, and Ana Piccolo.

For our last four years at MIT, our environment at home was enriched by our role as the Graduate Resident Tutors (GRT) at Baker House, MIT's undergraduate dormitory. I cannot say enough about Baker's superb house team, including: house masters Dava Newman and Gui Trotti; house manager Jon Nolan; resident life associates Emily Giorse, Emily Flores and Mellissa Thompson; fellow GRTs Jeannette and Josh Fiala, Chris Cassa, Eileen Higham, Elle and Will Ouimet, Julie and Neel Shah, Renee Smith, Joy Marie Johnson, Shannon Dong and Thomas Coffee; and the numerous, exceptional undergraduate Baker residents who've become life-long friends.

Several ESD and Sloan students have also contributed greatly to my work and life at MIT, including: Travis Franck, Mark Sin, Fuencis Marino, Ali Mostashari, Anup Bandiwadekar, Katherine Martin, Satwik Seshasai, Jorge Olivera, Ronda Jordan, Danielle Wood, Daniel Livengood, Jijun Lin, David Zipkin, Ayanna Samuels, Betsy Masiello, Gabriel Weinberg, Karen Tapia-Ahumada, Yingxia Yang, Siddharth Rupani, Gina Kim, Masahiro Sugiyama, Kenny Ching, and Tony Lim.

Finally, many friends helped us feel welcomed in Boston area and made it easy to cope with the highs and lows; these include: Ashish (and Sarayu) Nimgaonkar, Anoop (and Divya) Rao, Vipin (and Shweta) Gupta, Mani (and Poornima) Sendurai, Vish (and Preethy) Ananthraman, Seemantini Nadkarni, Mukul Agarwal, Manish Deopura, Ashish Kapoor, Neha Soni, Lavanya Sharan, Lavanya Marla, Anna Agarwal, , Mukul Kumar Singh, Saikat (and Sujata) Guha, Pushkar and Sangita Phatak, Nihar Sawla, Anurupa Ganguly, Kavita Radhakrishnan, Sejal Patel, Noel Lee, Prutha and Pritam Shah, Sirish and Gauri Nimgaonkar, Snehal and Nipa Buch, Marek and Annea Pycia, Richa Kumar, and Rajendra Kumar.

Chintan Vaishnav
Cambridge MA

Table of Contents

ABSTRACT **4**

ACKNOWLEDGEMENTS **8**

TABLE OF CONTENTS **13**

LIST OF FIGURES **17**

LIST OF TABLES **19**

CHAPTER 1: INTRODUCTION **20**

1.1 Introduction **20**

1.2 Paper I - From Herding Sheep to Herding Cats: Can the Regulations of an Integral Age Work in a Modular Age? **20**

1.2.1 Problem and Research Method 20
1.2.2 A Summary of Results 22

1.3 Paper II - Anticipating Uncertainty in Telecommunications Regulation, Competition, and Innovation **25**

1.3.1 Problem and Research Method 25
1.3.2 A Summary of Results 26

1.4 Paper III - From Animal Trainer to Wildlife Conservationist: Balancing Regulation and Innovation in the Modular Age **29**

1.4.1 Problem and Research Method 29
1.4.2 A Summary of Results 29

CHAPTER 2: FROM HERDING SHEEP TO HERDING CATS: CAN THE REGULATION OF AN INTEGRAL AGE WORK FOR A MODULAR AGE? **34**

2.1 Introduction **34**

2.2 From Integral to Modular Age: A Paradigm Shift **36**

2.1.1 Technology Dynamics 36
2.1.2 Industry Structure and Corporate Strategy Dynamics 38
2.1.3 Consumer Preference Dynamics 41

2.2 Regulation of Voice Communications in the Integrated Age **43**

2.3 Regulatory Response to the Modular Age **45**

2.4 Research Method **48**

2.5 Case Research: An Analysis of Pre. vs. Post-Internet Regulatory Environments 50
2.5.1 Case Selection and Setup 50

2.6 Two Models to Assess Regulation in the Modular Age 52
2.6.1 Regulatory Compliance Model 53
2.6.2 Competition in Telecommunications Model 56

2.7 Results and Discussion 59
2.7.1 Model Base Behaviors 59
2.7.2 Regulators Mental Model Focused on Efficiency, Not Objective 61
2.7.3 Case Research Results: Techtronic Shifts in the Center of Gravity of Control 64
2.7.4 Model Results: Challenges for Compliance and Competition 68

2.8 Conclusions 76
2.8.1 Objectives: Relevant, but Must be Pursued at the Societal Level 76
2.8.2 Obligations: Incremental Regulation Must be Abandoned 77
2.8.3 Enforcement Mechanisms: Must be Conscious of the Dynamic Complexity of the Modular Age 77

2.9 From Herding Sheep to Herding Cats 78

CHAPTER 3: ANTICIPATING UNCERTAINTY IN TELECOMMUNICATIONS REGULATION, COMPETITION, AND INNOVATION 79

3.1 Introduction 79

3.2 Research Method 82
3.2.1 Research Method Overview 82
3.2.2 Telecommunications System as a System of Systems 83
3.2.3 Application of Systems Theory 85

3.3 Case Research: Misperceptions of Technology Disruptions 86

3.4 A Systems Model of Regulation, Competition, and Innovation in Telecommunications 91
3.4.1 The Dynamics of Technology Disruption (Consumer-Firm Dynamics) 91
3.4.2 The Dynamics of Industry Disruption (Technology-Firm-Industry Dynamics) 97
3.4.3 The Consensus Conjecture (Regulation-Firm-Industry Dynamics) 101
3.4.4 Model Calibration 103

3.5 Results 105
3.5.1 Multiple Disruptions Base Behavior 105
3.5.2 Analysis of Uncertainty 108

3.6 Conclusion 117
3.6.1 Limits to Disruption 117
3.6.2 Three Popular Disruption Myths 120

3.7 Dynamic Complexity: Anticipation, Observation, and Measurement 122
3.7.1 Anticipation 122
3.7.2 Observation and Measurement 127

CHAPTER 4: FROM ANIMAL TRAINER TO WILDLIFE CONSERVATIONIST: BALANCING REGULATION AND INNOVATION IN THE MODULAR AGE............. 129

4.1 Introduction 129

4.2 Research Method 131

4.3 Research Stage I: Emergent Behavior and the Regulator's New Role 132
4.3.1 Phases of Disruption 132
4.3.2 Emergent Behavior in Telecommunications System 134
4.3.3 Stage I Results 140

4.4 Research Stage II: Can the Existing Policy Levers Achieve FB? 142
4.4.1 Optimization I: Maximize Compliance 143
4.4.2 Optimization II: Balance Compliance, Competition, and Innovation 144
4.4.3 Optimization III: Balance Compliance Cost, Innovation, and Competition 146
4.4.4 Optimization IV: Balance Compliance, Innovation, Competition, and Compliance Cost 147
4.4.5 Stage II Results 148

4.6 Research Stage III: Can any Unexplored Policy Levers Achieve the FB? 150
4.6.1 Two New Policy Levers that Theoretically Solve the Regulatory Puzzle 150
4.6.2 Stage III Results 153

4.7 Conclusion 163
4.7.1 The Regulator's New Role in the Modular Age: Balance Compliance, Innovation, Competition, and Compliance Cost 163
4.7.2 Existing Policy Levers are Inadequate for Achieving the FB Outcome 163
4.7.3 Three Conditions for Achieving the FB Outcome 164
4.7.4 Two Unexplored Policy Levers—Limiting Significant Market Power and Building Broad-based Consensus—can Achieve the FB Outcome 166

4.8 From Animal Trainer to a Wildlife Conservationist 168

CHAPTER 5: CONCLUSION, LIMITATIONS, AND FUTURE WORK 169

5.1 Conclusion 169
5.1.1 What Does Not Work: The Existing Arrows in Regulatory Quiver are Blunt 169
5.1.2 What Needs To Be Done: The New Role for Telecommunications Regulators 171
5.1.3 How To Do It: Balancing Regulation and Innovation in Telecommunications 173

5.2 Limitations 177

5.3 Directions for Future Work 180

APPENDIX A - A BRIEF EVOLUTIONARY OUTLINE OF STATUTORY DEFINITIONS AND FCC JURISDICTION 182

APPENDIX B - THE MODEL 185

Causal Loop Diagrams 185

Model-Sectors Diagram 188

Parameter-input Diagrams 188

Alphabetical Listing of Model Equations 195

APPENDIX C – INSTRUCTIONS FOR REPRODUCING EXPERIMENTS 227

Reproducing Chapter 2 Figures 227

Reproducing Chapter 3 Figures 230

Reproducing Chapter 4 Figures 234

APPENDIX D – NOTES ON MODEL VALIDATION AND TESTING 237

REFERENCES 239

List of Figures

Figure 1: From Single to Multi-mode Competition in Technology 37
Figure 2: From Integrate to Modular Industry Structure 39
Figure 3: From Low to High Consumer Choice 41
Figure 4: A four-layer model of open data network (adapted from the hourglass on page 122 of Realizing the Information Future: The Internet and Beyond, Copyright 1994, The National Academy of Sciences)... 42
Figure 5: Regulatory Compliance in the Integral Age 45
Figure 6: A Hierarchical Decomposition of the Telecommunications System 49
Figure 7: Required, Achievable, and Actual Compliance 59
Figure 8: Partial or Delayed Regulation 60
Figure 9: Disruption Base Case - Entrant Disrupts Incumbent....................................... 60
Figure 10: FCC Organization Chart (July 2009) 63
Figure 11: Stakeholder Interest - From Concentrated to Dispersed Across the Value Chain 65
Figure 12: Stakeholder Interest – Diminishes Inside the Network Core and Swells at the Network Edge 66
Figure 13: From a Single Dominant Interest to Multiple Factions 68
Figure 14: Sensitivity - Average Utilized Compliance with Different Consensus 69
Figure 15: Interpreting Average Utilized Compliance 70
Figure 16: Partial Regulation Provides Inadequate Compliance 72
Figure 17: Dynamic Complexity Obscures the Timing of Delayed Regulation.............. 73
Figure 18: The Impact of Product or Service Characteristics on the Competitive Outcome 75
Figure 19: The Impact of Market Characteristics on Competitive Outcome................... 76
Figure 20: The Double Helix 81
Figure 21: Extended Hierarchy behind the Endogenous Model 84
Figure 22: Gear Model and Near Decomposability 85
Figure 23: Resource Allocation under the Threat of Disruption 95
Figure 24: Calibration with PSTN Data... 104
Figure 25: Calibration with VoIP Forecast 105
Figure 26: Endogenously Generated Multiple Disruptions 106
Figure 27: Multiple Disruptions and the Dynamics of Double Helix............................ 107
Figure 28: Network Effect Phase Plot 109
Figure 29: Relative Switching Cost vs. Time of Disruption.. 110
Figure 30: Four Stacked Phase Plots to show Maximum Entrant Market Share when Consumer Prefers Compatibility, Innovation, Quality, and Price 111
Figure 31: Entrant's Functional Control and Likelihood of Industry Disruption 113
Figure 32: Incumbent's Dimensional Complexity and the Likelihood of Disruption..... 114
Figure 33: Incumbent's Agility and Likelihood of Disruption 115
Figure 34: Regulatory Uncertainty and the Clockspeed 116
Figure 35: Entrant Firms Remain More Modular with higher Antitrust Regulation...... 116
Figure 36: Limits to Technology and Industry Disruption 118
Figure 37: Three Popular Disruption Myths 121
Figure 38: Phases of Disruptions 134

Figure 39: Average Utilized Compliance 135
Figure 40: Average Utilized Innovation and Quality 136
Figure 41: Average Utilized Market Power 138
Figure 42: Average Compliance Cost 139
Figure 43: Tradeoffs across Disintegration and Integration - Compliance, Cost, Quality vs. Innovation and Competition 141
Figure 44: Regulation at Entry Optimization - Compliance at Low Cost, but No Innovation and Competition (Regulation Creates Barrier to Entry) 144
Figure 45: Delayed Regulation Optimization - Innovation and Competition, but less than Required Compliance and High Compliance Cost 145
Figure 46: Partial Regulation - Low Cost, and High Innovation, Competition, but Little Compliance 147
Figure 47: Partial and Delayed Regulation Optimization - Required Compliance, Innovation and Competition, but High Cost 148
Figure 48: Causal structure explaining the logic behind the two policy levers 151
Figure 49: High Modularity under Limited Market Power in Post-disruption Period ... 154
Figure 50: High Competition under Limited Market Power in Post-disruption 155
Figure 51: High Innovation under Limited Market Power in Post-disruption Period 156
Figure 52: Lower Compliance and Higher Coordination Cost with Limiting Market Power in Post-disruption Period 157
Figure 53: Relationship between Modularity of the Industry Structure and the Effort Necessary to Build Consensus 158
Figure 54: Higher Compliance under High Broad-based Consensus 159
Figure 55: Lower Compliance Cost under High Broad-based Consensus 160
Figure 56: But the Innovation remains high and the market power remains low 161
Figure 57: Policy Levers 1 and 2 can also Eliminate Incremental Regulation 162
Figure 58: Consumer and Firm Dynamics 185
Figure 59: Technology, Firm, and Industry Dynamics 186
Figure 60: Firm and Industry Dynamics 186
Figure 61: Regulation, Firm, and Industry Dynamics 187
Figure 62: Complete Causal Structure 187
Figure 63: Model Sectors Diagram 188

List of Tables

Table 1: From Integral to Modular Age - A Radical Change in the Regulatory Paradigm 36
Table 2: Functional Control From Inside the Network Core to Its Edges 38
Table 3: From Low to High Clockspeed........ 41
Table 4 Economic and Social Regulation of PSTN........ 44
Table 5 Modes of VoIP and the Current Regulatory Terms 47
Table 6: Incremental Regulation of the Entrants 48
Table 7: Content Analysis Setup to Study Pre vs. Post-Internet Regulatory Environments 51
Table 8: Conceptual Analysis Setup to Study Pre vs. Post-Internet Regulatory Environments 52
Table 9 Technology identified as “disruptive technology” in popular media (The New York Times) 87
Table 10 Christensen’s conditions for disruptive technology........ 88
Table 11 Potentially disruptive technologies in computers or telecommunications industry and their fit with Christensen’s conditions 89
Table 12 Potentially Disruptive Technologies and the Industrial Order 91
Table 13: Anticipating the Dynamics of Competition 125
Table 14: Anticipating Regulatory Dynamics 126
Table 15: Tradeoffs across the Periods of Disruptions 142

Chapter 1: INTRODUCTION

1.1 Introduction

This research analyzes the question of how a telecommunications regulator can balance regulations with innovation at a reasonable cost. This question has gained critical importance for telecom regulators worldwide as the unregulated Internet technologies such as voice and video over Internet disrupt the regulated traditional technologies such as telephony and television *and* the historical paradigm of the regulator. The traditional paradigm for telecommunications regulation assumes a well-defined set of services, offered by a well-identified operator (or a small group of them) in a well-circumscribed geographical area. The Internet has shattered each of these foundations. Successful regulation in the modular age created by the Internet requires a radically new regulatory paradigm and approach. Consequently, this thesis describes and analyzes the new telecommunications paradigm and explores its implications for an appropriate regulatory paradigm. The explicit objective is to systematically understand regulatory objectives, constraints, and opportunities in the modular age, so that critical regulatory objectives can be met without losing the bonanza of innovation and value the Internet has brought.

This dissertation is divided into five chapters. Chapters 2, 3, and 4 are written as stand-alone papers, yet together they say a single story. These chapters are bracketed by an introduction (chapter1) and conclusion (chapter 5). Chapters 2 and 4 present the current regulatory challenge and its solution, respectively. They may be read as a sequel. Chapter 3 studies uncertainties that surround technology and industry disruption, which is an area of interest to managers and policymakers alike. The present chapter summarizes the three papers (chapters) to follow, providing a comprehensive overview of the dissertation to a casual reader.

1.2 Paper I - From Herding Sheep to Herding Cats: Can the Regulations of an Integral Age Work in a Modular Age?

1.2.1 Problem and Research Method

The existing U.S. telecommunications regulations were created in the integral age. [1] In that paradigm, each operator was vertically integrated and controlled the total functionality necessary to deliver a service; a few such operators controlled the industry; they faced low competition and were under limited pressure to adopt innovation; and consumers had limited choice. The Internet has introduced a polar opposite paradigm—the modular age. In this paradigm, each firm controls only a subset of the total functionality necessary to constitute a service; many modular firms interoperate to deliver a service; firms compete fiercely and are under great pressure to innovate; and consumers

[1] Paper 1 and 3 are targeted for an outlet such as the Telecommunications Policy Journal. While the references to appropriate literature are kept out to shorten the summaries, appropriate grounding in literature will be provided for each paper in their respective chapters.

enjoy a far greater choice due to the multi-modal competition among multiple technologies. Entering the modular age raises a number of questions for telecommunications regulation: *Can the regulatory structure designed in an integral age—in its objectives, obligations, and mechanisms—work for a modular age?* Although transitioning from an integral to a modular age dramatically flips the environment, the current regulatory response to this dramatic shift has been hesitant to shift its intellectual roots. The purpose of this paper (Chapter 2) is to examine the ongoing debate around regulation of the Internet, using the lenses of the disruptive shifts in technology, industry, and consumer experience. The analysis uses the regulation of voice communications in the United States as a representative case.

Metaphorically, this is a tale of three animals – elephant, sheep, and cats. From the time the FCC was established (in 1934) until the break up of AT&T, the telecommunications regulator was a keeper of an elephant (AT&T). The elephant was monolithic and slow, but powerful and demanding because it faced no competition. It had negotiated with its keeper a suitable confinement in the form of the 1934 Telecommunications Act.

With the break up of AT&T, the regulator became a shepherd herding a few sheep (the Baby Bells). The sheep were inherently docile – not too competitive and not too innovative. To control the sheep, the shepherd needed just a crook and a little guidance that came in the form the Telecommunications Act of 1996 and its enforcement.

But the transition from an integral age to a modular age transforms the regulator's role from that of a shepherd to a herder of cats. The cats are fiercely competitive, highly innovative, and agile. Whereas the sheep worked by consensus, the cats are highly independent. Controlling the cats requires new schemes – a net around them, a set of incentives (mice, catnip?), or something else. Control mechanisms for these species must be radically different. The previous approaches cannot control the cats. The disruptive change in the industry fabric can only be matched with disruptive change in the regulatory approach to managing the industry.

Our research approach is built upon the principles of systems analysis. The telecommunications system is viewed as one the many subsystems that interact to fulfill the objectives of the social system (the society). The dynamics of the telecommunications system emerges from the interaction of four subsystems: regulatory dynamics, corporate strategy dynamics, consumer dynamics, and technology dynamics. The regulatory objectives to be fulfilled are conceived as an emergent property of such a system of systems.

The research uses two models and a case study. The models use coupled-differential equations with feedback, and are kept minimally endogenous[2]. They capture the interactions within the telecommunications system over which the regulatory decisions take effect. The first model examines the system-level regulatory compliance as the modular age disrupts the integral age. The second model examines entrant-versus-incumbent competition as a function of the various forces, including regulation.

[2] The models will be made fully endogenous in Paper II to study the uncertainty.

The case study analyzes the regulatory environment of the pre vs. post-Internet periods, both quantitatively and qualitatively. For the analysis, public comments in response to the Telecommunications Act of 1996 NPRM[3] are compared with those in response to the IP-Enabled Services NPRM published in 2004. These two FCC dockets form a natural experiment; the 1996 Act centers solely on the public switched telephone networks (PSTN) and mentions the term “Internet” just once, whereas the IP-Enabled Services NPRM centers on the Internet and is the first document to acknowledge the serious threat that Internet-based services pose to the existing regulations. The analysis demonstrates that the differences in the integral and modular age are indeed reflected in the regulatory record. It then further explores the nature of the regulatory environment in the modular age.

1.2.2 A Summary of Results

The appropriateness of a regulatory regime can be evaluated along three dimensions: the objectives it serves including cost & innovation outcomes, the obligations it imposes to fulfill those objectives, and the mechanisms it uses to enforce those obligations. Collectively, these dimensions determine the degree of compliance achieved and the total costs of achieving this compliance. The OBJECTIVES may be evaluated by asking the following question: are they appropriate for the telecommunications system to fulfill? The regulation of voice communications has traditionally fulfilled five objectives: three of them are social objectives (law enforcement, public safety, and equal opportunity objectives) and two are economic objectives (competition and economic development).

This paper argues that these objectives remain appropriate for the voice communications regulations to fulfill in the modular age, but they are currently being pursued at the wrong level. The debate about the regulatory objectives is currently stuck at the level of which technologies or industries (wired, wireless, internet telephony, etc.) ought to fulfill them. This seems inappropriate. For example, public safety is a societal objective that has generated emergency calling (E911) obligations for the telecommunications system. The PSTN providers have been burdened with the emergency calling obligations since 1976. However, ever since wireless telephony and Voice over Internet Protocol (VoIP) became viable competitors to the PSTN, the regulatory process has engaged in a debate as to whether and when to extend the emergency calling obligations to these new entrants. The answer ought to be clear, but it hasn’t been because the public safety debate has been pursued at the level of technologies. At the societal level, the telecommunications system is one of many subsystems that facilitate public safety. If the telecommunications system as a whole fails to aid public safety because some technologies are not regulated, other subsystems—maybe non-technical ones—will have to pick up the slack. But this consideration has not been recognized in the discussion.

---

[3] Precisely, the Implementation of the Local Competition Provisions in the Telecommunications Act of 1996 Notice for Proposed Rulemaking.

The OBLIGATIONS may be understood by asking the following questions: Are they appropriate for fulfilling the objective at hand? Who should bear them, and when? For the obligations to be apt, every regulatory objective must be pursued at the societal level first. Only then can the obligations for the communications system as a whole, or for the technologies or industries within it, be correctly understood. Pro-market regulatory regimes have already responded to the "who" and "when" questions with incremental regulation. Incremental regulation can take two forms: partial regulation, where the regulatory scope permanently excludes certain types of firms or technologies from regulation; or delayed regulation, where the regulatory scope temporarily excludes certain types of firms or technologies but includes them later. Significant uncertainty in the early stages of technology disruption has been the driving force for use of incremental regulation in periods of technological disruption. Managing incremental regulation necessarily involves decisions about the regulatory scope and timing.

This paper argues that incremental regulation is futile in the modular age. Limiting regulatory scope in a modular architecture creates perverse incentives. At the industry level, it provides incentives to the regulated firms to flee to the unregulated technology segments. At the global level, it ignites competition in laxity between nation-states trying to lure both consumers and firms with lighter regulatory burdens.

As for the timing of incremental regulation, the far higher dynamic complexity of the modular age renders impractical any hope for effectiveness in the timing-related decisions. First, the regulator struggles to determine if the regulation is too-early or too-late, because many competing factors mediate the rate of technology and industry disruption, making it virtually impossible to predict how rapidly an unregulated segment might erode existing regulatory compliance. Next, the regulator cannot be sure of the outcome post-regulation, because the modular age offers far higher flexibility to consumers, firms, and technologists to strategically manipulate the competitive outcome, the dynamics of which the regulator often does not fully comprehend and cannot fully anticipate. So, to understand the appropriate scope or timing of regulation, the dynamic complexity of the modular age must be understood as well as possible. Paper 2 focuses on further understanding the dynamic complexity.

The ENFORCEMENT MECHANISMS may be evaluated by asking whether they are effective for the system to be regulated? The enforcement mechanism for traditional telecommunications regulation has been command-and-control. This mechanism worked because in the integral age the industrial interests were concentrated, which made it possible for the regulator to know whom to command and where to control. The regulatory fights were easier to identify and address. Also, as a firm possessed full functional control over a service, it could easily develop and deploy compliance mechanisms post-regulation.

The modular age completely changes the rules of the game. The modular forces blunt the mechanisms of command-and-control. First, the regulator finds it difficult to determine where a command-and-control mechanism ought to focus, because the post-Internet era has multiple players in the value chain, including consumers, each a capable interest group with a distinct viewpoint on regulatory mechanisms and objectives. Next, command-and-control mechanisms are ill-suited for building consensus around regulatory issues, which is imperative for meeting critical societal objectives, as the lack of consensus inflicts a high coordination cost that could prevent meeting regulatory objectives altogether. The modular structure shifts the center of gravity of control from a single dominant interest to multiple, from the center of the network to its edges, and from the corporations to corporations-plus-consumers. This is a tectonic shift that demands completely different enforcement mechanisms.

This paper concludes that for the aforementioned reasons, the regulatory modes of the integral age cannot work for the modular era, in their objectives, obligations, and enforcement mechanisms. To design regulations that are appropriate and practical for the modular era, the following combination must occur: the regulatory debate around objectives must be pursued at the societal level; the necessary obligations must follow from the objectives construed at the societal level; the incremental regulation being utilized for imposing obligations must be abandoned; and new enforcement mechanisms, conscious of the dynamic complexity of the modular age, must be designed. Paper 3 discusses how to achieve such an outcome.

--

1.3 Paper II - Anticipating Uncertainty in Telecommunications Regulation, Competition, and Innovation

1.3.1 Problem and Research Method

Decision making under the constant threat of disruption is a difficult task whether you are a policymaker, manager, consumer, or technologist.[4] Difficulties arise from the bewildering array of uncertainties that surround the disruption phenomenon. This paper examines: *How can regulators and managers improve decisions taken amidst the uncertainty that surrounds the disruption of an integrated technology and industry by a modular one?* The purpose of this paper is to understand these uncertainties from the perspective of dynamic complexity in feedback systems. The paper attempts to improve our current understanding of the technology and industry disruption phenomenon at three levels. First, the paper maps the existing theories in technology and industry disruption into a single, dynamic model to explore the structure of influences that drives the various possible industry and technology trajectories. Second, the model makes endogenous key parameters that the existing theories have considered exogenous. By doing so, the model can address not only what the various scenarios of uncertainty and their outcomes are, but also when each scenario arises in the first place and how it may persist. Finally, the paper includes consideration of the strategic behaviors of firms (derived from unstructured interviews) to explain how different actors may change the game. With the help of these features, the paper discusses the impact of the various uncertainties—technological, market, organizational, regulatory, or that of the industry structure—at two levels. First, at a theoretical level, it discusses the conditions under which a disruption may or may not take place, thereby discussing the assumptions and limits of two disruption theories; namely: Clayton Christensen's work on technology disruption[5], and Charles Fine's work on industry disruption and clockspeed[6]. Next, it discusses broadly how policymakers, managers, consumers, and technologists can anticipate the behavior of a number of parameters of practical importance.

The research starts with a qualitative case study to investigate the following question: do potentially disruptive technologies always displace the existing industrial order? This is an important question to start with, because the loose and opportunistic use of the term "disruptive technology" today, by the media and experts alike, can mislead decision makers every time a new technology appears on the horizon. The case research uses a combination of content analysis and industrial statistics. First, it analyzes several important media publications to enumerate technologies they proclaimed as "disruptive technology" in the period between 1997, when the term was coined by Clayton Christensen, and August 2008. Next, with the help of the Global Industry Classification Standards, it ties these technologies to the industries they were expected to disrupt. Finally, it studies the industrial order of the industries threatened with disruption for the

---

[4] Paper 2 is targeted for either the Journal of Industrial and Corporate Change, or the Journal of Innovation and Product Management.
[5] More famously, "disruptive technology," in Ref. Innovator's Dilemma
[6] Ref. Clockspeed

years 2001 and 2007. The analysis shows that in the communications industry alone, where changes ought to be easier to visualize because of its rapid rate of change, a potentially disruptive technology often does not succeed (i.e., no technology disruption). Further, it finds that technology disruption does not always mean industry disruption; in other words, in some cases, a new technology may disrupt the old, but the industrial order does not change because the leaders of the old technology continue to lead the new market. To understand what factors explain such variation in the outcome, the research then turns to a dynamic model that more broadly captures the uncertainties involved.

The single, dynamic model in this paper situates the two models discussed in Paper 1 in the appropriate theories, and makes the parameters in those models endogenous. First, to model the dynamics of technology disruption, several parameters of the simple diffusion model, such as quality, innovation, price, and resources of the firms, are made endogenous. Next, to explain the dynamics of industry disruption, the industry-level modularity is made endogenous, which allows for understanding the level of organizational rigidity, dimensional complexity, and functional control the firms experience as one industry disrupts another. Finally, the dynamics of regulation are added to explain how the cost and resources required for regulatory compliance affects competition during technology and industry disruption; and conversely, how the disruption affects the level of regulatory compliance, and the time necessary to achieve it. The model is analyzed under market, technology, organizational, and regulatory uncertainty. The scope of this model is limited to a scenario where a *modular* technology and industry disrupts an *integrated* technology and industry, which is sufficient for studying the Internet's disruption of traditional technologies. Careful judgment is required to port the lessons of this paper to other scenarios of disruption.

1.3.2 A Summary of Results

At a theoretical level, the research discovers several limits to technology and industry disruption. The paper first discusses the limits to technology disruption, meaning conditions under which an entrant technology fails to displace the incumbent technology. It identifies two sets of conditions the lead to such a situation. First, a technology disruption is less likely when the incumbent's product or service enjoys strong network effects. The case research supports this finding. It shows that indirect network effects have prevented technology disruption in both operating systems as well as the wireless operators markets. Second, a technology disruption is less likely in markets where consumers prefer innovation in product or services far less compared to their low price, high quality, and high compatibility.

The paper next discusses the limits to industry disruption, meaning conditions under which a new technology displaces the old but the entrant firms do not displace the incumbent firms. Such a situation arises when the incumbent loses the market share initially, but then it regains the lost market to become a leader in the new technology. The paper identifies two sets of conditions for such a situation to occur. First, an industry disruption is less likely when the incumbent can significantly affect the switching behavior through a variety of strategies. The case research confirms this finding. It shows that the incumbents in computers and communications industries strategically utilize high switching costs to retain or regain their large consumer bases. Second, an industry disruption is less likely when incumbents are able to innovate while maintaining certain quality. Incumbents are typically stacked against natural barriers to rapid innovation such as rigidity of their organization and high dimensional complexity of their product. Yet, there are examples of incumbents radically restructuring their products in order to innovate while offering lower than before but acceptable quality to their consumers. Third, an industry disruption is less likely when entrant struggle to offer quality due to lack of functional control or market power. Being able to offer system-level quality is easier when a firm has system-level functional control. Such a system-level functional control is present when a firm owns critical functional components involved in delivering a service, or when the interfaces are standardized and a modular firm can reliably assert control over the end-to-end service to offer quality. Modular entrants in nascent markets often lack such control. Moreover, in a situation where they cannot accumulate market power because of competitive or regulatory reasons, they may lack the ability to deliver the necessary quality, either by developing it on their own or by contracting with other firms for it.

At a practical level, the research provides guidance to practitioners on understanding uncertainty. First, it uncovers three myths about disruption that arise commonly. Incumbents often believe that disruptors cannot offer quality so there will be no technology disruption, which is a myth that leads to incumbent's response that is slower than necessary. Analysts often believe that every entrant technology is inherently superior so there is sure to be technology and industry disruption, which is a myth that creates hype around every new technology. Corporate leaders often believe that a highly agile firm will survive disruption, which is a myth that leads to disregarding other structural influences that may be more important than firm's agility. Each of these myths arises due to the misperceptions of feedback in complex systems.

Next, the research provides guidance on how to anticipate parameter behavior under uncertainty before, during, and after disruption. It discusses the system-level structural implications that arise because of how the causes and effects are arranged in the whole system. The paper explains the structural implications using two types of structural forces: reinforcing and balancing. It elaborates upon the several structures of each type that the model identifies. In reinforcing structures a change is amplified, so a growth leads to further growth and a decline to further decline. In balancing structures a change is countered, so either a growth or a decline is countered. Structural influences demonstrate why dislodging the incumbent can be so difficult. In the communications industry, the incumbent's large installed base reinforces three of its strengths – high quality, low price, and high compatibility. Hence, a potentially disruptive entrant needs a great innovation to overcome these forces. The structural forces also explain several sources of lock-in. For example, integrated structures have a tendency to remain integrated, and modular structures to remain modular. These observations argue that the small market share of a modular entrant at the time of entry is not enough reason to ignore the entrant as the reinforcing forces may help it grow rapidly. Also, once a modular structure disrupts and becomes dominant, it might persist because of the lock-in, so the disruption has real consequences.

Finally, the paper discusses the challenges of observing and measuring parameters.

1.4 Paper III - From Animal Trainer to Wildlife Conservationist: Balancing Regulation and Innovation in the Modular Age

1.4.1 Problem and Research Method

Juxtapose the social and economic objectives served by the existing telecommunications regulations, and evaluate what the modular age has done to them from the societal perspective, and you shall see a very different role emerging for the regulatory agency in the new world. The modular forces naturally promote the economic objectives such as competition and innovation, but they derail critical social objectives such as law enforcement and public safety. The regulator's new role should be to achieve the following vital combination, which we define as the *first best* (FB) outcome: regulatory compliance, innovation, and competition are maximized subject to compliance cost constraints. In other words, the necessary regulatory compliance is achieved, the high innovation and competition are preserved, and the reasonable cost of compliance is maintained. This paper asks: *How can such a balance of regulation, innovation, competition, and cost be achieved in the modular age of the Internet?*

The research begins with analyzing regulatory compliance, innovation, competition, and compliance cost as emergent behaviors of the systems model developed through papers 1 and 2. It then proceeds in three stages. In the first stage, we investigate whether the FB can be achieved *using the currently-known policy levers* such as the scope and timing of regulation. For this investigation, we subject the model to a set of optimization exercises. In each exercise, the desired objective function needs to be achieved by varying the scope and timing of regulation. The optimization exercises are organized in an increasing order of complexity. They show that partial and delayed regulations cannot achieve the FB, and that balancing the four attributes involves tradeoffs.

Hence, in the second stage, we carry out policy analysis on the systems model *to seek levers that are capable of achieving the desired balance, but that have not been exploited by the policymakers yet.* Once we find such policy levers that would, in theory, achieve the desired balance, in the third stage of the research, we discuss how the objectives, obligations, and enforcement mechanisms might be devised to implement the policies it in the practical sense, and from the systems perspective. For the third stage, we extend the Pre- vs. Post-Internet Regulation Case Research, already introduced in Paper 1.

1.4.2 A Summary of Results

The first optimization exercise demonstrates that if the regulatory compliance alone had to be maximized, the policy of comprehensive regulation, where all market entrants are regulated at the time of entry, achieves the necessary regulatory compliance, but it does so at the cost of innovation and competition. Here, unless the entrant enjoys a giant price and performance advantage over the incumbents that cannot be dwarfed by their regulation, the regulation creates a barrier to entry. This exercise shows that there is indeed a tradeoff in increasing compliance versus innovation and competition.

The second optimization exercise shows that if compliance had to be balanced with just innovation and competition but not cost, the regulator can do better if they accept a delayed regulation of the entrant; meaning, they give up regulation at the time of entry so as to let the modular entrant enter. Such a finding validates the regulatory tendency to leave nascent entrants unregulated; for example, the exclusions of the Internet from the 1996 Act. In theory, delayed regulation may work if entrant can be regulated as soon as it has a sufficiently large consumer base but no later, as such careful management of the timing of regulation provides the best possible payoff in terms of both regulation and innovation. Unfortunately, however, there are several undesirable effects. First, the average compliance only reaches a level that can be achieved in a fully modular structure, which may be inadequate for the objective at hand. Next, as discussed in Paper 1, such a management of the timing of regulation is too difficult in the post-Internet environment because of the dynamic complexities. Finally, such improvement in compliance and innovation, achieved using delayed regulation, comes at a disproportionately large compliance cost due to the inordinate coordination cost of fully regulating the modular value chain.

The third optimization exercise shows that if all four – compliance, innovation, competition, and cost – had to be balanced; the regulator can do better if in addition to the delayed regulation, they accept partial regulation of modular value chain, where the regulatory scope includes only those firms that can easily comply with regulation, thereby reducing the coordination cost. Such a finding validates the regulatory tendency for leaving out the difficult to regulate technologies; for example, the partial regulation of IP-Enabled services such as VoIP. However, we know from Paper 1 that such partial regulation is unsustainable as it provides perverse incentives for the regulated firms at the industry as well as global level in a dynamic environment. But more importantly, even after accepting both partial and delayed regulation, the average compliance remains inadequate for fulfilling the critical regulatory objectives.

The first stage of research above concludes that the existing arrows in the regulatory quiver are blunt. Nonetheless, the above analysis does illuminate the theoretical conditions that must be met if the compliance, innovation, competition, and cost had to be balanced. These conditions are as follows: the modular structure must disrupt and win (i.e., regulation must not act as a barrier to entry); the modular structure must remain modular even after gaining market power (i.e., regulation must prevent significant accumulation of market power to maintain competitive pressure); and the modular structure must have the ability to comply with regulations at low cost (i.e., regulation must ensure that the coordination costs remain low). The policy analysis in the second stage of research explores which new policy levers must be pulled to achieve such an outcome.

The policy analysis on the systems model contends that the highest leverage regulatory solution for meeting the above-listed theoretical conditions is a combination of two policies: to guard against the build up of significant market power, and to lower the coordination cost in modular industries by building consensus around the regulatory issues. The following logic drives this recommendation. When a modular industry disrupts an integrated one, there is a great lack of consensus among firms around the regulatory issues. This lack of consensus causes two problems: it increases the time required to build compliance mechanisms, and it inflicts a large coordination cost that inflates the total cost of compliance, both of which reduce the overall compliance. Further, the coordination costs pose entry barriers for the nascent entrants. Since meeting regulatory requirements in a modular industry necessitates that all firms coordinate, such increase in coordination cost is inevitable. For example, when devices, applications, and access networks involved in delivering a single service are provisioned by separate parties, they must necessarily coordinate actions to comply with public safety or law enforcement requirements. Additionally, as the modular components compete fiercely over territories in a modular value chain, there will be a constant disagreement over who should bear the coordination cost. One market-based solution for reducing coordination cost is to let the modular firms integrate, but such integration comes at the cost of consolidation of market power, less standard interfaces, and lower pressure for innovation adoption. Hence, the coordination cost and the modularity of the industry structure, together, play a central role in balancing the compliance, innovation, competition, and cost, and the regulator is the best suited to balance these attributes by controlling the coordination costs and the level of integration in the industry structure. Controlling the coordination cost and the level of integration require the regulator to use two policy levers: building broad-based consensus around regulatory issues, and limiting the consolidation of market power in the communications industry. These levers allows the regulator to increase compliance levels by containing the time and cost of developing compliance mechanisms, and to keep the innovation and competition high by reducing the barrier to entry as well as by maintaining the competitive pressure to innovate and adopt innovations.

Limiting the consolidation of market power and building broad based consensus may be a nice theoretical solution, but are the regulators equipped to achieve it at the practical level? As established in Paper 1, to design regulations that are appropriate for the modular age in a practical sense, the following combination must occur: the regulatory debate around objectives must be pursued at the societal level; the necessary obligations must follow from the objectives construed at the societal level; the incremental regulation being utilized for imposing obligations must be abandoned; and a new enforcement mechanism conscious of the dynamic complexity of the modular age must be designed.

This paper argues that to be able to address the objectives at the societal level, the FCC must be empowered to, and in fact must take a philosophical position on regulatory objectives, and thereby on the resulting obligations. While the dynamic complexity of the environment may complicate the enforcement of regulations, it does not obscure what the philosophical position on each objective ought to be. For example, the FCC must clearly state that objectives such as law enforcement and public safety cannot be compromised, and technologies that aspire to substitute existing channels of voice communications will be required to find a way to comply with the necessary obligations. Similarly, the FCC must clearly state that it considers promoting multi-modal competition and innovation to be of critical importance. Therefore, the interconnection obligations will be considered across any two technologies, not just within a single mode such as PSTN. Similarly, universal service obligations may be fulfilled by any acceptable substitute, not just PSTN.

Taking a clear philosophical stance on issues like these will help in several ways. First, it will prevent the entrenched interests from defocusing the regulatory debates. The analysis of the public comments, posted in response to the 2004 IP-Enabled Services NPRM, shows how the absence of a clear position on the objectives allows the political economy of entrenched interests to hijack the regulatory debate away from being objective-centered. For example, the state vs. federal, or local vs. long-distance service interests currently overwhelm the debate about the access charges, which ought to be centered around how to achieve the objective of high competition. Similarly, interests trying to preserve the compensations that currently benefit them monopolize the debate about universal service, which ought to be centered on how socio-economic benefit may be brought to remote areas through new technologies. As a result, today, the regulatory proceedings spend enormous energy on appeasing the entrenched interests, which ultimately does not achieve the goal.

The second advantage of taking a clear position is that it reduces the regulatory uncertainty, and thereby makes both incumbents and entrants less risk averse. Firms do not risk investment in differentiating themselves from the competition when there is uncertainty about regulations that may neutralize the advantage. A clear position on the objectives makes it clear for the firm if they should expect to be regulated. And guaranteed regulation is often better than a threat of regulation.

The third advantage of taking a clear position is that the obligations that follow will eliminate misalignment that currently exists between opportunities, objectives, obligations, and capabilities. The obligations that follow from public safety, equal opportunity, and universal service objectives would then more aggressively leverage the new technologies that offer improved ways to achieve these objectives. The obligations that follow from critical areas such as law enforcement would not be partial or delayed. And, the obligations would not burden only parts of the value chain when the capacity to meet the obligation has moved to the other parts as a result of the movement in the functional control.

Of course, simply taking a philosophical position will not be sufficient. To fulfill the objectives at the societal level, the government institutions, more broadly, and the FCC itself, more specifically, will have to organize differently. The fragmentation of government and the regulatory agency does not currently empower any party to be responsible for understanding and achieving the objectives at the societal level. While the full exploration of how to reorganize the government or the FCC is beyond the scope of this thesis, here is an example.

We know from our analysis that a merger between two firms can potentially compromise two objectives: promoting multi-modal competition and innovation experienced by an average consumer. Yet, no merger in telecommunications industry to date has evaluated competition between multiple technologies, nor has any been viewed as a precursor to the impending loss of innovation. The reason clearly is the fragmented organizations sharing responsibility for evaluating a merger. The FCC is organized in technology-specific silos such as wireline, wireless, and media. bureau. Despite that fact that large telecommunications firms today are invested in all technologies, every merger evaluation is assigned only to one of the FCC bureaus. Hence, the multimodal competition perspective could easily fall between the cracks. The FCC evaluates a merger from only the "public interest" perspective. It is the Department of Justice (DoJ) that assesses if the merger will "substantially lessen" the competition, but the DoJ does not have the technological perspective, let alone that of multi-modal technology. FCC's "public interest" is also inadequate. It only involves the analysis of how the merger affects the consumer welfare, and does not recognize that with a merger, the industry integrates, product interfaces may go from standardized to proprietary, and the industry may turn from one that was innovation-focused to the one that is quality-focused.

Apart from taking a position on objectives and reorganizing the agency as appropriate, to be able to build broad-based consensus, a whole new set of capabilities and processes will have to be added to the enforcement bureau. Broad-based consensus may be built in two ways: by bringing all stakeholders to the negotiation table, or via the process of standards. The enforcement bureau has never included negotiators, nor have they participated in standard body meetings. It may need to acquire both of these skills. Their paradigm has been command-and-control, which only uses fines and punishment. Unfortunately, the modular age renders the current enforcement paradigm of command-and-control ineffective because of the enormous dynamic complexity. Today, the firms cannot easily comply with regulation because of the inordinate coordination cost due to the heterogeneity of architectures and competitive interests. The regulator must focus on reducing the firm's effort required to comply, so the firms can focus on their core competencies. Being able to negotiate a broad-based consensus around regulatory issues will allow the FCC to reduce the burden of compliance on modular firms, so that these firms can comply with regulation and innovation at the same time.

Metaphorically, in the modular age, the role of the regulatory agency has gone from that of an animal trainer to a wildlife conservationist. The animal trainer cared only about compliance, but the wildlife conservationist cares also cares about the survival of species. The trainer, like a policeman, curtailed unwanted activity, whereas the conservationist, like a parent, is interest in a balance, where animals are playful but also grow into responsible citizens of the jungle.

Chapter 2: FROM HERDING SHEEP TO HERDING CATS: CAN THE REGULATION OF AN INTEGRAL AGE WORK FOR A MODULAR AGE?

2.1 Introduction

Existing U.S. telecommunications regulations were created in the integral age. In that paradigm, each operator was vertically integrated, controlling the total functionality necessary to deliver a service; a few such operators controlled the industry; they faced low competition and were under limited pressure to adopt innovation; and consumers had limited choice. The Internet has introduced a polar opposite paradigm—the modular age. In this paradigm, a firm controls only a subset of the total functionality necessary to constitute a service; many modular firms interoperate to deliver a service; firms compete fiercely and are under great pressure to innovate; and consumers enjoy a far greater choice due to the multi-modal competition among multiple technologies. Entering the modular age raises a number of questions for the telecommunications regulation: *Can the regulatory structure designed in an integral age—in its objectives, obligations, and enforcement mechanisms—work for a modular age?* This paper delivers a clear answer to this question (No!) and identifies the reasons why the objectives, obligations, and enforcement mechanisms of regulations of the integral age cannot work for the modular age.

During the 1980s and '90s, there was much written about Telecommunications Policy in the United States. Several books provide detailed discussions of the regulatory challenges, decisions, rationales, and important court cases ((Krattenmaker and Powe 1994), (Benjamin, Lichtman et al. 2006)). Much of this literature is focused on the regulatory challenges of going from monopoly to competition after AT&T's break up in 1984 ((Sapolsky 1992), (Stanbury and Institute for Research on Public Policy. 1986)), the genesis of the Telecommunications Act of 1996 ((Telecommunications Policy Research Conference, Brock et al. 1996), (Telecommunications Policy Research Conference, Gillett et al. 1999)), and the impact of deregulation in telecommunications ((Tunstall 1986), (Wilson 2000)). However, this literature barely mentions the modular age created by the Internet, understandably so, as the meteoric rise of the Internet through the 1990s and 2000s would have been impossible to predict.

The recent academic literature has acknowledged the radical shift from an integral to a modular age introduced by the Internet. It poses arguments about the structure of the communications industry that has gone from a value chain to a value network (Li and Whalley), and about the large choice available to consumers that has altered the competitive landscape for the incumbent as well as making real the new regulatory challenges such as net neutrality(Pouwelse, Garbacki et al. 2008). This literature also calls for broader structural and technological remedies for future regulation (Cammaerts and Burgelman 2000). There is generally a growing recognition that the emergence of Internet-based services has implications for future communications regulation, market structure and competition. This literature explicitly underscores the urgent need for further research on the implications of this shift (de Bijl and Huigen 2008).

This paper examines the appropriateness of a regulatory regime for the modular age. The research approach builds upon the principles of systems in order to broadly analyze the regulator's role and critique decisions taken thus far. We view the communications industry as a complex system, with dynamic components such as technology, firms, consumers, regulators. The regulatory objectives are conceived as an emergent property of such a system of systems. We analyze the appropriateness of a regulatory regime along three dimensions: the *objectives* it serves, the *obligations* it imposes to fulfill those objectives, and the *enforcement mechanisms* it uses to enforce those obligations. We find this three-part framework, originating from the recent political economy literature (Reiner 2002), more comprehensive for evaluating regulation than using any one dimension, which involves tradeoffs. Focusing solely on objectives eases legitimating policy but makes assigning responsibility difficult; focusing on obligations eases assigning responsibility but makes legitimating policy difficult; and focusing on enforcement mechanisms makes a policy more measurable and ostensibly objective but may suffer in terms of legitimacy and appropriate assignment of responsibility. Thus, we analyze the ongoing debate around the regulation of the Internet using two lenses. The change in the regulatory paradigm is analyzed using the lens of the disruptive shifts experienced by the technology, industry, and consumers. And the appropriateness of the regulatory regime is analyzed using the lens of objectives, obligations, and enforcement mechanisms. The research uses the regulation of voice communications in the United States as a representative case.

Broad theoretical analyses of telecommunications regulation of the kind we undertake in this paper (and Paper 3) has been traditionally based upon economic theory (Laffont and Tirole 2000), legal theories(Kennedy and Pastor 1996), or technological architecture (layered regulation argument in (Nuechterlein and Weiser 2005)). All of these approaches focus heavily on the efficiency of implementing regulation in a *static* scenario. The dynamics of technology, industry structure, and consumer behavior are considered exogenous to their mathematical or analytical models. *The research in this paper (and Paper 3) focuses on the <u>dynamic</u> complexity in the telecommunications system.* It strives to make the behaviors of firms, consumers, and technologists endogenous with respect to regulation and competition. Recent works have already shown that in the new environment of high flexibility and choice, policy and regulation indeed influence the technology choice to a varying degree (Huigen and Cave 2008).

Our work should not be misconstrued as opposing the economic principles or legal doctrines. The contributions of the economic and legal theories in understanding the problems of interconnections and other types of incentive regulations are already well-known. But both economic and legal theory pursue regulatory *efficiency* while considering one or more of the objectives, obligations, enforcement mechanisms, or institutional arrangements as given. *By contrast, our research is interested in understanding how the regulatory <u>objectives</u> might be fulfilled, even if that takes redesigning regulatory obligations, enforcement mechanisms, and reorganizing the institutions.*

The remainder of this paper is organized as follows. We begin by discussing the paradigm shift of integral to modular age, providing evidence and illustrations for it. We will then discuss regulation of voice communications in the integral age, and the hesitant regulatory response to the onset of the modular age. Following that, we use case research and two models to assess whether this regulatory response is appropriate, and then end with conclusion.

2.2 From Integral to Modular Age: A Paradigm Shift

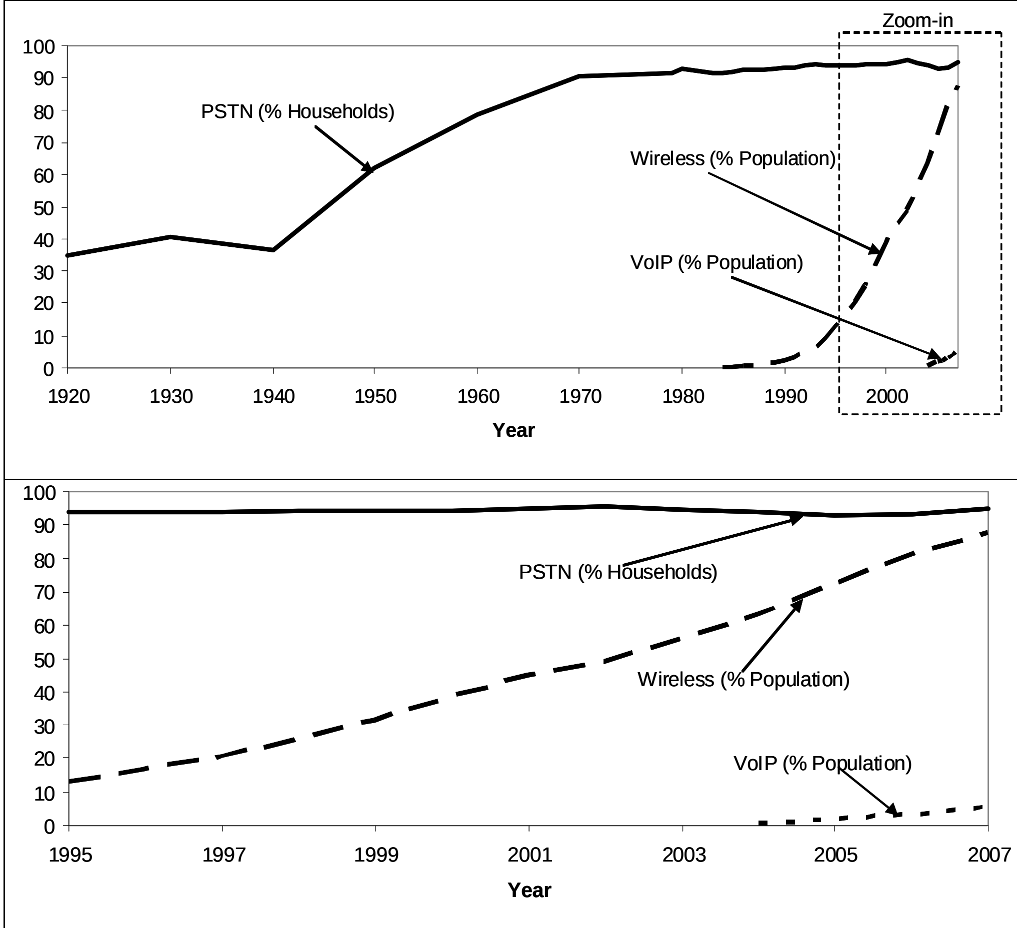
The Modular Age radically changes the dynamics of technology, corporate strategy, consumer preference, and consequently the regulation. In this section, we show illustrations of this radical shift summarized in Table 1.

Integral Age	Modular Age
Technology Dynamics	
Single mode competition	Multi-mode competition **(Discontinuity)**
Intelligence in the network core	Intelligence at the network edges **(Discontinuity)**
Industry Structure/Corporate Strategy Dynamics	
Integrated	Modular **(Discontinuity)**
Low competition	High competition
Low innovation adoption	High innovation adoption
Low clockspeed	High clockspeed
Consumer Preference Dynamics	
Less choice	More choice **(Discontinuity)**
Difficult to introduce innovation	Easier to introduce innovation **(Discontinuity)**
Regulatory Dynamics	
Narrowly tailored regulation, as appropriate for the Integral Age	**?**

Table 1: From Integral to Modular Age - A Radical Change in the Regulatory Paradigm

2.1.1 Technology Dynamics

The modular age changes the technology dynamics in two important ways. First, it changes the competition from single model (*among* technologically-similar multiple PSTN providers) to multi-mode (*between* wired technologies such as PSTN, wireless technologies, and the Internet technologies that work both on the wired and wireless technologies). Figure 1 illustrates the three voice communications technologies in the United States. Here, the effective penetration of wireless or VoIP technologies may be considered higher than it appears as it is measured on % population basis.



(a) Multi-mode Competition

(b) Zoom-in

Figure 1: From Single to Multi-mode Competition in Technology[7]

Second, in the modular age, the functional control has migrated from that inside the network core towards the network edges. Table 2 shows how the migration of functionality affects control over the functional components of a single voice call. To be commercially viable, any voice communication service must offer five fundamental functions: setup and terminate the call, transport voice, secure the channel, maintain user's privacy, bill the user. The plethora of other features that a service may offer is not a part of what is minimally necessary. Table 2 shows that in traditional (PSTN) as well as wireless telephony, the control over all five fundamental functions resided in telephone switches and base stations that constituted the network core. By contrast, in Internet-based technologies such as VoIP, particularly peer-to-peer VoIP, the control over four of five fundamental functions has migrated to the network edge. In computer science, the

---

[7] Sources:
PSTN: Statistical Trends in Telephony, 2008, Wireline Competition Bureau, The Federal Communications Commission, http://www.fcc.gov/wcb/iatd/trends.html
Wireless: Commercial Mobile Radio Services (CMRS) Competition Reports, 1995-2008,Wireless Telecommunications Bureau, The Federal Communications Commission, http://wireless.fcc.gov/index.htm?job=cmrs_reports
VoIP: eMarketer estimates, obtained via MIT library access to InfoTech Trends (http://infotechtrends.com/login.htm)

reason for such a movement of functionality to network edges can be traced back to the end-to-end principle (Saltzer, Reed et al. 1984).

Technology	Functions of a Typical Voice Call				
	Setup and terminate the call	**Transport voice**	**Secure the channel**	**Maintain user's privacy**	**Bill the user**
PSTN (Traditional)	In the Network Core	In the Network Core	In the Network Core	In the Network Core	In the Network Core
Wireless Telephony	In the Network Core	In the Network Core	In the Network Core	In the Network Core	In the Network Core
VoIP (Internet-based)	**At the Network Edge**	**At the Network Edge**	**At the Network Edge**	**At the Network Edge**	In the Network Core

Table 2: Functional Control From Inside the Network Core to Its Edges

2.1.2 Industry Structure and Corporate Strategy Dynamics

The modular forces dramatically alter the dynamics of industry structure and corporate strategy. The industry structure for both PSTN and wireless telephony was integrated. By contrast, the industry structure for the multi-mode competition is highly modular. Figure 2 contrasts the integrated ownership of the PSTN value chain with the fragmented the ownership of the multi-mode technology value chain. It shows that the PSTN value chain was owned and controlled by a vertically integrated operator, whereas each link of in the multi-mode value chain is provisioned by different set of firms.

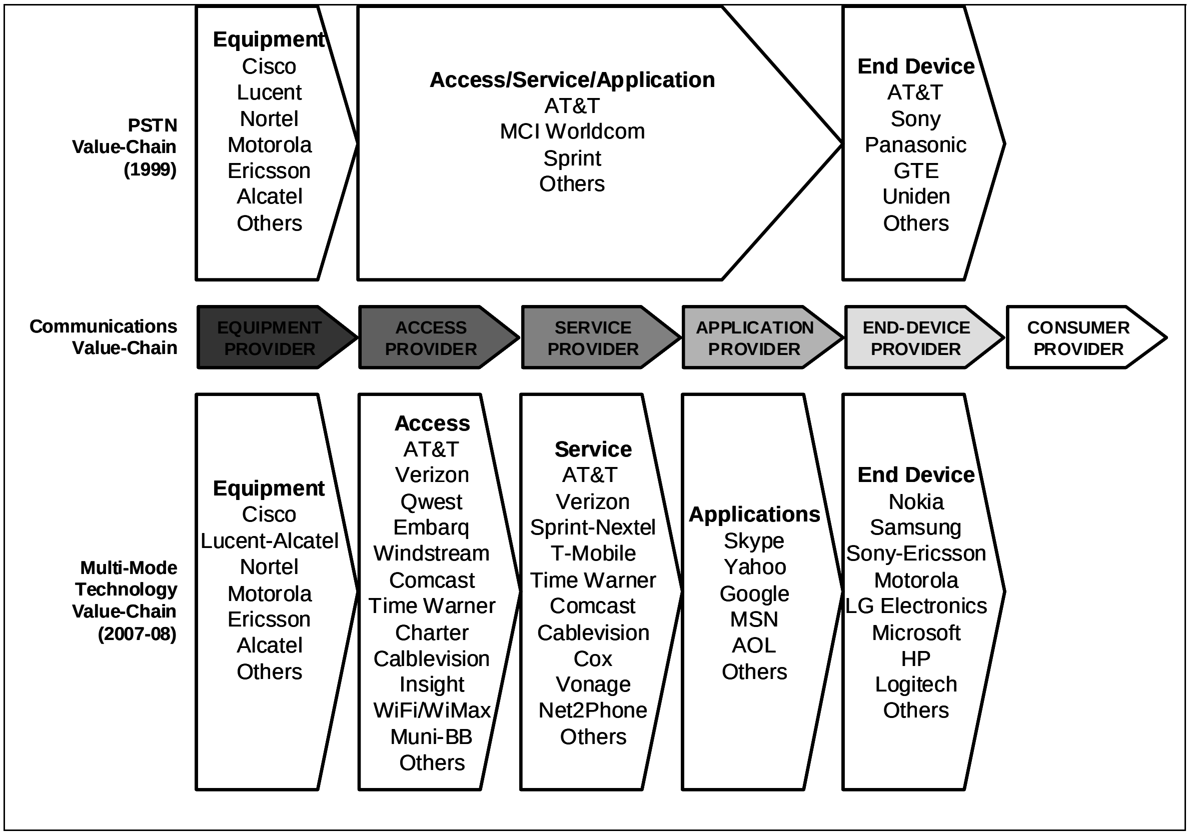


Figure 2: From Integrate to Modular Industry Structure[8]

The corporate strategy dynamics also change in several ways. First, the modular age has induced far higher competition than before from several perspectives. From a service perspective, before the 1990s, the competition was mainly *within* a technology (i.e. between the different PSTN providers), but now it is also inter-modal (i.e. *across* the PSTN, wireless, and VoIP providers). According to the 2007 National Health Interview Survey ("NHIS"), 14.5 percent of adults, or one out of every 7 (or 18% of households with phone service), lived in households with only wireless phones in the second half of 2007, up from 11.8 percent in 2006, 7.8 percent in the second half of 2005, and more than quadruple the percentage (3.5 percent) in the second half of 2003(Wireless Competition Bureau 2009). From a value chain perspective, the competition was contained *within* each

[8] Sources:
PSTN Value Chain:
Graham-Hackett, M. (1999). Industry Surveys: Computers-Networking, Standards & Poor's.
, Wohl, P. (1999). Industry Surveys: Telecommunications-Wireline, Standards & Poor's.

Multi-mode Technology Value Chain:
Bensinger, A. (2008). Industry Surveys: Communications Equipment, Standards & Poor's.
, Kessler, S. and K. Kawagauchi (2008). Industry Surveys: Computers-Consumer Services & the Internet, Standards & Poor's.
, Rosenbluth, T. (2008). Industry Surveys: Telecommunications-Wireline, Standards & Poor's.
, Rosenbluth, T. and K. Kawagauchi (2008). Industry Surveys: Telecommunications-Wireless, Standards & Poor's.

link (e.g., an equipment provider competed with other equipment providers, a service provider with other service providers, and a device provider with other device providers), but now it is *among* the different links of the value chain (e.g., the service providers and application or device providers are competing for territory, or the service and access providers are in a fierce competition, and so on). Recently released data shows how peer-to-peer traffic generated by the web-based applications are changing the competitive landscape for the access and service providers (Pouwelse, Garbacki et al. 2008)

Next, with higher competition, corporations are under far greater pressure to adopt innovation than before. Before the breakup of AT&T, its research arm, Bell Laboratory, made breakthrough inventions but did not have the competitive pressure to adopt them. For example, in networking-related research alone, Bell Laboratory invented data networking in as early as the late 1940s, but became serious about its adoption only when they carried out the first trial of the digital subscriber lines (DSL) in the 1980s. Similarly, they proposed the cellular network in 1947, but it installed the first cellular network in Chicago in the 1970s[9]. By contrast, today the pressure to adopt innovation has altered the character of corporate research altogether. The corporate research labs today have a research agenda that is shorter term, and increasingly aligned with the bottom line on the corporation's balance sheet.[10]

Finally, the modular age induces higher clockspeed; in other words, the time available to make critical business decisions is shorter. We know that clockspeed may be measured along product, process, and organizational dimensions, but measuring it is complex (Fine 1998). Unfortunately, the US government's data collection does not gather any data directly pertinent to clockspeed. Hence, disparate observations must be combined to understand why the clockspeed of the communications value chain has increased. To begin with, research on measuring industry clockspeed has shown that the telecommunications equipment industry has a slower clockspeed than the personal computers and consumer electronics industries ((Mendelson and Pillai 1999), figure 1). As the functionality migrates from the network core to its edges and processor speeds increase due to Moore's law, the architecture of the telecommunications equipment increasingly resembles that of personal computers. With this metamorphosis, the product life cycles in the telecommunications equipment industry are shortening over time ((Mendelson and Pillai 1999), figure 3), indicating the increased clockspeed of the telecommunications industry. The interview data in Table 3 confirms this increasing clockspeed by showing how the time between two product releases has shrunk for communications equipment. The product release cycle before the Internet was, on an average, 3 years. It has now compressed to less than a year. The time available to make decisions is far shorter today than before.

Before 1990s	Between 1990-2000	During 2000-2008
~ 2.5-3 years	~1-2 years	~6 months-1 year

[9] Constructed from Bell Lab's historical timeline available at, http://www.alcatel-lucent.com/wps/portal/BellLabs/History
[10] Hecht, J. (2007). Bell Labs: Over and Out. New Scientist. (http://www.newscientist.com/article/mg19325895.500-bell-labs-over-and-out.html)

Table 3: From Low to High Clockspeed[11]

2.1.3 Consumer Preference Dynamics

The modular age radically changes the dynamics of consumer preference. First, the consumers enjoy a far greater choice today than before. Figure 3 shows how the consumer choice has changed from year 2000 to year 2007 in each mode of technology. It shows that more than 85% of the US population today enjoys a choice of three or more providers of PSTN, wireless communications, and Internet broadband service, each. Second, it is much easier for the consumer to introduce innovations. The best example of this change is the burgeoning array of open source freeware (**ref?**).

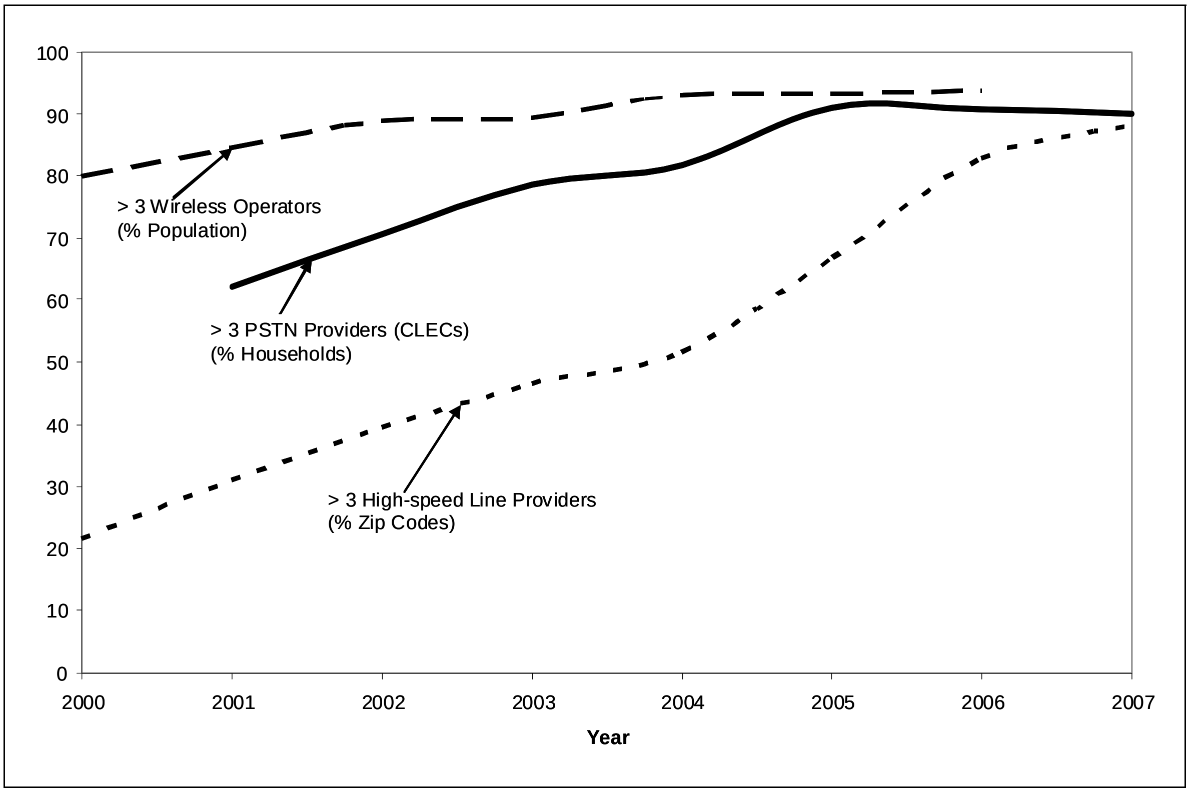


Figure 3: From Low to High Consumer Choice[12]

---

[11] As the data for measuring clockspeed is not officially recorded, the information in this table is produced with unstructured interviews with major telecommunication equipment vendors who participate in the Communications Futures Program (http://cfp.mit.edu) at MIT.

[12] Sources:
PSTN: Wireline Competition Bureau, F. (2008). Local Telephone Competition: Status as of December 31, 2007, Federal Communications Commission.

Wireless Operators, from reports such as the following between 2000-2006,
Wireless Competition Bureau, F. (2000). Fifth Annual Commercial Mobile Radio Services Competition Report, Federal Communications Commission.
, Wireless Competition Bureau, F. (2006). Eleventh Annual Commercial Mobile Radio Services Competition Report, Federal Communications Commission.

As the Internet becomes more ubiquitous, its hourglass architecture of the Internet, shown in Figure 4, is likely to continue offering consumers even a higher choice. The hourglass is an abstraction illustrating the Internet architecture's ability to accommodate a variety of applications over a variety of network technologies.

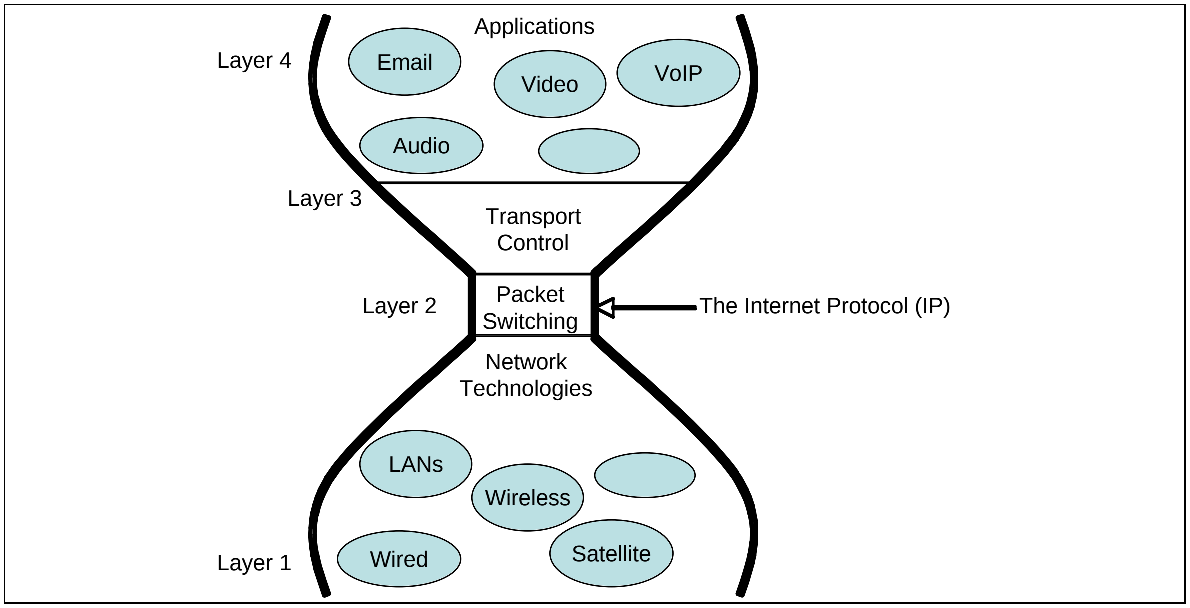


Figure 4: A four-layer model of open data network (adapted from the hourglass on page 122 of Realizing the Information Future: The Internet and Beyond, Copyright 1994, The National Academy of Sciences)

Many of the changes discussed above are discontinuities introduced by breakthrough inventions or landmark decisions. They radically alter the trajectory of change in a sustainable manner. Multi-modal competition is a discontinuity that was introduced by a combination of inventions such as cellular telephony, digital transmission, optical-fiber communication; and it is here to stay as the wireless, broadband technologies mature along side the PSTN. The modular architecture is a discontinuity that was introduced with the decision to breakup AT&T's monopoly in PSTN; and it is here to stay as long as the competitive pressure from multi-modal competition persists. The burgeoning innovation, at the network edge and by corporations and consumers alike, is a discontinuity that was introduced by the advent of packet switching; and it is here to stay as long as the modular, hourglass-like architecture of the Internet survives. What do these discontinuities mean for regulation? To answer this question, we must first understand the theory and practice of regulation in voice communication.

High-speed Internet Lines:
Wireline Competition Bureau, F. (2008). High-Speed Services for Internet Access: Status as of December 31, 2007, Federal Communications Commission.

2.2 Regulation of Voice Communications in the Integrated Age

Voice communications in the United States have a long history of regulation. The Federal Communications Commission (FCC), the US telecommunications regulatory agency, was created by the Communications Act of 1934 to regulate the PSTN. The purpose of this paper is not to review the history. Several excellent accounts detail the chronological development of regulation in voice communications ((Nuechterlein and Weiser 2005), (Kennedy and Pastor 1996)). We are interested in examining those regulations that continue to be important as we enter the modular age.

In 2004, when the FCC invited public comments on how to regulate Internet-Enabled Services such as Voice over Internet Protocol (VoIP), it acknowledged for the first time the serious threat the Internet-based services pose to the existing regulations, and identified a set of economic and social regulation that continue to be of critical importance. We will first outline these regulations using the three-part framework of: *objectives* they serve, *obligations* they impose to fulfill those objectives, and *enforcement mechanisms* they use to enforce those obligations.

Two areas of economic regulation continue to be relevant for the modular age: the rate regulation of the interconnection (access) charges imposed to fulfill the objective of promoting competition (or preventing monopolistic behavior); and the universal service regulation imposed to fulfill the objective of economic development by including high-cost and low-income areas. Three areas of social regulation continues to be relevant for the modular age: emergency calling regulation imposed to facilitate public safety objectives, Communications Assistance for Law Enforcement Act (CALEA) imposed to facilitate law enforcement objectives, and disability access regulation imposed to facilitate equal opportunity objectives. Each area of regulation has a set of obligations that the "telecommunications service"[13] providers must fulfill. Table 4 summarizes the *objectives* and the *obligations* for each regulation.

Regulation	**Objectives**	**Obligations**[14]
Economic Regulation		
Interconnection (Access) Charges	Competition	1. Call-originating company pays per-minute access charges to call-terminating company
Universal Service	Economic Development	1. Long-distance companies must contribute to the USF[15] 2. Companies servicing high-cost, low-income areas receive subsidy from the USF

[13] To mean "the offering of telecommunications for a fee directly to the public, or to such classes of users as to be effectively available to the public, regardless of facilities used." Appendix A provides a brief evolutionary outline of statutory definitions such as this one.

[14] The obligations are presented in a language distilled from the legal statutes. The process of summary and a detailed list of statutes relevant to each area can be found in Chapter 2 of the author's masters thesis, Vaishnav, C. (2005). Voice over Internet Protocol (VoIP): The Dynamics of Technology and Regulation. Technology and Policy Program. Cambridge, Massachusetts Institute of Technology**:** 166.

[15] Universal Service Fund (USF)

Social Regulation		
Emergency Service (911/E911)	Public Safety	1. Telecommunications provider identifies an emergency call and route to appropriate PSAP[16] 2. Telecommunications provider provides call-back information of the caller 3. Telecommunications provider provides location of the caller
Wiretapping (CALEA)	Law Enforcement Capability	1. Telecommunications provider provides call-identifying information such as the source, destination and the duration of a call 2. Telecommunications provider records conversations (lawful intercept) upon court request 3. Telecommunications provider submits recorded information securely, while ensuring user's privacy
Disability Access	Equal Opportunity	1. Equipment manufacturer manufactures accessible telecommunications equipment 2. Telecommunications provider provides text and voice relay service 3. Telecommunications providers must not install network features, functions or capabilities not compliant with disability access requirement

Table 4 Economic and Social Regulation of PSTN

The FCC's primary *enforcement mechanism* so far has been command-and-control. The FCC conducts two types of enforcement proceedings. First, under section 207 of the Communications Act of 1934, anyone aggrieved by a carrier's unlawful conduct may file a complaint and may recover the full damage sustained. Second, the FCC has independent authority to investigate violations of the Act, its regulations, and filed tariffs. Before the Telecommunications Act of 1996, the FCC's complaint procedures were generally invoked by the disgruntled consumers, but post-1996 Act the FCC also entertains complaints about business-to-business conduct. The FCC has the authority to fine violations. For run-of-the-mill violations, its authority is limited, but where a common carrier "repeatedly" and "willfully" violates its legal obligations, the Commission can assess a far higher "forfeiture penalty."[17]

Over time, the enforcement mechanisms, but more likely other factors such as the functional control enjoyed by the integrated firms, have rendered a high order of regulatory compliance in the PSTN. Figure 5 shows the levels of regulatory compliance

[16] Public Service Answering Point (PSAP) coordinating the police, the fire and the medical response.
[17] This summary of FCC's current enforcement mechanisms is borrowed from Nuechterlein, J. E. and P. J. Weiser (2005). Digital crossroads : American telecommunications policy in the Internet age. Cambridge, Mass., MIT Press.

Universal Service, Emergency Calling, and Wiretapping regulation[18]. The figure makes several important points. First, the obligations in each of these areas are being met higher than 95% of the time. Second, in two of the three areas depicted, such high level of compliance has been achieved over several decades. Finally, and unfortunately, the setting of the modular age has begun to erode regulatory compliance just as such high level of compliance was achieved.

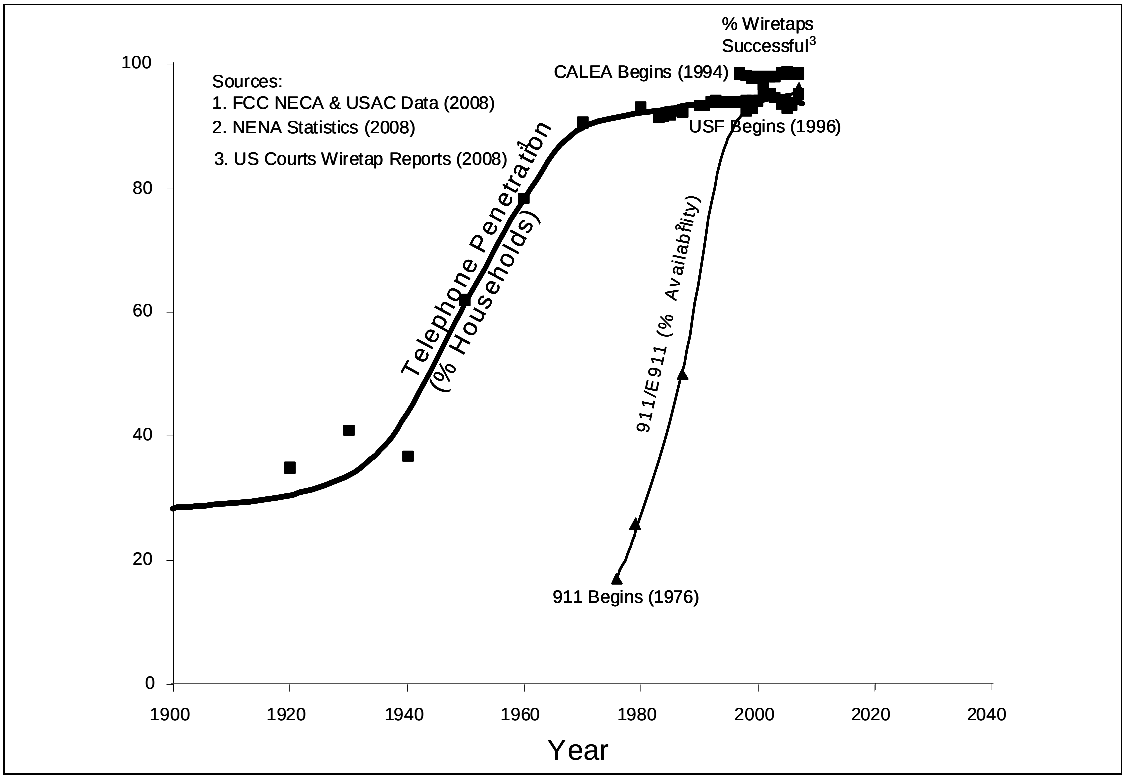


Figure 5: Regulatory Compliance in the Integral Age

2.3 Regulatory Response to the Modular Age

Ever since the IP-Enabled Services NPRM was published in 2004, the regulatory action has demonstrated that the objectives for the five areas of regulation, stated in Table 4, continue to be relevant for the telecommunications system. In the area of economic regulation, the FCC has undertaken what it terms "comprehensive reform" of Intercarrier Compensation, and Universal Service regulation[19]. The FCC has also adopted orders to

[18] The remaining two areas are excluded because, for interconnection charges the percentage compliance is not a meaningful measure; and for disability access the compliance statistics is not available. That said, in both areas, the carriers comply with regulation.

[19] These reform span several FCC dockets: *High-Cost Universal Service Support*, WC Docket No. 05-337; *Federal-State Joint Board on Universal Service*, CC Docket No. 96-45; *Lifeline and Link Up*, WC Docket No. 03-109; *Universal Service Contribution Methodology*, WC Docket No. 06-122; *Numbering Resource Optimization*, CC Docket No. 99-200; *Implementation of the Local Competition Provisions in the Telecommunications Act of 1996*, CC Docket No. 96-98; *Developing a Unified Intercarrier Compensation Regime*, CC Docket No. 01-92; *Intercarrier Compensation for ISP-Bound Traffic*, CC Docket No. 99-68; *IP-Enabled Services*, WC Docket No. 04-36

extend social regulations for emergency calling, CALEA, and disability access regulation.[20] With the increased emphasis on homeland security post-9/11 attacks, the FCC, in response to an FBI petition, has expanded CALEA obligations to Internet, Broadband and VoIP service. It also moved around the same time to include VoIP under 911/E911 regulation (2005).

In each of these proceedings, the central question has been, who should bear the obligations and when. The FCC has responded to the challenge with incremental regulation. Incremental regulation takes place in two ways: *partial regulation*, where the regulatory scope permanently excludes certain types of firms or technologies; or *delayed regulation*, where the regulatory scope temporarily excludes certain types of firms or technologies but includes them later.

The providers of the Internet service (classified by the 1996 Act as "information service"[21]) were left unregulated under the Telecommunications Act of 1996 as information service was considered nascent. Starting with 2004 IP -Enabled Services NPRM, the FCC has begun regulating Internet services, but only incrementally. The FCC has concluded that VoIP services that are categorized as "interconnected" service are subject to CALEA and E911 regulation as telecommunications carriers. The peer-to-peer "unmanaged" service is not regulated.[22] As summarized in Table 5, the FCC considers Phone-to-Phone and PC-to-Phone VoIP as "interconnected" service and regulates them with emergency calling, CALEA, and disability obligations (listed in Table 4); whereas it considers PC-to-PC VoIP as "unmanaged" service, and does not regulate it.

Wireless telephony has similarly faced incremental regulation. In this case, the FCC grafted social regulations such as emergency calling (known as, wireless E-911) on to a service that was already mature. The wireless telephony was already available to more than 50% of the US population when the petition for wireless E-911 was made in

---

[20] Report and Order: E911 Requirement for IP-Enabled Service Providers. WC Docket No. **05-196,** Second Report and Order and Memorandum Opinion and Order: Communications Assistence for Law Enforcement Act and Broadband Access and Services. FCC No. **06-56,** Report and Order: Disability Requirement for IP-Enabled Service Providers. WC Docket No. **07-110**

[21] To mean "the offering of a capability for generating, acquiring, storing, transforming, processing, retrieving, utilizing, or making available information via telecommunications, and includes electronic publishing, but does not include any use of any such capability for the management, control, or operation of a telecommunications network or the management of a telecommunications service."

[22] In the exact language of the order, "Law Enforcement describes interconnected or mediated VoIP services as those services that offer voice communications calling capability whereby the VoIP provider acts as a mediator to manage the communication between its end points and to provide call set up, connection, termination, and party identification features, often generating or modifying dialing, signaling, switching, addressing or routing functions for the user. Law Enforcement distinguishes interconnected communications from "unmanaged" or "peer-to-peer" communications, which involve disintermediated communications that are set up and managed by the end user via its customer premises equipment or personal computer. In these unmanaged, or disintermediated, communications, the VoIP provider has minimal or no involvement in the flow of packets during the communication, serving instead primarily as a directory that provides users' Internet web addresses to facilitate peer-to-peer communications."

the year 2000 (see Figure 1).[23] The full compliance is expected only by 2012, assuming no schedule overruns.

Typically, the regulator cites the underlying uncertainty surrounding the impact of regulation on competition, and vice versa, to justify incremental regulation. By partial regulation, they intend to improve the regulatory efficiency in meeting a mandated regulatory compliance, since firms or technologies that are difficult to regulate are not regulated. And by delayed regulation, they intend to achieve higher competition, as nascent and innovative technologies are initially left unregulated.

Mode	Service Example	Regulatory Classified	Current Regulation
Phone-to-Phone	VoCable, VoDSL, Vonage, 8x8	"interconnected" service (i.e., PSTN interconnection)	**Regulated** with emergency calling, CALEA, and disability obligations
PC-to-Phone	SkypeOut,Net2Phone	"interconnected" service	
PC-to-PC	Skype, Yahoo, IM, Google Chat	"unmanaged" service (i.e., no PSTN interconnection)	**Not regulated**

Table 5 Modes of VoIP and the Current Regulatory Terms

The enforcement mechanism for the modular age continues to be command-and-control. For areas of regulation where the FCC has adopted regulatory orders, it provides the regulated services a "safe harbor" period after which they must file a letter or form to indicate their level of compliance. For example, in the case of emergency calling, the FCC required interconnected VoIP providers to file a letter detailing compliance in 120 days of adopting the order[24]. This period was 90 days in the case of CALEA order.[25] In "comprehensive reform" of interconnection charges and universal services, the FCC proposes to continue the practice of requiring the regulated parties to file periodic reports. The FCC does recognize that the there will need to be coordination among the different parties in the value chain to deliver regulatory compliance. For example, in the case of E911, it recognizes that, "the deployment of E9-1-1 requires the development of new technologies and upgrades to local 9-1-1 PSAPs, as well as coordination among public safety agencies, wireless carriers, technology vendors, equipment manufacturers, and local wireline carriers."[26] However, it does not initiate any specific actions for the coordination.

[23] http://www.fcc.gov/Bureaus/Wireless/News_Releases/1999/nrwl9016.html
[24] Commission Requires Interconnected VoIP Providers to Provide Enhanced 911 Service, 05/19/2005, http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-258818A1.pdf
[25] FCC Adopts Order to Enable Law Enforcement to Access Certain Broadband and VoIP Providers, 05/03/2006, http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-265221A1.pdf
[26] http://www.fcc.gov/pshs/services/911-services/enhanced911/Welcome.html

Regulatory Aspect	Response to the Modular Age
Objectives	Remains relevant for the telecommunications system
Obligations	Extended to new technologies using incremental regulation
Enforcement Mechanisms	Continues to be command-and-control

Table 6: Incremental Regulation of the Entrants

Table 6 summarizes the regulatory response to the modular age. The FCC's response indicates that the objectives remain relevant for the telecommunications system to fulfill, the obligations are being incrementally extended to new technologies, and the enforcement mechanisms continue to be command-and-control. Is such a regulatory response appropriate for the modular age? To answer this question, we now use a case research and two dynamic models.

2.4 Research Method

This research uses the systems approach to evaluate whether the current objectives, obligations, and enforcement mechanisms would work in the modular age. The following five principles of systems are deployed through this research: synthesis, hierarchy, emergent behavior, feedback, and statistical and strategic behavior. Each principle will be introduced in the appropriate place.

At the highest level, what differentiates the systems approach from others is its use of synthesis for the inquiry. Synthesis can be defined as a three-step process ((Ackoff 1999), p.17):

1. Identifying a containing whole (system) of which the thing to be explained is a part,
2. Explaining the behavior or properties of the containing whole,
3. Then explaining the behavior or properties of the thing to be explained in terms of its role(s) or function(s) within its containing whole[27].

Such an exercise shows that the social system (the society) is containing whole (the system) whose objectives the telecommunications system fulfills. Therefore, the appropriateness of the objectives, obligations, and enforcement mechanisms of telecommunications regulation must be evaluated from the perspective of how well they fulfill the societal objectives. Figure 6 illustrates a hierarchical decomposition of such a system of systems.

Such hierarchical decomposition is founded upon the argument that complex systems are hierarchic ((Simon 1981), Chapter 8). Simon defined a hierarchic system, or

[27] Synthesis reverses the three-step order of analysis, which is: (1) decomposition of that which is to be explained, (2) explanation of the behavior or properties of the parts taken separately, and (3) aggregating these explanations into an explanation of the whole.

hierarchy, to mean "a system that is composed of interrelated subsystems, each of the latter being in turn hierarchic in structure until we reach some lowest level of elementary system." Two caveats to this definition, also offered by Simon, are important to consider. First, it is somewhat arbitrary as to where we leave off the partitioning and what subsystems we take as elementary. Second, not all systems adhere to the rules of a strict hierarchy. In a strict hierarchy, "each of the subsystems is subordinated by an authority relation to the system it belongs to." By contrast, in the system of interest to this research, the relationships may be more complex, ranging from no relationship among subsystems to more than just the strict hierarchic relationship.

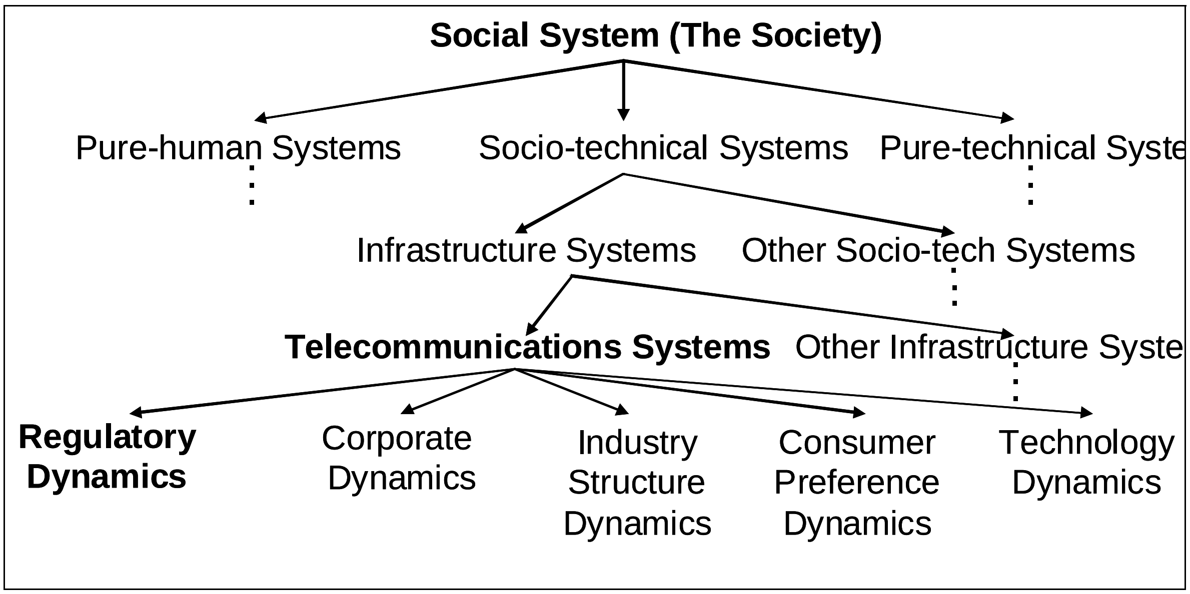


Figure 6: A Hierarchical Decomposition of the Telecommunications System

The hierarchical decomposition demonstrates two important observations. First, the telecommunications system is one of the many infrastructure systems that contribute to achieving the social objectives. The infrastructure systems themselves fall into the class of socio-technical systems, meaning systems where the complexity arises due to the interaction of technical and human factors (Magee and de Weck 2004). Second, the behavior of the telecommunication system itself emerges as a result of not just the regulatory dynamics, but the interaction of regulatory-, corporate strategy-, industry structure-, consumer preference-, and technology dynamics.

With this understanding as a backdrop, we will now describe the research method, consisting of one case research and two dynamic models, designed to answer the question of interest: Can the regulation designed in an integral age—in its objectives, obligations, and enforcement mechanisms—work for a modular age?

2.5 Case Research: An Analysis of Pre. vs. Post-Internet Regulatory Environments

So far, we have shown that radical changes defining the transition from the integral to modular are indeed taking place. We have also discussed that the regulatory response to this radical shift has been incremental. But do the modular forces reflect themselves in regulatory matters? This is the question that motivates the analysis of pre vs. post-Internet regulatory environments in this case research. The answer will validate our implicit assumption that the regulator must respond to the shift to modular age.

2.5.1 Case Selection and Setup[28]

For the analysis, public comments against the Telecommunications Act of 1996 NPRM[29] are compared with those against the IP-Enabled Services NPRM published in 2004. These two FCC dockets form a natural experiment; the 1996 Act centers solely on the public switched telephone networks (PSTN) and mentions the term "Internet" just once, whereas the IP-Enabled Services NPRM centers on the Internet and is the first document to acknowledge the serious threat the Internet-based services pose to the existing regulations.

Pre-Internet Environment Case (The 1996 Telecom Act NPRM)	Post-Internet Environment Case (The IP-Enabled Services NPRM)
FCC Docket: 96-98 **Released:** 05/23/1996 **Period Analyzed:** 05/1996 – 03/2009 **Total Public Comments:** 10763 **Total Comments Analyzed:** 6626 (randomly selected) **Each Comment Coded with Commenter's:** Value Chain Position (*Categories:* Equipment, Access, Service, Application, Device, Consumer), Stakeholder Type (*Categories:* Corporation, Interest Group,	**FCC Docket:** 04-36 **Released:** 04/06/2004 **Period Analyzed:** 06/2004 – 03/2009 **Total Public Comments:** 2053 **Total Comments Analyzed:** 2053 **Each Comment Coded with Commenter's:** Value Chain Position (*Categories:* Equipment, Access, Service, Application, Device, Consumer), Stakeholder Type (*Categories:* Corporation, Interest Group,

[28] To harvest thousands of public comments from FCC's electronic document management system, EDOCS (http://hraunfoss.fcc.gov/edocs_public/), a software was developed using web-programming languages (XHTML, XML and XPath) and Perl scripting. An Excel database was then used for further analysis. I sincerely thank Jesse Sowell for the architecture and programming of the first version of the software. Those trying to replicate this feat should know that currently the FCC does not have the ability to compile all comments against a docket and issue it on a physical medium such as a CD, so comments have to be downloaded individually. Also, while EDOCS reduces much work with its ability to tabulate all comments in response to a given document, their tabulation of comments has many peculiarities as some records in the comments database are manually edited and have additional fields, which necessitates that the web programs be tailored to such peculiarities (a truly laborious undertaking).

[29] Precisely, the Implementation of the Local Competition Provisions in the Telecommunications Act of 1996 Notice for Proposed Rulemaking

Independent, State Regulator, Federal Regulator) , Technology Type (*Categories:* PSTN, Internet, Cable, Wireless, Satellite, Utility, Any)	Independent, State Regulator, Federal Regulator) , Technology Type (*Categories:* PSTN, Internet, Cable, Wireless, Satellite, Utility, Any)

Table 7: Content Analysis Setup to Study Pre vs. Post-Internet Regulatory Environments

In the first phase of analysis, we perform *content analysis* on the two NPRMs as detailed in Table 7. The content analysis reveals who the stakeholders are (i.e., Corporation, Interest Group, Independent, State Regulator, or Federal Regulator), which technologies (i.e., PSTN, Internet, Cable, Wireless, Satellite, Utility, or Any[30]), and which value chain position they represent (i.e., Equipment-, Access-, Service-, Application-, Device Provider, or Consumer). The comparative analysis is intended to reveal how the stakeholder interest changes from 1996 to 2004, the two NPRMs representative of integral and modular age, respectively.

The second phase of analysis, we perform *conceptual analysis* on a sample of comments from the two NPRMs as detailed in Table 8. The conceptual analysis reveals the position of a stakeholder on the central issue of the respective NPRM. For the 1996 Telecom Act NPRM, the stakeholders took a position the central issue of: whether or not to unbundle the local loops. For the 2004 IP-Enabled Services NPRM, they took a position on the central issue of: whether or not to regulate VoIP. In both cases, a sample of 400 comments is taken to keep the error under 5%. [31]

Pre-Internet Environment Case (The 1996 Telecom Act NPRM)	**Post-Internet Environment Case (The IP-Enabled Services NPRM)**
FCC Docket: 96-98 **Sampling Technique:** Stratified Sampling **Total Public Comments:** 10763 **Population:** 6626 (comments analyzed for content analysis) Equipment Providers: 195 (2.94%) Access Providers: 1860 (28.07%) Service Providers: 3501 (52.84%) Application Providers: 165 (2.94%)	**FCC Docket:** 04-36 **Sampling Technique:** Conceptual Analysis **Total Public Comments:** 2053 **Population:** 2053 (comments analyzed for content analysis) **Existing Concepts Searched For:** Forbear(ance), Ancillary (Jurisdiction) **Conceptual Sample:**

[30] "Any" is used when the commenter takes a position in their comment that is agnostic to technology.

[31] Having decided that we are willing to tolerate 5% error in estimating the population parameters, the sample size of 400 is determined as follows. Assume that the set of all comments represents a binary population where each commenter takes a position for unbundling (or VoIP regulation) with probability p, and conversely against it with probability q. Further, lets assume that the population is equally divided on the issue ($p = q = 0.5$), then the minimum sample size necessary keep the error under 5% must be:

$$n = pq(\frac{Z_c}{E})^2 = (0.5)(0.5)(\frac{1.96}{0.05})^2 = 384$$

Where, z_c is the critical standard normal deviate for 95% confidence interval, and E is the error Kachigan, S. K. (1986). Statistical analysis : an interdisciplinary introduction to univariate & multivariate methods. New York, Radius Press.

.

Device Providers: 47 (0.71%) Consumers: 858 (12.95%) **Stratified Sample:** Total Comments: 400 Equipment Providers: 12 (2.94%) Access Providers: 112 (28.07%) Service Providers: 211 (52.84%) Application Providers: 10 (2.94%) Device Providers: 3 (0.71%) Consumers: 52 (12.95%)[32] **Each Comment Coded for Commenter's Position:** For Unbundling, Against Unbundling	Total Comments: 404 **Each Comment Coded for Commenter's Position:** VoIP Regulation, No VoIP Regulation

Table 8: Conceptual Analysis Setup to Study Pre vs. Post-Internet Regulatory Environments

A different statistical sampling technique is used for each NPRM to draw the most representative sample. For the 1996 NPRM, a *stratified sample* is taken based upon the proportion of comments from each link in the value chain in the parent population. Stratified sample provides the best estimate of the stakeholder position across the value chain in the population. The sampled comments are then read to deduce the commenter's position on the issue of unbundling.

For the 2004 NPRM, the stratified sampling is not the best technique to use because the NPRM covers five areas of regulation (reviewed in Table 4), and comments often focus narrowly on one or more of issues, whereas our interest is in the meta-question: whether or not to regulate VoIP. Therefore, here we *sample on the basis of two existing concepts*—forbearance and ancillary jurisdiction—defined by the FCC that directly speak to this meta-question.[33] "Forbearance" refers to FCC's ability to forbear from applying Title II (or common carrier) obligation to VoIP. Whereas "Ancillary Jurisdiction" refers to FCC's ability to apply ancillary regulation to VoIP despite its classification as Title I ("information service"). We first look for comments that use the terms "forbear" and "ancillary" to find that 404 of the 2053 comments use these terms. We then read the comments to see the commenter's position on VoIP regulation.

2.6 Two Models to Assess Regulation in the Modular Age

How must the regulator respond to the modular age? This is the question that motivates the two models presented in this section. The first model (Regulatory Compliance Model) examines the behavior of system-level regulatory compliance as the modular technology and industry disrupts the integrated. The second model (Competition in

[32] These proportions are

[33] In conceptual analysis, a concept is chosen for examination, and the analysis involves quantifying and tallying its presence Krippendorff, K. (1980). Content analysis : an introduction to its methodology. Beverly Hills, Sage Publications.

The focus here is on looking at the occurrence of selected terms within a text or texts, although the terms may be implicit as well as explicit.

Telecommunications Model) examines the behavior of competition as a function of the various forces, including regulation. To start with, both models are kept minimally endogenous. They will be made fully endogenous in Chapter 3, which leads a more in-depth discussion of the uncertainty. The complete model is documented in Appendix B.

The models use coupled-differential equations with feedback. In a simple definition, "feedback is a closed path connecting in sequence the parts of a system in interaction." (Wiener 1948) The existence of feedback, directly or otherwise, has been in human consciousness for a long time (Richardson 1991)[34]. But feedback got recognized as a major organizing principle for systems when Norbert Weiner considered Cybernetics to include: "systems with dynamics in which circular process of a feedback nature played an important part."[35] With Weiner's work, systems thinkers recognized that feedback and its dynamics were isomorphic across a variety of system—technical, human, or socio-technical—but a sustained contribution to using feedback across social sciences came from Jay Forrester and his students (Hughes 2000). Forrester asserted, such "feedback processes govern all growth, fluctuation, and decay…[They] are the organizing structure around which system dynamic models are constructed." (Forrester 1999)

There are two classes of feedback. "One class of feedback system – balancing (negative) feedback – seeks a goal and responds as a consequence of failing to achieve the goal." In balancing structures a change is countered, so either a growth or a decline is countered. "A second class of feedback system – reinforcing (positive) feedback – generates growth processes where in action builds a result that generates still greater action." (Forrester 1971)In reinforcing structures a change is amplified, so a growth leads to further growth and a decline to further decline. Both types of feedback are present in the two models presented below.

2.6.1 Regulatory Compliance Model

Modeled here is a competition between two firms – an incumbent and an entrant. Each firm is assumed to represent a typical firm in their industry. So the incumbent is vertically integrated in technology architecture and the ownership; whereas the entrant is modular in both. Using a single firm to represent the industry does challenge us cognitively, since we must imagine the single firm to represent a cluster of firms when the industry is modular. But such a conceptual leap is worthwhile for several reasons. First, because using a single firm excludes from the model the dynamics of competition *among* modular firms, thereby greatly extending our ability to closely understand the competition *between* a modular and an integrated industry. Second, including the dynamics of multiple modular firms does not alter or enrich the insights for the issues we are interested in.

[34] Richardson in his work *Feedback Thought in Social Science and Systems Theory* traces great many theories to demonstrate that many eminent scientists dating back to ancient Greece were feedback thinkers and great many social theories are essentially feedback thoughts.
[35] Interestingly, Wiener's Cybernetics often gets confused with feedback control. In reality, his text goes in to many other areas related to control and communication.

In these models (and throughout this research), several properties, such as regulatory compliance and competition, are conceived as emergent behaviors of the system. The modern definition of *emergent behavior* reads as “behaviors of a system that are discovered (i.e., properties that were there but latent), those that emerge spontaneously over time or space, and those that arise in response to behavior of other systems and environments.” ((ESD) 2004)

2.6.1.1 Formulations

Regulatory Compliance

The regulatory compliance, referred to as *Actual Compliance*, Z_i, represents the number of consumers of the firm *i* who currently use a service compliant with regulation. The Actual Compliance for a firm grows it as develops and deploys compliance mechanisms, and falls if the firm’s compliance mechanism becomes obsolete as the technology or the regulatory requirements change. Compliance mechanisms themselves may involve developing and deploying technology or other processes such as contracts, protocols, etc.

Equation 1: Actual Compliance

$$\frac{d\boldsymbol{Z_i}}{d\boldsymbol{t}} = \boldsymbol{X_i} - \boldsymbol{Y_i}$$

Where $i = 1$ (incumbent), 2 (entrant)

Where X_i is the *Compliance Mechanism Deployment* and Y_i is the *Compliance Mechanism Obsolescence*. And *i* can assume values 1 (for the incumbent) or 2 (for the entrant).

Required Compliance

The compliance mechanisms are developed and deployed in order to fill a gap between the *Required Compliance*, Z_i^*, as required by the regulator, and the Actual Compliance. The “gap” could be positive when, for instance, a technology gets burdened with new regulation, but it can also be negative if the technology is deregulated. Figure 5 showed how such a process of closing the gap between the required and actual compliance levels occurred for universal service, public safety, and law enforcement regulations. For example, in the case of universal service the required compliance level is to make telephone service available to all (100%) households, and actual compliance has been at 90% or higher since 1970. Structurally, this process of closing the compliance gap is a balancing feedback structure.

Equation 2: Required Compliance

$$X_i = \frac{(Z_i^* - Z_i)}{\tau_i^x} * POP, \quad Z_i^* > Z_i$$

$$Y_i = \frac{(Z_i^* - Z_i)}{\tau_i^y} * POP \ , \quad Z_i^* < Z_i$$

POP is the Potential Market, the meaning of which changes depending upon the regulation in question. For universal service, for instance, *POP* may be in number of households, but for emergency calling it may be in the total population. τ^x is the *Time to Comply*, or the time it takes to meet the required compliance level, and τ^y is the *Time to Obsolescence*, or the time taken for the loss of compliance. One might imagine that τ^x may be far greater than τ^y. Such a formulation allows us to more generally think about compliance and obsolescence as dynamically changing properties of a regulated system regardless of the exact regulation being fulfilled.

Required vs. Achievable Compliance

In the integral age, it was possible for the industry to achieve the required level of compliance, as only a few operators controlled the industry, and each operator was vertically integrated and individually controlled the total functionality necessary to deliver a service. In the modular age, it is questionable whether industry as a whole can achieve the required level of compliance. The central reason for the lower achievable compliance in the modular age is the changing nature of consensus among the stakeholders, which we will explore further in the Results section below.

Hence, the formulation for *Compliance Mechanism Deployment* and *Compliance Mechanism Obsolescence* (Equation 2) must include *Achievable Compliance*, Z'_i.

Equation 3: Required and Achievable Compliance

$$X_i = \frac{[MIN\ (Z_i^*, Z_i') - Z_i]}{\tau_i^x} * POP, \quad Z_i^* > Z_i$$

$$Y_i = \frac{[MIN\ (Z_i^*, Z_i') - Z_i]}{\tau_i^y} * POP \ , \quad Z_i^* < Z_i$$

In the integrated industry the required compliance is achievable ($Z_i^* = Z_i'$). By contrast, in the modular industry the required compliance may not be achieved ($Z_i' \leq Z_i^*$).

Average Utilized Compliance

As modular industry competes with the integrated industry, the regulatory compliance an average consumer experiences, *Average Utilized Compliance*, Θ, is an emergent behavior that is mediated by several factors. First, the two industries may be regulated differently (different required compliance). Next, they may have different achievable compliance. Finally, they may have different *Market Shares*, S_i. Hence, Average Utilized Compliance is the market share weighted sum of the Actual Compliance.

Equation 4: Average Utilized Compliance

$$\Theta = \sum_i Z_i * S_i$$

2.6.2 Competition in Telecommunications Model

Adoption

The adoption of communication services occur as the population goes from being Potential Market, *POP*, to *Potential Adopters*, *O*, to be divided into *Adopters* of each firm, N_i. The number of people who will eventually choose to use communication service, N^*, is the equilibrium demand and is a function of the minimum price available, P^{min} (Sterman 2000).

Equation 5: Market Size

$$N^* = MIN\ (POP, POP^r * MAX\left(0, 1 + \frac{\sigma(P^{min} - P^r)}{POP^r}\right)) \ ,$$

Where σ is the slope of the demand curve, P^{min} is the lowest price available in the market, and P^r is the reference price which N^* becomes the reference population POP^r. For the ease of calibration demand curve slope is calculated from the elasticity of demand, ε_d, at the reference point (POP^r, P^r).

Equation 6: Slope of the Demand Curve

$$\sigma = -\varepsilon_d \left(\frac{POP^r}{P^r}\right)$$

The number of potential adopters, *O*, is the difference between the number of people who will ever adapt, N^*, and those who have currently adopted.

Equation 7: Potential Adopters

$$O = N^* - \sum_i N_i$$

The number of adopters each firm has, N_i, at any time results from a balance of three decisions by consumers – *Adoption*, D_i, into the market; *Exit*, E_i, from the market; or *Switching*, F_i, to other service.

Equation 8: Adopters

$$N_i = D_i - (E_i + F_i)$$

Each adopter is assumed to purchases only one service. Cognitively, this assumption may contradict the consumer behavior in the communications market, where each consumer often purchases both the PSTN as well as the Internet service. In that sense, the resulting market shares for the two firms ought to be understood as fraction of communication each consumer does using one or the other service.

The adoption occurs according to the standard Bass diffusion model (Norton and Bass; Bass, Krishnan et al. 1994), modified to include initial adoption and adoption from switching.

Equation 9: Adoption

$$D_i = O_i\left(\alpha + \frac{\beta N_i}{POP}\right) + S_i^A \sum_i S_i, \qquad \text{When } O_i > 0$$

The first term of Equation 9 represents the initial adoption. The initial adoption takes place due to the impact of external influences represented as *Advertising*, and the *Word of Mouth* (WOM) that depends upon the sociability of the population. Here, α captures the strength of external influences such as advertising, and β is the strength of social factors such as WOM. The second term of Equation 9 captures adoption due to switching. The firm's *Market Share of Product Attractiveness*, S_i^A, determines how many of the total consumers who decide to switch ($\sum S_i$) at a given time would adopt firm *i*'s service.

Adopters select from incumbent's or entrant's product based on their *Product Attractiveness*, A_i. The product attractiveness is a function of four attributes of each service: the installed base of adopters, N_i; *Price*, P_i; *Quality* (*Primary Performance*), Q_i; and *Innovation* (*Ancillary Performance*), I_i. The consumer choice is formulated using a standard logit choice model ((Sterman, Henderson et al. 2007), (Wooldridge 2006)).

Equation 10: Market Share of Product Attractiveness

$$S_i^A = A_i \Big/ \sum_j A_j$$

Equation 11: Product Attractiveness

$$A_i = \exp\left(\varepsilon_n \frac{N_i}{N^r}\right)\exp\left(-\varepsilon_p \frac{P_i}{P^r}\right)\exp\left(\varepsilon_q \frac{Q_i}{Q^r}\right)\exp\left(\varepsilon_i \frac{I_i}{I^r}\right)$$

Where, ε_n, ε_p, ε_q, and ε_i are the sensitivities of attractiveness to the installed base, price, quality, and innovation, respectively. Notice that the increase in price reduces the attractiveness of service, while the increase in other attributes increases product attractiveness. Also, N^r, P^r, Q^r, and I^r are the reference values which ensure that when the value of the attribute goes below (in the case of price), or goes above (in the case of other attributes) the reference value, the attribute begins to affect the product attractiveness more heavily. Also, dividing attributes by their reference values make the sensitivities ε comparable dimensionless quantities.

The term $\exp\,(\varepsilon_n\, N_i/N^r)$ represents direct network effects. Direct network effects are present if "adoption by different consumers is complementary, so that each consumer's adoption payoff, and his incentive to adopt, increases as more others adopt" (Fisher and Massachusetts Institute of Technology. Dept. of Economics. 1990).

Some fraction of consumers may switch to other firm's service based on the switching costs. A product or service "has classic switching costs if a buyer will purchase it repeatedly and will find it costly to switch from one seller to another. Switching costs arise due to the product characteristics or due to contracts" (Fisher and Massachusetts Institute of Technology. Dept. of Economics. 1990).

Equation 12: Switching

$$S_i = (1 - \gamma_i)N_i$$

Where, γ_i captures the switching cost of the service, and its value is negatively correlated with the switching costs, so the higher the firm's switching cost the lower the number of consumers switching away from it.

The Market Share, S_i, of each firm is firm's share of the total adopters.

Equation 13: Market Share

$$S_i = N_i \Big/ \sum_j N_i$$

Finally, adopters exit the market when the price rises. There is inverse relationship between the loss of consumers and the market share of attractiveness. So, the less attractive the service, the more consumers the firm loses when the market shrinks.

Equation 14: Market Exit

$$E_i = O_i\,(1 - S_i^A)\,, \qquad \text{When } O_i < 0$$

Finally, the Price is set equal to the Total Cost, C_i, which is a sum of the Fixed Cost (C_i^f), Marginal Cost (C_i^v), and Compliance Cost (C_i^z). As we are not interested in studying the profits firms make, in this model the profit margin is excluded from the pricing strategy. Hence, the market share is the basis for understanding the competition.

Equation 15: Price

$$P_i = C_i = C_i^f + C_i^v + C_i^z$$

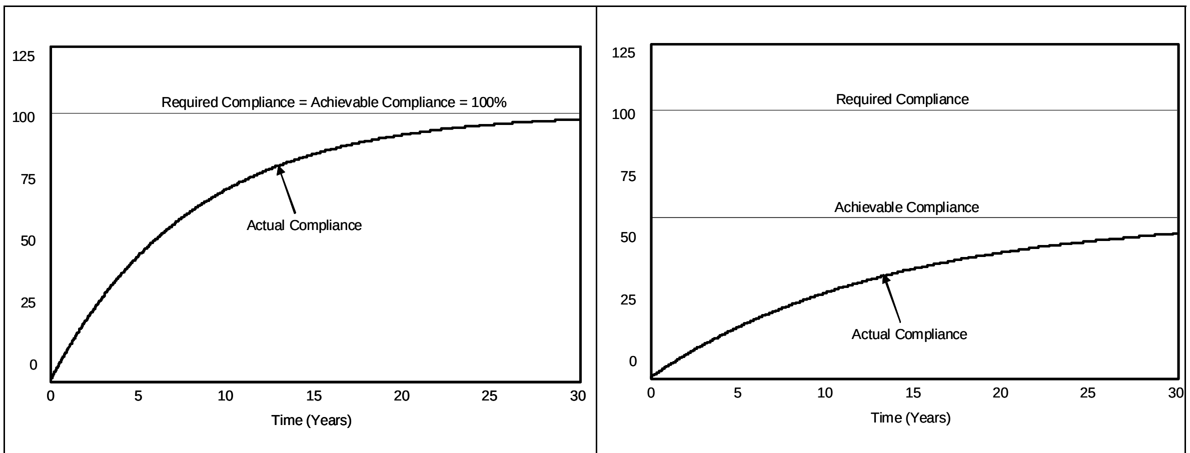
2.7 Results and Discussion

2.7.1 Model Base Behaviors

Regulatory Compliance Model

The Regulatory Compliance Model behaves as expected with respect to the required, achievable, and actual level of compliance. Figure 7 illustrates how deploying compliance mechanisms closes the gap between the actual and the required or achievable compliance. Figure 7(a) illustrates a case when the achievable compliance is equal to that required. By contrast, Figure 7(b) illustrates the case when achievable and required compliance are not equal, in which case the actual compliance rises to the lower of the two levels. The regulator determines the level of compliance required, whereas the level of achievable compliance is determined by several factors that we will discuss through the remainder of this paper (and the thesis).

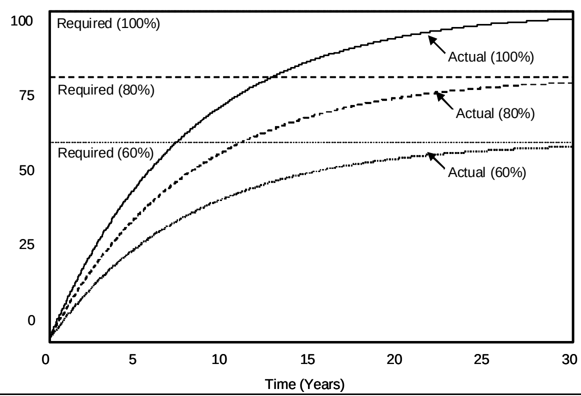
The model is run for 30 years. This duration is based upon the regulatory and competitive timeframes recently experienced. In recent regulation, emergency calling (E911) was introduced in 1976 and has taken approximately 30 years to achieve >90% compliance. Similarly, in recent competition, the wireless technology has taken approximately 30 years to diffuse. The actual compliance is formulated as a first-order exponential smooth, bearing in mind that the lower levels of compliance may be easier to achieve, but achieving higher levels gets increasingly difficult (for example, it is easier to make the denser urban areas compliant before the remote areas). Appendix C provides instructions on all model outputs presented in this thesis.



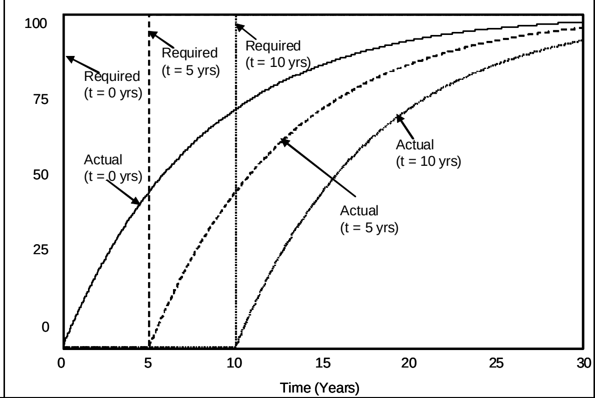
(a) Required Compliance = Achievable Compliance	(b) Achievable Compliance < Required Compliance

Figure 7: Required, Achievable, and Actual Compliance

As regulation may be incremental (i.e., partial, delayed, or both), Figure 8 shows the model behavior under partial or delayed regulation. Figure 8(a) illustrates the behavior of actual regulatory compliance under partial regulation (i.e., when the regulatory scope permanently excludes certain firms or technologies) Figure 8(b) shows the behavior of actual regulatory compliance under delayed regulation (i.e., when the regulatory scope temporarily excludes certain types of firms or technologies but includes them later).



(a) Partial Regulation



(b) Delayed Regulation

Figure 8: Partial or Delayed Regulation

Competition in Telecommunications Model

The Competition in Telecommunications Model also behaves as expected. It allows us to understand the various aspects of competition between the two firms. Figure 9 shows the competitive outcome when the model is set up for the modular entrant to disrupt the integrated incumbent. At time 0, the incumbent owns the entire market. The entrant enters the market at year 5. The model parameters are set such that the disruption occurs over 18 years.

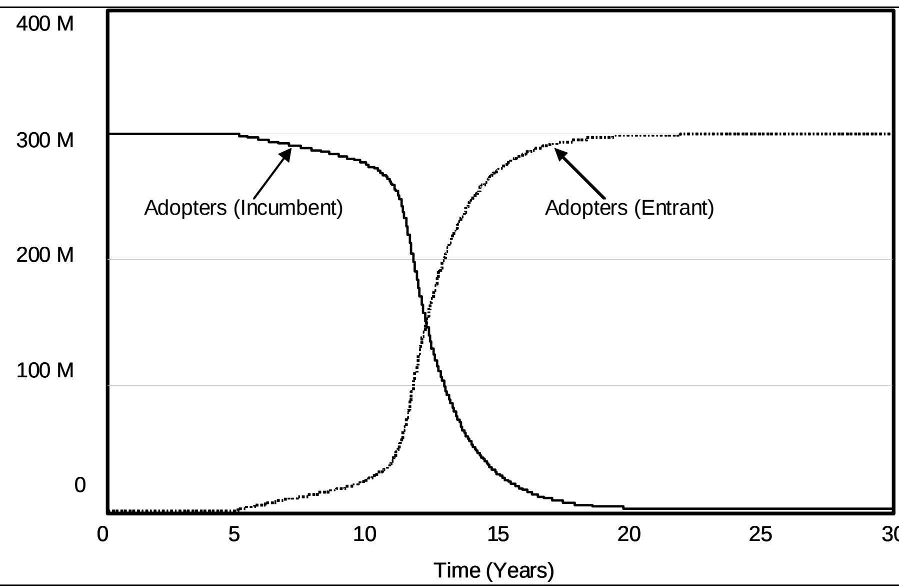


Figure 9: Disruption Base Case - Entrant Disrupts Incumbent

To achieve the base behavior in Figure 9, several attributes of each service (innovation, quality, and price) and the market (switching costs, and network effect) are initialized as follows. It has been identified that in a typical scenario of disruption, the entrant has lower price, lower quality (primary performance), but higher innovation (ancillary performance) as compared to the incumbent (Christensen 1997). The setup mimics these conditions. For the market, a small fraction (5% a month) of consumers is allowed to consider switching away from their current service. Based upon the attractiveness of each service, a consumer considering switching may or may not ultimately switch in a given time period. The network effects are present and affect both services; in other words, services interoperate only minimally, and so they enjoy some level of network effects from their respective installed base. The quality, innovation, and switching costs are exogenous and remain constant through the simulation. Hence, among all factors affecting the adoption, the network effect (installed base) is the only one that introduces nonlinearity.

2.7.2 Regulators Mental Model Focused on Efficiency, Not Objective

Earlier in this paper, we have discussed that FCC's actions subsequent to the 2004 IP-Enabled Services NPRM indicate that the social and economic objectives raised clearly remain relevant. However, qualitative analysis of this NPRM, the regulatory actions so far, and some unstructured interviews indicate that the FCC's present *mental model* is largely focused on the *efficiency* of implementing regulation rather than on understanding or achieving the objectives at the societal level. Moreover, from the organizational point of view, no one at the FCC is responsible for understanding the whole system.

The FCC's present mental model can be deduced from a set of assumptions stated in the 2004 NPRM that undergird much of the regulatory actions for the Internet services. These assumptions can be viewed as a set of constraints within which the desired regulatory outcome must be achieved.

First, the FCC clearly desires to extend the existing statutory framework onto the new technologies, as indicated by the statements like the following that state that the FCC hopes to:

> *"Consider IP-enabled services within a legal framework comprised of statutory provisions and jurisdictional precedent, prior Commission orders, ongoing Commission proceedings and state actions relating to IP-enabled services."*
> *Appropriate Legal and Regulatory Framework section of IP-Enabled Services NPRM*

> *"Find statutory classification that is consistent with the past."*
> *Appropriate Legal and Regulatory Framework section of IP-Enabled Services NPRM*

Second, the FCC clearly desires to regulate IP-Enabled Services narrowly and incrementally (partial or delayed) as necessary, as understood from statements such as the following:

> *"Requirements must be tailored as narrowly as possible, to ensure that it does not draw into its reach more services than necessary."*

Appropriate Legal and Regulatory Framework section of IP-Enabled Services NPRM

"Achieve [narrow regulation] by dividing IP-enabled services into different categories and regulate incrementally as necessary."
Appropriate Legal and Regulatory Framework section of IP-Enabled Services NPRM

"Find appropriate jurisdictional basis or bases and jurisdictional distinctions between the various classes of IP-enabled services."
Appropriate Legal and Regulatory Framework section of IP-Enabled Services NPRM

Much of this thinking focuses on how to design obligations rather than whether they will achieve the objective. As discussed earlier, the FCC has also operationalized this vision through the incremental regulation of IP-Enabled Services for the social objectives such as emergency calling, CALEA, and disability access. Also, the inclusion of Internet-based technologies in the so called "comprehensive reforms" for economic objectives, such as interconnection charges and universal service, can also be argued as reactive, and in response to the growing complains from firms providing Internet and other technologies (2008). Thus far, we cannot site a single FCC proceeding that undertakes regulation across all technology modes – wireline, wireless, and broadband – in order to achieve the objective at the societal level.

The reason the FCC has not considered the implications of the paradigm shift from the integral to modular age more holistically may have to do with the organization of the FCC as an agency and the authority it has been given. Although, the purpose of this paper is not to pursue this hypothesis, some preliminary inferences can be drawn. Figure 10 shows the FCC's current organization chart. At the top level, "the FCC is directed by five Commissioners appointed by the President and confirmed by the Senate for 5-year terms, except when filling an unexpired term. The President designates one of the Commissioners to serve as Chairperson." At the operational level, "[t]he Commission staff is organized by function. The Bureaus' responsibilities include: processing applications for licenses and other filings; analyzing complaints; conducting investigations; developing and implementing regulatory programs; and taking part in hearings. [The] Offices provide support services." The bureaus, which are organized into technology-specific silos such as wireline, wireless, media, and so no, determine the FCC's fragmented perspective of the system. Taking a closer look reveals that each bureau has its own technology division, and is further fragmented into issue or sub-technology specific responsibilities. As a result of its organization, there is no entity at the FCC today that is systematically assigned responsibility to understand the whole telecommunications system.

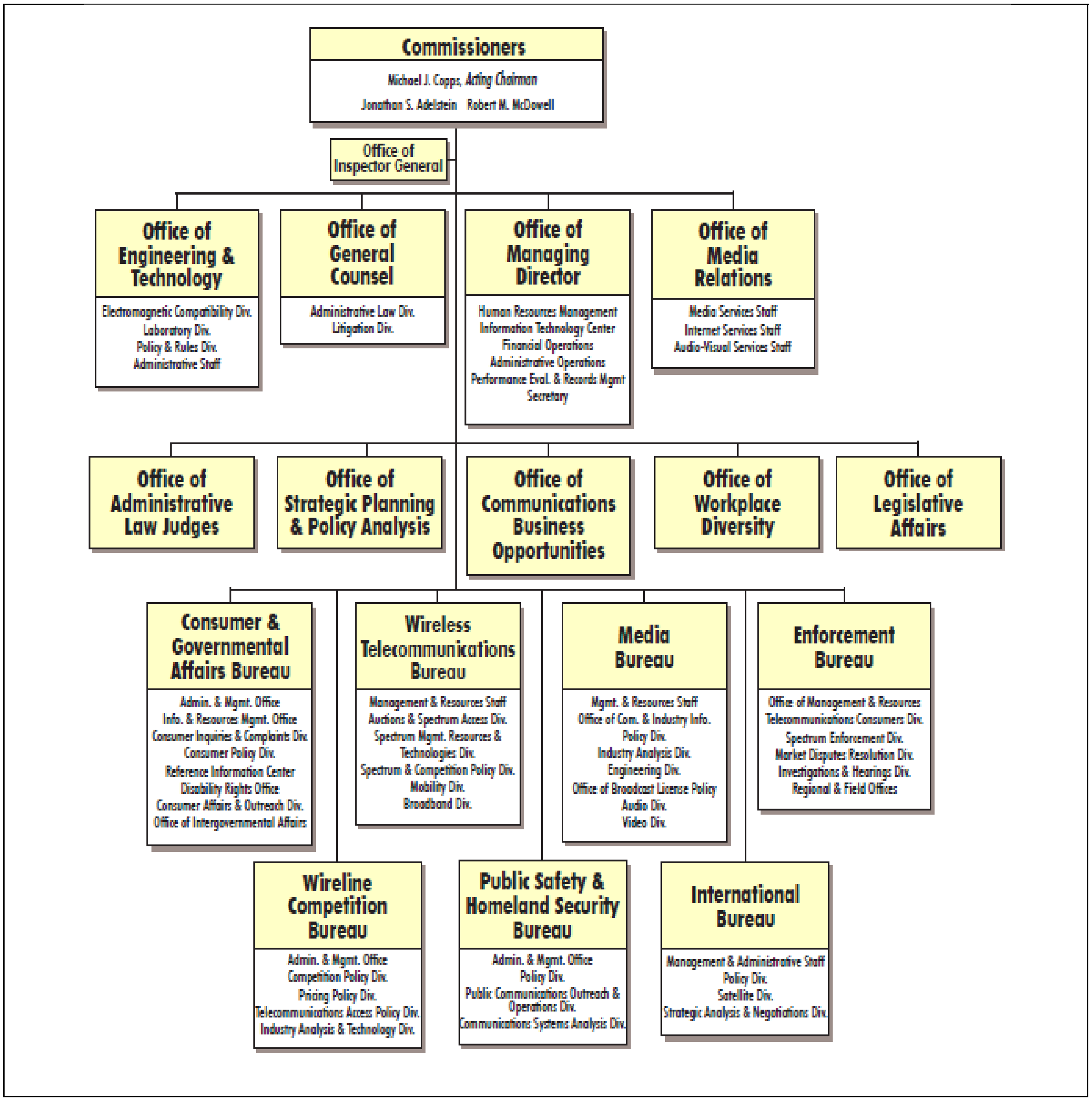


Figure 10: FCC Organization Chart (July 2009)[36]

The entity within the FCC that comes the closest to having the systems perspective is the Office of Strategic Planning and Policy Analysis (OSP), as it is "responsible for working with the Chairman, Commissioners, Bureaus and Offices to develop a strategic plan identifying short and long term policy objectives for the agency…[and] is responsible for monitoring the state of the communications industry to identify trends, issues and overall industry health, and produces staff working papers. The Office acts as expert consultants to the Commission in areas of economic, business and market analysis and other subjects that cut across traditional lines such as the Internet. The Office also reviews legal trends and developments not necessarily related to current FCC proceedings, such as intellectual property law, Internet and e-commerce issues."

[36] http://www.fcc.gov/fccorgchart.html

However, several unstructured interviews reveal that there is no one responsible for looking at the whole system, as indicated by the following quotes:

> *"No one here is looking at the systems view."*
> *Interview with Dr. Mark Bykowski, Economist, OSP, FCC, on December 8th, 2007.*

> *"Broad models are more relevant to EU than US. EU uses an overarching model and than works down (or at least it seems so). US works on case-by-case basis, there is little attempt to have over-arching principles."*
> *Interview with Dr. Evan Kwerel, Economist, OSP, FCC, on December 8th, 2007.*

2.7.3 Case Research Results: Techtronic Shifts in the Center of Gravity of Control

The question of first order with the case research is whether the comparison of the two proceedings validates the shift from the integral to the modular age as observed in Table 1. The content analysis results presented in this section validate that the major changes in technology and industry structure that we identified indeed reflect in the regulatory record. Furthermore, the analysis illuminates several tectonic shifts in the center of gravity of control in the communications value chain that can have grave implications for the future regulation.

2.7.3.1 Stakeholder Interests: From Concentrated to Dispersed

Figure 11 demonstrates the shift in the center of gravity of control from concentrated on a part of the communications value chain in 1996 to dispersed among corporations and consumers across the communications value chain in 2004. Shown here is the fraction of comments contributed by each link in the value chain in 1996 vs. 2004. Figure 11 validates that the shift from integrated to a modular industry structure (and thereby the control), as observed in Table 1 and depicted in Figure 2, does indeed reflect in the regulatory proceedings.

For the 1996 Telecommunications Act, more than 80% of comments came from the access or service providers, so the stakeholder interest was highly concentrated. In fact, here, the concentration of interest was even more than it seems because the distinction between the access and service provider was made in the analysis only because of the issue central to the Act. The majority of comments in the 1996 Telecommunications Act were on the issue of whether to unbundle the local loop. From the perspective of this issue, Incumbent Local Exchange Carriers (ILECs) that owned the local loops are considered access providers in this analysis. However, for all practical purposes, the access providers also provided service. A negligibly small fraction of comments from equipment, application and service providers in 1996 is a reflection of vertically-integrated service providers who often also served these parts of the value chain. By contrast, for the 2004 IP-Enabled Services NPRM the comments, the interests are dispersed across the value chain, including the consumers, and more independently identifiable.

Since many firms today are invested in serving more than one function in the value chain, the analysis classifies them according to their central tendency. For example, though the incumbent service providers such as AT&T and Verizon have invested in applications and devices, they are classified as service providers in this analysis. In all cases where there maybe ambiguity about how to classify a commenter, they are classified on the basis of the position in the value chain they represent in their filed comments, or their organization's mission statement. Once classified, the commenter's classification is held constant through the analysis.

The absence of concentrated interest in the communications value chain of the modular age challenges the current enforcement mechanism of command and control because it complicates the determination of who to command and where to control. Furthermore, the shift in control from being concentrated to dispersed represents increasing interdependence in the communications value chain for delivering services as well as regulatory compliance. From the functionality perspective, the interoperability among dispersed, competition interests is often achieved by technical standards, but such standards neither exist for guaranteeing the interoperability necessary for achieving the regulatory compliance, nor are they being facilitated by the regulator today.

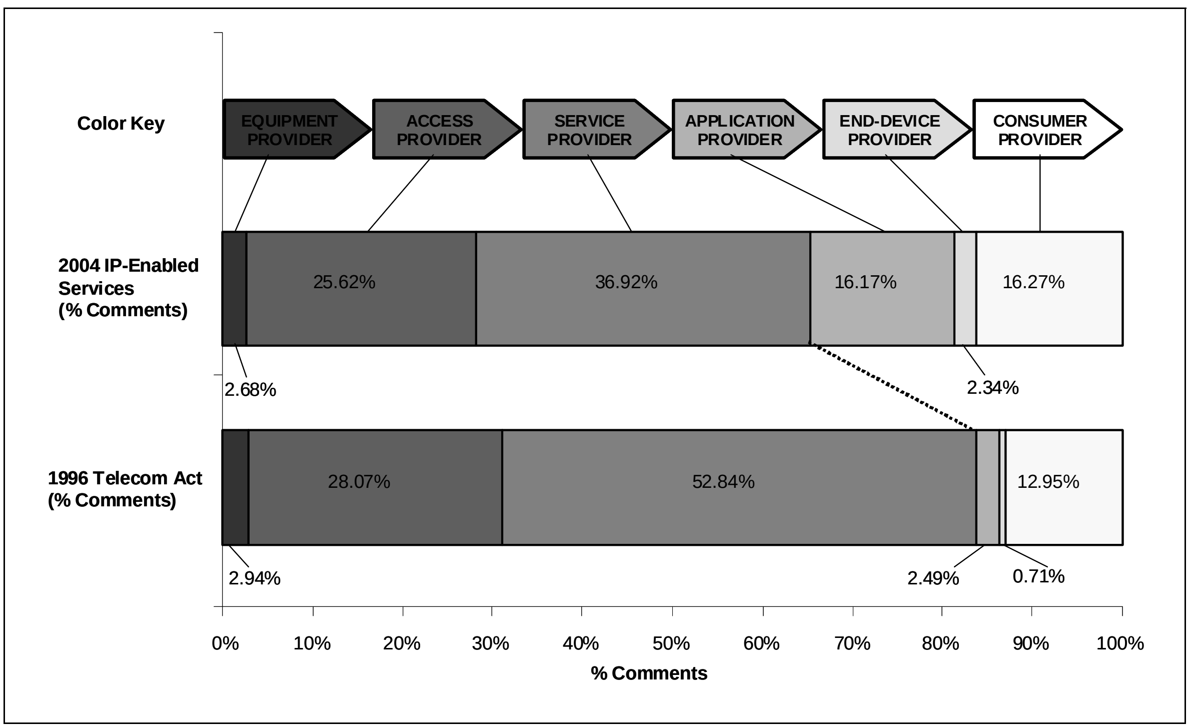


Figure 11: Stakeholder Interest - From Concentrated to Dispersed Across the Value Chain

2.7.3.2 Stakeholder Interests: From the Network Core to the Edge

Figure 12 shows the shift in the center of gravity of control from the network core in 1996 to the edge of the network in 2004. It depicts the percentage change in the fraction of comments from each value chain position between 1996 and 2004. Figure 12 validates that the technological shift of functional control from inside the network core to its edges, as observed in Table 1 and Table 2, does indeed reflect in the regulatory proceedings.

The analysis shows that between 1996 and 2004, the stakeholder interest among the links of the value chain provisioning the network core has diminished, whereas that among the links provisioning the edge of the network has ballooned.

The shift from the network core to the edge has important implications for regulation. First, it shows the growing misalignment between who bears the regulatory obligations versus where lies the functional control and activity. The obligations of traditional regulations were exclusively core-centric and were born by the service providers, but the functional control and activity has now moved into the applications and devices that currently remain unregulated. Also, the comments from edge-base players, such as the application and device providers, represent independent and powerful interests with opinions that are often in direct opposition to interests in the other parts of the value chain.

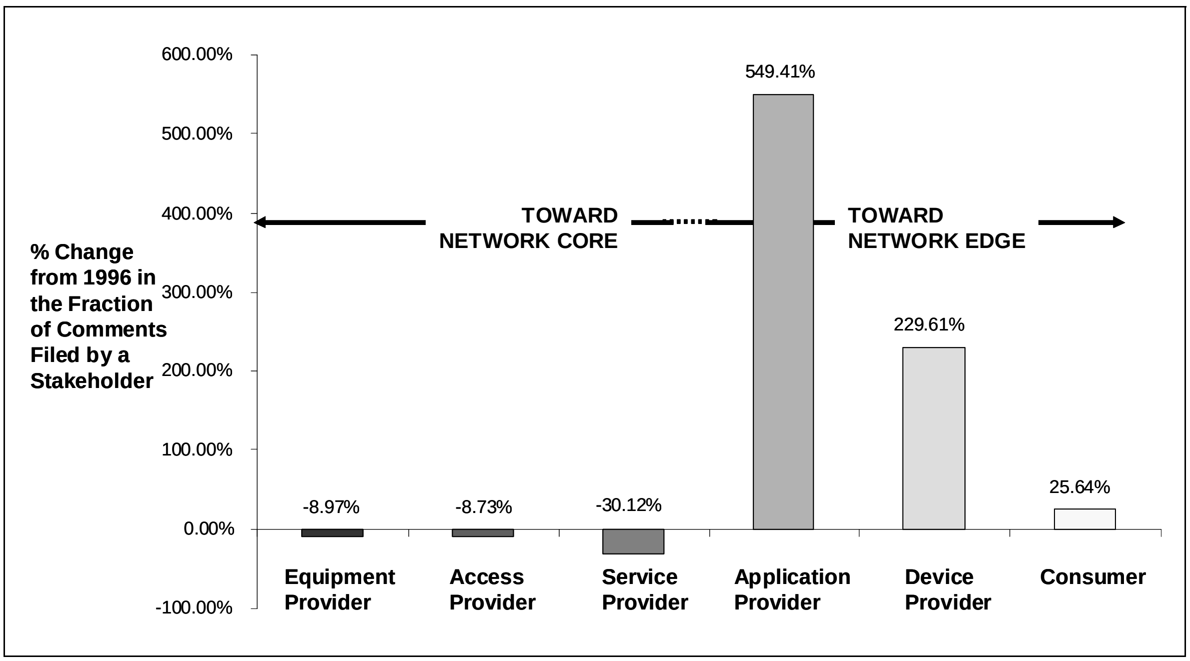


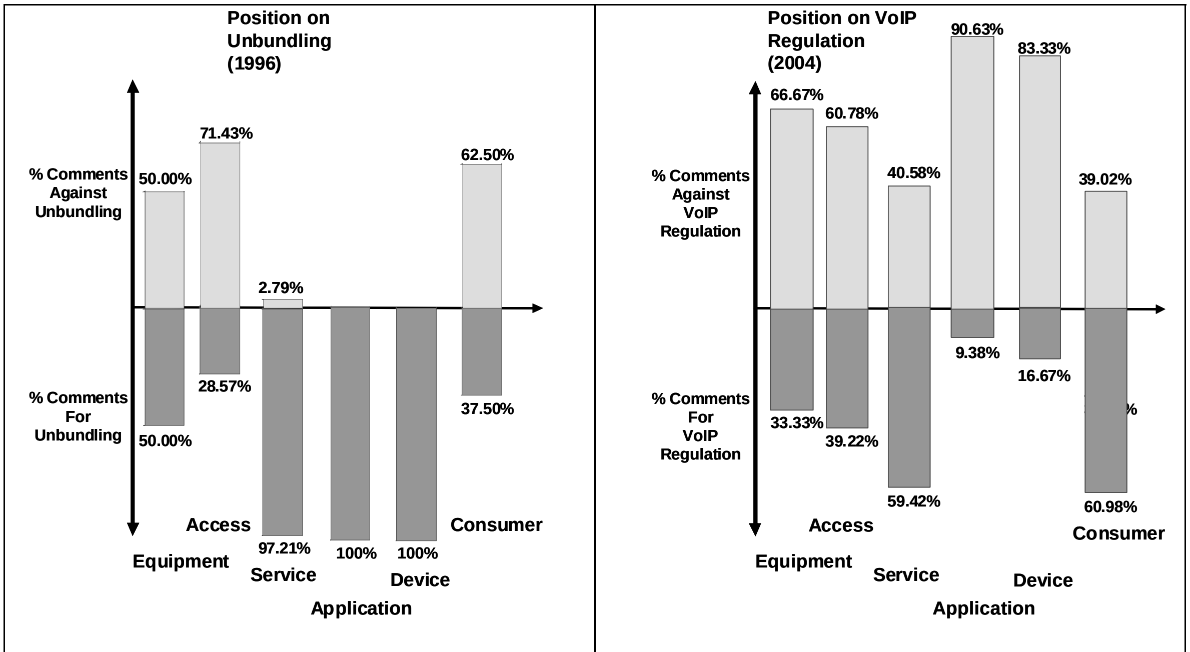
Figure 12: Stakeholder Interest – Diminishes Inside the Network Core and Swells at the Network Edge

2.7.3.3 Communications Value Chain: From Higher to Lower Consensus on Regulatory Issues

Figure 13 shows the results of conceptual analysis. It demonstrates that when analyzed from the perspective of stakeholder positions on the regulatory issues, the communications value chain has gone from higher consensus across the communications value chain on regulatory issues in 1996 to lower in 2004. The insight about this shift from higher to lower consensus was not observed in Table 1, but has emerged from the case research, as informed by the process of building and parameterizing the two models. Figure 13 shows how the stakeholder opinion is divided across the central question in each NPRM. The juxtaposition of Figure 13(a) and (b) shows that the communications value chain had a single divide across the value chain, whereas the value chain today has multiple factions.

The central question for the 1996 Telecommunications Act was whether or not to unbundle local loops. The comments in response showed that the central division then was between access providers and service providers. The application, end-device providers, and the major equipment providers sided with their most important customer – the service provider. Only a few, small equipment manufacturing firms who supplied to rural, local carriers sided with the access providers to protect their exclusive relationship.

By contrast, the response to 2004 IP-Enabled Services is different. The central issue of that NPRM was whether or not to regulate IP-Enabled Services. The analysis shows that there are multiple factions along the communications value chain who are in disagreement. The application and device providers are against VoIP regulation because they provide many of the new services such as PC-to-Phone and PC-to-PC based VoIP, which are currently unregulated. They either argue for no regulation because the regulatory compliance is difficult to develop given the Internet architecture, or they argue that nascent providers like them should not be burdened with regulation. The service providers are in favor of VoIP regulation because their networks are compliant with regulation, and lobbying for the regulation of their competitors protects their competitive advantage due to regulatory compliance. The access providers are mixed in their response because many incumbent access providers have diversified into building broadband networks. These broadband providers are against VoIP regulation (particularly, social regulation such as emergency calling and wiretapping), whereas those not invested in broadband are in favor of regulating VoIP in order to protect their competitive advantage. The consumers, largely rural, are in favor of VoIP regulation to ensure they continue to get served. An interesting observation here is that each faction in the value chain is surrounded by factions with an opposing interest, but all links must continue to interoperate to provide competitive service.



(a) Position on Unbundling for the 1996 Act NPRM (error <5%)	(b) Position on VoIP Regulation for the IP-Enabled Services NPRM (error <5%)

Figure 13: From a Single Dominant Interest to Multiple Factions

The shift from higher to lower consensus over regulatory issues has multiple implications. First, the combination of lower consensus with higher interdependence (discussed earlier) has historically meant higher coordination costs and longer time taken to comply with regulation ((Hounshell 1984), (Levinson 2006)). *As a result, we conjecture in this model that increasing modularity may sharply increase the coordination cost, limiting the achievable compliance in modular structures.* The exact nature of the relationship between modularity and the time to comply or coordination cost are not well understood, still a very long time required to build consensus and a very high coordination costs in a highly modular industry can be inferred from the many historical cases, where modular industries have fought long-drawn battles over developing common standards.

Next, the combination of lower consensus with high flexibility offered by the Internet architecture also challenges the sustainability narrowly construed regulatory obligations or enforcement mechanisms, since in the new environment new types of services may arise to create regulatory arbitrage.

2.7.4 Model Results: Challenges for Compliance and Competition

The model analysis shows that the nature of modular forces and the dynamic complexity of the paradigm challenge the regulatory thinking on both compliance and competition. This section discusses the findings.

2.7.4.1 The Lack of Consensus May Prevent the Modular Structure from Achieving Required Compliance

In an ideal world, the entrant's disruption of the incumbent may drop the average compliance (achieving the objective) temporarily, but ultimately; the entrant firms develop compliance mechanism to meet regulatory objectives at the necessary level. Given the nature of the tectonic shifts discussed above, when a modular structure disrupts an integrated one, the average utilized compliance may not achieve the required level of due to inordinate coordination costs and time necessary to comply in a highly modular structure. Although, the exact measure of the coordination cost is difficult to derive, its presence introduces uncertainty and changes the level of Achievable Compliance and Time to Comply. As a result, the Average Utilized Compliance can be far less than required, as shown in Figure 14, which shows the output of a set of sensitivity tests on the model.

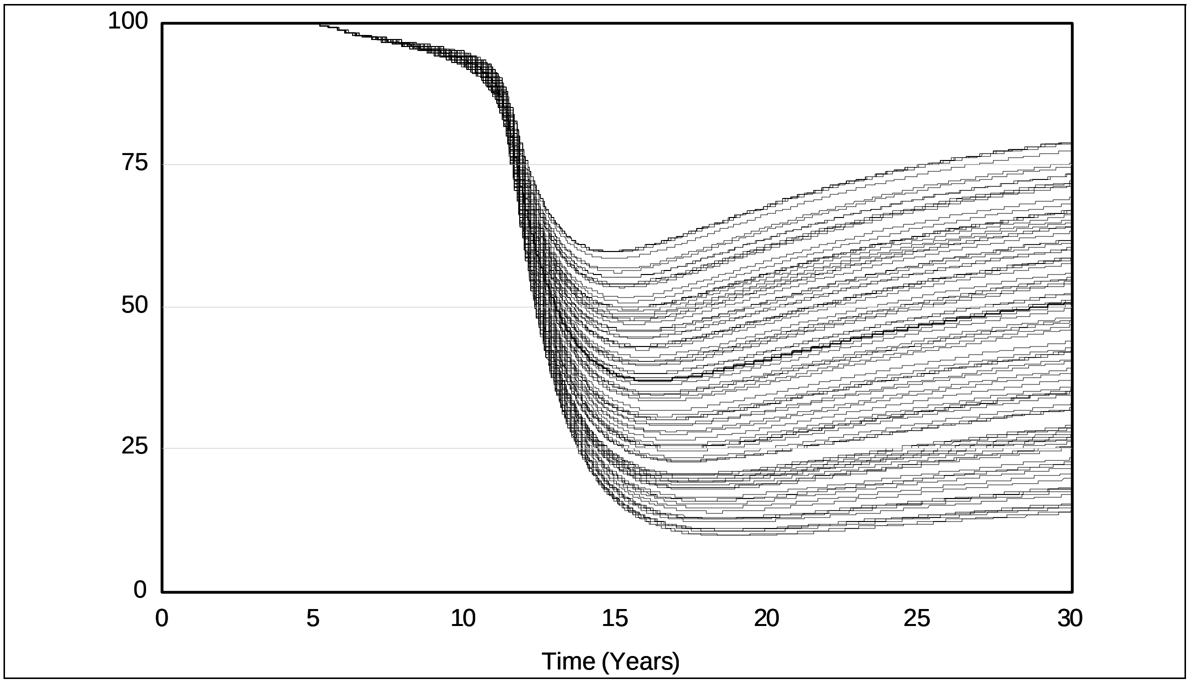


Figure 14: Sensitivity - Average Utilized Compliance with Different Consensus

This analysis shows that lower consensus around regulatory issues, and the resulting increase in both coordination costs and time to comply, can be an impediment to achieving the desired regulatory compliance in the first place. However, as argued earlier, the current enforcement mechanisms do not focus on building consensus, reducing coordination costs, nor time required to comply with regulation.

2.7.4.2 Partial Regulation May Provide Inadequate Compliance and Perverse Incentives

To understand the impact of partial regulation, we must first understand the nature of Average Utilized Compliance, meaning the fraction of communication occurring over compliant networks. Figure 15 shows an example of how the Average Utilized

Compliance is determined by two factors: regulation and competition. To simplify the analysis, this example is deliberately kept static. Suppose the regulator imposes regulation on 100% of the incumbent firms, but regulates only certain types (50%) of entrant firms. Now, imagine the following two competitive equilibriums. First, where the incumbent keeps 80% of the market and the entrant keeps 20%. Second, where the equilibrium is the opposite, the incumbent keeps 20% and the entrant wins 80%. As per Equation 4, the Average Utilized Compliance in the two cases is starkly different. In the first case, 90% of communication occurs on compliant service (see Figure 15(a)), where as only 50% of communication is compliant in the second (see Figure 15(b)). This example shows that when multiple technologies compete, even though there may be no change in the required level of compliance, the effective compliance level can be far lower than that expected.

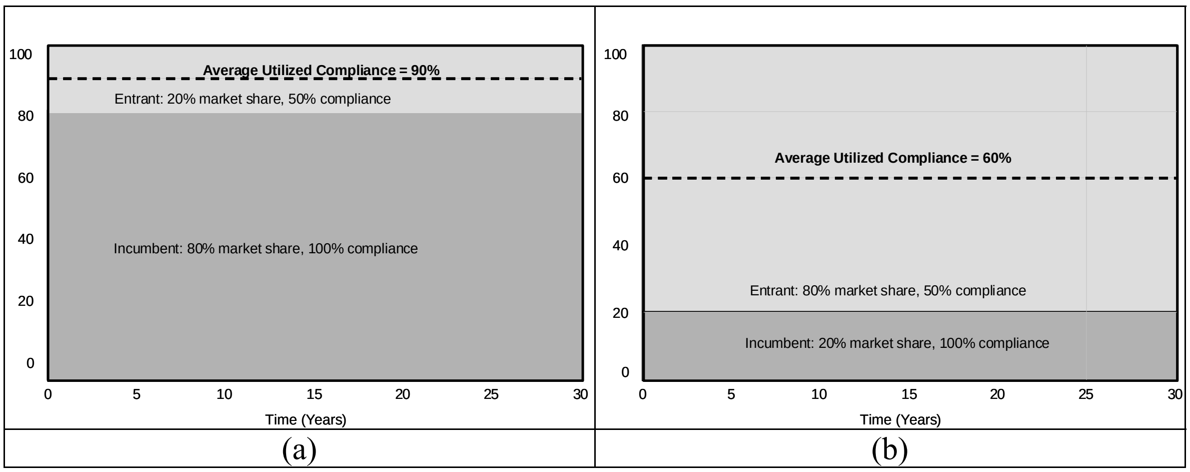
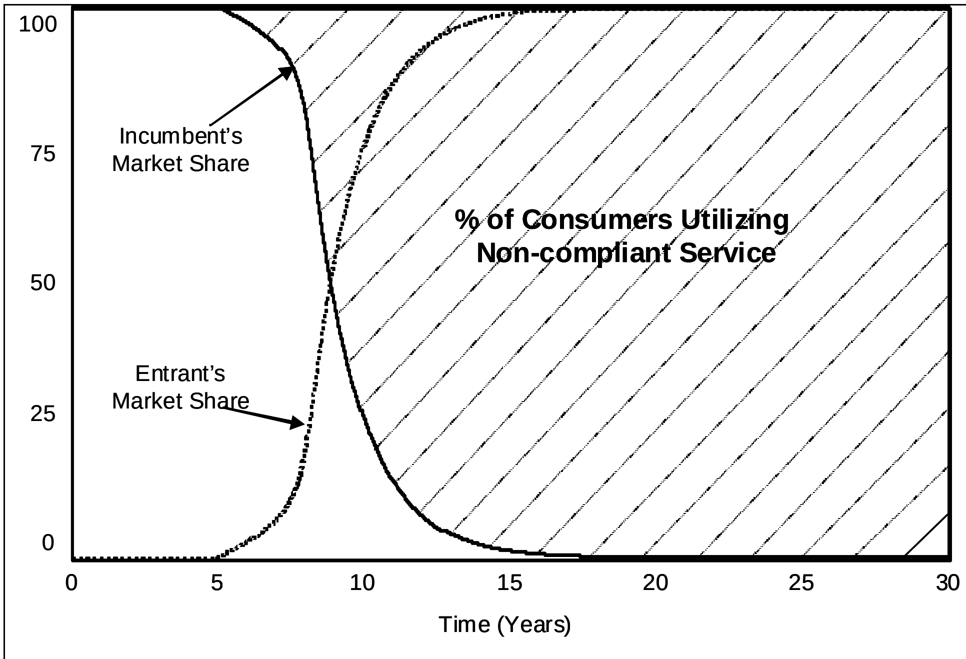


Figure 15: Interpreting Average Utilized Compliance

The dynamically changing market share has implications at multiple levels. At one level, if we assume that the firm's characteristics do not change over time (which is what our current model formulation assumes since the service, market, and industry attributes remain exogenous, and constant through the simulation), the dynamics of competition has two simple implications. First, as shown in Figure 16(a), when the regulatory scope excludes an entire technological mode, there is a loss of utilized compliance if the unregulated mode disrupts the regulated ones. An example of this situation in the recent regulatory history is the case of wireless E911, where the emergency calling regulation excluded wireless operators until the year 2000, when wireless communication had already penetrated 50% of the US market. Second, as shown in Figure 16(b), when the regulatory scope includes every technology mode, but excludes certain types of technology providers, the utilized regulatory compliance can be far lower than that required or measured.

To understand the example in Figure 16(b), consider a case when a fully compliant incumbent providing one mode of technology gets disrupted by a set of entrants providing another mode of technology. Further, only certain types of entrants are regulated. Now, if the entrant firms fully disrupt the incumbents, and equally divide the market share among them, the resulting utilized compliance can be far lower than necessary. The reason is that even though entrants who are regulated deploy compliance mechanisms to close the gap between the required and actual compliance, some of the market share remains with the entrants who are unregulated. Such is the case of emergency calling regulations today, which includes all modes of voice communication (PSTN, Wireless, and VoIP), but excludes some wireless technologies such as push-to-talk, and some VoIP technologies such as peer-to-peer. Starting in year 2009, the VoIP providers who interconnect with the PSTN are required to report their compliance level for emergency calling to the FCC. As a result, from the perspective of the compliance level required and measured by the FCC, there may appear to be a high level of regulatory compliance, but a large percentage of consumers may be utilizing non-compliant networks such as peer-to-peer VoIP, which the FCC neither regulates nor measures the compliance of. Hence, in both cases, partial regulation may lead to inadequate Average Utilized Compliance.



(a) Unregulated Mode Disrupts

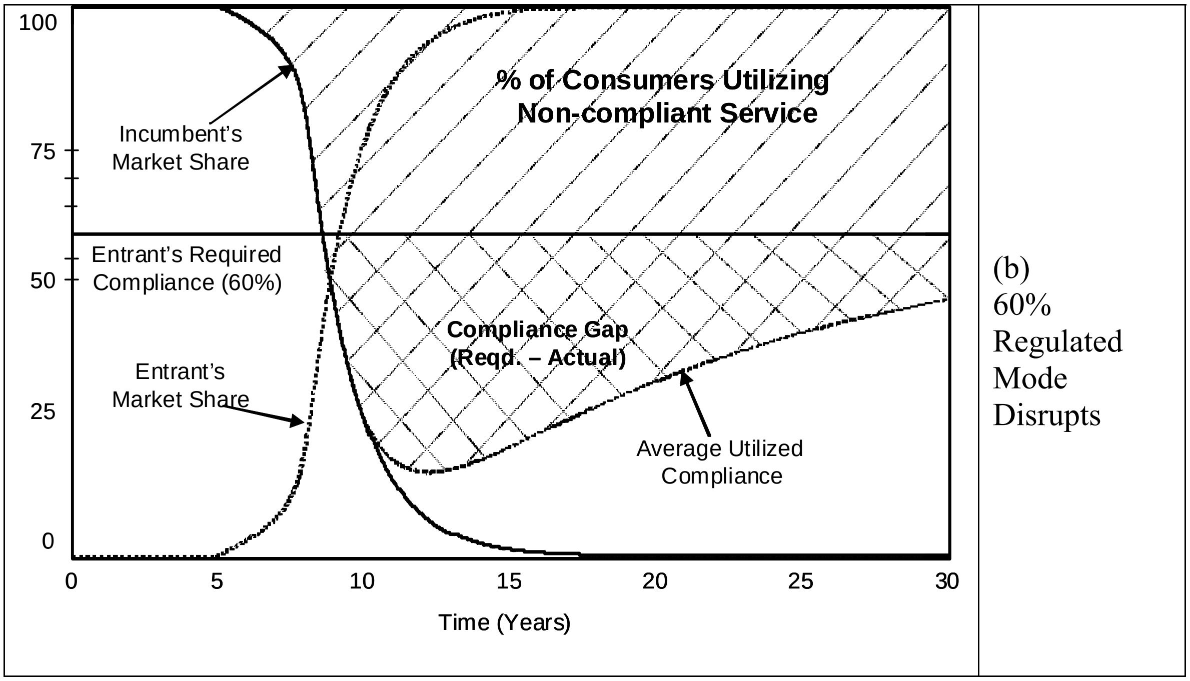


Figure 16: Partial Regulation Provides Inadequate Compliance

At another level, the dynamically changing market share represents the perverse incentives present in the environment that has even broader implications in the modular age. First, because of the flexibility the hourglass architecture of Internet (depicted in Figure 4) offers, we cannot really assume that the firm's characteristics remain constant over time.[37] The firms naturally morph to fit the competitive landscape, and partial regulations in a modular environment provide even further incentives for doing so. Hence, even when the incumbent is not disrupted, to take advantage of the partial regulation, they may offer services that are currently unregulated. Hence, the utilized compliance may be lower than what appears, even though the market shares do not change.

Next, with the architecture of the Internet, firms can offer services without requiring the consumer or the service provider to stay within a geographical area. This flexibility can spur a "competition in laxity" (Murphy 2002) between nation-states trying to lure both consumers and firms with less regulation. Hence critical regulatory objectives such as public safety and law enforcement require capability and coordination among nation states, not just among industry players.

Finally, thinking back at the hierarchical view of the telecommunications system, presented in Figure 6, the implications of partial regulation appear even graver. When the utilized compliance is lower than what is adequate at the societal level, because the regulatory scope excluded some providers, the burden of meeting compliance naturally falls on other subsystems. For example, if telecommunications providers do not aid

[37] We will relax this assumption in the next paper when we study uncertainty further.

public safety or law enforcement adequately, some other, maybe labor-intensive, services will have to substitute for them, and so on.

2.7.4.3 The Dynamic Complexity Obscures the Timing of Delayed Regulation

The dynamic complexity that surrounds the disruption scenario makes it difficult to implement delayed regulation. Suppose there is no uncertainty about the service, market, or industry, and the omniscient regulator knows the rate at which the entrant would disrupt the incumbent, Figure 17 shows that even in such a scenario, a minor difference in the timing of regulation can completely alter the competitive outcome. In practice, however, regulators do not possess such fine grained control over the regulatory proceedings, as visible from the number of extensions filed and granted against any major FCC proceedings (Furchtgott-Roth 2006). Furthermore, many factors that mediate the occurrence and the rate of disruption obscure the management of delayed regulation even further, so such an assumption of omniscience itself is idealistic.

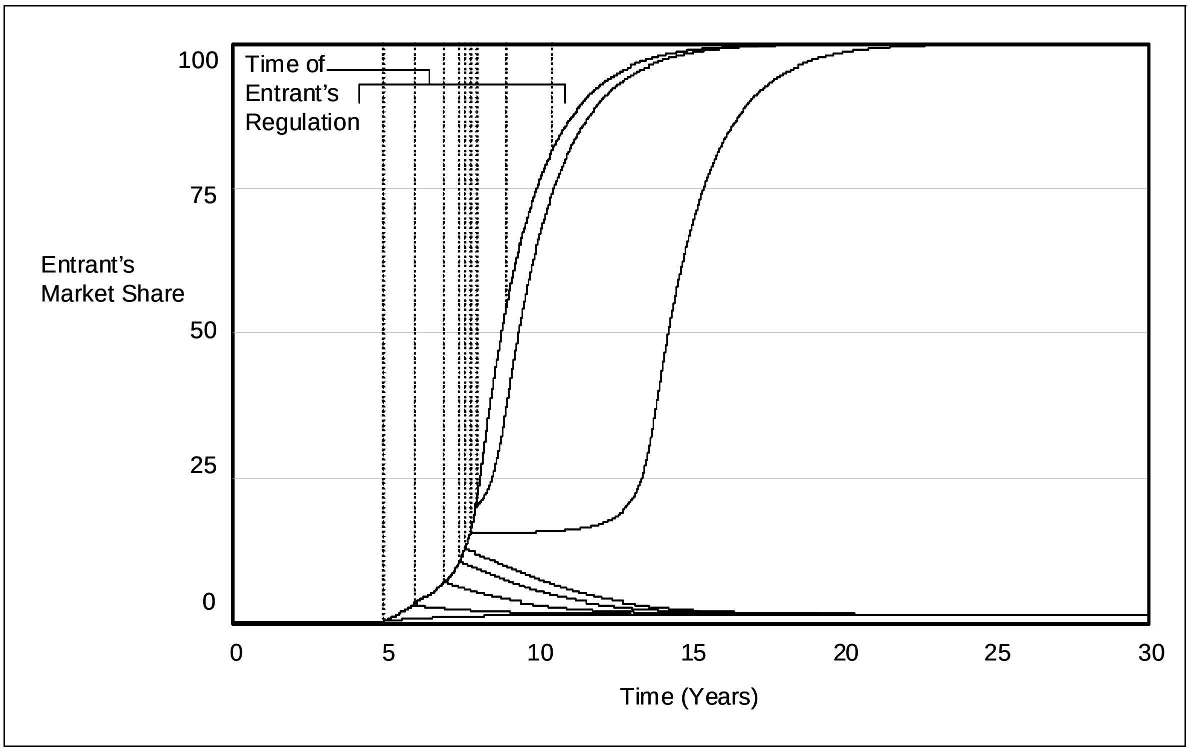
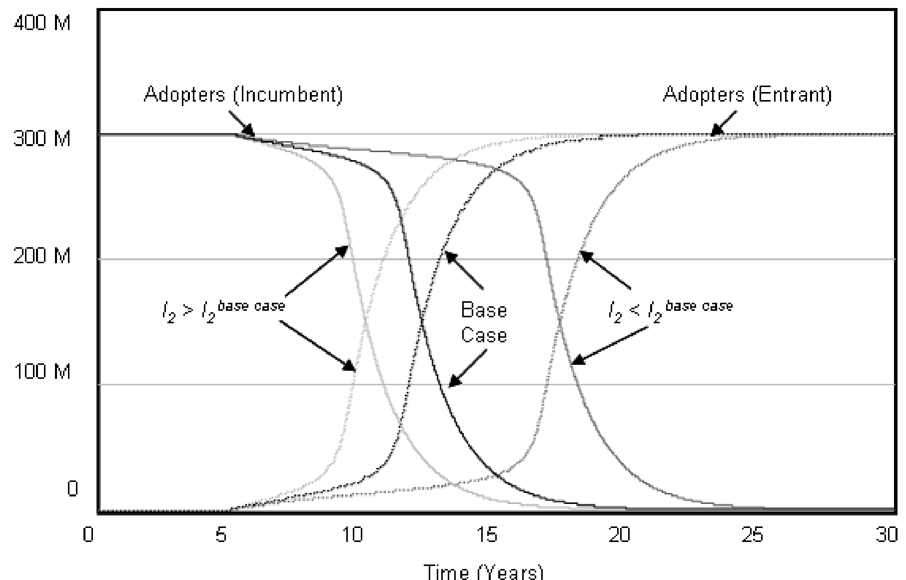
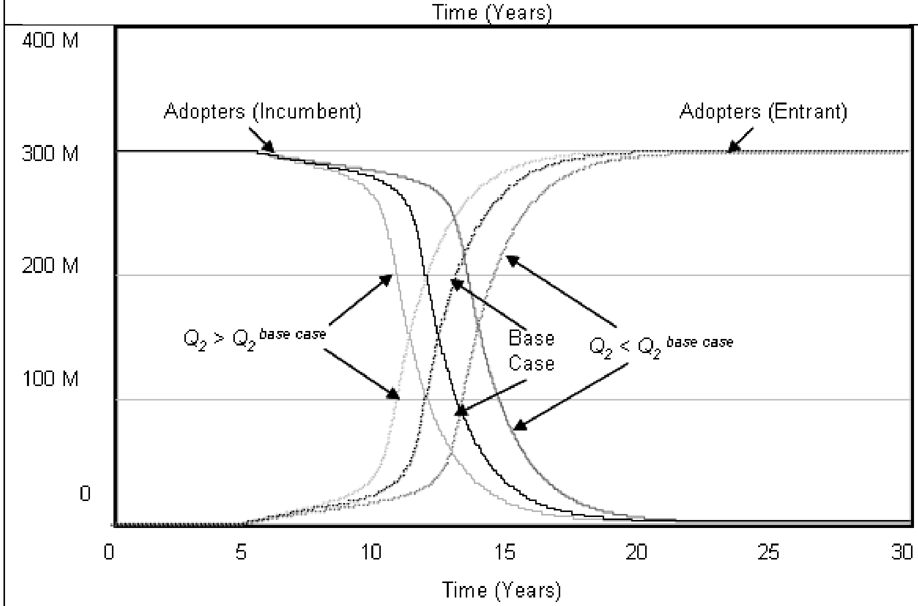


Figure 17: Dynamic Complexity Obscures the Timing of Delayed Regulation

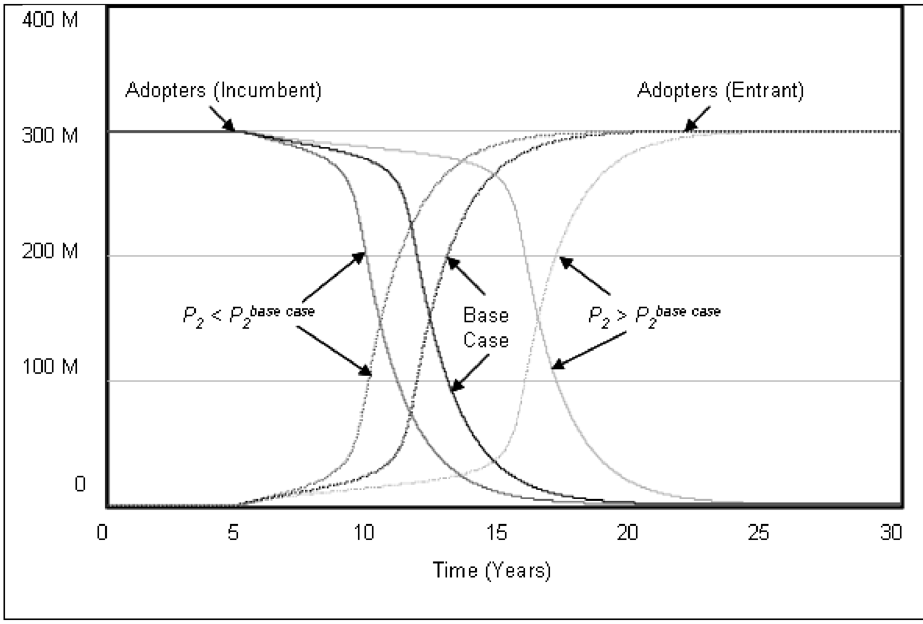
Figure 18 shows how the uncertainty about the attributes of service such as innovation, quality, and price introduce a high degree of dynamic complexity. In each simulation the entrant's attribute is varied while keeping the incumbent's attributes unchanged. The outcome is intuitive in that an increase in quality or innovation, or a decrease in price of the entrant's service lets it disrupt the incumbent more rapidly.



(a)
Innovation



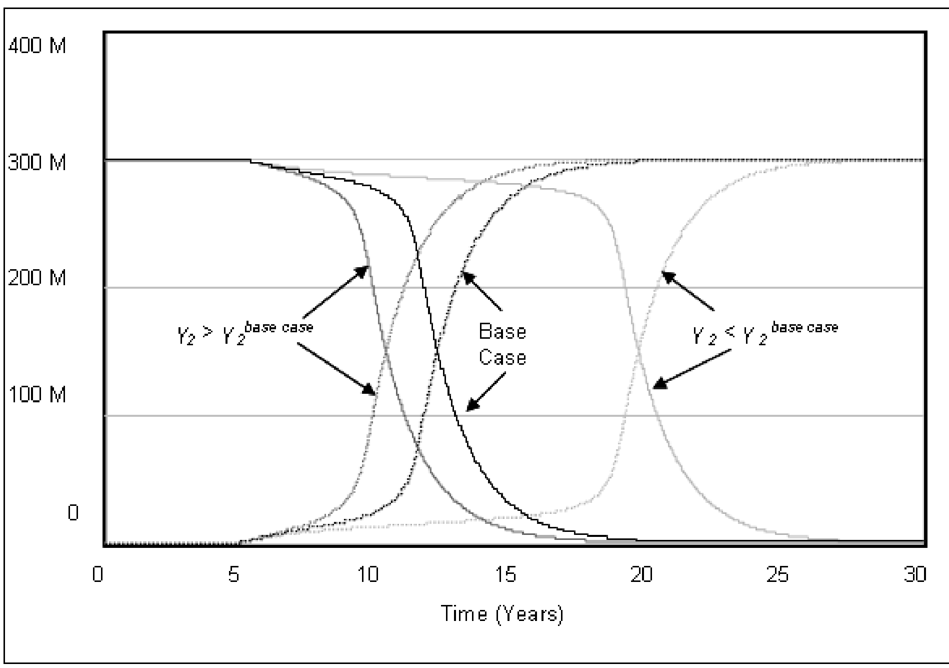
(b)
Quality



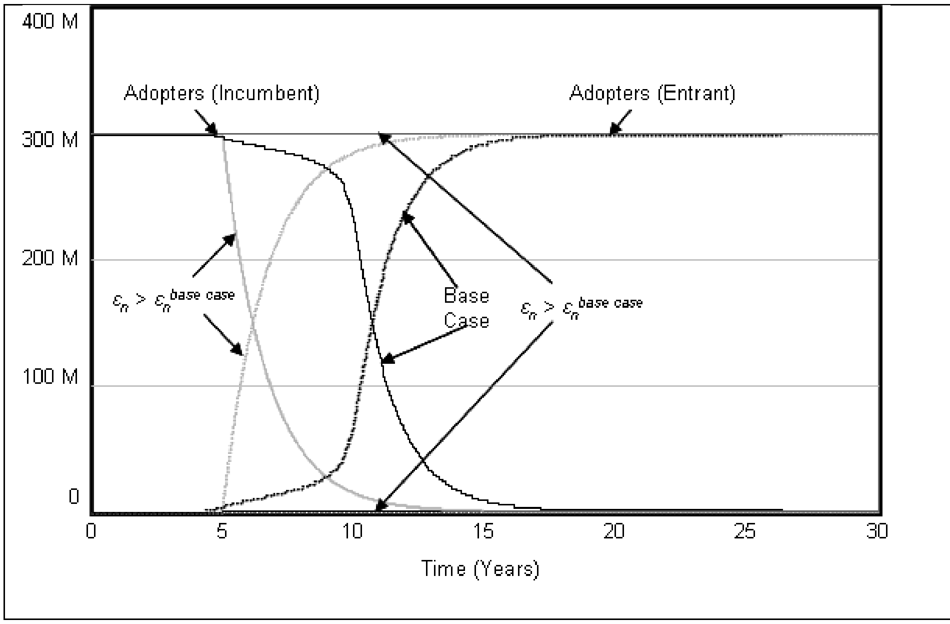
(c)
Price

Figure 18: The Impact of Product or Service Characteristics on the Competitive Outcome

Figure 19 shows how the uncertainty about the attributes of market such as switching costs and network effects too introduce a high degree of dynamic complexity. Figure 19(a) shows that an increase in switching cost for the entrant's consumers leads to more rapid disruption. Figure 19(b) shows that the level of network effect has the potential to determine whether the disruption occurs in the first place. Very strong network effect could prevent disruption, mid-range network effects lead to winner-takes-all (WTA) outcome, and the absence of network effect leads to an equilibrium that is not WTA.



(a)
Switching Cost



(b)
Network Effect

Figure 19: The Impact of Market Characteristics on Competitive Outcome

Together, Figure 18 and Figure 19 make two points. First, that many competing factors mediate the occurrence as well as the rate of disruption. Second, consumers, firms, and technologists could strategically manipulate these parameters to change the competitive outcome. To understand this dynamics complexity well, each of this parameter must be made endogenous, either structurally or behaviorally, which is a topic covered in Paper 2. Understanding this outcome in addition to the above discussion on how the rate of disruption itself is mediated by a number of factors illuminates that the far higher dynamic complexity of the modular age renders impractical any hope that decisions related to the timing of regulation can be effectively made in this the new environment.

2.8 Conclusions

2.8.1 Objectives: Relevant, but Must be Pursued at the Societal Level

In this paper, we have shown that the five objectives, three social objectives (law enforcement, public safety, and equal opportunity objectives) and two economic objectives (competition and economic development), that were traditionally served by the regulation of voice communications remain relevant. However, they must first be debated from the societal perspective.

The debate about the regulatory objectives is currently stuck at the level of which technologies or industries (wired, wireless, internet telephony, etc.) ought to fulfill them. This is inappropriate. For example, public safety is a societal objective that has generated emergency calling (E911) obligations for the telecommunications system. The PSTN providers have been burdened with the emergency calling obligations since 1976. However, ever since wireless telephony and Voice over Internet Protocol (VoIP) became viable competitors to the PSTN, the regulatory process has engaged in a debate as to whether and when to extend the emergency calling obligations to these new entrants. The answer ought to be clear, but it hasn't been because the public safety debate has been pursued at the level of technologies. At the societal level, the telecommunications system is one of many subsystems that facilitate public safety. If the telecommunications system as a whole shirks its duty to aid public safety because some technologies are not regulated, other subsystems—maybe non-technical ones—will have to pick up the slack. But this fact has not been recognized.

Successfully refocusing the FCC's mental model on societal objectives before considering the efficiency of implementing obligations may take reorganizing the agency so that it can understand the implications of the modular age for the whole telecommunications system.

2.8.2 Obligations: Incremental Regulation Must be Abandoned

This paper argues that incremental regulation is futile and must be abandoned in the modular age. Limiting regulatory scope in a modular architecture leads to inadequate compliance and creates perverse incentives at two levels. At the industry level, it provides incentives to the regulated firms to flee to the unregulated technology segments. At the global level, it ignites competition in laxity between nation-states trying to lure both consumers and firms with less regulation.

As for the timing of incremental regulation, the far higher dynamic complexity of the modular age obscures the timing-related decisions. First, the regulator struggles to determine if the regulation is too-early or too-late, because many more competing factors now mediate the rate of technology and industry disruption, which makes it difficult to predict how rapidly an unregulated segment might erode the existing regulatory compliance. Next, the regulator cannot be sure of the outcome post-regulation, because the modular age offers far higher flexibility to consumers, firms, and technologists to strategically manipulate the competitive outcome, the dynamics of which the regulator currently does not understand. So, to understand the scope or timing of regulation, the dynamic complexity of the modular age must be well understood. The next chapter focuses on further understanding the dynamic complexity.

2.8.3 Enforcement Mechanisms: Must be Conscious of the Dynamic Complexity of the Modular Age

The enforcement mechanism for traditional telecommunications regulation has been command-and-control. This mechanism worked because in the integral age the industrial interests were concentrated, which made it possible for the regulator to know who to command and where to exert control. The regulatory fights were easier to identify and address then. Also, as a firm possessed full functional control over a service, it could easily develop and deploy compliance mechanisms post-regulation. The modular age completely changes the rules of the game.

The modular forces blunt the mechanisms of command-and-control. First, the regulator finds it difficult to determine where a command-and-control mechanism ought to focus, because the post-Internet era has multiple, equally capable interest groups that lack consensus over critical regulatory objectives. Next, the command-and-control mechanisms are completely ill-suited for building consensus around regulatory issues, which is imperative for meeting critical societal objectives, as the lack of consensus inflicts a very high coordination cost that could prevent meeting regulatory objectives altogether. Essentially, the modular structure shifts the center of gravity of control from a single dominant interest to multiple, from the center of the network to its edges, and from a single divide to multiple factions. This is a tectonic shift that demands completely different enforcement mechanisms.

2.9 From Herding Sheep to Herding Cats

Metaphorically, this is a tale of three animals – elephant, sheep, and cats. From the time the FCC was established (in 1934) until the break up of AT&T, the telecommunications regulator was a keeper of an elephant (AT&T). The elephant was monolithic and slow, but powerful and demanding because it faced no competition. It had negotiated with its keeper a suitable confinement in the form of the 1934 Telecommunications Act. With the break up of AT&T, the regulator became a shepherd herding a few sheep (the Baby Bells). The sheep were inherently less competitive, less innovative, and docile. They worked by consensus. To control a herd of sheep, the shepherd needed just a crook and a little guidance that came in the form the Telecommunications Act of 1996 and its enforcement. But the transition from an integral age to a modular age transforms the regulator's role from that of a shepherd who herded a few sheep to one who must now herd many cats. The cats are fiercely competitive, highly innovative, and agile. Most importantly, however, the cats lack consensus and are highly independent. To control cats requires a completely new mindset – maybe a net around them, or a set of incentives such as the mice, or something else. Neither the elephant's confinement, nor the crook used for the sheep will work for the cats. In other words, the effective control mechanisms for these species are radically different. Similar is the case of regulation in the integral versus the modular age: the effective control mechanisms for the two environments are starkly different.

Chapter 3: ANTICIPATING UNCERTAINTY IN TELECOMMUNICATIONS REGULATION, COMPETITION, AND INNOVATION

Decision making under the constant threat of disruption is a difficult task whether you are a policymaker, manager, consumer, or technologist. [38] Difficulties arise from the bewildering array of uncertainties that surround the disruption phenomenon. This chapter examines: *How can regulators and managers improve decisions taken amidst uncertainty that surrounds the disruption of an integrated technology and industry by a modular one?* The chapter investigates these uncertainties from the perspective of *dynamic complexity in feedback systems*. Whereas the inquiry in chapters 2 and 4 are more of interest to regulators, the analysis in this paper ought to interest managers and regulators alike.

3.1 Introduction

In 1997, in his work leading up to the best-selling book *The Innovator's Dilemma*, (Christensen 1997) Clayton Christensen made critical observations about the conditions under which established firms lose market to an entrant with what he called *disruptive technology*. In the years to follow, this work became highly influential in managerial decision-making. In the process, however, as it happens with many influential theories, disruptive technology became a buzz word, being "thrown around" in contexts that often go far beyond the claims Christensen originally made.

Christensen's original arguments, as summarized from the more academic references (Christensen 1992; Christensen 1992; Christensen and Rosenbloom 1995; Christensen, Suárez et al. 1996) rather than the more popular paperbacks (Christensen 1997; Christensen and Raynor 2003), were that understanding when an entrant might have an advantage over the incumbent requires understanding of three interlocking forces: technological capability (incremental versus radical, or architectural versus component innovations (Henderson and Clark 1990)); organizational dynamics (capability enhancing versus capability destroying innovations (Anderson and Tushman 1990)); and the third force – value network – the context within which the firm identifies and responds to customers' needs, procures inputs and reacts to competitors (Christensen and Rosenbloom 1995). Further, he argued that firm's competitive strategy, and particularly its past choices of markets to serve, determines its perceptions of economic value in new technology, and in turn shapes the rewards it will expect to obtain through innovation.

[38] A note to the reader: This chapter is targeted for either the Journal of Industrial and Corporate Change, or the Journal of Innovation and Product Management. Therefore, it may give a flavor appropriate to those journals. Additionally, this chapter also serves as a placeholder for some insights that are relevant but do not fit elsewhere in the dissertation. As a result, occasional thoughts might appear to be drifting from the central inquiry of this chapter.

Christensen's work documented several industries that were disrupted successfully, including disk drive industry where giants like IBM were the victims, excavator manufacturing industry where the hydraulic excavators wiped out the entire population of mechanical excavator manufacturers, and steel manufacturing where mini steel mills disrupted vertically integrated steel mills (Christensen 1997).

The above pattern Christensen identified is simple to understand and quite pervasive in many industries. What is misleading, however, is the loose and opportunistic use of the term "disruptive technology" by the popular media and experts alike. As a case research in the beginning of this chapter involving tens of technologies will demonstrate, technologies that media prematurely declared as "disruptive technology" has often failed to disrupt the existing industrial order.

Should such an over zealous use of the phrase "disruptive technology" bother us? On one hand, the threat of disruption makes incumbents paranoid about losing the market, while making new entrants hopeful of inventing the next disruptive technology. Arguably, such hopes and fears create more competition in the market place. On the other hand, however, incorrectly calling every technology disruptive, could lead to inefficient strategic decisions by managers and policymakers.

Every time a new technology appears on the horizon, policymakers and managers wrestle with the question of how to understand the threat of disruption, even though the two may have different concerns. Regulators may be concerned with fulfilling social and economic objectives (described in chapter 2, or similar ones depending upon the area of regulation). While the managers, depending upon who they represent, incumbents or entrants, may be concerned with how to survive disruption or how to create one, respectively. This research will show that media and experts alike systematically misperceive the threat of disruption. The technologies they proclaim as disruptive do not often displace incumbent technologies, and where they do, incumbents—not the entrants—remain dominant in the new technology paradigm.

To understand why such is the case, we investigate two specific questions in this chapter. First, *does every potentially disruptive technology cause technology disruption?* Second, *does technology disruption always mean industry disruption? Technology disruption* occurs when a set of technologies displace a previous set of technologies to serve the same function. For example, in telephone switching, the first wave of technology disruption occurred when electromechanical switches replaced human-operator based switches and the second wave came when transistor-based switches replaced the electromechanical ones. *Industry disruption* occurs when a new set of industry structure (or players) displaces the incumbent industry structure (or players). The computer industry offers a well-known example, where a vertical industry structure has been replaced with a horizontal one. Here, there is technology disruption such as personal computers displacing mainframes, but also industry disruption where Intel and Microsoft displaced giants like IBM.

Like founding the analysis of technology disruption on Christensen's early insights, we found our analysis of industry disruption on Charles Fine's early insights on industry disruption. In 1998, Charles Fine, in his work *Clock Speed: Winning Industry Control in the Age of Temporary Advantage*, presented the dynamics of how industry/product structure evolves from integral to modular, and back. With an illustration called the *double helix*, [39] Fine argued that, "When the industry structure is vertical and the product architecture is integral, the forces of disintegration push toward a horizontal and modular configuration. The forces include: 1. The relentless entry of niche competitors hoping to pick off discrete industry segments; 2. the challenge of keeping ahead of the competition across the many dimensions of technology and market required by an integral system; and 3. The bureaucratic and organizational rigidities that often settle upon large, established companies." On the other hand, said Fine, "when an industry has horizontal[/modular] structure, another set of forces push toward more vertical integration and integral product architectures. These forces include: 1. Technical advances in one subsystem can make that the scarce commodity in the chain, giving market power to its owners; 2. Market power in one subsystem encourage bundling with other subsystems to increase control and add more value; [and] 3. Market power in one subsystem encourages engineering integration with other subsystems to develop proprietary integral solutions." Reproduced in Figure 20 is Fine-Whitney's illustration of the forces of double helix.

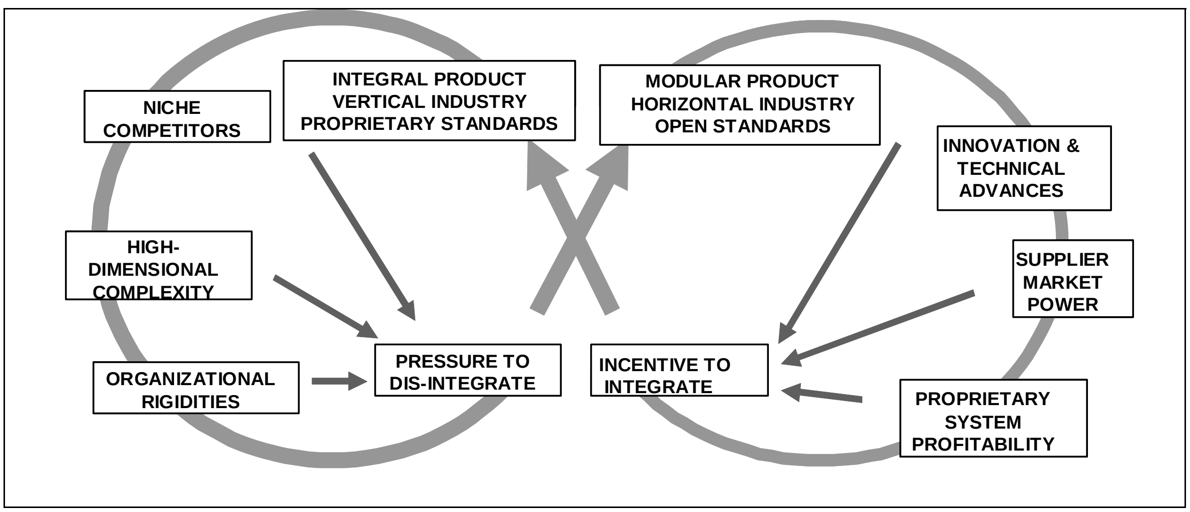


Figure 20: The Double Helix

The double helix more generally describes the long wave of industry structure going from integral to modular, and back. It does not mandate that this evolution from one form of industry structure to another involve technology disruption (new technology displacing

---

[39] Pp. 49 of Fine, C. H. (1998). Clockspeed : winning industry control in the age of temporary advantage. Reading, Mass., Perseus Books.

This work first appeared in an unpublished paper Whitney, D. E. and C. H. Fine (1996). Is the make-buy decision process a core competence.

the old). Hence, the investigation of the conditions under which technology disruption translates to industry disruption is a special case of the double helix framework.

Broadly, the research in this chapter is a study on the impact of the various uncertainties—market, technological, organizational, regulatory, or that of the industry structure—at two levels. First, at a theoretical level, we discuss the conditions under which a disruption may or may not take place, thereby discussing the assumptions and limits of two disruption theories; namely: Clayton Christensen's work on technology disruption, and Charles Fine's work on industry disruption and clockspeed. Second, at a practical level, we expose several popular beliefs about disruption that turn out to be myths once the uncertainties involved are understood better. Finally, we discuss the challenges of anticipation and measurement during disruption.

The research in this chapter calls for broadening the agenda for research around disruption phenomena. Our investigation here must not be misconstrued as a contradiction of Christensen or Fine's work. In fact, we start with their observations as the bases for our model. The idea here is to embed his work in a broader context, so as to build upon it, hoping that such an exercise will expand our understanding of the conditions for industry disruption.

The remaining of the paper is organized as follows. We begin the case research that surveys the popular media's usage of the phrase "disruptive technology." We show that in two fast clock speed industries – computers and telecommunications – the technologies media proclaimed as disruptive eventually failed to disrupt the industry structure. To study the reasons for such an outcome, in the following section we develop a systems model of regulation, competition and innovation in telecommunications. In the results section we analyze the model behavior under market, technology, organizational and regulatory uncertainty. With this analysis, in the conclusion section, we discuss limits to technology and industry discussion, myths surrounding the disruption phenomena. Finally, we will discuss anticipation under uncertainty and the difficulties with observing and measuring some parameters.

3.2 Research Method

3.2.1 Research Method Overview

The research starts with a qualitative case study to investigate the following question: do potentially disruptive technologies, proclaimed by the media, always displace the existing industrial order? The case research uses a combination of content analysis and industrial statistics. First, we analyze several important media publications to enumerate technologies they proclaimed as "disruptive technology" in the period between 1997, when the term was coined by Clayton Christensen, and August 2008. Next, with the help of the Global Industry Classification Standards, we tie these technologies to the industries they were expected to disrupt. Finally, we study the industrial order of the industries threatened with disruption for the years 2001 and 2007. The analysis shows that in the communications industry alone, where changes ought to be easier to visualize because of its rapid rate of change, a potentially disruptive technology often does not succeed (i.e., no technology disruption). Further, it finds that technology disruption does not always mean industry disruption; in other words, in some cases, a new technology may disrupt the old, but the industrial order does not change because the leaders of the old technology continue to lead the new market. To understand what factors explain such variation in the outcome, the research then turns to a dynamic model that more broadly captures the uncertainties involved.

The single, dynamic model in this paper situates the two models discussed in Paper 1 in the appropriate theories, and makes the parameters in those models endogenous. First, to model the dynamics of technology disruption, several parameters of the simple diffusion model, such as quality, innovation, price, and resources of the firms, are made endogenous. Next, to explain the dynamics of industry disruption, the industry-level modularity is made endogenous, which allows for understanding the level of organizational rigidity, dimensional complexity, and functional control the firms experience as one industry disrupts another. Finally, the dynamics of regulation are added to explain how the cost and resources required for regulatory compliance affects competition during technology and industry disruption; and conversely, how the disruption affects the level of regulatory compliance, and the time necessary to achieve it. The scope of this model is limited to a scenario where a *modular* technology and industry disrupts an *integrated* technology and industry, which is sufficient for studying the Internet's disruption of traditional technologies. Careful judgment is required to port the lessons of this paper to other scenarios of disruption.

Before detailing the case research or the model, we discuss how our research approach continues to rest upon the principles of systems.

3.2.2 Telecommunications System as a System of Systems

In chapter 2, we used the hierarchical decomposition to show how the behavior of the telecommunication system emerges as a result of the interaction of regulatory, corporate strategy, industry structure, consumer preference, and technology dynamics. We now extend this hierarchy to comprehensively understand uncertainty in telecommunications system. The extended hierarchical decomposition shown in Figure 21 forms the underpinning of how the two models of chapter 2 are made endogenous in this chapter, forming a single, dynamic model of telecommunications to study uncertainty.

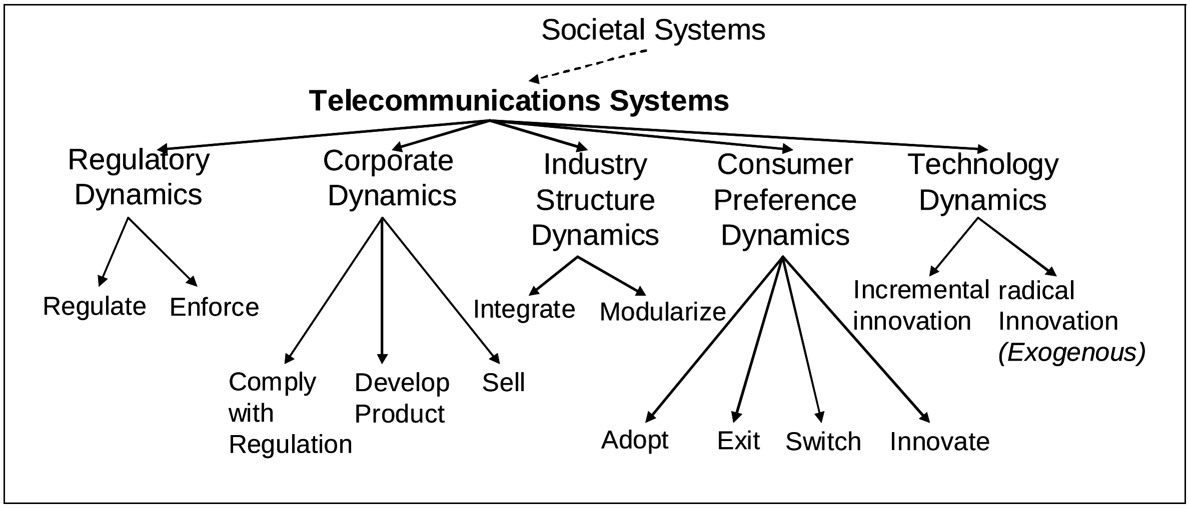


Figure 21: Extended Hierarchy behind the Endogenous Model

In this model, the regulators regulate by determining the scope and timing of regulation, and enforce those regulations. The corporations (or firms) work to comply with regulation, but they mainly focus on developing and selling products. They decide how much resource to allocate to quality versus innovation. The industry structure consisting of these firms either integrates or modularizes. Although, not shown here, these industry structure changes come about as a result of firms deciding to consolidate or outsource, respectively. Consumers make four decisions: to adopt, exit, switch from one service to another, or innovate. The consumer innovation may or many not circumvent regulation. The technology itself develops incrementally, within an industry, or radically, typically when an entrant disrupts an incumbent.

With such a model, we can study five types of uncertainty: regulatory, market, organizational, industry, and technological uncertainty. Uncertainty arises because of the actions of regulators, firms, consumers, or because of the nature of technology. The uncertainty in industry structure also results from these factors. The *regulatory uncertainty* arises because firms are uncertain about the regulatory action. In the previous chapter, we discussed the scope and timing related uncertainty. In this chapter, we will study the impact of antitrust regulation, which more directly affects the resulting industry structure. The *market uncertainty* arises from the actions of firms and consumers. On the supply side, firm's decision to affect switching costs and network effect, or to integrate/modularize introduces uncertainty. On the demand side, the consumers' preference for quality, innovation, price, and compatibility introduces the uncertainty. The *organizational uncertainty* arises because of how agile or sluggish a firm may be in allocating resources to quality vs. innovation. In a single industry, modular industry structure makes firms more agile than when the industry structure is integrated. But across different industries, firms may be more or less agile depending upon the nature of product or service at hand. The *industry uncertainty* arises from the actions of firms, regulators, and the nature of technology. Factors such as technological architecture's influence on firm's ability to integrate or modularize, or antitrust regulation's influence on firm's accumulation of market power introduces variation in the rate at which the industry structure becomes integral or modular. Finally, *technological uncertainty* arises from inherent architectural differences across different technologies that lead to inherently different ability to attain quality levels, innovation levels, and cost structures. The central concern of this chapter is: how each type of uncertainty affects our current understanding of disruption.

3.2.3 Application of Systems Theory

Metaphorically, the dynamics studied here may be thought of as interlocking gears, as shown in Figure 22. The intuition here is that a change in one subsystem leads to changes in other subsystems and in the system as a whole. To study the uncertainty, we first analyze the subsystem-level behavior using analysis. We then synthesize the understanding into a systems level behavior. This chapter studies subsystem level behavior, and the next chapter studies the emergent behavior in the whole system.

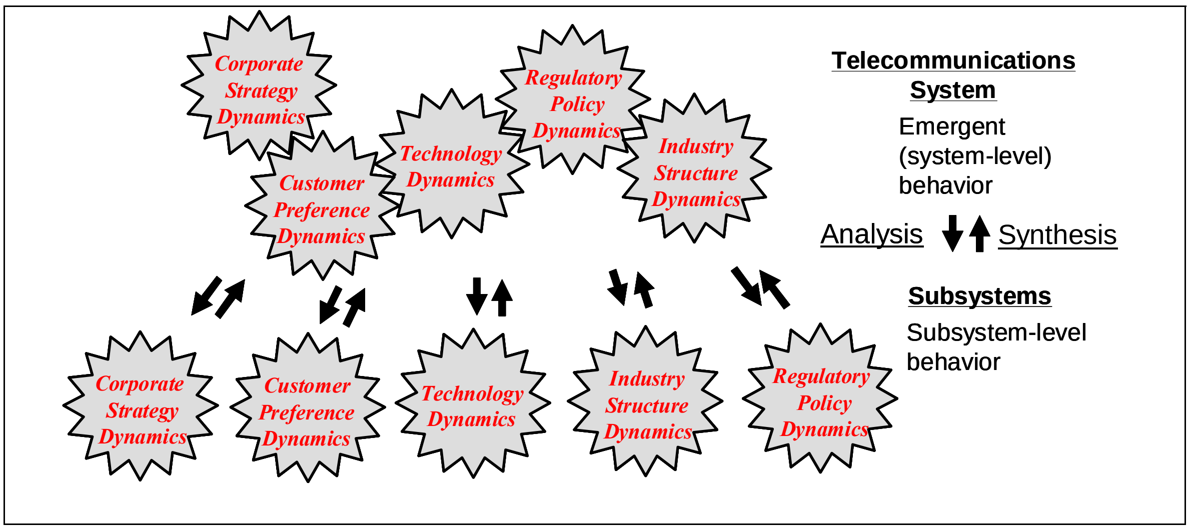


Figure 22: Gear Model and Near Decomposability

From a theoretical perspective, the central issue with using both analysis and synthesis to study emergent behavior is the arguable irreducibility of the higher order behavior of the whole into the lower order behaviors of the parts. Systems thinkers opine differently on this topic. For example, for systems biologists, emergent properties seem highly-irreducible, whereas for systems engineers they seem at least weakly reducible. To justify our use of both analysis and synthesis, such that the lessons learned with the analysis at subsystem-level can indeed be used to facilitate the understanding of the emergent behavior synthesized for the whole system, we rely upon Herbert Simon's key insight that resolves the dilemma of irreducibility by arguing that emergence can have a stronger or weaker interpretation (chapter 8, The Architecture of Complexity: Hierarchic Systems in (Simon 1981)).

According to Simon, "Applied to living systems," emergence makes a "strong claim that the putting together of their parts will not produce them or account for their character and behaviors," which he referred to as stronger interpretation of emergence. "Applied to non-human systems," by contrast, "emergence simply means that the parts of a complex system have mutual relations that do not exist for the parts in isolation," which he called the weaker interpretation of emergence. "By adopting this weak interpretation," Simon said, “we can adhere to reductionism in principle even though it is not easy (often not even computationally feasible) to infer rigorously the properties of the whole from the knowledge of the properties of the parts.” *Simon’s weak interpretation of emergence is what allows us to use analysis (reductionism) in socio-technical system, but also build theories of the higher-level emergent behavior by using synthesis.*

Further, our hierarchical decomposition of the telecommunications system heavily relies upon Simon’s theory of *near decomposability*, which he summed up the theory of near decomposability with “two prepositions: (1) in a nearly decomposable system the short-run behavior of each of the component subsystems is approximately independent of the short-run behavior of the other components; (2) in the long run the behavior of any one of the components depends in only an aggregate way on the behavior of the other components.”

The theory of near decomposability should be understood in conjunction with Simon’s weaker interpretation of emergence. The first preposition of the near decomposability theory allows us to, in principle, use analysis (or reductionism) in the short run to study subsystem-level behavior separately even though ultimately we may be interested in system-level emergent behavior. The second preposition of the near decomposability theory, in principle, allows us to infer rigorously the behavior of the whole in the long run from the knowledge of the behavior of the parts in aggregate. The study of uncertainty at subsystem level of this chapter, and the study of emergent behavior of the next chapter rest upon the foundation of the notion of weak emergence and the theory of near decomposability, as proposed by Simon.

3.3 Case Research: Misperceptions of Technology Disruptions

Let us first examine how many of the media-proclaimed “disruptive technologies” go on to displace the existing industrial order. For this examination, we analyze the contents of popular media for technologies that were declared as disruptive technologies subsequent to Christensen’s best selling book *The Innovator’s Dilemma*. Table 9 shows the technologies the New York Times[40] identified as “disruptive technology” anytime before March 2008.

Potentially Disruptive Technology	Industry[41]	Source
Organic LED	Electronic Equipment Manufacturers	(Eisenberg 1999)
Nano science in chip manufacturing	Semiconductor Equipment	(Markoff 1999)
Open Source Software	Computers: Systems Software	(Lohr 2000; Lohr

[40] We have restricted our analysis to New York Times (NYT) because the analysis of additional sources such as The Wall Street Journal and Business Week has a great overlap with NYT in technologies they declared as disruptive.
[41] We have used the industry classification provided by The Global Industry Classification Standard (GICS), a collaboration between Standard & Poor’s and Morgan Stanley Capital International, to classify the potentially disruptive technologies.

		2000)
Online Book Stores	Retail, Internet Services	(Gould 2000)
e-Port (Internet-based Advertising)	Advertising, Internet Services	(Kane 2000)
Digital Photography	Photographic Products	(Legomsky 2000)
Gigabit Ethernet	Communications Equipment	(Markoff 2000)
Online Investment Firms	Investment Banking and Brokerage	(McGEEHAN and Hakim 2000)
Online Journals	Publishing	(Nagourney 2001)
WiFi Mesh Networks	Wireless Telecommunications Services	(Markoff 2002)
Segway Scooter	Automobile Manufacturer	(Riordan 2002)
Alternative Energy - Solar, Biomass, Wind, Hydrogen	Oil and Gas Exploration and Services, Electrical Utilities	(Cortese 2003)
P2P Service Providers	Telecommunications Service	(Fallows 2004)
P2P File Sharing	Movies and Home Entertainment	(Varian 2005)
Online Shopping	Retail	(Lohr 2005)
Online Book Content	Publishing	(Peck 2006)
Online Commodity Futures Exchange	Commodity Futures Exchange	(Bajaj 2006)
YouTube (Political Advertising)	Advertising	(Carr 2006)
YouTube (Video Content Distribution)	Movies and Entertainment, Publishing	(Carr 2006)
Paint Films	Auto Parts and Equipment	(Brooke 2007)
Advertising using Social Networks	Advertising	(Stelter 2008)

Table 9 Technology identified as "disruptive technology" in popular media (The New York Times)

Just a glance at Table 9 lists several technologies that represent significant innovations; for example, open source software, digital photography, online shopping, and P2P file sharing. These are technological paradigms that have come to stay. However, the question we are interested in is: have these technologies displaced the existing industrial order?

To answer the above question, we first restrict our analysis to two fast clock speed industries – computers and telecommunications industries. We make such a choice consciously, as in these industries the change is rapid and provides better opportunity to study changes in the industry structure in a short period of time. Going forward, in this chapter we will study three potentially disruptive technologies: Open Source Software (Computer Systems Software Industry), WiFi Mesh Networks (Wireless Telecommunications Services Industry) and peer-to-peer (P2P) Service Providers (Telecommunications Service Industry). An example of P2P service is P2P VoIP such as Skype, Yahoo Messenger, etc., which is of central interest to this dissertation.

In Christensen's case of disruptive technologies, the disruption occurs when the entrant's technology has lower price and lower primary performance, but a great promise of ancillary performance in the future (Christensen 1997) when compared to the incumbent's technology. The primary performance refers to the features of the incumbent's technology that the customers care the most about. It can be thought of as the product/service quality. The ancillary performance refers to the additional benefits the new technology is likely to offer. It can be thought of as the product/service innovation. For example, in the case of VoIP, quality and reliability of a voice call can be considered the primary performance (or quality); whereas the integration of voice, video, and text that the P2P VoIP services offer can be considered ancillary performance (or innovation). Table 10 summarizes Christensen's conditions for disruptive technology.

Firm	**Price**	**Primary Performance** (Quality)	**Ancillary Performance** (Future Innovation)
Incumbent	High	High	Low
Entrant	Low	Low	High

Table 10 Christensen's conditions for disruptive technology

We must first ask the question: do technologies we propose to study fit Christensen's conditions listed in Table 10? For an entrant technology to fit Christensen's conditions it must have lower price, lower primary performance and higher future ancillary performance when compared to the incumbent. Table 11 shows that all the other three technologies we consider fit Christensen's conditions.

Potentially Disruptive Technology (Table 9 column 1)	**Price compared to Incumbent**	**Primary Performance compared to Incumbent**	**Ancillary Performance (future) compared to Incumbent**
Open Source Software	(Low) Many open source software are free	(Low) Initially, most open source softwares have poor reliability and ease of use. They also have more bugs.	(High) Open source software has quick turnaround on bug fixing and allows users to modify the code to their needs
WiFi Mesh Networks	(Low) Cheaper to build and operate than wireless networks	(Low) Lower mobility than wireless networks	(High) - Better speed in most places compared to wireless networks - Ability to switch between wireless and wired networks
P2P Service Providers	(Low) Many P2P Services such as Skype, IM are free	(Low) Less reliability and ease of use compared to telephony or television	(High) - Voice, Text, Video convergence - File sharing

Table 11 Potentially disruptive technologies in computers or telecommunications industry and their fit with Christensen's conditions

We now come to our main question: do technologies that fit Christensen's conditions (listed in Table 11) displace the existing industrial order? To investigate this question, we compare the industrial order pertinent to each potentially disruptive technology from the year 2000 with that in 2007. One might question the choice of the two years; particularly from the perspective that the WiFi Mesh Network and P2P Service Providers did not quite commercially exist in the year 2000. We would argue that the ideas did exist in other shapes or forms then, only that today they have acquired new names. Table 12 shows the analysis.

Potentially Disruptive Technology	**Industrial Order in 2000**	**Industrial Order in 2007**	**Key Observations**
Open Source Software	Top Software Suppliers (S&P 2000) 1. Microsoft 2. IBM	Top Software Suppliers (S&P 2007) 1. Microsoft	**No industry disruption** • Microsoft Windows controlled 90% of

	3. Computer Associates Int'l 4. Oracle 5. HP 6. SAP 7. Sun Microsystems 8. Unisys 9. Compaq Computers 10. Novell	2. IBM 3. Oracle 4. SAP 5. Symantec 6. HP 7. EMC 8. CA 9. Adobe 10. Fujitsu	the operating systems market in 2000 and continues to do so in 2007 • Open source operating systems such as Linux still holds low single digit penetration worldwide (S&P 2007)
WiFi Mesh Networks	Top Mobile Operators (S&P 2000) 1. Verizon 2. SBC/Bellsouth 3. Others 4. AT&T Wireless 5. Sprint PCS 6. Nextel 7. AllTel 8. VoiceStream Wireless	Top Mobile Operators (S&P 2007) 1. AT&T (after Bellsouth acquisition) 2. Verizon Wireless 3. Sprint Nextel 4. T-Mobile 5. Alltel 6. US Cellular 7. Leap Wireless 8. Dobson Communications	**No industry disruption** • US has 65000 WiFi Hotspots • Incumbents like AT&T and T-Mobile own 20000 Hotspots (1/3rd of the US total) • Handset Incumbents like Nokia, Samsung, Panasonic and (in the US) an entrant Apple Inc. lead the Wireless/WiFi dual phone market (S&P 2007)
P2P Service Providers	Long Distance Call Providers (S&P 2000) 1. AT&T 2. WorldCom 3. Others 4. Sprint	Leading Broadband Providers (S&P 2007) 1. AT&T 2. Comcast 3. Verizon 4. Time Warner 5. Charter 6. Qwest 7. Cablevision 8. Embarq 9. Windstream 10. Insight	**Major industry changes** **Early to predict disruption** • Telecommunications Access and Service has undergone a rapid change in the industry structure • The change is more broadly affected by the increasing processing speed and the Internet penetration • Incumbents such as

			AT&T and Verizon are still big; some through mergers and acquisitions • The P2P Service itself is successful in some economies like Japan/Korea, but slow in others

Table 12 Potentially Disruptive Technologies and the Industrial Order

Table 12 shows that Open Source Software and WiFi Mesh Networks have failed to displace the existing industrial order so far. In the case of Open Source Software, the paradigm has steadily gained market share, but the total market it captures is rather small. More curiously, in the case of WiFi Mesh Networks the incumbents of wireless telecommunications service, such as AT&T and T-mobile, have emerged as leaders in the new technology market. Finally, the case of P2P Service Providers is still open. Many forces are at play here. First, there is the shift from the traditional telephone and television networks to the more Internet-based services using cable or digital subscriber line (DSL) broadband. Then, there is the ever increasing computing power and the rise of the World Wide Web. The industrial order in this case is changing rapidly, but its early to say if the incumbents are losing.

So, what preserves the industrial order despite the technological breakthrough in the above cases? We contend that there are five types of uncertainties at work: regulatory, market, organizational, industrial, and technological. To help us understand the effects of these factors, in the following section we present a systems model of regulation, competition and innovation in telecommunications.

3.4 A Systems Model of Regulation, Competition, and Innovation in Telecommunications

We present the systems model by organizing it along the two theories of disruption, or equivalently, along clusters of subsystems to make it most intuitive. Deeper understanding of subsystem-level behavior will impart richer analysis of the different types of uncertainty, undertaken later in this chapter. Deeper understanding of the system as a whole will make accessible the emergent behavior, discussed mostly in the next chapter.

3.4.1 The Dynamics of Technology Disruption (Consumer-Firm Dynamics)

In the previous chapter, we introduced Regulatory Compliance Model and Competition in Telecommunications Model. Both models were kept minimally endogenous. In the Regulatory Compliance Model, closing the compliance gap was made endogenous, but factors that affect achieving the compliance, such as time to develop and deploy compliance mechanisms, achievable level of compliance, etc., were left exogenous. In Competition in Telecommunications Model, the adoption process was endogenous, but the product/service attribute that affect adoption, such as the price, quality, and innovation, were left exogenous. A virtue of such minimally endogenous models is that they allow for examining the outcome under all possible combinations of the values of the exogenous parameters. But their drawback is that there is no sense of what drives the exogenous parameters, so we cannot say which scenario of uncertainty (i.e., combination of parameter values) are most likely to arise and for how long each may persist. To overcome this drawback, we will now make the various parameters endogenous.

Equation 11 of chapter 2 showed that consumer choice depends upon product/service attractiveness, which is driven by four attributes: compatibility, price, primary performance (quality), ancillary performance (innovation). We made a conscious choice to include price, primary, and ancillary performance in this formulation, as such a model would let us explore the observations Christensen made about technology disruption (see Table 10). Compatibility (or Network Effect) was added to the product attractiveness formulation because it is so often present in the market for communications goods and services that excluding it would leave any model of communications industry underspecified.

Christensen's framework, which was qualitative, focuses on the context within which the firm identifies and responds to customers' needs, procures inputs and reacts to competitors. The only factor that is endogenous in his framework is firm's competitive strategy, particularly its past choices of markets to serve, which determines its perceptions of economic value in new technology or innovation. In this chapter, we build upon this endogenous notion of competitive strategy, but go beyond it by making price, primary performance, and ancillary performance endogenous.[42] For making these parameters endogenous, we rely on theories where possible; where theories are not developed, we base the formulations on unstructured interviews conducted with managers working for incumbents or entrants in the communications market. The formulations below illuminate several factors beyond firm's competitive strategy, such as changing regulation, architecture of technology, and industry structure that affect these attributes in the model below.

Endogenous Price

Equation 15 in chapter 2 showed that price, P, in this model is set equal to cost, C, disregarding margins and profit. We decided to not include the profit margin in this formulation because, as observed by Christensen, in a scenario of disruption, the important factor determining how entrants and incumbents can price their service is the fundamental difference in their cost structures. As such, the formulation for pricing strategy itself can be quite involved when growth and decline of market share of a single firm is studied (Paich and Sterman 1993; Sterman, Henderson et al. 2007). All of this complexity is avoided here.

[42] Remember, compatibility was already made endogenous in chapter 2 to formulate network effects.

The price is made endogenous by two formulations: economies of scale formulation that affects the marginal cost, C^v, and firm's decision to make vs. outsource functionality formulation that affects the fixed cost, C^f. For simplicity, each piece of the cost function adjusts in a piecewise linear fashion. Equation 16 introduces these two factors into the price equation.

Equation 16: Endogenous Price

$$P_i = C_i = (C^f_{min}\frac{M_i}{M^{max}} + C^f_{max}(1 - \frac{M_i}{M^{max}})) + (C^v_{min}\frac{S_i}{S^{max}} + C^v_{max}(1 - \frac{S_i}{S^{max}})) + C^z_i$$

Firm's fixed cost varies between the minimum value when the firm is fully modular, C^f_{min}, and its maximum value when the firm is fully vertically integrated, C^f_{max}, based on firm's modularity, M_i, as compared to the maximum modularity, M^{max}, the architecture permits. Firm's variable cost varies between the minimum value, C^v_{min}, and the maximum value, C^v_{max}, based on the economies of scale. If the firm dominates the market ($S_i \approx S^{max}$), the variable marginal cost is closer to the minimum value because of the economies of scale; whereas when the firm's installed base is small ($S_i \ll S^{max}$), the firm benefits little from the scale and the marginal cost is closer to the maximum. We will make the last component of this equation, Compliance Cost, C^z_i, endogenous later in the section on the dynamics of regulation.

Endogenous Quality and Innovation

The level of innovation (ancillary performance), I_i, of each firm's service depends only upon three factors: its maximum architectural limit, I^{max}_i, the attention/resources the firm devotes to it, R^i_i, and the time necessary for it to improve/deteriorate, τ^i_i. Similarly, the level of quality (primary performance), Q_i, of each firm's service depends only on three factors: its maximum architectural limit, Q^{max}_i, the attention/resources the firm devotes to it, R^q_i, and the time necessary for it to improve/deteriorate quality, τ^q_i. Equation 17 juxtaposes the identical formulations for innovation and quality; although; we shall see next that the two differ in how they are made endogenous.

Equation 17: Innovation and Quality

$$\frac{dI_i}{dt} = I^g_i - I^l_i$$

Where, I^g_i= Innovation gain, and I^l_i= Innovation loss.

$$I^g_i = R^i_i\frac{(I^{max}_i - I_i)}{\tau^i_i}, (I^{max}_i > I_i)$$

$$I^l_i = \frac{(I_i - I^{max}_i)}{\tau^i_i}, (I_i > I^{max}_i)$$

$$I^g_i = I^l_i = 0, (I_i = I^{max}_i)$$

$$\frac{dQ_i}{dt} = Q^g_i - Q^l_i$$

Where, Q^g_i= Quality gain, and Q^l_i= Quality loss.

$$Q^g_i = R^q_i\frac{(Q^{max}_i - Q_i)}{\tau^q_i}, (Q^{max}_i > Q_i)$$

$$Q^l_i = \frac{(Q_i - Q^{max}_i)}{\tau^q_i}, (Q_i > Q^{max}_i)$$

$$Q^g_i = Q^l_i = 0, (Q_i = Q^{max}_i)$$

Making Innovation and quality endogenous will require understanding what drives the resources allocated, maximum limit, and time to change each parameter. We begin with resources.

Resource Allocation

Each firm has a total attention, A_i, that gets divided into attention to innovation, A_i^i, quality, A_i^q, and compliance, A_i^z. Similarly, each firm has a total resources, R_i, gets divided into attention to innovation, R_i^i, quality, R_i^q, and compliance, R_i^z. Such a resource formulation is motivated by research in strategic management (Gary 2005). Here, both firms (industries) are assumed to be endowed with equal total attention/resources. Such an assumption means that both firms have the necessary resources for product development; the only decision they make is which aspect of the service – innovation, quality, or compliance – must they focus on. In reality, more dominant firms or industries control more resources and the competition for resources exists not in a single but across all industries. Hence such an assumption weakens the lessons we can draw about the exploitation of market power to an extent.

Equation 18: Attention and Resources

$$A_i = A_i^i + A_i^q + A_i^z$$
$$R_i = R_i^i + R_i^q + R_i^z$$

Attention here simply specifies the amount of resources a firm intends to allocate towards achieving a particular attribute. Separating attention (or intended resource allocation) from the actual resource allocation lets us introduce firm's agility in refocusing resources when necessary (discussed later). Firm's attention and resources are formulated as follows.

The formulation for how firms diversify resources between innovation and quality in a dynamic setting, in an industry where disruption has already occurred, and at the level of abstraction necessary for our model, does not exist in the literature. Therefore, we must derive a behavioral formulation for attention/resource allocation from unstructured interviews. Such a formulation is akin to behavioral game theory model, where incumbent and entrant firms play a dynamic game of incomplete information for multiple rounds (Gibbons and National Bureau of Economic Research. 1996).

Figure 23 shows how firms allocate resources when threatened with a potential disruption, as deduced from several interview quotes. When there is no threat of disruption and the competition is well understood, established firms primarily focus on quality, and the focus on innovation adoption is low. The established firms focus on innovation only with the entry of non-traditional entrants. Moreover, they often rely on expected growth of the entrant technology's market share to determine how much attention to pay to innovation (ancillary performance). Such behavior can be deduced from the following quote from a senior manager working for a large incumbent:

"Incumbent cares about ancillary performance only with: the entry of the non-traditional competitor, and the growth of its market share." Director, CTO Organization, Incumbent A[43]

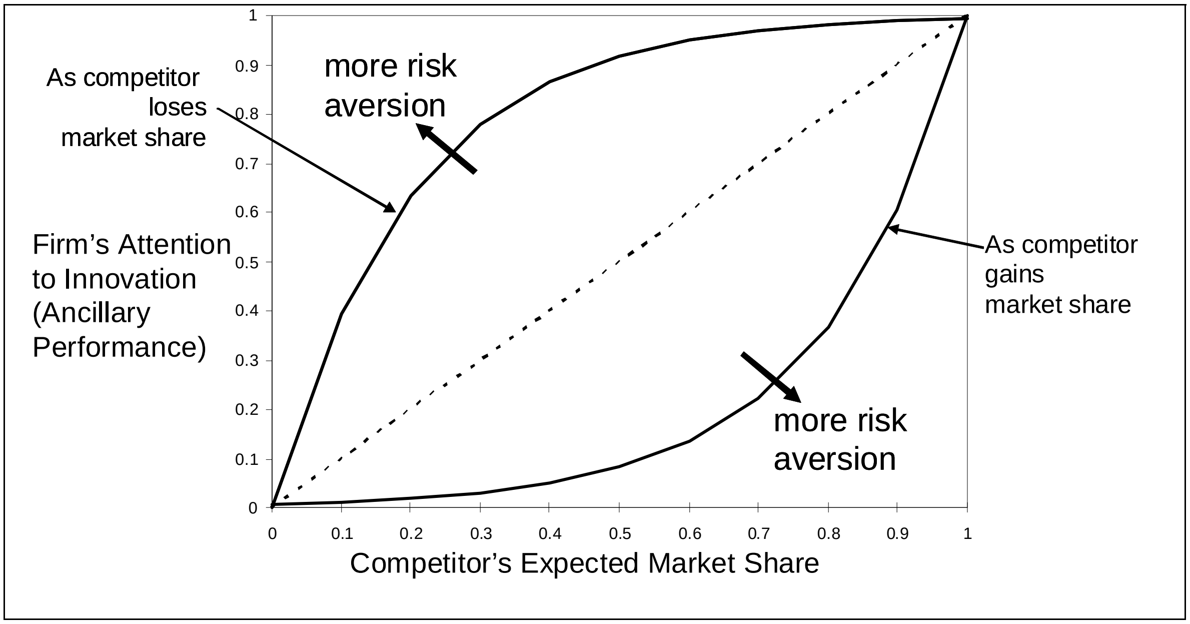


Figure 23: Resource Allocation under the Threat of Disruption

The formulation for incumbent's (dominant firm's) attention to innovation, A_1^i, is therefore:

Equation 19: Attention to Innovation

$$A_1^i = f(E(S_2))$$

Where,
$E(S_2)$ is the Entrant's (competitor's) Expected Market Share
f = function for Effect of Entrant's Market Share on Incumbent's Attention to Innovation (Ancillary Performance).

The convex curve in Figure 23 shows the shape of A_1^i.

Entrant's Expected Market Share, $E(S_2)$, is formulated using a standard trend function as in (Sterman 2000) pp. 634. The Effect of Entrant's Market share on Incumbent's Attention to Ancillary Performance, function *f*, can be deduced from quotes such as the following:

[43] As requested by some interviewees, we have replaced their exact identities with more generic Incumbent A, Entrant A, etc., because of the strategic nature of the information in this part of the research.

"First [when the entrant enters] the question is whether this is a price game or a performance game. Then, you realize the future is [in] ancillary [services]." Chief Strategist and Architect, Incumbent B

Such a quote exhibits risk aversion on the part of established firm when responding to potential disruptions. Equation 20 shows the formulation or function *f*, where λ is the coefficient of risk aversion, the greater the λ the more is the risk aversion.

Equation 20: The Effect of Entrant's Market Share on Incumbent's Attention to Innovation

$$f(x) = e^{-\lambda (1-x)}$$

Note that since the total attention, A_i, is constant and fixed, knowing attention to innovation takes us one step closer to knowing attention to quality, A_i^q, as per Equation 18.

To complete the discussion of attention to innovation and quality, we must also discuss how firms diversify resources in the reverse direction (i.e., from innovation to quality). This is shown in Figure 23 with a concave curve, which can be best understood by following it from the top-right corner. The top-right corner can be imagined as representing an entrant who is fully focused on innovation at the time of the market entry and attempting to disrupt the incumbent who has full market share. Such a starting position is consistent with the following quote:

"After the prototype phase, majority of the attention is on developing new features (ancillary performance) and a little on scale and reliability (primary performance)." CTO, Entrant A

As the entrant gains market share, its consumers expect it to focus on what they perceive as entrant's core product or service. Entrant's shift in focus from innovative prototyping to serving the mass market with quality also exhibits some risk aversion, and hence the concavity in the curve that exhibits this behavior (see Figure 23).

The attention firm pays to innovation or quality translates into actual resource allocation after the Resource Reorientation Time, τ_i^r. This reality is deduced from the following quotes:

"First you have to write a report, then convince the leadership [about the reallocation], and then the people who will work on it (the new idea)." Director, CTO Organization, Incumbent A

"You have to redeploy your best people. Your best people are steeped into the old paradigm. Ideally, you want them to lead the new one too, so you have to take them along. This takes time." Chief Strategist and Architect, Incumbent B

Equation 21: Resources to Innovation

$$\frac{dR_i^i}{dt} = R_i^g - R_i^l$$

Where, R_i^g= Resource to innovation gain, and
R_i^l= Resource to innovation loss.

$$R_i^g = \frac{\left(A_i^i - R_i^i\right)}{\tau_i^r}, (A_i^i > R_i^i)$$

$$R_i^l = \frac{\left(R_i^i - A_i^i\right)}{\tau_i^r}, (R_i^i > A_i^i)$$

$$R_i^g = R_i^l = 0, (R_i^i = A_i^i)$$

If we make Resource Reorientation Time, τ_i^r, endogenous in Equation 21, we will have made endogenous resources to innovation (and thereby to quality). However, as we know from Equation 17, making resources endogenous is only the first of three steps in making innovation endogenous as the ultimate level of innovation/quality depends not only upon resources allocated to achieve it, but also on their architectural limit, and the time necessary it to improve/deteriorate. All of these factors, including τ_i^r, depends upon industry dynamics (precisely, on *double helix*), which we tackle next.

3.4.2 The Dynamics of Industry Disruption (Technology-Firm-Industry Dynamics)

We will now make endogenous the industry structure (represented by modularity) and its impact. Formulations in this section are based upon the double helix. To quickly recap, the double helix argues that when the industry structure is vertical the forces of disintegration push toward a horizontal and modular configuration. The forces include::

1. *Niche Competition:* The relentless entry of niche competitors hoping to pick off discrete industry segments;
2. *Organizational Rigidity:* The challenge of keeping ahead of the competition across the many dimensions of technology and market required by an integral system; and
3. *Dimensional Complexity:* The bureaucratic and organizational rigidities that often settle upon large, established companies.

On the other hand, it argues that when an industry has horizontal/modular structure, another set of forces push toward more vertical integration and integral product architectures. These forces include:

4. *Market Power:* Technical advances in one subsystem can make that the scarce commodity in the chain, giving market power to its owners;
5. *Industry Integration:* Market power in one subsystem encourage bundling with other subsystems to increase control and add more value; and
6. *Technological Integration:* Market power in one subsystem encourages engineering integration with other subsystems to develop proprietary integral solutions.

We will now use these insights to make the industry structure endogenous.

Endogenous Modularity

Modularity increases as the interfaces standardize and decreases as they become proprietary.

Equation 22: Modularity

$$\frac{dM_i}{dt} = M_i^g - M_i^l$$

M_i^g is modularity gain, which occurs with interface standardization and firms outsourcing functionality. As stated in argument 1 of the double helix above, such interface standardization increases as the relentless entry of niche competitors pick off discrete industry segments.

Equation 23: Interface Standardization and Functional Outsourcing

$$M_i^g = \alpha_s \, g(S_{i-})$$

Where,
α_s = Maximum Fractional Rate of Interface Standardization, and
g = Effect of competitor's market share on interface standardization.

α_s is exogenous, and depends upon the rate at which factors such as architecture and sometimes regulation permits industries to become modular. Equation 33 shows the formulation or function g, where μ is the coefficient of interface standardization, the more conducive the architecture for standardizing interfaces the higher is μ, and vice versa.

Equation 24: The Effect of Competitor's Market Share on Interface Standardization

$$g(x) = e^{-\mu\,(1-x)}$$

The interface standardization rate increases towards α_s and is convex in competitor's market share.

Similar formulation is used for the loss of modularity, M_i^l, where, according to arguments 4, 5, and 6 of the double helix, rising market share reduces modularity by pushing the architecture and industry structure to become more integral. The set of equations in Equation 25 show the formulation. Notice that the loss of modularity depends upon firms own market power (unlike the modularity gain, which depended upon competitor's market power).

Equation 25: Interfaces becoming Proprietary and Functional Integration

$$M_i^l = \alpha_p \, h(S_i)$$

Where,

α_p = Maximum Fractional Rate of Making Interfaces Proprietary, and

h = Effect of firm's own market share on making interfaces proprietary.

$$h(x) = e^{-\nu\,(1-x)}$$

Where,

ν is the coefficient of making interfaces proprietary

Antitrust regulation plays an important part in determining the amount of market power accumulation that occurs within a single firm or a collection of them. So, regulation influences both α_p, which is exogenous, and ν. In regulatory regimes with more restrictions on the accumulation of market power the values of α_p and ν are low, and vice versa.

In this model, a single attribute—modularity—describes the state of each industry structure. Modularity represents the level of integration/modularization in both technology and industry structure for that service. Importantly, this model only applies to cases where the modularity of technology and industry structure are positively correlated.

Organizational Rigidity's and its Impact on Resource Allocation

Argument 3 of the double helix identified that firms in vertically integrated industries become bureaucratic and experience organizational rigidities. We use this insight to make the resource reorientation time, τ_i^r, endogenous.

Equation 26: Endogenous Resource Reorientation Time

$$\tau_i^r = \tau_{min}^r \frac{M_i}{M^{max}} + \tau_{max}^r (1 - \frac{M_i}{M^{max}})$$

The formulation in Equation 26 models that since firms in the most modular structure experiences the lowest organizational rigidity, such firms are agile and take the least amount of time to reorient resources, τ_{min}^r. Conversely, firms in the most integrated structure become rigid. Such firms lose the ability to refocus priorities quickly and experience longest resource reorientation times, τ_{max}^r. With Equation 26 and Equation 21, we have made endogenous the resource part of the innovation and quality equation (Equation 17). The formulation here is kept linear; although, in reality, resource reorientation time may be more non-linear in modularity. Specifically, more modular structures may be even more agile and more integrated structures even more rigid.

Dimensional Complexity and its Impact on Innovation and Quality

Argument 2 of the double helix identified that firms in vertically integrated industries struggle to keep ahead of the competition because of the dimensional complexity across the many technologies and market. We use this insight to endogenously determine the architectural limits on innovation, I_i^{max}, and quality, Q_i^{max}.

Equation 27: Endogenous Architectural Limits on Innovation and Quality

$$I_i^{max} = I^{max}\frac{M_i}{M^{max}} + I^{min}(1 - \frac{M_i}{M^{max}})$$
$$Q_i^{min} = Q^{min}\frac{M_i}{M^{max}} + Q^{max}\left(1 - \frac{M_i}{M^{max}}\right)$$

I^{max} and Q^{max} are architectural upper bounds of innovation and quality, respectively; whereas I^{min} and Q^{min} are architectural lower bounds of innovation and quality, respectively. We assume that both incumbent and entrant industry are ultimately capable achieving the same level of quality and innovation, given the right conditions. In other words, since in this model, like in real life, incumbents ultimately have the right to cannibalize their old product architecture and divert attention/resources to the architecture that is more like that of the entrant, despite the delay involved in doing so, some incumbents can ultimately attain the same level of innovation as entrants. Similarly, entrants are allowed to ultimately attain the level of quality the incumbents offer.

The formulation in Equation 27 models the following scenario: when the industry structure integrates (modularity reduces), firms in such industries can achieve higher quality because of higher functional control, but they struggle to innovate because of growing dimensional complexity. Conversely, as the industry structure becomes modular, firms in such industries can achieve higher innovation because they focus on fewer modules and so they are dealing with lower dimensional complexity, but the system level quality suffers because of lower system-level functional control.

With Equation 27, we have made endogenous the architecture limits part of the innovation and quality equation (Equation 17). This formulation is also kept linear to simplify analysis.

Functional Control and its Impact on Innovation and Quality

We use the dimensional complexity insight (Argument 2) of the double helix further to make the time necessary to improve/deteriorate performance, τ_i^i, and quality, τ_i^q.

Equation 28: Endogenous Time Necessary to Improve/Deteriorate Innovation/Quality

$$\tau_i^i = \tau_{min}^i\frac{M_i}{M^{max}} + \tau_{max}^i(1 - \frac{M_i}{M^{max}})$$
$$\tau_i^q = \tau_{max}^q\frac{M_i}{M^{max}} + \tau_{min}^q(1 - \frac{M_i}{M^{max}})$$

τ^{i}_{min} and τ^{q}_{min} specify the minimum time necessary to improve innovation and quality their maximum achievable values, respectively; whereas τ^{i}_{max} and τ^{q}_{max} specify the minimum time necessary to improve innovation and quality to their maximum achievable values, respectively. It is easier to think about these times in terms of the time to improve innovation/quality rather than to deteriorate it. However, the same constants are used for the gain as well as loss of innovation/quality.

The formulation in Equation 28 models behavior where quality can be improved in a shorter time in an integrated structure because of the functional control but the innovation takes longer. Conversely, improving innovation takes shorter when the industry structure is modular but the quality takes longer to improve. The formulation here is also kept linear to simplify the analysis. With Equation 28, we have made endogenous the only remaining parameter determining innovation and quality formulation in Equation 17.

Next, we will connect—to recall chapter 2—the Competition in Telecommunications Model to the Regulation Model, which will allow us to make cost (price) and resources fully endogenous, as we will formulate the Compliance Cost, C^{z}_{i}, in the endogenous price equation (Equation 16), and Resources to Regulation, R^{z}_{i}, in the endogenous resources equation (Equation 18).

3.4.3 The Consensus Conjecture (Regulation-Firm-Industry Dynamics)

The relationship between industry structure and the ability to comply with regulation as well as the cost of doing so is not well understood. However, based on the case research in chapter 2, which showed a shift from higher to lower consensus over regulatory issues, *we conjecture in this model that increasing modularity may sharply increase the coordination cost and time to comply, limiting the achievable compliance in modular structures.* The exact nature of the relationship between modularity and the time to comply or coordination cost are not well understood, still a very long time required to build consensus and a very high coordination costs in a highly modular industry can be inferred from the many historical cases, where modular industries have fought long-drawn battles over developing common standards (Hounshell 1984; Levinson 2006). [44] The formulations below rest upon this conjecture. In the next chapter we will discuss the implications of this conjecture further.

Time to Comply and Achievable Compliance

We begin by assuming that the desired level of compliance is possible to achieve *under integrated technology and industry structure.* The level of regulatory compliance in PSTN has demonstrated this point (see Figure 5). As discussed in chapter 2, for recent regulations such as E911, it has taken us approximately 30 years to be fully compliant.

[44] For more details on historical cases see footnote 81.

We can think of this duration as minimum time to comply, τ^x_{min}. The industry-level time to comply, τ^x_i, can then be formulated as in Equation 29.

Equation 29: Time to Comply

$$\tau_i^x = \frac{\tau^x_{min}}{\left(1 - e^{-\sigma(M^{max} - M_i)}\right)} \;, \sigma \geq 1$$

Here, σ is the coefficient of effort required to build consensus, which takes a value such that the time for an industry to comply with regulation is convex in modularity. The formulation renders an inordinately long time necessary to comply in a fully modular industry, indicating the impossibility of achieving high compliance in a very modular structures.

Achievable compliance is formulated as in Equation 30. This formulation shows that as the modularity of the industry structure increases, the achievable compliance falls from that achievable in an integrated industry structure, Z^{max}, in a convex fashion, until it reaches the minimum achievable compliance, Z'_{min}.[45]

Equation 30: Achievable Compliance

$$Z'_i = Z^{max}\left(1 - e^{-\sigma(M^{max} - M_i)}\right), \quad Z'_{min} \leq Z'_i \leq Z^{max}$$

Equation 29 and Equation 30 complete the formulation for how competition and industry structure affect the regulatory compliance (see Equation 3 and Equation 1). We will now formulate the other half, i.e., how regulation affects competition with the help Compliance Cost, C^z_i, and Resources to Regulation, R^z_i.

Compliance Cost and Resources to Regulation

We make several assumptions to simplify formulations for compliance cost, and resources to regulation. As for the cost, we assume that regulated firms pass the compliance cost on to their consumers. As for the resources, we assume that regulated firms (and not regulators) always provide the resources necessary for regulatory compliance. Moreover, we assume that a regulated firm devotes a finite maximum amount of resources, R^z_{max}, to regulatory compliance, thereby limiting the maximum compliance cost to C^z_{max}.

Equation 31shows the formulation for Compliance Cost, C^z_i. It shows that when the industry is fully integrated, the cost of compliance reaches a minimum, C^z_{min}, as the functional control is high and little coordination is required between firms for achieving compliance.[46] Moreover, vertically integrated firms also enjoy the economies of scale in

[45] This formulation can be simplified by letting the achievable compliance go to zero. However, we assume that some minimum compliance, which may be far lower than that required and, may still be achievable in a fully modular structure. As indicated by the formulation for time to comply, such low achievable compliance may also take a very long time to achieve in a fully modular structure.

[46] In reality, Compliance Cost may be thought of as having three components: Fixed Cost of Deployment, Marginal Cost of Maintenance, and Marginal Cost of Coordination. Since the fixed and marginal cost are

deploying regulatory mechanisms. As the modularity of the industry structure increases, the compliance cost approaches its maximum value in a convex fashion.

Equation 31: Compliance Cost

$$C_i^z = C_{max}^z \, e^{-\sigma(M^{max} - M_i)} , C_{min}^z \leq C_i^z \leq C_{max}^z$$

With Equation 31, not only can we make the cost, hence the price, fully endogenous (see Equation 16). Together with innovation and quality, the endogenously generated price makes the product/service attractiveness fully endogenous (see Equation 11).

Equation 32 shows the formulation for resources to regulation, R_i^z. It shows that when the industry is fully integrated, the minimum resources need to be allocated to regulation since the vertically integrated firms have the necessary functional control to achieve regulation. As the modularity of the industry structure increases, resource allocate to regulation approach the maximum value in a convex fashion.

Equation 32: Resources to Regulation

$$R_i^z = R_{max}^z \, e^{-\sigma(M^{max} - M_i)}, R_{min}^z \leq R_i^z \leq R_{max}^z$$

With Equation 32, we can not only make resources fully endogenous (see Equation 18), but knowing resources to regulation as well as resources to innovation (Equation 21) now makes it possible to deduce resources to quality, R_i^q.

We now have a fully endogenous model systems model of regulation, innovation, and competition in telecommunication. In the sections to follow, we will first calibrate the model with PSTN data and VoIP forecasts to provide a form of validation. We will then study its behavior under different types of uncertainty.

3.4.4 Model Calibration

Figure 24 the outcome of an exercise where the fully endogenous systems model is calibrated against PSTN data since 1935. The figure illustrates a good fit between the data and the model outcome. The business cycle in PSTN data, represented by overshoots and dips, are not present in the model outcome because there is no capacity formulation in the model. Omitting capacity formulation is a conscious choice we have made for two reasons. First, this research concerns disruptive trends that occur over a long period and not on individual business cycles. Second, in the communications industry today, firms

present for both incumbent as well as the entrant industry, we have considered only the coordination cost, which in our view is really the key differentiating factor between an integrated and a modular industry.

are less paranoid about building capacity as compared to which innovative trends to pursue and what might disrupt them.[47]

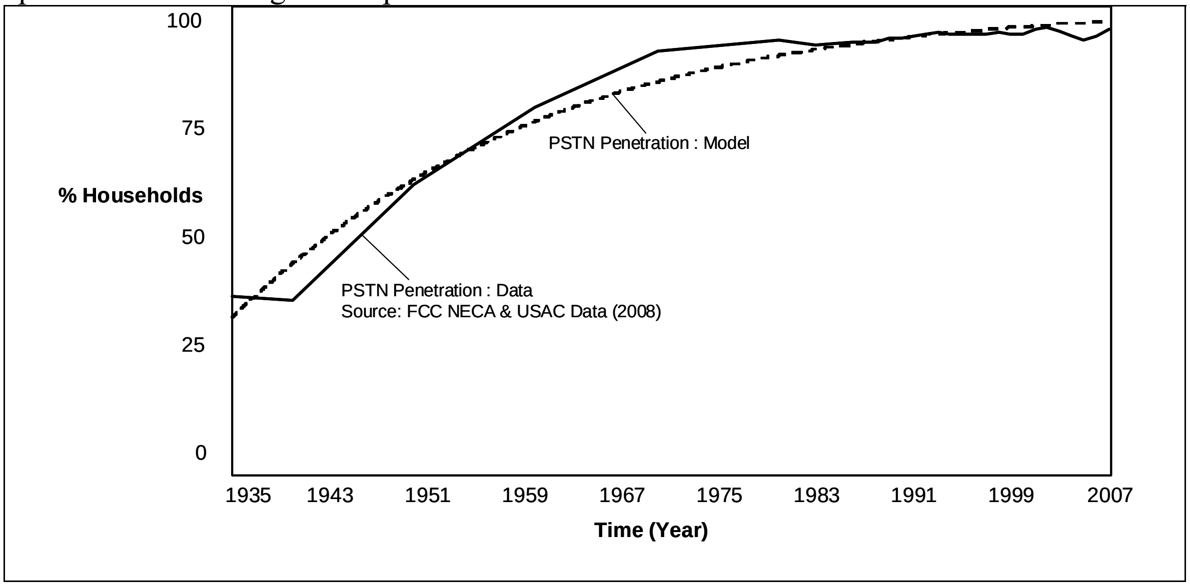


Figure 24: Calibration with PSTN Data

In the above calibration against PSTN data, there was no entrant. So, the calibration algorithm modifies only those factors that affect adoption such as advertizing, word of mouth, and network effect. By contrast, Figure 25 shows the outcome of model calibration against a VoIP forecast, where the calibration algorithm also varies parameters affecting firm's product attractiveness to calibrate two industries (PSTN and VoIP) in competition.

[47] Capacity concerns do exist from the perspective of "net neutrality," so if we were to study that issue with such a model, adding capacity would be worth considering.

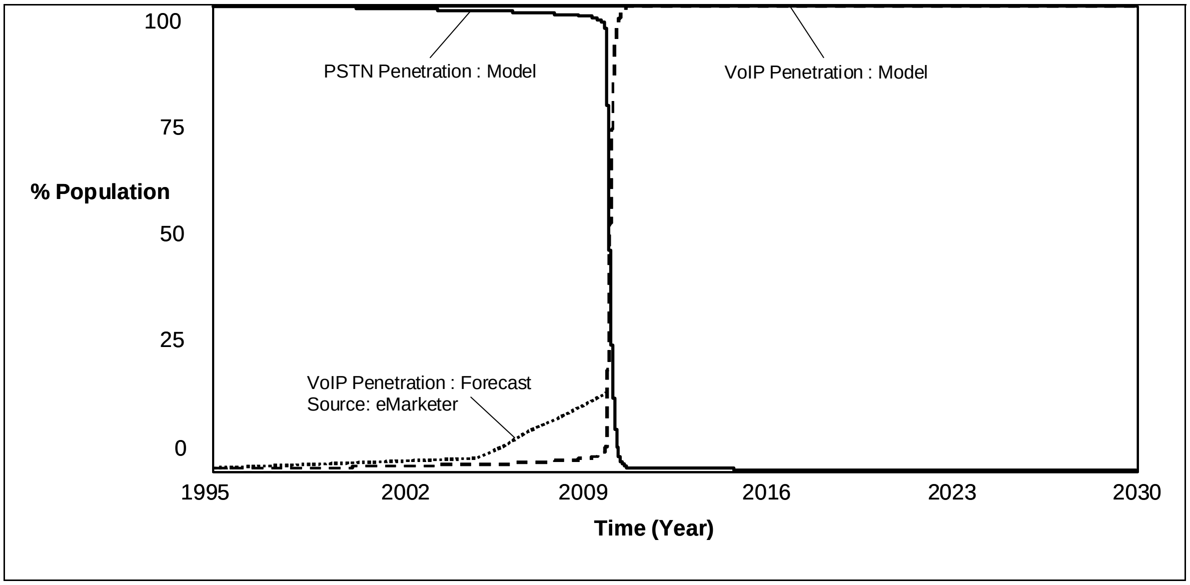


Figure 25: Calibration with VoIP Forecast

The outcome of VoIP calibration shows a strikingly disappointing reality. From the analysis of three different forecasts (only one of which is shown here), it shows that *all commercially available VoIP forecasts today are wrong!* We can say this because after running more than 3000 different combinations of parameter values, the calibration algorithm consistently shows that the a good fit with commercial VoIP forecast is achieved only when a constant fraction of switching is allowed from incumbent to the entrant, setting all other effects to zero. Meaning, all commercial forecast models have no uncertainty such as firm's response to disruption, changes in industry structure, etc. Such assumption is completely fictional! While disappointing in a way, such outcome endorses the importance of studying uncertainty, the main thrust of this chapter, even further.[48]

3.5 Results

3.5.1 Multiple Disruptions Base Behavior

Results in chapter 2 showed how a model of competitive dynamics, where most of the product/service attribute are exogenous, generates a pattern for a modular technology and industry disrupting an integrated one. In this chapter, we must begin the analysis of the endogenous model developed in this chapter with a question: Can a pattern of modular industry disrupting an integrated one be simulated with the fully endogenous model? Figure 26 shows that such a model is capable of generating not just a single, but multiple subsequent disruptions. Hence, such a model may even be used for studying industries such as telephone switching where there are multiple waves of disruption.

[48] Please follow Appendix D for understanding model validation beyond this calibration exercise.

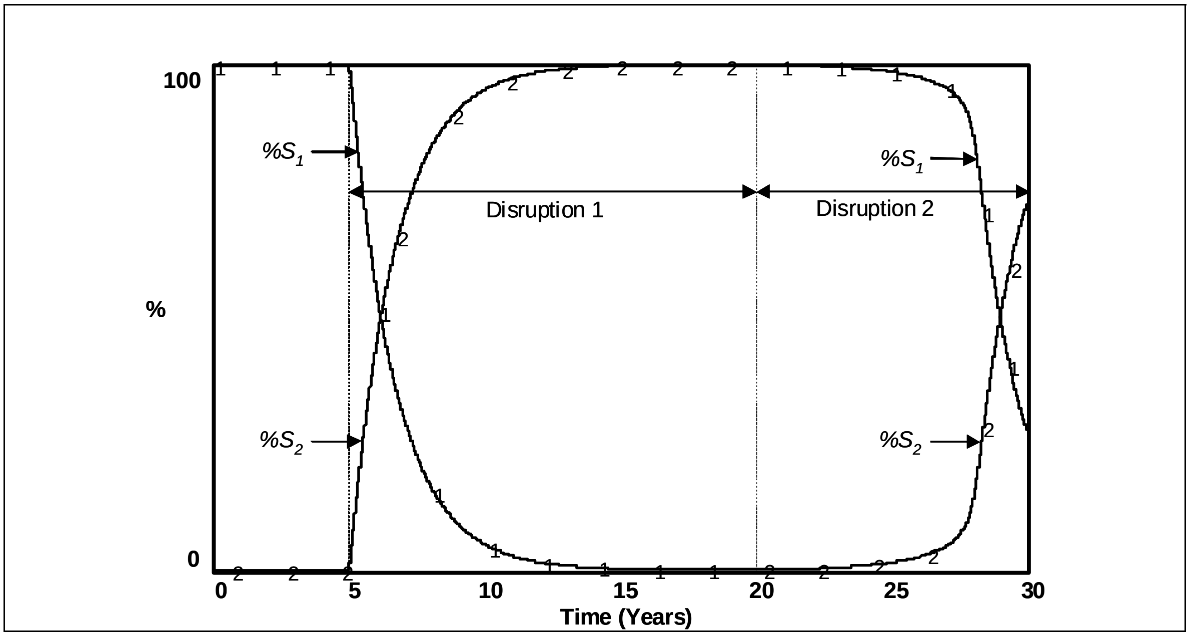


Figure 26: Endogenously Generated Multiple Disruptions

The simulation in Figure 26 is set up such that the modular entrant enters at year 5 and is regulated at year 10. The incumbent disrupted is fully integrated and compliant with regulation. Initially, the product attributes are set up such that the entrant has lower price, lower quality (primary performance), and higher innovation (ancillary performance) as compared to the incumbent, as per Christensen Conditions (see Table 10).

Such a model generates multiple disruptions because it makes endogenous the industry dynamics (the dynamics of double helix). The double helix dynamics can be understood by following Figure 27. To start with, multiple disruptions depicted above forms the backdrop here (see lines 1 and 2). Before the entrant's market entry (year 5), the incumbent represents a firm in a highly integrated industry (see line3 showing near zero modularity, so a highly integrated structure). As expected, at the time of market entry, the entrant offers a service that is highly attractive on the innovation dimension (line 5), but weak on the quality dimension (line 6). Entrant also offers somewhat attractive price (line 7), but currently enjoys no benefits of network effect (line 8) because it has a small installed base.

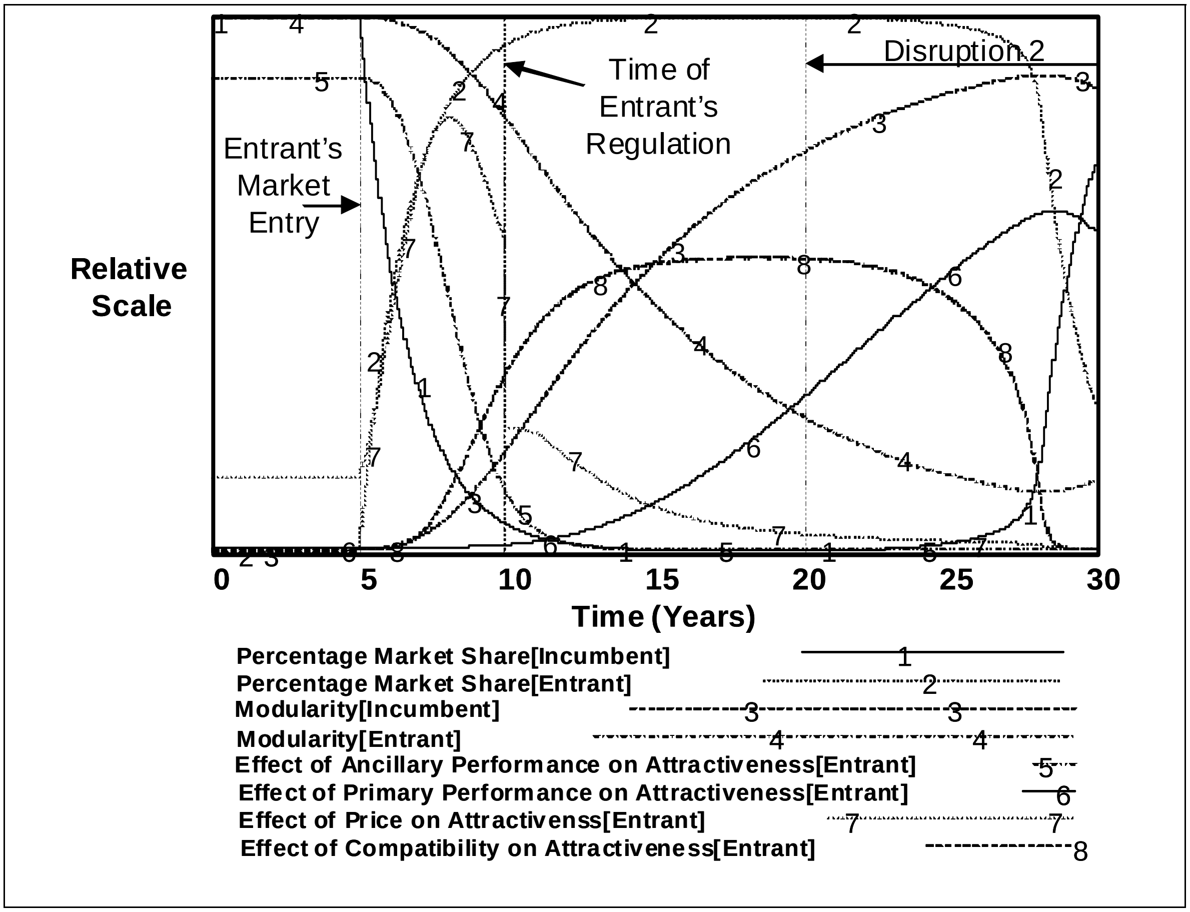


Figure 27: Multiple Disruptions and the Dynamics of Double Helix

As modular niche entrants gain market share (line 2), the incumbents begin to disintegrate in order to become less organizationally rigid and shed dimensional complexity (i.e., their modularity increases, line 3). As entrants gain market power, however, they integrate at the level in terms of control and architecture (i.e., their modularity reduces, line 4). The functional control gained from integration facilitates entrants to attain higher quality. And entrants' growing installed base requires them to focus on quality. Jointly, these factors lead to higher quality service from entrants (line 6). The opposite are the dynamics of innovation. With integration, entrant's product/service grows in scope and dimensional complexity, which limits their ability to innovate. Moreover, the focus on quality leaves them with fewer resources to innovate. These factors begin to reduce the innovativeness of the entrant's service (line 5). With increasing market share, entrants initially enjoy economies of scale, so their already lower price becomes even more attractive (line 7). However, with integration, their fixed costs grow, increasing price. An additional blow to entrant's price advantage (attractiveness) comes with regulation (at year 10). With higher installed base, entrants also enjoy the benefits of network effects they did not have before (line 8). At the onset of the second disruption, the originally modular entrants look much like the incumbents they had disrupted several years back – highly integrated, with high quality, but low innovation adoption and less attractive price – setting stage for the next wave of disruption.

3.5.2 Analysis of Uncertainty

We can now turn to different types of uncertainty that blur this pristine vision of successful disruption.

3.5.2.1 Market Uncertainty

As stated earlier, market uncertainty arises from the actions of firms and consumers. On the supply side, we study uncertainty that arises from firm's decision to affect network effect (by determining who to interoperate with) and switching costs. On the demand side, we study the uncertainty introduced because of how consumer value quality, innovation, price, and service compatibility.

Network Effect

To recap, direct network effects are present if adoption by different users is complementary, so that each user's adoption payoff, and his incentive to adopt, increases as more others adopt (Fisher and Massachusetts Institute of Technology. Dept. of Economics. 1990). Figure 28 shows the highest market share the entrant achieves during a simulation[49] for different levels of network effect. This plot is produced by aggregating the outcomes of many runs with different levels of network effect.

Figure 28 shows that *strong network effects can prevent technology disruption.* It shows a sudden phase shift in the entrant's maximum market share, *max* $\%S_2$, as a function of the level of network effect, illuminating two regions: (1) a region of weak network effect where the entrant disrupts, and (2) a region of strong network effect where there is no disruption and the incumbent retains the market. More importantly, it shows that strong network effect produces a winner takes all (WTA) outcome. When the network effect is strong, it has higher influence on product attractiveness as compared to other factors such as price, quality, innovation or switching costs. As a result, strong network effect helps the incumbent retain its entire market share. Conversely, when the network effects are weak, factors such as lower price and higher innovation give entrant the advantage and the WTA outcome is less likely. At a theoretical level, these insights have been known to information economists (Chapter 31, Coordination and Lock-In: Competition with Switching Costs and Network Effects, by Joseph Ferrell and Paul Klemperer in (Armstrong and Porter 2007)); however, the results here are generated in a fully endogenous framework, and are posited in the context of a modular force disrupting and integrated one.

[49] Note that we do not study here the equilibrium market share because the model we have built is a disequilibrium model. Hence, the only meaningful parameter to study is the highest market share a firm achieves.

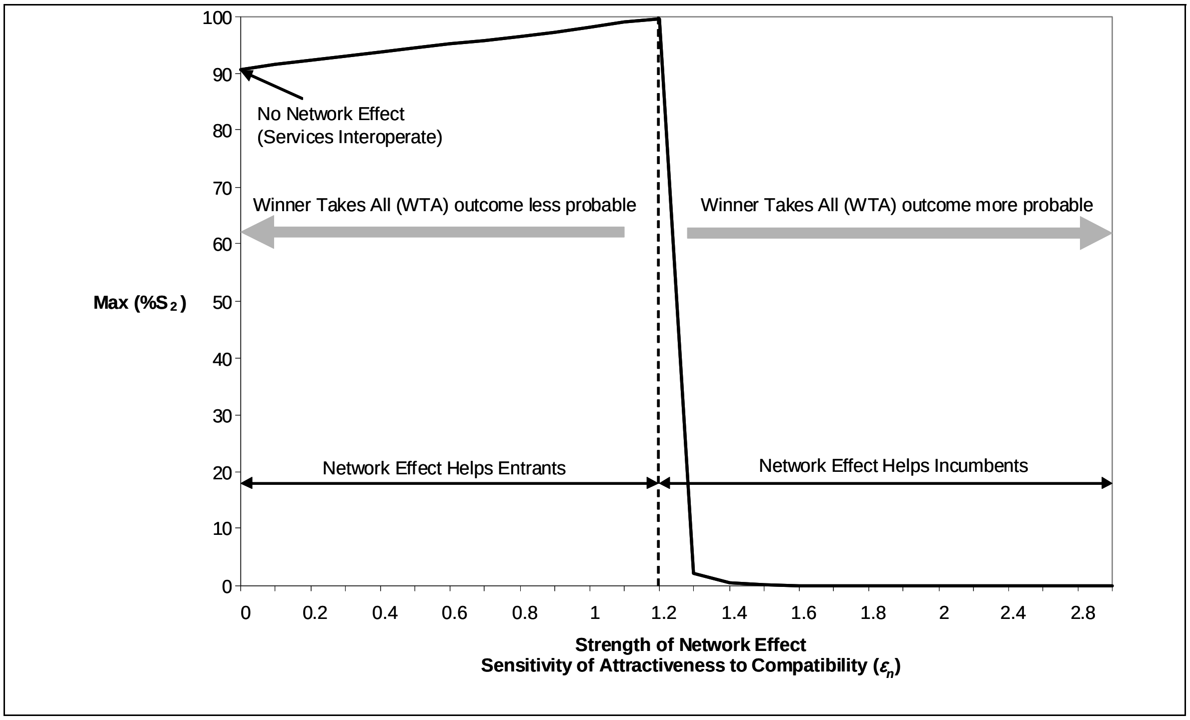


Figure 28: Network Effect Phase Plot

Switching Cost

A product/service has classic switching costs if a buyer will purchase it repeatedly and will find it costly to switch from one seller to another. Switching costs arise due to the product characteristics or due to contracts (Fisher and Massachusetts Institute of Technology. Dept. of Economics. 1990). Figure 29 shows how switching costs affect the time of disruption; precisely, when entrant's market share overtakes of the market share of the incumbent. This plot is produced by aggregating the outcomes of many runs, where the switching cost for the incumbent's service is different from that of for the entrant.

Figure 29 shows that *when incumbents can affect switching behavior, bigger difference between incumbent's and entrant's switching costs (incumbent's being higher) delays technology disruption and makes industry disruption less likely.* Such an outcome may be intuitive, but it has profound implications for both competition and regulation. As for competition, if the disincentives induced by higher switching costs make it less attractive for consumers to switch away from the incumbent; they stymie entrant's growth and delay disruption by entrant's technology even though in the new technological paradigm might ultimately win. More importantly, such ability to throttle the rate of disruption gives incumbents the time to compete strategically, giving rise to two possibilities. First, some incumbents may now become leaders in the new technology through altering their product/service, so there may be no industry disruption. Second, the technological solution, which emerges through such a drawn out phase of competition, may be of an intermediate form that combines some innovations of the entrant's service, while retaining some, often undesirable, characteristics of the incumbent's service.

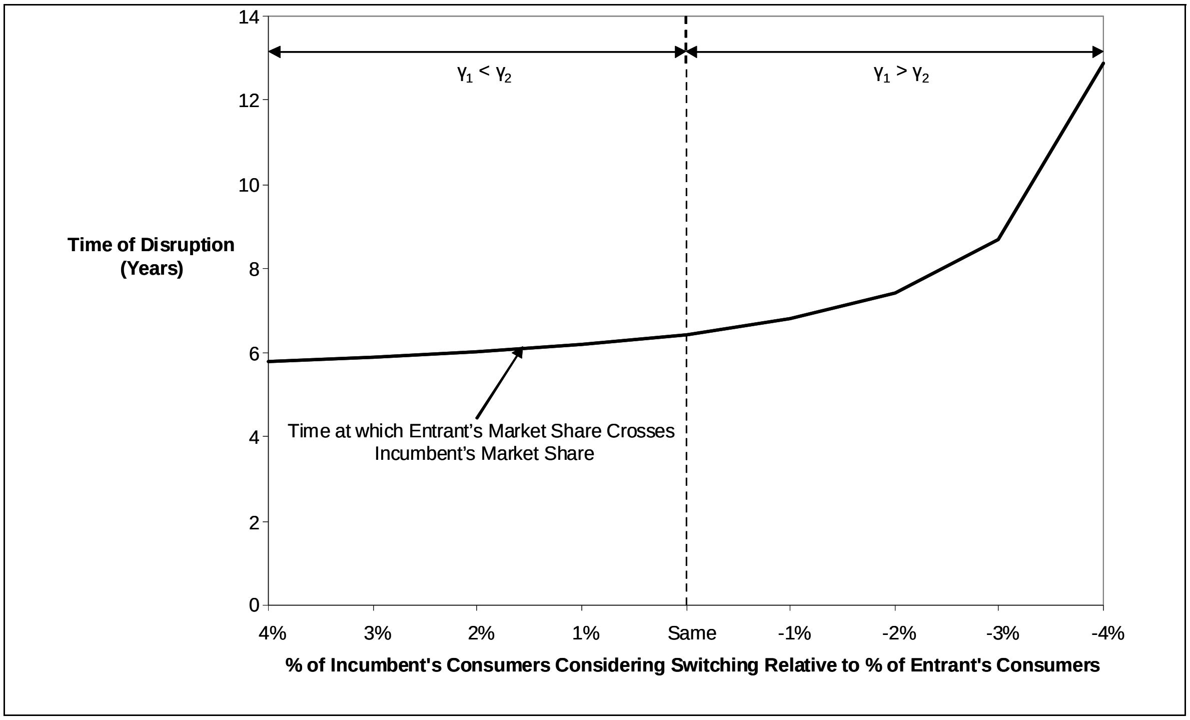


Figure 29: Relative Switching Cost vs. Time of Disruption

As for regulation, switching costs are important to understand for several reasons. First, markets with lower switching costs are more competitive and fair. In communications markets where there are geographical restrictions (e.g., high cost, low population density areas) or where incumbents otherwise possess market power, they will create switching cost disadvantages for the entrants. Second, since switching costs can change the timing of disruption, they interact with the timing of delayed regulation. In chapter 2 we argued that the timing of delayed regulation is tricky (see Figure 17). The ever changing switching costs further complicate delayed regulation.

Consumer Choice

Figure 30 shows maximum market share the entrant attains during a simulation, *max* $\%S_2$, as a function of how sensitive are the consumers to innovation, quality, price, and compatibility, varied individually. Each line on the plot is a result of aggregating the outcomes of many runs, where the sensitivity of attractiveness to that attribute (e.g. sensitivity of attractiveness to innovation, ε_i) is varied while keeping other sensitivities constant. The plot shows limits to technological disruption, and can be interpreted as follows.

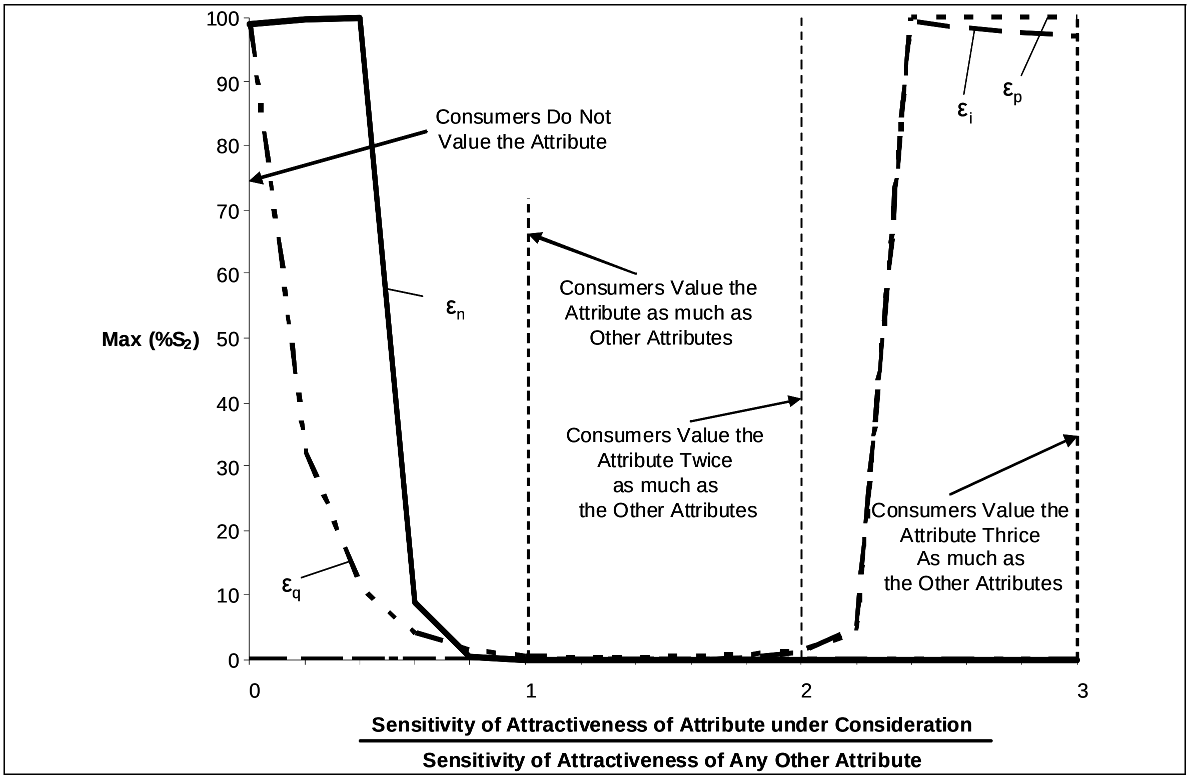


Figure 30: Four Stacked Phase Plots to show Maximum Entrant Market Share when Consumer Prefers Compatibility, Innovation, Quality, and Price

A value of 1 on the x-axis corresponds to the values of sensitivities set such that they render equal maximum effect of all four attributes—innovation, quality, price, and compatibility—on the resulting product attractiveness. [50] Traveling to the right of 1, consumer's sensitivity to the given attribute increases, and traveling to the left it decreases. Value of 2, and 3 on the x-axis correspond to a market where an average consumer prefers that attribute (e.g., innovation) twice or thrice as much as other attributes, respectively. In other words, a larger fraction of the potential market finds a given attribute attractive. A value of 0 on the x-axis corresponds to a market where consumers are indifferent to the attribute. On the y-axis, a high value of *max* $\%S_2$ corresponds to technological disruption, and lower values (especially, less than 50%) correspond to no technological disruption.

The graphs demonstrate that *technology disruption is less likely in markets where consumers prefer quality and compatibility over innovation and low price.* Conversely, technological disruption is more likely in price-sensitive markets willing to take risk by adopting innovative services despite their poorer quality and compatibility compared to those offered by their competitors.

3.5.2.2 Technological Uncertainty

[50] Mathematically, this sentence translates to the following:

$$\exp\left(\varepsilon_n \frac{N_{max}}{N^r}\right) = \exp\left(-\varepsilon_p \frac{P_{max}}{P^r}\right) = \exp\left(\varepsilon_q \frac{Q_{max}}{Q^r}\right) = \exp\left(\varepsilon_i \frac{I_{max}}{I^r}\right)$$

Technological uncertainty arises from inherent architectural differences across different technologies that lead to different ability to attain quality levels, innovation levels, and cost structures. Just like the above analysis of market uncertainty, technological uncertainty can also be studied with numerous permutations of in achievable quality and innovation levels. However, since the inherent differences in quality or innovation of any two products/services are so difficult to understand and argue for, the analysis in this section is limited to those technological uncertainties that are of practical importance.

The results in this section show that excepting the cases where competing technologies have completely different physical limits, for example electro-mechanical switches and transistor switches, differences perceived in competing technologies can be mythical because technological uncertainties are often poorly understood.

Disruptor Cannot Offer Quality Myth

Technology incumbents often believe that entrants can never catch up with their product/service quality. When confronted with a question: why is incumbent's initial response to potential disruption slow? Incumbents typically respond by saying, "we initially believed entrants have just entered a very complex space, and they would not attain high quality (reliability and stability) for a long time to come."[51]

We simulate the entrant's lack of functional control by assigning a large value (4 times the normal value) to Entrant's Time to Acquire Primary Performance, τ_2^q. Such a setting simulates a scenario where the entrant inherently lacks functional control and takes longer to develop quality. Figure 31 shows that even with such a disadvantage, the entrant may disrupt and retain high control over the market for a long time (see lines 1 and 3). The incumbents may survive but only after massive restructuring. In other words, incumbents fully divert their resources (charts for resource allocation not shown here) to entrant-like innovations in order to survive. Hence, the experiment in Figure 31 argues that *Incumbent's belief that entrants cannot catch up on the quality dimension is a myth.*

Why should experienced managers representing incumbents then believe that entrants will not catch up on quality? To investigate this question, we look for conditions under which incumbents can retain market share given the slow to catch up entrant. Through model analysis, we find that incumbents retain market share without sustaining much damage only when industry structure dynamics are considered exogenous (see lines 2 and 4). Hence, the myth about entrant's inability to catch up on quality dimension arises because of the *misperceptions of feedback*. Evidence for such misperceptions of feedback in managerial decision making in general is already present from systematic experimentation in management science (Sterman 1989).

[51] From Author's interview with Chief Strategist and Architect, Incumbent B.

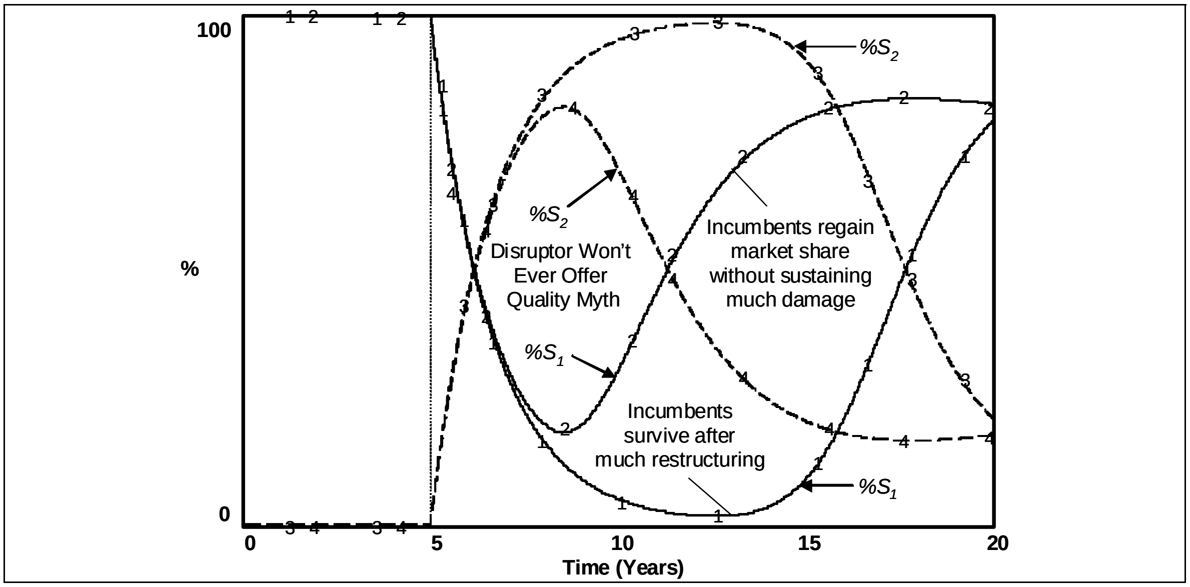


Figure 31: Entrant's Functional Control and Likelihood of Industry Disruption

Entrant Inherently Superior Myth

Many analysts come to a premature conclusion that entrant's technology is far superior to the currently dominant incumbent technology it is competing with. They prematurely conclude that incumbent is inherently incapable of competing on the innovation dimension because of their dimensional complexity.

We simulate the incumbent's disproportionately high dimensional complexity by assigning a large value (4 times the normal value) to Incumbent's Time to Acquire Ancillary Performance, τ_1^i. Such a setting simulates a scenario where the incumbent is inherently so dimensionally complex that it takes longer to develop innovation. Figure 32 shows that even with such a disadvantage, the incumbent stands a better chance at making a come back (see lines 1 and 3) than a complete impossibility of that happening that the analysts predicted (see lines 2 and 4). The experiment in Figure 32 argues that *analyst's belief that every entrant technology is inherently superior and incumbents can never successfully respond to them may be a myth.*

Why do analysts believe for one technology after another that the entrants are superior and the incumbents will inevitably be disrupted? To investigate this question, we look for conditions under which entrants can retain market share given the dimensionally complex incumbent. Through model analysis, we find that entrants retain market share without much competition from incumbents when industry structure dynamics are considered exogenous (see the outer set of market share curves in Figure 32). Hence, the myth about entrant's superiority also arises because of the misperceptions of feedback.

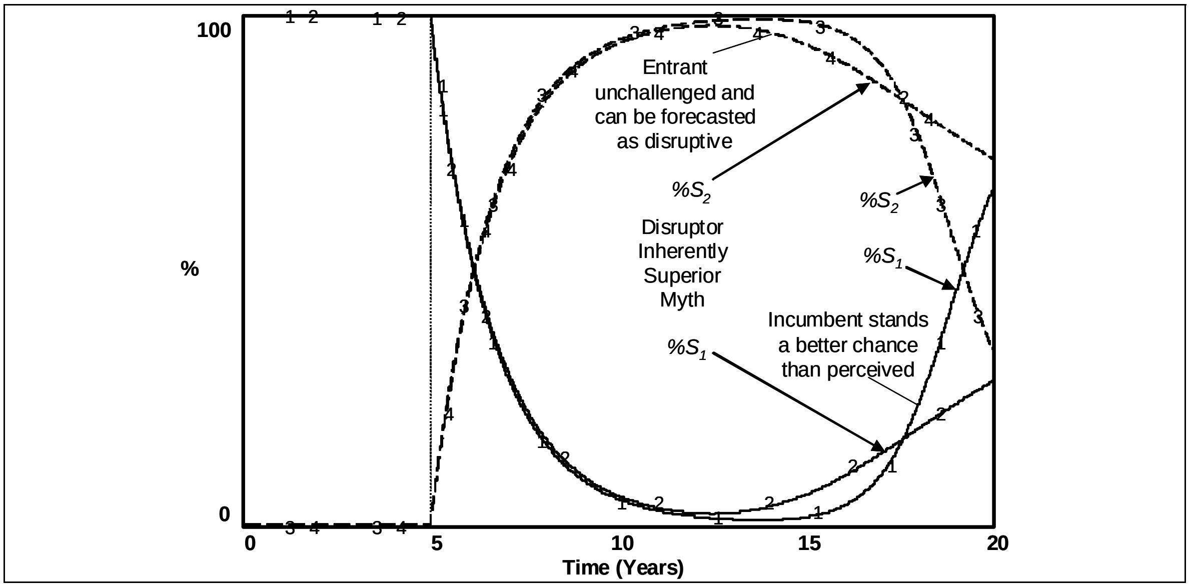


Figure 32: Incumbent's Dimensional Complexity and the Likelihood of Disruption

3.5.2.3 Organizational Uncertainty

The *organizational uncertainty* arises because of how agile or sluggish a firm may be in reallocating resources to quality vs. innovation. As such, in a given industry, firms in a modular industry structure more agile than those in an integrated structure. But across different industries, firms may be more or less agile depending upon the nature of product or service at hand.

Agility is Everything Myth

Corporate leaders often believe that firm's agility in responding to the challenges of the market place is what sets the successful firms apart from the unsuccessful ones. With such a belief, organizations often get focused on responding rapidly as opposed to strategically given the dynamic complexities.

We simulate the higher agility of the incumbent by assigning a small value (1/4th the normal value) to Incumbent's Resource Reorientation Time, τ_1^r. Such a setting simulates a scenario where the vertically integrated incumbents are inherently more agile than the entrants if the entrants also were vertically integrated. Figure 33 shows that even with such an advantage, the incumbent may struggle to compete (see lines 1 and 3). Firm's agility alone can salvage the incumbent only in a limited case when architectural limits do not apply to quality and innovation, and incumbents can withstand pressure from niche competition without having to make structural changes (see lines 2 and 4). Such an idealized scenario does not exist in practice. The experiment in Figure 33 argues that *corporate leader's belief that agility is everything in order to succeed may be a myth.*

Such a myth may also arise from the misperceptions of feedback in a complex environment. Intuitively, it appears that the more rapid the firm's response to the new priorities (i.e., the lower the firm's organizational rigidity) the better it will be able to complete. However, the model analysis shows that surviving disruption requires balancing the loss of one set of competency while acquiring the new ones. Specifically, for incumbents it means balancing the los of quality with adoption of new innovations.

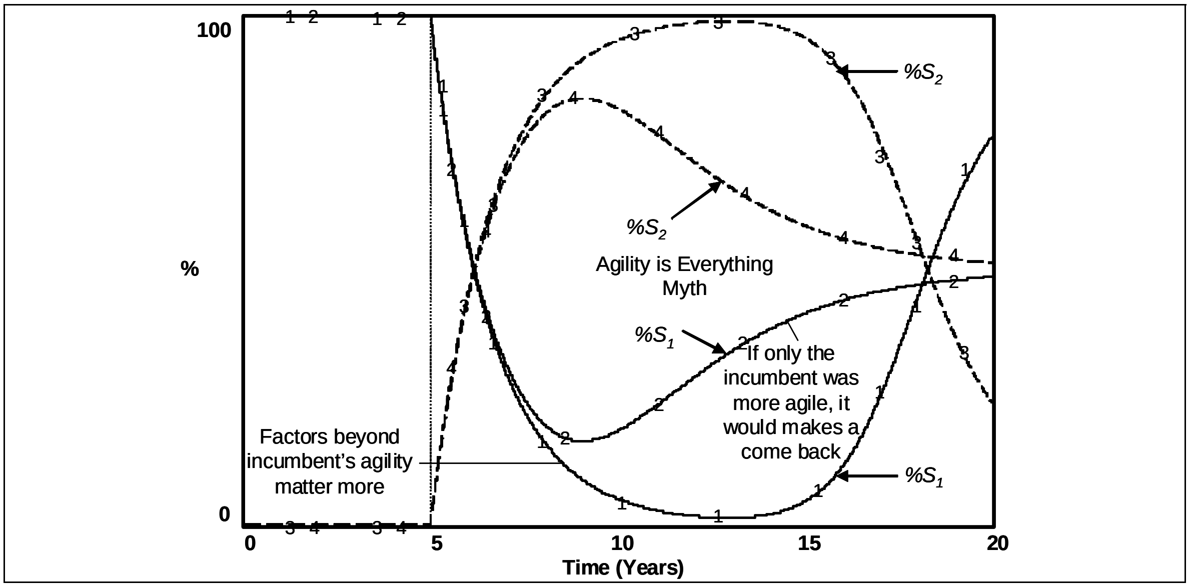


Figure 33: Incumbent's Agility and Likelihood of Disruption

3.5.3.4 Regulatory Uncertainty

The *regulatory uncertainty* arises because firms are uncertain about the regulatory action. In chapter 2 we discussed how regulatory costs and resources can pose entry barriers for entrants. Naturally, when such is the case neither technology nor industry disruption is very likely. In this chapter, we discus the uncertainty in antitrust regulation, the area of regulation that directly affects how integrated or modular the industry will ultimately be.

We simulate the level of antitrust regulation and its impact on industry structure by running three simulations, each with a different value for Maximum Fractional Rate of Making Interfaces Proprietary, α_p. In the first simulation, α_p is set to simulate an environment of *low to no antitrust regulation* ($\alpha_p = 0.1$, the industry structure can fully consolidate in a span of 1-3 years), where firms can gain market power and industry can consolidate rapidly. In the second simulation, α_p is set to simulate an environment of *narrow antitrust regulation* ($\alpha_p = 0.01$, industry can consolidate in a span of 10-12 years), where there are restrictions for a single firm to accumulate market share in a single industry. In the third simulation, α_p set to simulate an environment of *comprehensive antitrust regulation* ($\alpha_p = 0.001$, industry can consolidate in a span of 100 years), where there are higher restrictions on accumulating market power for a single firm or a collection of them, and within a single industry or across several industries.

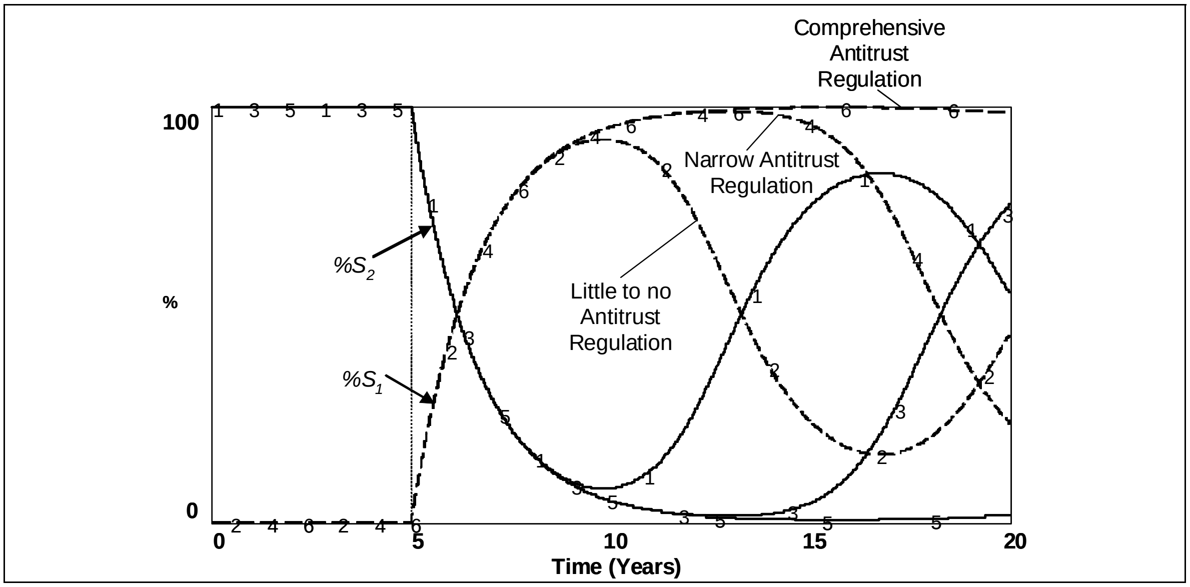


Figure 34: Regulatory Uncertainty and the Clockspeed

Figure 34 shows the results. It shows that *antitrust regulation changes the industry clockspeed.* In other words, whereas it does not prevent technology or industry disruption, antitrust regulation does affect how often industries and consumers experience the shockwaves of the accumulation of market power. As shown in Figure 35, the average firm is small when antitrust regulations are more comprehensive and vice versa.

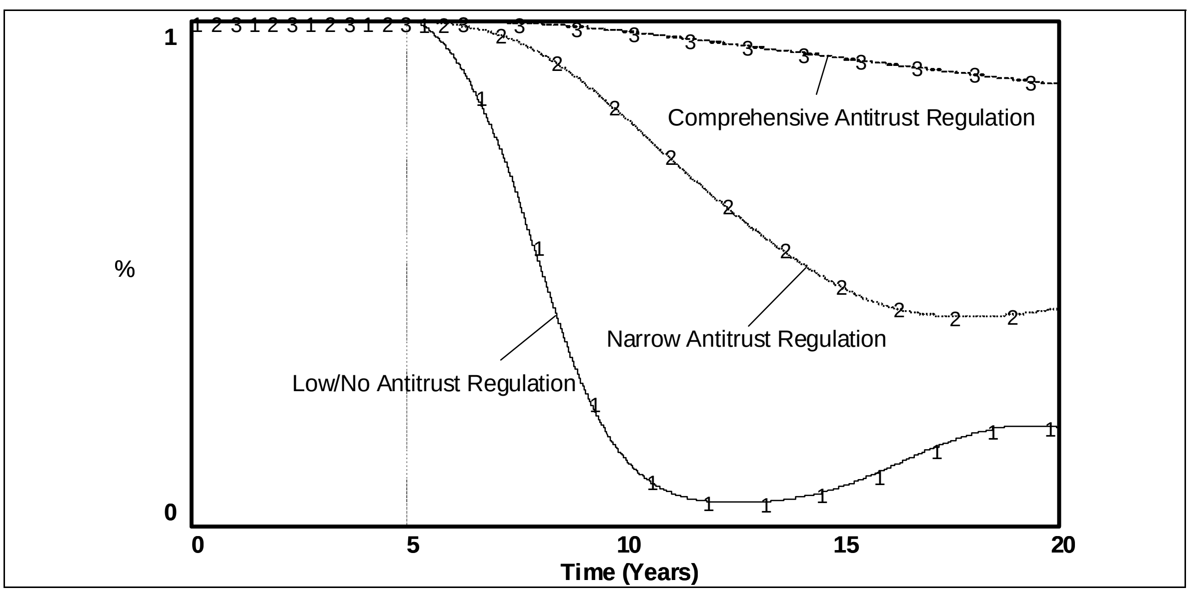


Figure 35: Entrant Firms Remain More Modular with higher Antitrust Regulation

Such a simulation of the levels of antitrust is not hypothetical. Both policies are construed broadly. The narrow antitrust regulation scenario corresponds to the nature of antitrust regulation in the United States, which concerns itself with the conduct of a single firm abusing market power or when multiple firms are involved in a merger. In either case, Horizontal Merger Guidelines sets forth the methodology that the enforcement agencies will apply in analyzing horizontal mergers (mergers between participants in the same industry).[52]

The scenario of comprehensive regulation is akin to the New Regulatory Framework for ICT under the European Union (EU), which states that, "[a]n undertaking shall be deemed to have significant market power if, either individually or jointly with others, it enjoys a position equivalent to dominance, that is to say a position of economic strength affording it the power to behave to an appreciable extent independently of competitors, customers and ultimately consumers." [53]

3.6 Conclusion

Combining the case analysis and the simulation results above shows that media and experts alike routinely misperceive the possibility of disruption. Not every potentially disruptive technology leads to technology disruption. And not every technology disruption results in industry disruption. The misperceptions of disruptive technologies arise when we fail to understand the dynamic complexity that arises from the stochastic nature of forces involved, or strategic behaviors of the different actors. In the discussion below, we first synthesize the results and discuss if they are valid for the cases we have considered in this chapter. Thereafter, we discus what to anticipate about the behavior of the various parameters that determine the dynamics of competition and regulation, and the difficulties involved in observing and measuring some of the parameters.

3.6.1 Limits to Disruption

Figure 36 summarizes the limits to technology and industry disruption as discovered through the analysis above.

[52] U.S. Department of Justice and Federal Trade Commission, *Horizontal Merger Guidelines*, 57 Fed. Reg. 41557 (April 2, 1992, as revised April 8, 1997), http://www.ftc.gov/bc/docs/horizmer.htm.
[53] Per Article 14, at 2, of the *Directive 2002/20.EC of the European Parliament and of the Council of 7 March 2002 on a common regulatory framework for electronic communications networks and services (Framework Directive)*, Official Journal of the European Communities, L 108, April 24, 2002.

	Industry Disruption	**No Industry Disruption**
Technology Disruption	• Weak Network Effect • Consumer highly price sensitive and willing to risk adopting innovative service with low quality and compatibility	• Incumbents can affect switching behavior heavily • Incumbents innovate while maintaining quality • Entrants struggle to offer quality due to lack of functional control or market power
No Technology Disruption	**Quadrant Not Studied** • General double helix dynamics without technology disruption	• Strong Network Effect • Consumer quality and compatibility over innovation and low price

Figure 36: Limits to Technology and Industry Disruption

Technology disruption is least likely, meaning entrant technology fails to displace the incumbent technology, under two sets of conditions. First, *technology disruption is less likely when the incumbent's product or service enjoys strong network effects.* In the cases we considered above, incumbent operating systems benefit from strong indirect network effects due to software applications that run on them. The wireless and wireline telecommunications have network effects due to calling plans such as free in-network calling, over and above the direct network effects from building an access network. Entrants of P2P Service are creating strong network effects of their own by offering buddy lists such as the one on Skype or IM. A classic strategy for entrants to neutralize the incumbent's network effect advantage is to make their product interoperate with the incumbent's product.

Second, *technology disruption is less likely in markets where consumers prefer service quality and its compatibility with other products or services more than the innovation or attractive low price the service offers.* The cases we have considered in this chapter confirm this observation. In the systems software market, open source software has not displaced the Microsoft's Windows operating systems because a large fraction of desktop and laptop operating systems users care more for compatibility than all other attributes.[54] In the wireless telecommunications service market, wireless technologies such as WiFi has penetrated far more in price-sensitive economies (Wireless Competition Bureau 2009) and population segments (e.g., younger consumers) who are less risk averse and love innovation. The same dilemma is present in the telecommunications service, where younger and price-sensitive populations have adopted P2P service such as VoIP far more

[54] By contrast, when it comes to server operating systems, not analyzed in this research, developers prefer quality (reliability and control they have over the operating system) far more than other attributes. So in server market, open source software, with its higher quality, has disrupted Windows operating system.

than older population who prefer PSTN service that has higher quality and compatibility (Wireline Competition Bureau 2008).

Industry disruption is least likely, meaning a new technology displaces the old but the entrant firms do not displace the incumbent firms, under three conditions. First, *industry disruption is less likely despite technology disruption when incumbents can significantly affect the switching behavior through a variety of strategies.* It may be obvious to state that higher switching costs lead to longer retention of the consumer. However, it is important to understand that a longer customer retention time gives the firm the time to reorient its resources for reacting to competition. The dynamics of retaining consumers by increasing switching costs seems to be quite well understood. Operating systems manufacturers bundle application software to increase switching costs (Cusumano and Yoffie 2000). Wireless operators subsidize handsets and sign multi-year contracts with customers. Cable or broadcast television operators tie up with content providers to offer programming – all in order to increase switching costs. On the entrant side, the most common strategy seen is to offer the service for free, at least initially, to compensate the consumers moving over from the incumbent for the switching costs they bear. For example, services like skype and IM are offered for free.

Second, *an industry disruption is less likely when incumbents are able to innovate while maintaining certain quality.* Incumbents are typically stacked against natural barriers to rapid innovation such as rigidity of their organization and high dimensional complexity of their product. Yet, there are examples of incumbents radically restructuring their products in order to innovate while offering lower than before but acceptable quality to their consumers. Among the cases we have considered in this chapter, incumbent equipment providers in the telecommunications services market such as Nortel, Lucent, etc. have responded to the threat of disruption by VoIP with both product cannibalization and business restructuring. Many of them, though much less powerful than they used to be, are still in the equipment manufacturing market (Bensinger 2008).

Third, *an industry disruption is less likely when entrant struggle to offer quality due to lack of functional control or market power.* Being able to offer system-level quality is easier when a firm has system-level functional control. Such a system-level functional control is present when a firm owns critical functional components involved in delivering a service, or when the interfaces are standardized and a modular firm can reliably assert control over the end-to-end service to offer quality. Modular entrants in nascent markets often lack such control. Moreover, in a situation where they cannot accumulate market power because of competitive or regulatory reasons, they may lack the ability to deliver the necessary quality, either by developing it on their own or by contracting with other firms for it. Among the cases we have considered, such a barrier to quality can be observed in the wireless telecommunications service market. In the United States, wireless telecommunications service market is heavily operator-controlled, and modular entrants such as handset vendors or WiFi/WiMax operators struggle to offer high quality new services that do not benefit operators who have must of the functional control.

3.6.2 Three Popular Disruption Myths

Misperceptions of feedback arise in complex systems due to numerous cognitive and other bounds on human rationality identified by the psychology of individual choice (Kahneman, Slovic et al. 1982; Simon 1982). Such misperceptions often produce systematic errors and biases. Systematic experimentation has shown that insensitivity to feedbacks in their decision environment can lead to poor managerial decisions (Sterman 1989). In this chapter we uncovered three myths that arise due to the misperceptions of feedback, each of which may be understood as a type II error as summarized in Figure 37.

The first myth, *Incumbent's belief that disruptors cannot offer quality so there will be no technology disruption*, arises naturally for incumbents who may have struggled for years to build quality into their products through numerous interactions with a wide variety of consumers. Moreover, when potentially disruptive entrants are modular, it may appear that they will never have the system-level functional control necessary for developing system-level quality.

When the managers do not correctly perceive the impact of firm's decision on the industry structure and vice versa, they may fail to anticipate that entrants, who lacked functional control necessary for attaining high quality and who focused largely on innovation at the time of market entry, may take several actions to change this situation once it has pressure from their growing consumer base to improve quality. First, with experience they may alter their product/service architecture to integrate adjacent modules and have more functional control. Additionally, they may acquire firms experienced in competing on the quality dimension. In this sense, mergers and acquisitions must be viewed broadly in that they not only increase control over functionality, but they increase control over the market by widening the consumer base, and most importantly, they bring to the entrants the knowhow for developing quality as workers transfer from incumbent to entrant firms. Generations of technologies, be it the automobile, bicycle manufacturing, or others, history suggests that it is this transfer of knowhow that leads to the next disruption when it may be least expected (Hounshell 1984). Among the cases we have considered in this chapter, VoIP is certainly a case where the entrants have caught up with the incumbents on the quality dimension faster than incumbent's expectation.

	Disruptor cannot offer quality, so no technology disruption	**Disruptor may learn to offer quality, so potential technology disruption**
Accept	Type II Error (*Disruptor cannot offer quality myth*)	Correct Choice
Reject	Correct Choice	

	Entrant inherently superior, so sure technology & industry disruption	Entrant's advantage temporary, so a fair chance for no disruption
Accept	Type II Error (*Entrant inherently superior myth*)	Correct Choice
Reject	Correct Choice	

	Highly agile firms will survive disruption	Factors beyond firm's agility determine its survival
Accept	Type II Error (*Agility is everything myth*)	Correct Choice
Reject	Correct Choice	

Figure 37: Three Popular Disruption Myths

The second myth, *analyst's belief that every entrant technology is inherently superior so there is sure to be technology and industry disruption*, may arise for several reasons. First, assuming that their interests are not aligned with the interests of the entrant firms, analysts may have a romantic vision of disruption from the successful disruptions they might have experienced in the past. When radical innovation that alleviate the fundamental constraints of the incumbent technology do appear, technology disruption becomes highly probable. For example, when electro-mechanical switches alleviated the fundamental constraint—the human operator—of the operator-based switches, there was an absolute technology disruption. Similarly, when transistor-based switches alleviated the fundamental constraint—the contact loss—of the electro-mechanical switch, there was again a technology disruption. But was there any industry disruption in these case? No! For instance, in the US, a single monopolist, AT&T, pioneered all three switching technologies.

The second reason for analyst's misperception may be their belief that incumbents are inherently incapable of competing on the innovation dimension because of their dimensional complexity. Analysts disregarding the dynamic complexity of disruption may fail to anticipate that the dimensionally complex incumbents may take several, at times drastic, actions to respond to the threat of disruption. The incumbents under competitive pressure may cannibalize their product and completely reinvent their architecture. In this case, there will be technology disruption, but some incumbents may emerge as market leaders in the new industry. Alternatively, incumbents may standardize product interfaces, spinoff parts of their businesses or outsource the work to niche, specialized competitors. As discussed earlier, Nortel, Lucent, etc. have responded to the threat of disruption by VoIP with both product cannibalization and business restructuring. These firms, though much less powerful than they used to be, are still in the equipment manufacturing market. But as our calibration exercise above showed, analyst models today completely disregard any such uncertainty.

The third myth, *corporate leader's belief that a highly agile firm will survive disruption*, may arise because they get focused on the speed with which the organization responds as opposed to understanding other factors that determine the competitive outcome. Successful strategic behavior in the face of potential disruption takes far greater understanding of the dynamic complexity. With such understanding, firms realize that depending upon the consumer segmentation and the clockspeed of technology; they need to slow down response along some dimensions while intensifying it along others in order to succeed.

In case of modular entrants disrupting the integrated incumbents, incumbents may believe that rapidly reorient resources to innovation is what may save them. But the focus ought to be on balancing the quality-capability and innovation-capability. Quality-capability is determined by not just the maximum quality that can be attained, but the time it takes to attain it. When disruption occurs incumbents suffer initially because they cannot innovate, but in the due course, they also suffer because focusing on innovation begins to weaken the appeal of their product/services on the quality dimension. One might feel that such an observation may simply be an artifact of the modeling assumption that the resources a firm has are constant. However, in a competitive environment, no firm can assume infinite resources, so the attending to one takes attention away from another is a reality. Hence, for the incumbent, the game is not simply that of how quickly they reorient resources to innovation, but also how they maintain the quality-capability which may be lost because of what they make vs. buy, and how much functional control they have to maintain certain desirable quality to meet the expectation of their consumers. Make vs. Buy decisions itself is an important area of research which is beyond the scope of this thesis (Whitney and Fine 1996).

3.7 Dynamic Complexity: Anticipation, Observation, and Measurement

The discussion so far focused on how to anticipate the likelihood of disruption in face of the various uncertainties. We conclude this chapter with a discussion of what can be anticipated about the various parameters that define competitive and regulatory dynamics if disruption were to take place. Additionally, we discuss the challenges of observing and measuring the parameters where relevant.

3.7.1 Anticipation

Table 13 shows what to anticipate about the parameters that define the competitive dynamics. It summarizes the anticipated behavior of each parameter in three different phases—in the integral age,[55] during disruption, and in the modular age.[56] Since

[55] In chapter 2, we defined the integral age in telecommunications as a paradigm, where each operator was vertically integrated and controlled the total functionality necessary to deliver a service; a few such

incumbents and entrants experience different set of forces during disruption, in this phase they may differ in their behavior for a given parameter. Since much of Table 13 is self-explanatory, we take two examples to explain the intended use of the table.

The dynamics of innovation, for example, may be understood as follows. In the integral age, when there is less competition from niche competitors, it can be expected that the overall innovation adoption will be low even though the firm might have the resources to innovate. In the disruption phase, as niche competition creates pressure to adopt innovation, incumbents are forced to pay attention to innovation. The entrants, on the other hand, might have increasing pressure to not just innovate but also to deliver higher quality. In the modular age, entrants that disrupted and incumbents that survived disruption have high innovation capacity, but also pressure to maintain certain quality to stay competitive. A closer look reveals that innovation-specific dynamics form a *balancing structure*.[57] Whereas the introduction of entrant's innovative service is what causes disruption, the increasing market share of the disruptor counter acts innovation in the post-disruption phase.

Take another example; the product/service quality is usually high in the integral age, as it gets perfected over a long time. With disruption, incumbents lose some level of quality as they must now understand new products/services before then can offer the same level of quality. Entrants, on the other hand, have the pressure to improve along the quality dimension. In the modular age, the quality of the disruptive technology continues to improve. Again, a closer look reveals that quality-specific dynamics form a *reinforcing structure*.[58] Whereas quality drops initially with the introduction of the disruptive technology, the increasing market share of the disruptors enhances the quality further as demanded by the firm's growing installed base.

	Competition Dynamics (Firm and Industry-level Forces)			
Parameter	**In Integral Age[59]**		**During Disruption[60]**	**In Modular Age[61]**
Innovation	Low pressure to adopt innovations	**i**	Increasing ability to innovate and pressure for innovation	Higher ability to innovate and pressure for innovation

operators controlled the industry; they faced low competition and were under limited pressure to adopt innovation; and consumers had limited choice.

56 In chapter 2, we defined the modular age as a paradigm, where each firm controls only a subset of the total functionality necessary to constitute a service; many modular firms interoperate to deliver a service; firms compete fiercely and are under great pressure to innovate; and consumers enjoy a far greater choice due to the multi-modal competition among multiple technologies.

57 In balancing structures a change in one direction is countered by forces in the opposite direction, so either a growth or a decline is countered.

58 In reinforcing structures a change is amplified, so a growth leads to further growth and a decline to further decline.

59 See footnote 54.

60 The use of letter, **i**, indicates to the forces incumbents experience; whereas, **e**, indicates the forces experienced by entrants

61 See footnote 55.

		adoption **e** High ability to innovate, but increasing pressure to divert focus to quality	adoption
Quality	High quality developed over a long time	**i** High ability to offer quality, but increasing pressure to divert focus to innovation **e** Increasing ability to develop quality and market pressure to do so	Improving quality
Fixed Costs	High but largely amortized	**i** Dropping with outsourcing **e** Increasing with integration of the adjacent modules	Lower and pertinent to the modules owned
Marginal Costs	Low due to economies of scale	**i** Increasing due to reducing economies of scale **e** Decreasing at module level with increasing economies of scale	Low at module-level, high at systems-level
Network Effect	Contract dependent among incumbents, but high for new entrants	Dependent upon interoperability between incumbents and entrants	Contract dependent amongst matured entrants and incumbents who survived, but high for new entrants
Switching Costs	Product/service, contract dependent	Product/service, contract dependent	Product/service, contract dependent
Industry Structure	Vertically integrated (in present research)	**i** Pressure to disintegrate in the early phase of disruption **e** Incentives to integrate in the later phase of disruption	Modular, horizontally concentrated with incentives for integration (in present research)

Organizational Form	Integrated, slow to respond, and with dimensionally complex product/services	**i** Adapting to competition through organizational restructuring, and product/service outsourcing **e** Modular, quick to adapt, fiercely competitive at module level	Constantly adjusting horizontal scale and vertical scope, balancing quality and innovation

Table 13: Anticipating the Dynamics of Competition

Two meta-level observations about the structural dynamics must be made. First, structural influences demonstrate why dislodging the incumbent can be so difficult. In the communications industry, the incumbent's large installed base reinforces three of its strengths – high quality, low price (due to economies of scale), and high compatibility. Hence, a potentially disruptive entrant needs a great innovation with a far better cost structure to overcome these forces. Second, the structural forces also explain several sources of lock-in. For example, integrated structures have a tendency to remain integrated, and modular structures to remain modular. These observations argue that the small market share of a modular entrant at the time of entry is not enough reason to ignore the entrant as the reinforcing forces may help it grow rapidly. Also, once a modular structure disrupts and becomes dominant, it might persist because of the lock-in, so the disruption has real consequences.

Table 14 shows what to anticipate about the parameters that define the regulatory dynamics. It is laid out and can be understood the same way as Table 13.

	Regulatory Dynamics		
Parameter	**In Integral Age**	**During Disruption**	**In Modular Age**
Actual Compliance	Close to the required level with a well-understood process of achieving it	Dependent upon compliance levels of competing services and their market shares	Can be inadequate compared to the required level, with the process of achieving it poorly-understood due to coordination issues. Frequently eroding due to circumvention of regulation

Achievable Compliance	High due to high functional control	Dropping due to incremental regulation, other regulatory decisions and competitive pressures	Low due to the effort necessary to coordinate and many competing interests, and constant circumvention of regulation
Compliance Costs	High but amortized deployment costs, low and regulated maintenance and coordination costs[62]	**i** Rising coordination costs with more competing interests, dropping maintenance costs with reducing market share **e** Lingering deployment costs with longer times to comply, rising maintenance costs with increasing market share, high coordination costs due to modular control	High coordination costs that are not well-understood
Fraction of Resources to Regulation	Perceived as small and under control, but often may not be	Rising for both incumbents and entrants	Can be large to cause smaller firms to fail

Table 14: Anticipating Regulatory Dynamics

The following meta-level insight emerges by comparing Table 13 and Table 14: *modularity increases technology clockspeed, reduces regulatory closkspeed and hence changes the feasible regions for the regulatory solutions.* As Internet-based services create greater modularity, technology clockspeed has increased on all three of its dimensions –product, process, and organizational. We demonstrated this fact in chapter 2 (see Table 3). By contrast, our research shows that in a more modular architecture and industry structure the regulatory clockspeed reduces. If one considers rendering a communications industry that is highly compliant with regulation as the product of regulation, such a product will now take longer to deliver and the process producing it

[62] Although not shown in the model formulation in this chapter, we experimented with various formulations for compliance costs before arriving at a conclusion that coordination cost is the most important component of the compliance cost (other components being deployment costs, and maintenance costs) for thinking about disruption by modular forces. A fixed deployment cost is likely to be present when there exists a compliance pap between the required and actual compliance the firm offers. Firms incur marginal maintenance cost of offering regulated service offered to each additional customer.

will also be drawn out. The only aspect of regulatory clockspeed that speeds up is the clockspeed of the regulatory agency. They must now be more vigilant and adaptable to the rapid changes in communications technology and industry. Together, changing clockspeeds of technology and regulation create new feasible regions for the regulatory solutions in the modular age. Exploring what these solutions is the topic of the next chapter.

3.7.2 Observation and Measurement

Many of the parameters and forces discussed in this research are observable but difficult to measure. Of course, not being able to measure them does not make them any less important. Discussed below are several such parameters.

Network Effect

Measuring the strength of the network effect accurately is not easy. What is easier is to detect the presence or absence of it. Also, it is possible to evaluate the different levels of the network effect nominally.

Switching Costs

As many factors, such as the nature of product/service, competition, contracts between the consumer and the supplier, and the culture at large, mediate the ultimate switching costs, observing or measuring it can be complicated, except in in some cases such as wireless telecommunications services in the United States where switching costs are glaringly obvious and they come in the firm of one or two year service contracts.

Fixed and Marginal Costs, Compliance Cost, and Resources to Regulation

Enormous information asymmetry exists in each of these areas that the firms exploit when bargaining with regulators. Much has been written about the efficiency of regulatory contracts when such asymmetry exists ((Laffont and Tirole 2000)). Although this literature considers technology exogenous to their models, many of the problems of information asymmetry discussed there are only exacerbated by a disruption like scenario.

Industry Structure and Organizational Form

Macro shifts in industry structure and organizational forms matters more from the regulatory perspective. These changes are observable by monitoring the industry activity. Micro shifts in industry structure or organizational form are very difficult to observe. These parameters are not quantifiable, and even if there was an attempt made to quantify them, the benefits of doing so for the regulators are not clear. Corporate managers do care about small and large shifts the industry structure as they are constantly negotiating their competitive position, but even they understand the shifts in industry structure more qualitatively.

Actual Compliance

Today, compliance in area such as E911, CALEA, and Universal Service is measured using a certain matrix (see chapter 2, Figure 5). Chapter 2 discussed how meeting regulatory objectives these regulations serve, namely public safety, law enforcement, and socio-economic development, in the modular age will require redesigning obligations. Hence, the matrix that currently measures compliance too will necessarily need to change for the modular age.

Achievable Compliance

In the integral age, for every new regulation the regulator could assume that the corporations had the ability to comply with them. As shown by the case research in chapter 2, corporations are divided today in their opinion as to how compliant they can be. Hence, the assessment of achievable compliance itself needs a new approach in the modular age.

Chapter 4: FROM ANIMAL TRAINER TO WILDLIFE CONSERVATIONIST: BALANCING REGULATION AND INNOVATION IN THE MODULAR AGE

4.1 Introduction

Juxtapose the social and economic objectives served by the existing telecommunications regulations, and evaluate what the modular age has done to them from the societal perspective, and you shall see a very different role emerging for the regulatory agency in the new world. The modular forces naturally promote the economic objectives such as competition and innovation, but they derail critical social objectives such as law enforcement and public safety. Consequently, in the modular age, the regulator's new role must be to achieve the following vital combination, which defines the *first best* (FB) outcome: the necessary regulatory compliance is achieved, the high innovation and competition are preserved, and the reasonable cost of compliance is maintained. This paper asks: *How can such a balance of regulation, innovation, competition, and cost be achieved in the modular age of the Internet?* Through a three-stage analysis of existing and new policy options, this paper proposes policy levers for achieving such a balance.

The most prominent and broad proposal on how to regulate VoIP has been the layered-oriented model for regulation. Before the FCC launched its IP-Enabled Services enquiry, a number of leading thinkers on telecommunications regulation in the United States spent considerable effort thinking about layered regulation. [63] These proposals were founded upon the arguments that regulatory separation of wireline telephony regulated under Title II of the Telecommunications Act, wireless telephony regulated under Title III, and cable services regulated under Title VI would not work in the age of Internet services, which can be offered over any access technology. These proposals argued that "the only rational way to regulate the Internet industry is to draw lines within the layering hierarchy to distinguish between (i) those layers (if any) that should be subject to continued economic regulation because there is insufficient competition within them and (ii) those layers that should not be subject to such regulation because they are presumptively competitive."[64]

---

[63] Kevin Werbach, "A Layered Model for Internet Policy", Journal on Telecommunications and High Technology Law (JTHTL) vol. 1 nbr. 1 (2002); Richard S. Whitt, "A Horizontal Leap Forward: Formulating a New Communications Public Policy Framework Based on the Network Layers Model", Federal Communications Law Journal vol 56 nbr. 3 (2004); John T. Nakahata, "Regulating Information Platforms: The Challenge of Rewriting Communications Regulation from the Bottom Up", JTHTL (2002); Rob Frieden, "Adjusting the Horizontal and Vertical in Telecommunications Regulation: A Comparison of the Traditional and a New Layered Approach", 55 Fed. Comm. L.J. 207; Douglas C. Sicker and Joshua L. Mindel, "Refinements of a Layered Model for Telecommunications Policy", JTHTL (2002); Lawrence Solum, "The Layers Principle: Internet Architecture and the Law", available on SSRN; and Philip J. Weiser, "Law and Information Platforms", JTHTL vol. 1 number 1 (2002).

[64] As summarized in Chapter 6 of Nuechterlein, J. E. and P. J. Weiser (2005). Digital crossroads : American telecommunications policy in the Internet age. Cambridge, Mass., MIT Press.

The layered approach advocated that there should be no regulation of VoIP services that run on top of the physical layer, as long as the provisioning of physical layer itself is competitive.

The layered approach ignored the dynamic issues that arise in the environment created by the Internet. Their static frame of analysis failed to anticipate that in an environment where firms, consumers, and technologists have a great deal of flexibility, such partial regulation would provide perverse incentives for the regulated to move to the unregulated services. And significant market power can arise even at the application layer (think Google), and just at the physical layer. Such an oversight is a classic demonstration of the pitfalls of decision-making in a complex system, where addressing a problem local to one part of the system gives rise to other problems elsewhere.

Today, because of such shortcomings, it is believed that "the layered model provides surprisingly little useful guidance to the regulator, and the guidance that it provides is often misleading. Moreover, it suffers from several profound defects: (1) a regulatory taxonomy that is just as arbitrary, confusing and misleading as the silos that it seeks to replace; (2) a fundamental lack of technological neutrality; and (3) an arrogant assumption that government can predict with certainty that all telecommunications for all time will be based on the model of the Internet. The layered model is a charming idea whose time has come – and gone." (Marcus 2006)

In the early days of the proposal for layered regulation, libertarian George Gilder had perceptively argued that the underlying issue the proposal must not ignore is the "ever changing trade-offs between integration and modularization…[and] the importance of regulation within the 'core' of the network as well as the edge. " Our thesis, developed over chapters 2, 3 and 4 of this thesis endorse Gilder's important insight.

In the contemporary literature, Pierre De Vries's recent work thematically parallels the approach taken in this paper (and more broadly in this thesis). De Vries suggests that the "Internet/Web" can be understood as a "complex adaptive social system," such as a forest or other ecosystem. [65] Based on system theory and the experience of ecosystem management, he proposes a conceptual framework of four principles for meeting regulatory goals that suits the dynamics of the "web": flexibility (determining ends, not prescribing means); delegation (giving markets and civil society the first shot at meeting social needs); big picture (taking a broad view of the problem and solution space); and diversity (enabling multiple solutions for policy problems by encouraging competition and market entry). The central thesis of his work is that the regulatory actions must be derived from a set of regulatory goals.

---

[65] Presented at the Technology Policy Research Conference (TPRC), 2008. Available through SSRN, De Vries, P. (2008). "Internet Governance as Forestry: Deriving Policy Principles from Managed Complex Adaptive Systems." SSRN eLibrary.

De Vries's work generates a number of interesting questions, but in the absence of a dynamic model, it remains at the conceptual level. In his work, De Vries correctly identifies the need to go beyond the conceptual model, so that well-tested and actionable suggestions can be offered with confidence.

We argue that when using systems principles, it is this transition from a conceptual to an actionable framework that is crucial to make. History argues that works of many systems thinkers gained traction only after such a transition was made. For example, biologists criticized Ludwig von Bertalanffy's early cry to use systems principles for the scientific enquiry (especially biology) until systems biology, through a variety of developments, made it possible to act upon some of Bertalanffy's early insights.

To briefly elaborate the point, in his 1968 text, *General System Theory*, Bertalanffy identified the importance of studying emergent phenomena in biological system, but his work was criticized as "philosophically and methodologically unsound because the alleged 'irreducibility' of higher levels of lower ones tended to impede analytical research whose success was obvious in various fields."[66] The methodological objection to irreducibility did not abate until the recent rise of systems biology, a recent field of study that has sustained much interest, which, through advances in experimental and computational techniques, observes "new emergent properties that may arise from the systemic view used by this discipline in order to understand better the entirety of processes that happen in a biological system." (Kitano 2001)

Hence it is important to go beyond the principles to carry out deeper analysis using modeling and other research methods. That is the journey the present research has been on (starting with (Vaishnav 2005; Vaishnav and Fine 2006), and now in this document).

4.2 Research Method

The research in this paper proceeds in three stages. The first stage is motivated by the following question: *What should be the regulators role in a system where a modular age disrupts an integral one?* We must begin with such a broad question because of the widespread disagreement among stakeholders over whether and how to regulate VoIP (already discussed in chapter 2). To answer this question, we analyze regulatory compliance, innovation, competition, and compliance cost[67] as emergent behaviors of the systems model developed through chapters 2 and 3. Naturally, it is legitimate to ask why analyze only these four parameters? First, compliance, competition, and innovation have

---

[66] p. 86 of Bertalanffy, L. v. (1968). General system theory; foundations, development, applications. New York,, G. Braziller.

. Unfortunately, the three criticisms presented here are Bertlanffy's own summary of the criticisms of GST. The original sources of these criticisms are not easy to trace, as he does not refer to them.

[67] Compliance Cost and Coordination Cost are used interchangeably in this paper, since coordination cost is the only component of the compliance cost that varies significantly with the modularity of the industry structure (as discussed in chapter 3 with our Coordination Cost Conjecture). The other two components of compliance cost, namely deployment and maintenance cost, apply both to entrant and incumbent, so they are eliminated to keep the analysis tractable.

been at the heart of telecommunications policy debates in the United States post the AT&T breakup. Additionally, our research argues that compliance cost will be an important factor for the regulators to understand in the modular age; although, today there is little focus on it.[68] The analysis in the first stage of research explains the tradeoffs across the various phases of disruption. It illuminates a set of outcomes the regulator must aim for at the system level that we define as the *first best* (FB) outcome.

Defining the FB outcome motivates the question for the second stage of research: *Whether the FB can be achieved using the* *<u>currently-known policy levers</u>* *such as partial and delayed regulation?* For this investigation, we subject the model to a set of optimization exercises. In each exercise, the optimization algorithm selects the best possible combination of regulatory scope (partial regulation) and timing (delayed regulation) to satisfy the desired objective function – for example, maximizing compliance. The optimization exercises are organized in the increasing order of complexity of the objective function. Discouragingly, these exercises show that the existing policy levers (partial and delayed regulation) cannot achieve the FB. However, they illuminate a set of conditions that must be met for achieving the FB outcome.

The inadequacy of the existing policy levers motivates the question for the third stage of research: *Are there* *<u>policy levers</u>* *that are capable of achieving the desired balance, but that have* *<u>not been exploited by the policymakers yet</u>*? To investigate this question, we carry out policy sensitivity analysis on the systems model, where we look for those assumptions that, when changed, enable certain policies to achieve the desired outcome.

We will now discuss each stage of research and its results sequentially.

4.3 Research Stage I: Emergent Behavior and the Regulator's New Role

As stated above, we begin by investigating the regulators role in a modular age. For this investigation, we study the emergent behavior in the telecommunications system where modular entrants disrupt integrated incumbents. In chapter 3, we modeled the dynamics of consecutive disruptions. We will now limit our analysis to a single disruption. Focusing on a single disruption cycle is sufficient for our analysis in this paper because the dynamics repeat in the subsequent ones. To guide our analysis of the emergent behavior, we divide the disruption period into sub-phases.

4.3.1 Phases of Disruption

We divided the dynamics of a single disruption into three periods: pre-disruption, disruption, and post-disruption (see Figure 38). The *pre-disruption period* may be defined as the period before the first entrant enters the market. The *post-disruption period* may be

[68] One more parameter—quality—can conceivably added to the list of four parameters studied in this paper; however, since a minimum service quality is necessary to succeed in a competitive market, to keep the analysis less complicated, the presence of competition is considered sufficient in defining the FB.

defined as the period after the last incumbent exits.[69] The period in between the two may be defined as the *disruption period*. We further divided the disruption period into two phases: disintegration-phase, and integration-phase. To understand these two phases, please follow on Figure 38 the line for Average Utilized Modularity, *Λ*, which represents the level of modularity an average consumer experiences. As shown in Equation 33, the *Λ* depends upon the modularity as well as the market share of each industry.[70]

In the *disintegration phase*, competition, within modular firms and between modular and integrated firms, creates pressure to disintegrate. Consequently, firms standardize interfaces modularizing the architecture, and outsource functionality modularizing the industry. By contrast, in the *integration* phase, modular firms gain market power and have incentives to integrate. Consequently, interfaces become proprietary integrating the architecture, and mergers and acquisitions integrate the industry structure.

Equation 33: Average Utilized Modularity

$$\Theta = \sum_i M_i * S_i$$

[69] The exit of the last incumbent may be thought more broadly as the exit of the last product or service that has the characteristics of the incumbent's dominant offering in the pre-disruption period. In this sense, the onset of post-disruption phase may occur not just due to market exit, but also as the incumbents morph into entrant-like firms.
[70] An industy's Utilized Modularity rises if both parameters, its Modularity and Market Share, increase, falls if one of them falls, and takes appropriate course (rises, falls, or remains unchanged) if one parameter increases and other decreases, depending upon the magnitude of their change.

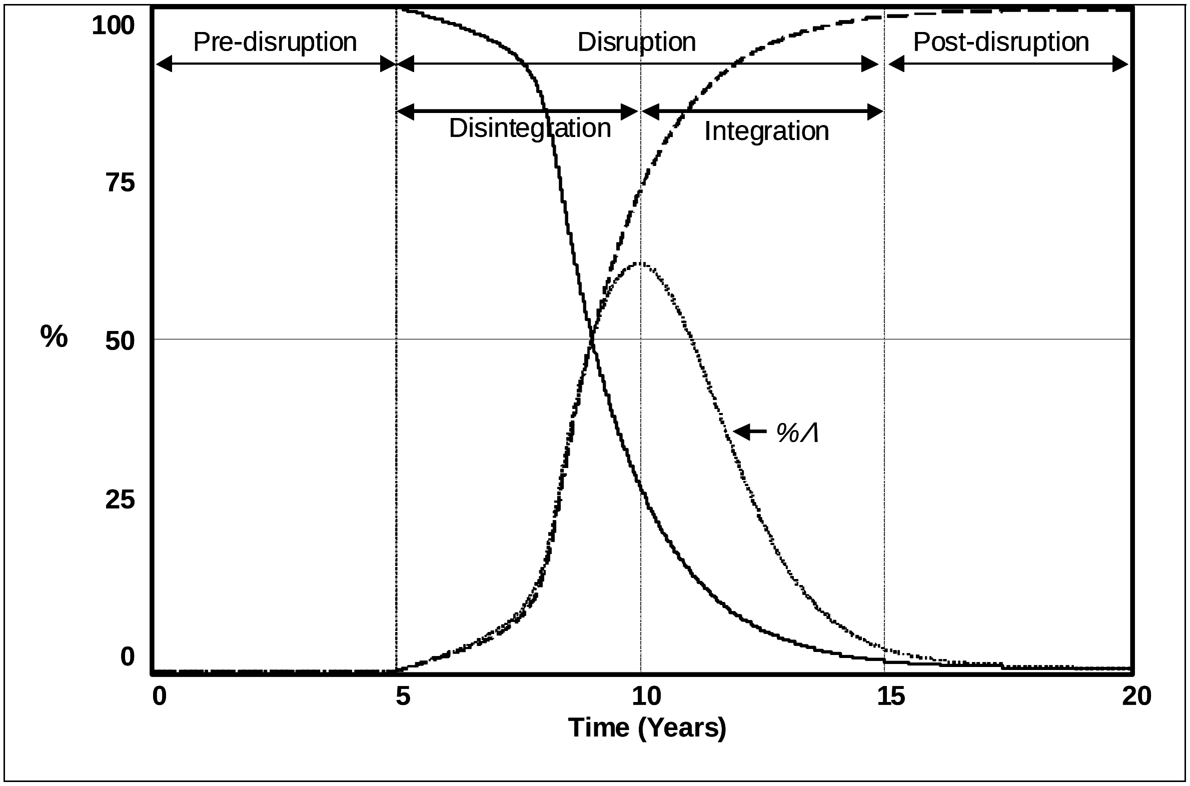


Figure 38: Phases of Disruptions

The behavior of compliance, innovation, competition, and compliance cost is very different across the three periods and two phases.

4.3.2 Emergent Behavior in Telecommunications System

4.3.2.1 Average Utilized Compliance (Θ)

We know from Equation 4 (reproduced below in Equation 34) that Average Utilized Compliance, Θ, is a market share weighted sum of each firm's (industry's)[71] Actual Compliance, Z_i. Thus, the effective level of compliance depends not just upon how compliant are the firms, but how much their service is utilized.

Equation 34: Average Utilized Compliance

$$\Theta = \sum_i Z_i * S_i$$

Θ represents the fraction of communications that occur over compliant networks (or alternatively, the fraction of an average consumer's communications that occur over networks with end-to-end regulatory compliance). Such a conceptualization is relevant because an average user today carries out a fraction of their voice communication over the regulated PSTN or wireless networks and the rest over the unregulated options such as peer-to-peer VoIP services (e.g., Skype).

[71] As discussed while setting up the model, each firm represents a typical firm in that industry.

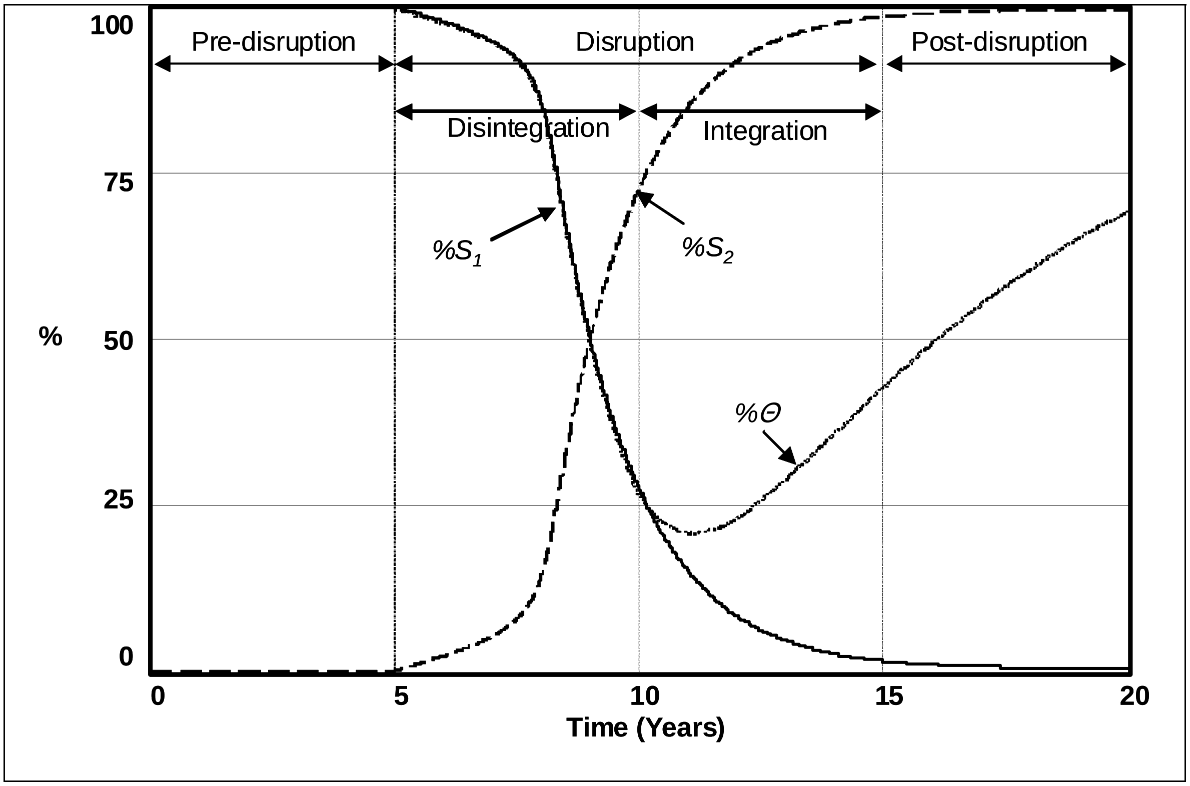


Figure 39: Average Utilized Compliance

In the pre-disruption period, all communications occur over compliant networks (i.e. *%Θ* is 100%) because incumbents own the entire market and their networks are fully compliant.[72] As the unregulated entrants gain market share, *Θ* drops, since a fraction of communication occurs over their non-compliant networks. Once entrants are regulated, *Θ* begins to rise. Several factors now determine its value at a given point in time. First, the required level of regulation of entrants (we assume full compliance is required). And second, the resulting modularity of the industry structure, which may be understood further as follows. In the disintegration phase, firms experience higher coordination costs and take longer to comply with regulation; hence the achievable compliance is low. Conversely, in the integration phase, as the industry integrates, firms possess greater control and can achieve higher regulatory compliance.

4.3.2.2 Average Utilized Innovation (*Π*) and Quality (*Φ*)

Average Utilized Innovation, *Π*, is a market share weighted sum of each firm's (industry's) level of innovation, I_i (see Equation 35). Thus, the effective level of innovation depends upon not just how much firms innovate, but also how much are those innovations marketed by firms and adopted by consumers. Average Utilized Innovation represents the level of innovation an average consumer experiences. Equation 35 also

[72] In reality, the incumbents are never 100% compliant, but we are using an idealized scenario to simplify the analysis.

shows the formulation for Average Utilized Quality, *Φ*. It is the trajectory of these parameters (Π and Φ) that is more informative than its level at a given point.[73]

Equation 35: Average Utilized Innovation (Π) and Average Utilized Quality (Φ)

$$\Pi = \sum_i I_i * S_i$$

$$\Phi = \sum_i Q_i * S_i$$

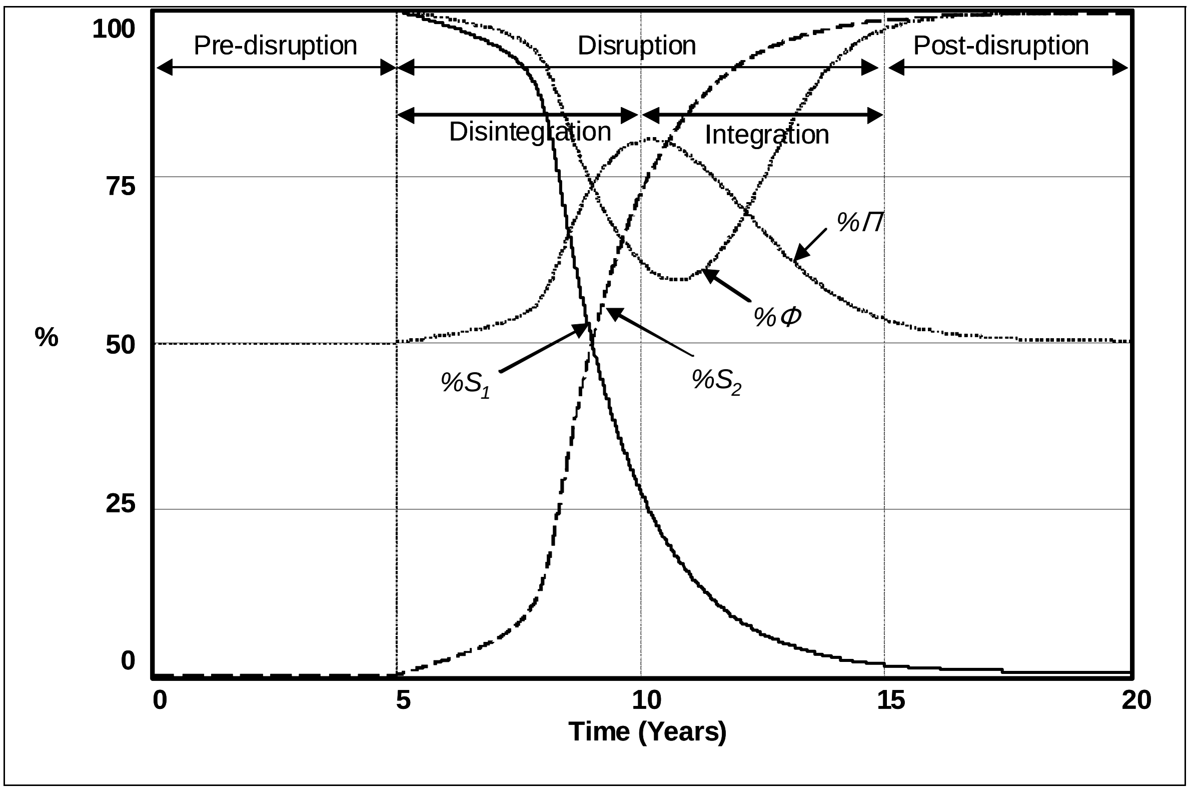


Figure 40: Average Utilized Innovation and Quality

In the pre-disruption period, in the absence of the threat of disruption, the incumbents are focused on quality and have little pressure to adopt innovation. This was the case of AT&T before breakup or even of Baby Bells before they were threatened by wireless or broadband access. As the more innovative but less quality-focused entrants disrupt, two distinct phases of dynamics take place. First, in the disintegration phase, innovation, *Π*, increases as consumers adopt the innovative services offered by the entrant, and also because the incumbents begin to focus on innovation adoption. We have seen this behavior in recent years through the transformation of incumbents such as AT&T, MCI

[73] As noted earlier in this chapter, FB definition does not explicitly consider quality because ensuring competition ensures a minimal quality. We touch upon the dynamics of quality in Figure 40 to demonstrate that certain minimum quality is sustained through the disruption.

and Sprint. The quality, Φ, however, suffers on average in the disintegration phase as the consumers use a mix of high and low quality services; for example, a mix of PSTN and peer-to-peer VoIP.[74]

By contrast, in the integration phase, those modular firms that gain higher market power must now focus on quality as demanded by their large consumer base. Hence, quality improves on average, but the innovation suffers. The loss of innovation cannot be salvaged by the higher innovation adoption among the erstwhile incumbents (i.e., the incumbents of pre-disruption period) because of their smaller market share. Thus, in the post-disruption period, the entrants become the new incumbents. They have the incentive structure to possess the same characteristics as the erstwhile incumbents – low innovation adoption and high quality. This discussion of the integration phase and post-disruption period may seem irrelevant, but we have begun to witness such tendencies to rapidly integrate among corporations such as Microsoft or Google that now actively compete in the communications value chain.

4.3.2.3 Average Utilized Market Power (Competition)

We study Average Utilized Market Power, Ψ, as a proxy for competition. Ψ is formulated as the inverse of Average Utilized Modularity, Λ (see Equation 36). Just as for Λ, Ψ too depends upon the modularity of each industry structure as well as the market share each has. Firms in more modular markets (high Λ) possess less market power (low Ψ), and vice versa.

Equation 36: Average Utilized Market Power

$$\Psi = 1 - \sum_i M_i * S_i$$

Ψ represents the market power an average consumer experiences. A low value of Ψ indicates the presence of the benefits of competition; whereas a high value indicates the presence of the drawbacks of market power as experienced by an average consumer.

In the pre-disruption period, there is high market power and low competition. We have seen this in the period before AT&T's breakup. During the disruption period, the incumbents and entrants alike face greater competitive pressures and possess lower market power. We are currently in this phase as IP-Enabled services such as VoIP threaten to disrupt PSTN. In the post-disruption period the competition reduces, as the incumbents and entrant who survive the disruption begin to exploit their market power. It

[74] One might observe that the Average Utilized Innovation, Π, reaches its peak earlier than Average Utilized Quality, Φ, reaches its valley. The reason for this behavior is the rate at which resources can be reoriented in integrated vs. modular firms. Average innovation rises quickly because when integrated incumbent become modular due to disruption, they become less rigid and can reorient resources to innovation relatively quickly. By contrast, the average quality reaches its valley slowly because when modular firms integrate, they become more rigid and become slower in their ability to reorient resources to quality. This difference in the resource reorientation rate determines how quickly the innovation improves or quality suffers.

is important to note that the market power entrants exploit may come from their market leadership in an adjacent industry. For example, the market power Google can leverage in offering voice communications service could come from its leadership position in other internet services.

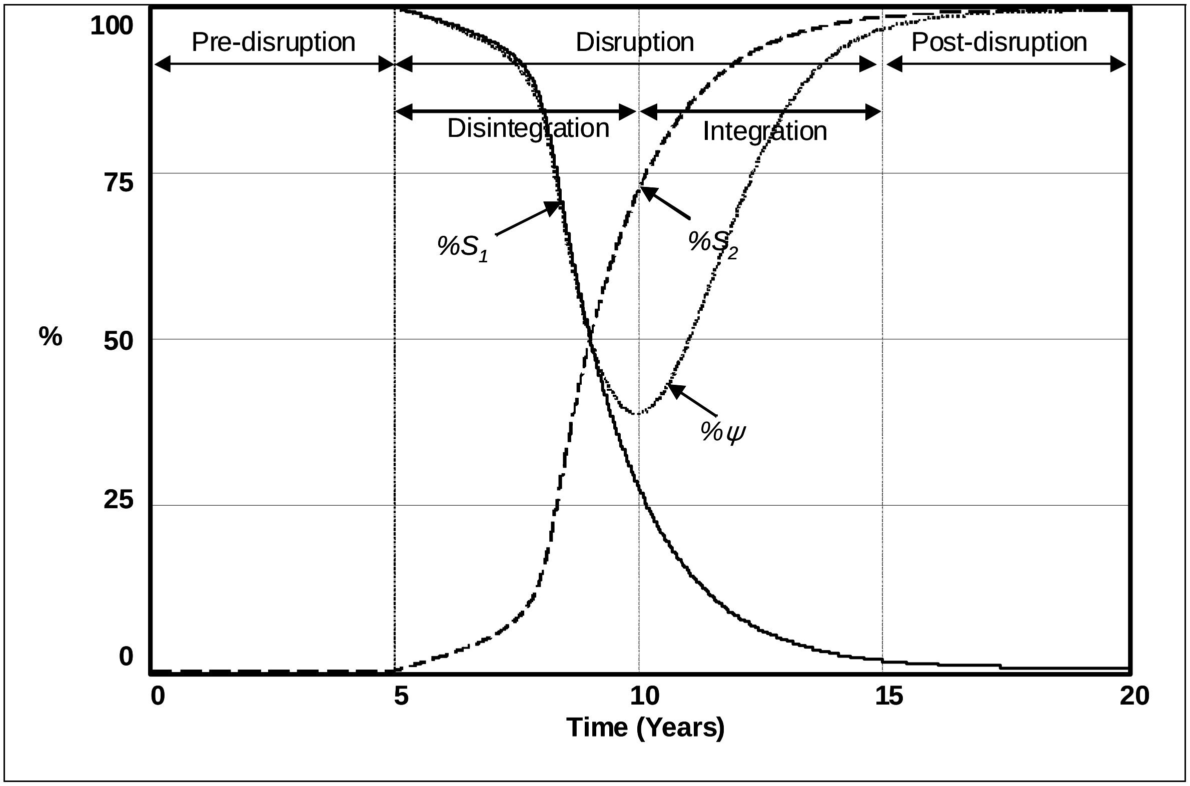


Figure 41: Average Utilized Market Power

4.3.2.4 Average Utilized Compliance Cost

Average Utilized Compliance Cost, *Ω*, is a market share weighted sum of each firm's (industry's) Coordination Cost, C_i^z, normalized with respect to the Maximum Coordination Cost, C^z_{max} .[75] Average Utilized Compliance Cost represents the marginal or per connection coordination cost a firm faces for complying with regulation.

Equation 37: Average Utilized Compliance Cost

$$\Omega = \sum_i \frac{C_i^z}{C_{max}^z} * S_i$$

[75] The normalization helps with optimization exercises that we undertake in research stage II. Since compliance cost is only a component of the total cost, *C*, the normalization scales the compliance cost between 0-1, thereby allowing us to compare it with other parameters used in optimization, such as Average Utilized Compliance, Average Utilized Innovation, etc.

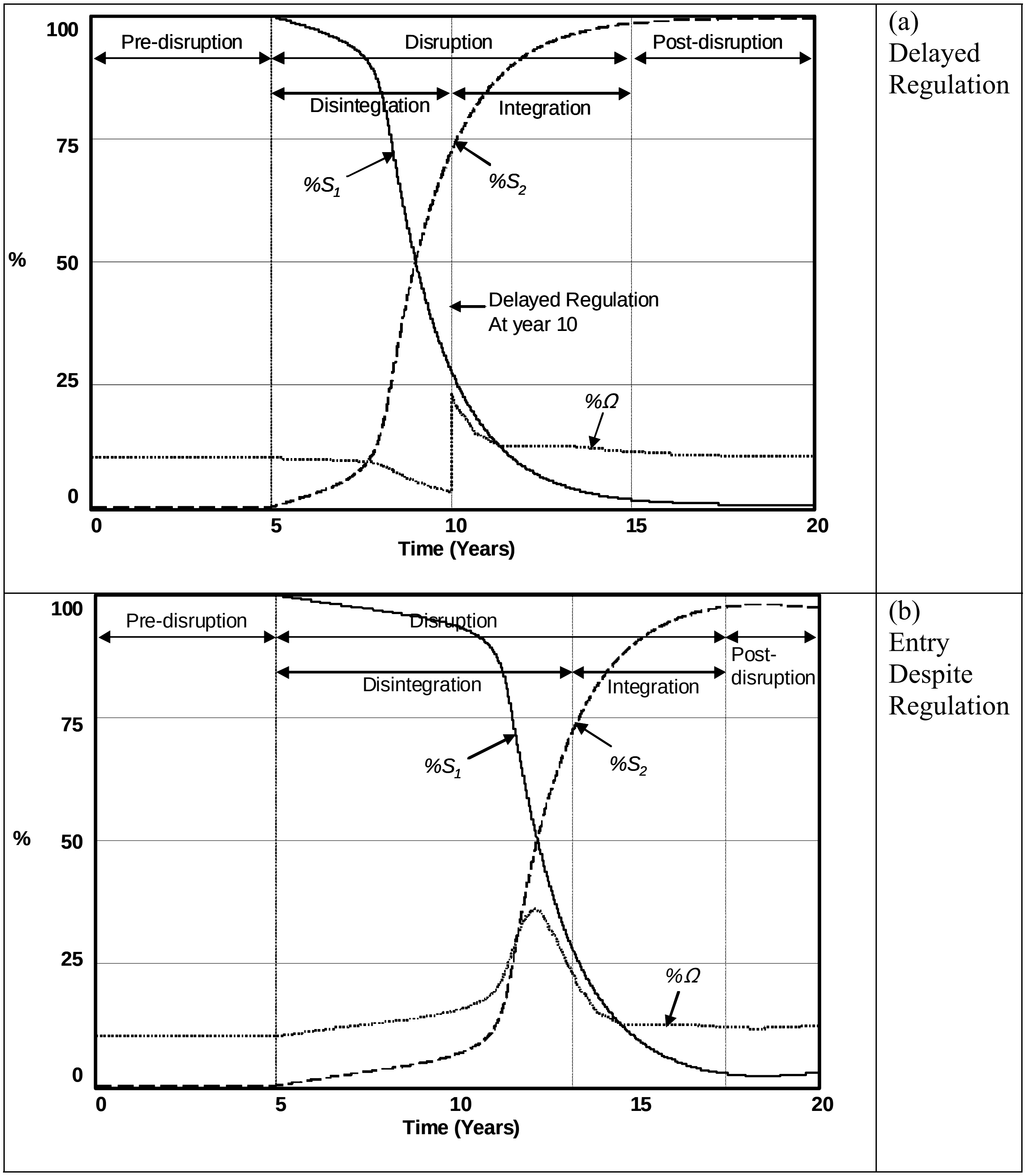


Figure 42: Average Compliance Cost

To explain the behavior of Average Utilized Compliance Cost, we compare the outcome of two simulations (see Figure 42). For simulations we have seen so far this paper, delayed regulation was used to allow the entrant to disrupt the incumbent. In such a scenario, as shown in Figure 42(a), the earliest the entrant could be regulated without posing a barrier to its entry was at the beginning of the "integration phase." As we know, in the integration phase, because the industry structure becomes less modular, firms incur lower coordination costs; hence, regulation after this point does not hamper firm's ability to compete.

Figure 42(b) simulates a different scenario to help us understand how Ω would have behaved before the integration phase (i.e., in the disintegration phase). In this simulation run, we increase the sensitivity of service's attractiveness to innovation, ε_i, such that consumers value innovation, which is entrant's natural strength, to a degree where they adopt entrant's service regardless of its regulation (i.e., its high, regulated price structure). Figure 42(b) shows that the coordination cost rises in the disintegration phase because the structure becomes more modular, before it begins to fall in the integration phase. This discussion illuminates an interesting fact: the delayed regulation removes the regulatory barrier to entry by avoiding regulation during the period of high coordination costs.

4.3.3 Stage I Results

We will now discuss the lessons we can learn from the above analysis of the emergent behaviors.

4.3.3.1 Tradeoffs across Periods of Disruption

If we superimpose the emergent behaviors discussed so far (see Figure 44), we can summarize the tradeoffs across the different periods of disruption as in Table 15. Just to remind the reader, each behavior in Figure 44 is normalized with respect to their respective maximum value, so what interests us about them here is not their magnitude but their trajectory.

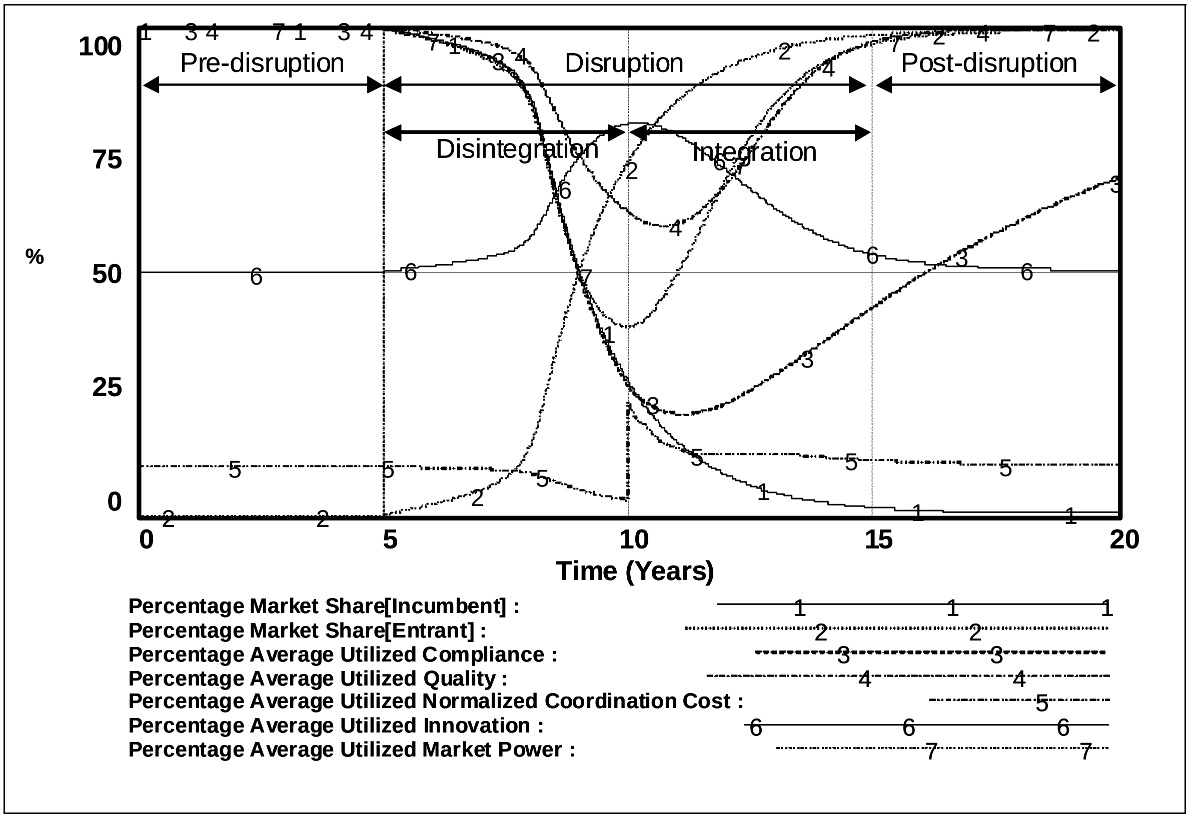


Figure 43: Tradeoffs across Disintegration and Integration - Compliance, Cost, Quality vs. Innovation and Competition

In the pre-disruption phase, there is the desirable level of regulatory compliance as well as service quality, and the cost of compliance is contained. However, integrated firms possess high market power so competition and innovation adoption are low. The transition from pre-disruption to disruption period reverses this situation, which is undesirable. The disruption period ushers the much desired innovation and competition, but jeopardizes regulatory compliance as well as service quality, and raises compliance cost. And then again, the transition from disruption to post-disruption period reverses the situation, bringing back a scenario similar to the pre-disruption period. Specifically, the post-disruption period restores the ability to comply with regulation as well as focus on quality, and reduces the compliance cost due to higher control, but may do so at the cost of innovation and competition.

	Pre-disruption Period	Disruption Period		Post-disruption Period
		Disintegration Phase	Integration Phase	
Desirable (at societal level)	High Compliance Low Compliance Cost High Quality	High Innovation Low Market Power	High Compliance Low Compliance Cost High Quality	
Undesirable (at societal level)	Low Innovation High Market Power	Low Compliance High Compliance Cost Low Quality	Low Innovation High Market Power	

Table 15: Tradeoffs across the Periods of Disruptions

4.3.3.2 Definition of the First Best (FB) Outcome[76]

If we evaluate the above flip-flop of desirable and undesirable outcomes across different periods of disruption from the perspective of two types of regulatory objectives (economic and social), introduced in chapter 2, the following role emerges for the regulator in the modular age. From the perspective of economic objectives such as competition and innovation, disruption promotes both. The regulator must think of ways to preserve these benefits in the post-disruption period. From the perspective of social objectives such as law enforcement and public safety, disruption can derail them. The regulator must think of ways to prevent disruption from compromising them. Consequently, the regulator's new role ought to be to achieve the following vital combination across the different periods of disruption, which we define as the *first best* (FB) outcome:

1. The necessary regulatory compliance is achieved,
2. The high innovation and competition are preserved, and
3. The reasonable cost of compliance is maintained.

The two arrows on Table 15 depict the undesirable effect that must be reversed to achieve the FB outcome.

Can the FB be achieved using the currently-known policy levers such as partial and delayed regulation? This is the question we explore in the next research stage II.

4.4 Research Stage II: Can the Existing Policy Levers Achieve FB?

In Chapter 2 we demonstrated how little confidence regulators can have in using existing policy levers such as partial and delayed regulation given the dynamic complexity of the environment of disruption. That analysis was carried out on a model where variables related to technology, corporate strategy, and industry structure were exogenous. We will now assess the efficacy of partial and delayed regulation in a fully endogenous model. In other words, we will assess whether applying the existing policy levers continues to be futile when we test them on the system as a whole, considering the interactions within it as a black box. With the help of a set of optimization exercises, we will study whether these existing levers can be used to achieve the FB outcome.

[76] The Theory of the Second Best concerns what happens when one or more optimality conditions cannot be satisfied in an economic model. Canadian economist Richard Lipsey and Australian-American economist Kelvin Lancaster showed in a 1956 paper that if one optimality condition in an economic model cannot be satisfied, it is possible that the next-best solution involves changing other variables away from the ones that are usually assumed to be optimal. Lipsey, R. G. and K. Lancaster (1956-1957). "The General Theory of Second Best." The Review of Economic Studies **24**(11): 11-32.

4.4.1 Optimization I: Maximize Compliance[77]

We start with an optimization exercise that has a simple objective function of maximizing Percentage Average Utilized Compliance, *%Θ*, [78] subject to the scope and timing of entrant's regulation. Equation 38 shows the setup.

Equation 38: Optimization I

$$\max_{\substack{0 \le Z_2^* \le 1 \\ 60 \le t_2^z \le 180}} \Theta$$

Where
Z_2^* is the required compliance for entrant, and
t_2^z is time of entrant's regulation[79]

Figure 44 shows the outcome. It shows that to maximize *%Θ,* the optimizer regulates the entrant fully (required compliance is 100%) at the time of entry (at year 5). Such a decision does render maximum compliance since heavy and early regulation poses a barrier to entrant's market entry, so incumbents continue to serve the market, and the compliance remains intact at the level offered by incumbents. Quality too remains at a level offered by the integrated incumbent. Once again, reminding us of the government-sanctioned monopoly of the pre-AT&T breakup era. On the down side, however, incumbents also possess high market power, and have little competitive pressure to adopt innovation.

---

[77] Powell optimization method is used here for optimization. The simulation package used, Vensim, carries out payoff calculation as follows. At each TIME STEP the values of all the variables are multiplied by the weights they have been given, and then they are multiplied by TIME STEP and added to the payoff. (The payoff is effectively always integrated using Euler integration.) The optimizer is designed to maximize the payoff, so variables for which more is better should be given positive weights and things for which less is better should be given negative weights. The weights should be set so that all elements are scaled to be of the same order of magnitude. Having done this you can adjust weights up and down to emphasize different aspects of the payoff. The payoff value realized is just the weighted combination of the different payoff elements integrated over the simulation. If you are interested in looking at the terminal values of a variable then in the model use the equation.

[78] The percentage values are calculated to make the parameters more intuitive. They just scale the parameter from 0-1 to 0-100.

[79] The time of entrant's regulation constrained between month 60 (entrant's market entry time) and 180 (10 years from entrant's market entry), just so the simulation package does not pick a value beyond the duration of the simulation.

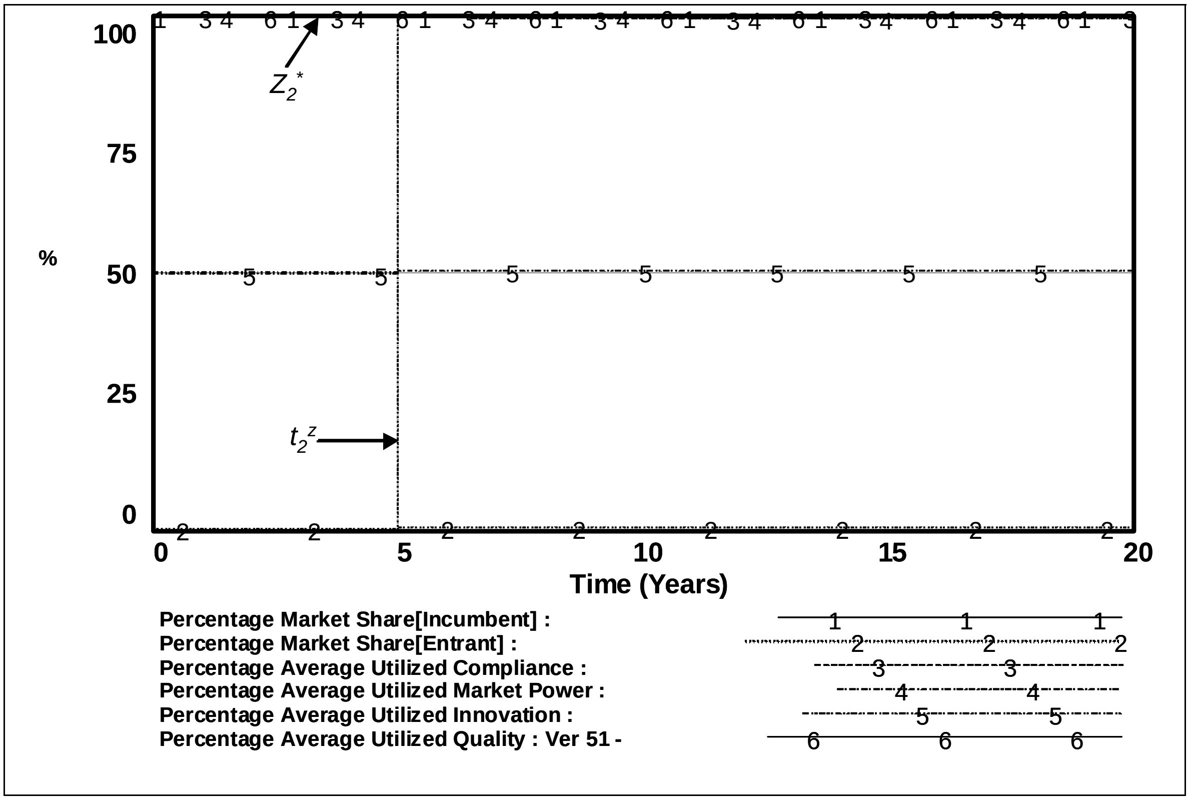


Figure 44: Regulation at Entry Optimization - Compliance at Low Cost, but No Innovation and Competition (Regulation Creates Barrier to Entry)

The next optimization exercise is designed to explore how the barrier to entry may be reduced to increase competition and innovation.

4.4.2 Optimization II: Balance Compliance, Competition, and Innovation

In this exercise, we set up an optimization to balance Percentage Average Utilized Compliance, $\%\Theta$, Percentage Average Utilized Market Power, $\%\Psi$, and Percentage Average Utilized Innovation, $\%\Pi$, subject to the scope and timing of entrant's regulation. Equation 39 shows the setup. The weights for compliance and innovation (w_Θ and w_Π, respectively) take a positive value indicating that the higher the compliance and innovation the better it is. The weight for market power, w_Ψ, takes a negative value indicating that the lower the market power the better it is. To indicate a bias against barrier to entry, high innovation is preferred more to high compliance ($w_\Pi > w_\Theta$), and low market power is preferred more to high compliance ($|w_\Psi| > w_\Theta$).

Equation 39: Optimization II

$$\max_{\substack{0 \le Z_2^* \le 1 \\ 60 \le t_2^z \le 180}} \; \boldsymbol{w_\Theta \Theta - w_\Psi \Psi + w_\Pi \Pi}$$

$$|w_\Psi| > w_\Theta$$
$$w_\Pi > w_\Theta$$

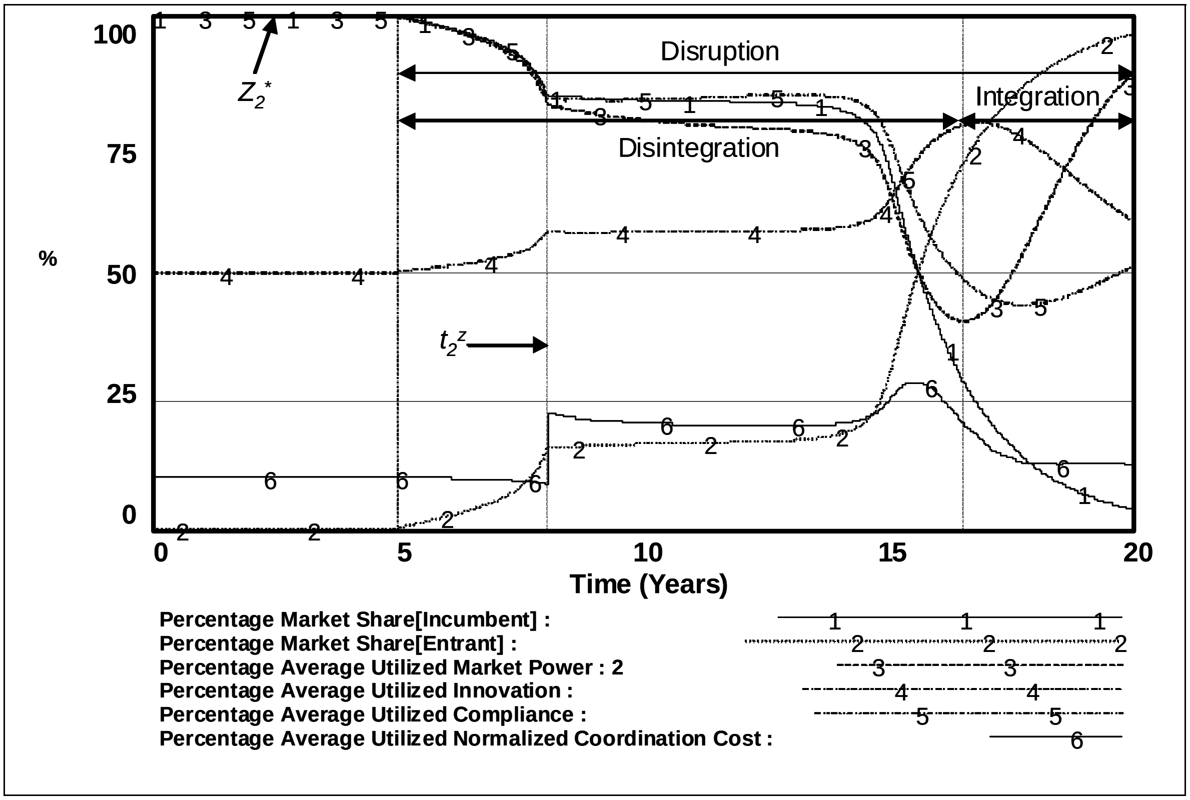


Figure 45: Delayed Regulation Optimization - Innovation and Competition, but less than Required Compliance and High Compliance Cost

Figure 45 shows the outcome. It shows that to balance compliance with innovation and competition, the optimizer chooses delayed regulation. In this simulation, the entrant enters at year 5 and is regulated at year 8. Entrant is regulated as soon as it matures sufficiently to disrupt the incumbent and no later. The regulation may delay disruption (see line 2) but does not pose a barrier to entry. During the disintegration, the competition (see line 3) and innovation (see line 4) show a gain, which is desirable. However, there are also undesirable effects. First, compliance (see line 5) drops below the required level. Next, the rising coordination cost in the disintegration phase (see line 6) may lower the achievable compliance and pose a barrier to entry for late entrants. Finally, the benefits of high innovation and competition, gained during distintegration, are lost in the integration phase.

This optimization exercise demonstrates that when looking at the whole system (i.e., in a fully endogenous model), delayed regulation may, in theory, help balance compliance with innovation and competition, but the coordination cost continue to be an issue. Also, delayed regulation does not overcome the drawback of the integration phase (i.e., the competition and innovation continue to drop in the post-disruption period).

The next optimization exercise is designed to explore how the coordination cost can be lowered without losing innovation and competition in the disintegration phase.

4.4.3 Optimization III: Balance Compliance Cost, Innovation, and Competition

In this exercise, we set up an optimization to balance Percentage Average Utilized Normalized Compliance Cost, $\%\Omega$, Percentage Average Utilized Market Power, $\%\Psi$, and Percentage Average Utilized Innovation, $\%\Pi$, subject to the scope and timing of entrant's regulation. Equation 40 shows the setup. The weight for compliance cost, w_Ω, takes a negative value indicating that the lower the coordination cost the better it is. In this optimization, equal preference is given to compliance cost, innovation, and market power ($|w_\Omega| = w_\Pi = |w_\Psi|$).

Equation 40: Optimization III

$$\max_{\substack{0 \le Z_2^* \le 1 \\ 60 \le t_2^z \le 180}} \; \boldsymbol{w_\Pi \Pi - w_\Psi \Psi - w_\Omega \Omega}$$

$$|w_\Omega| = w_\Pi = |w_\Psi|$$

Figure 46 shows the outcome. It shows that to balance compliance with innovation and competition, the optimizer chooses partial regulation. In fact, it leaves the entrant unregulated, using the extreme form of partial regulation. The entrant enters at year 5, and since it is not regulated (i.e., no barrier to entry), it goes on to disrupt the incumbent (see line 2). During the disintegration phase, the competition (see line 3) and innovation (see line 4) retain the desirable gain from optimization exercise II. The coordination cost falls with disruption, since the disrupting entrant is not regulated, so has no need to coordinate for regulatory compliance. Unfortunately, however, as the entrant is left unregulated, there is a complete loss of compliance (see line 5). Also, the benefits of high innovation and competition continue to be lost in the integration phase.

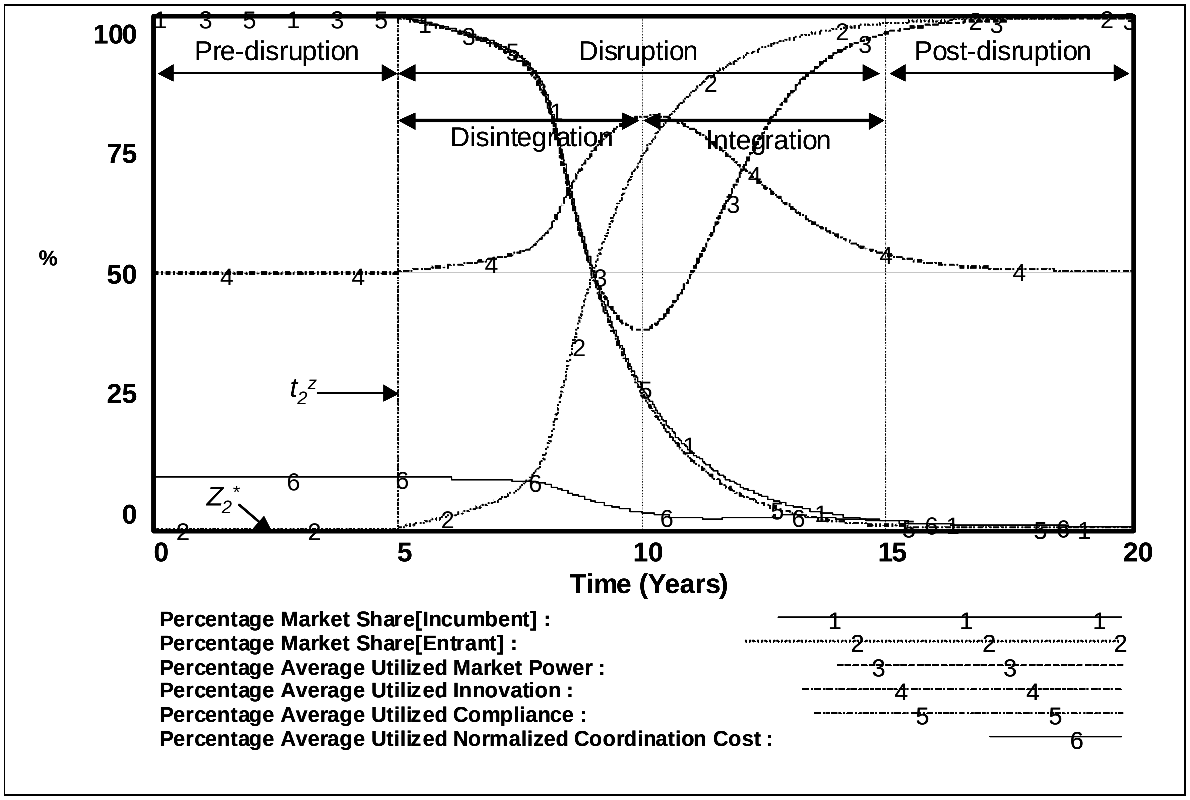


Figure 46: Partial Regulation - Low Cost, and High Innovation, Competition, but Little Compliance

This optimization exercise demonstrates that when looking at the whole system, partial regulation may, in theory, help balance compliance cost with innovation and competition, but does so at the cost of compliance itself. And similar to delayed regulation, partial regulation too does not overcome the drawbacks of the post-disruption period.

The next and final optimization exercise is designed to explore what level and timing of regulation offers the best balance of all four emergent behaviors – compliance, innovation, competition, and compliance cost.

4.4.4 Optimization IV: Balance Compliance, Innovation, Competition, and Compliance Cost

In this final exercise, we set up an optimization to balance Percentage Average Utilized Compliance, *%Θ*, Percentage Average Utilized Market Power, *%Ψ*, and Percentage Average Utilized Innovation, *%Π*, and Percentage Average Utilized Normalized Compliance Cost, *%Ω*, subject to the scope and timing of entrant's regulation. Equation 41 shows the setup. The weights for the objective function are set similar to that in optimizations II and III.

Equation 41: Optimization IV

$$\max_{\substack{0 \le Z_2^* \le 1 \\ 60 \le t_2^z \le 180}} \; w_\Theta \Theta - w_\Pi \Pi - w_\Psi \Psi - w_\Omega \Omega$$

$$w_{\Theta} < |w_{\Omega}| = w_{\Pi} = |w_{\Psi}|$$

Figure 47 shows the outcome. It shows that to balance high compliance, with high innovation as well as competition, but low compliance cost, the optimizer chooses to do both partial and delayed regulation of the entrant. As a result, the entrant enters at year 5 and disrupts the incumbent (see line 2). Competition (see line 3) and innovation (see line 4) rise during the disintegration phase of disruption period. The coordination cost falls with disruption, since the disrupting entrant is not regulated at the market entry, but shoots up as soon as it is regulated. Since delayed regulation occurs with the onset of the integration phase, the coordination costs steadily fall to their minimum level (see line 6). The compliance level continues to drop below the required level in the disintegration phase (see line 5), but recovers in the integration phase. Finally, as seen before, the benefits of high innovation and competition continue to be lost in the integration phase.

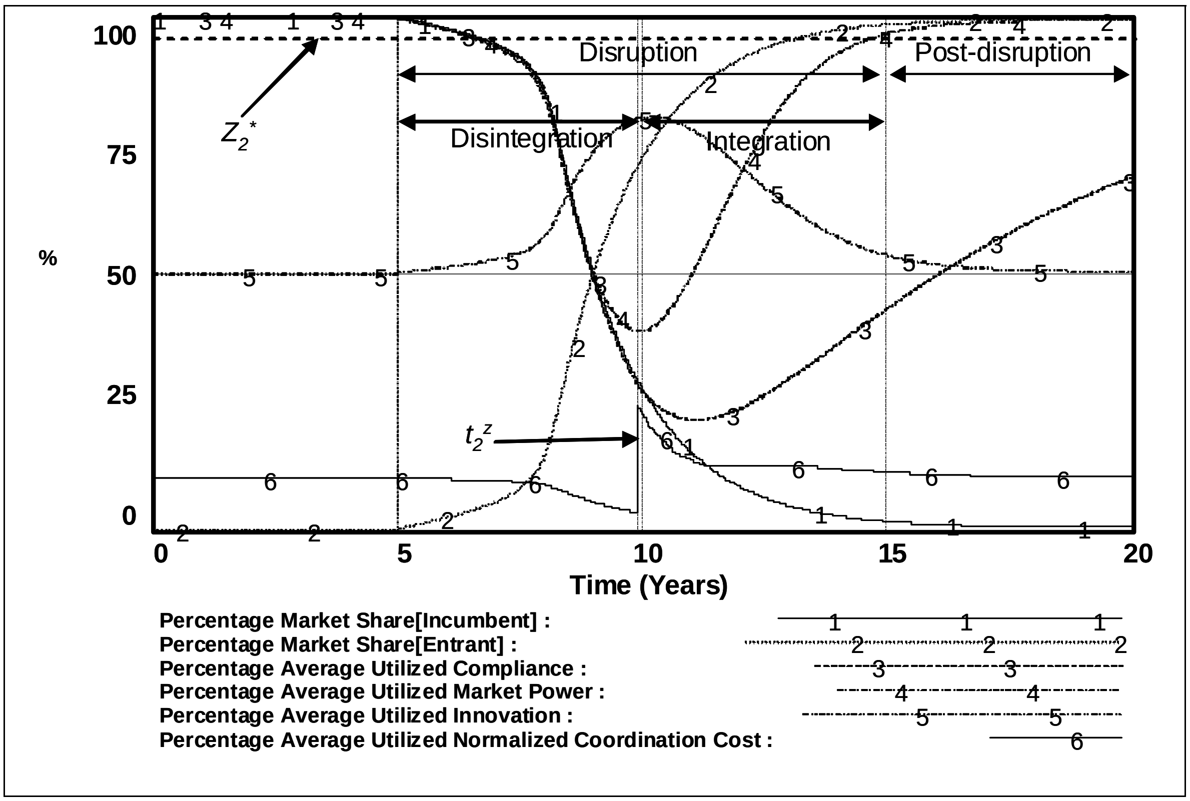


Figure 47: Partial and Delayed Regulation Optimization - Required Compliance, Innovation and Competition, but High Cost

This optimization exercise demonstrates that when looking at the whole system, partial regulation and delayed regulation still render lower than required compliance, and do not remedy the post-disruption loss of innovation and competition.

4.4.5 Stage II Results

4.4.5.1 Existing Policy Levers Cannot Achieve the FB

Together, optimization exercises II, III, and IV show that existing policy levers – partial and delayed regulation – cannot attain the FB outcome. They may achieve high innovation and competition while containing the coordination cost, but the necessary level of compliance cannot be ensured, and vice versa. More importantly, the existing policy levers offer no remedy for the post-disruption tradeoffs. Through the integration phase, the entrants consolidate to become the new incumbents. The consolidation of the industry may reduce the effort to build consensus necessary for regulatory compliance, but the benefits of the high level of competition and innovation are lost.

Hence the second stage of research above concludes that the existing arrows in the regulatory quiver are blunt. They alone cannot achieve the desired outcome. In chapter 2, we demonstrated how difficult it is to implement partial or delayed regulation. We have now shown that they are also inadequate for achieving the FB outcome.

Despite the disappointing conclusion above, the above analysis does illuminate the theoretical conditions that must be met if the compliance, innovation, competition, and cost had to be balanced.

4.4.5.2 Conditions for balancing Compliance, Competition, Innovation, and Cost

From the outcome of the optimization exercises, we can derive conditions for balancing compliance, competition, innovation, and cost. In going from optimization I to II, we learned that if compliance, innovation and competition had to be balanced, the modular entrants who are innovative must be allowed to enter, so that either they disrupts the incumbents, or they create the competitive pressure for the incumbents to consider destructing their less innovative services creatively.

Next, through optimization II, and III we learned that if we had to avoid partial and delayed regulation and still allow weaker entrants to disrupt, the modular structure must have the ability to comply with regulation at a low cost. If that is not the case, the resulting compliance turns out to be far less than required, or the high coordination cost acts as an entry barrier for entrants.

Finally, through optimization II, III, and IV, we learned that the advantages of disruption, such as high competition and innovation, must be preserved in the post-disruption period. If the industry remains modular, there will be higher competition and innovation even in the post-disruption period.

In summary, the conditions for achieving the desired balance between compliance, competition, innovation and cost (i.e. the FB outcome) are as follows:

1. The modular structure must enter and create competitive pressure,
2. The modular structure must have the ability to comply with regulations at low cost, and
3. The modular structure must remain modular in the post-disruption period.

The policy analysis in the third stage of research explores which new policy levers must be pulled to achieve such an outcome.

4.6 Research Stage III: Can any Unexplored Policy Levers Achieve the FB?

Through the stage II of research, we learned that existing policy levers do not work for achieving the FB. In stage III of research, we investigate whether there are a set of policy levers not yet explored by the regulators that may achieve the desired combination. For this investigation, we use *Policy Sensitivity Analysis* on the systems model. The idea behind policy sensitivity analysis is to ask whether changing assumptions makes certain policies more or less desirable.[80]

4.6.1 Two New Policy Levers that Theoretically Solve the Regulatory Puzzle

Our policy sensitivity analysis, detailed in Appendix D, yields two high-leverage policy levers that might achieve the FB. These levers are: (1) limiting significant market power (SMP) accumulation and (2) building broad-based consensus around regulatory issues in a modular industry structure. The first policy lever remains under emphasized by the US Telecommunications Regulators, [81] and second one is virtually absent from policy debates. Figure 48 is an abstraction explaining the causal structure behind why the two policy levers might work. After explaining the causal structure, we will discuss test results, demonstrating that the policy levers do work.

---

[80] Precisely, "sensitivity analysis asks whether [our] conclusions change in ways important to [our] purpose when assumptions are varied over the plausible range of uncertainty." Further, "Policy analysis exists when a change in assumptions reverses the impacts or desirability of a proposed policy." (p. 883 of Sterman, J. (c2000). Business dynamics: systems thinking and modeling for a complex world. Boston, Irwin/McGraw-Hill.
)

[81] Limiting market power has always been a major thrust since the creation of the FCC in 1934, but, in the United States, interconnection regulations remains the main mechanism for limiting market power, which is far narrower than what we will discuss in the conclusion section of this paper.

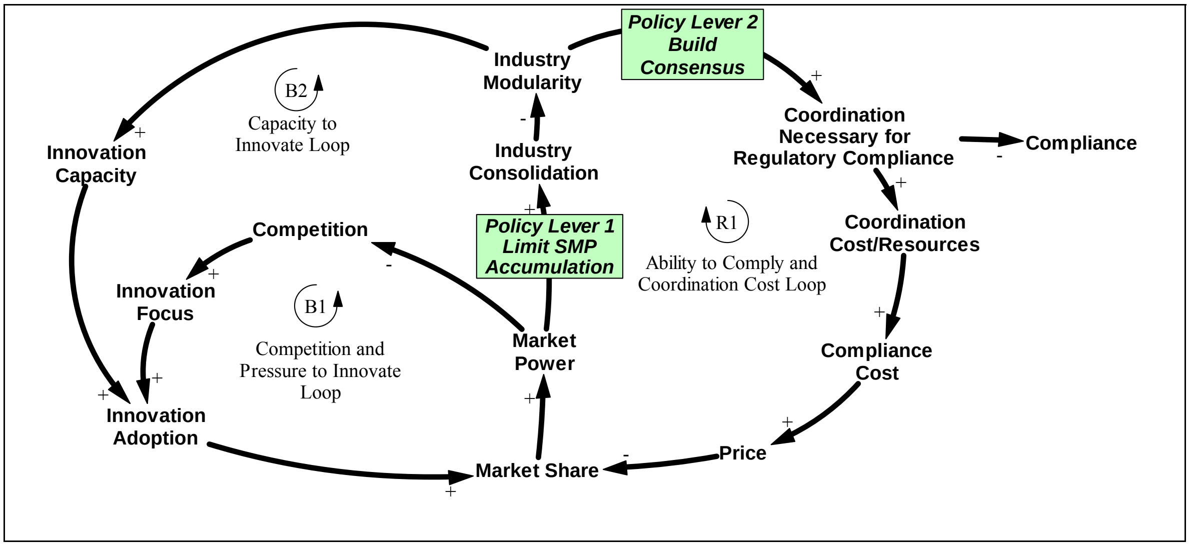


Figure 48: Causal structure explaining the logic behind the two policy levers

Competition and Pressure to Innovate

When a firm gains more market share (bottom center of Figure 48) its market power increases. As firms gain market power the industry becomes less competitive. As competition reduces, firms are under less pressure to innovate, which reduces innovation adoption. However, a firm adopting less innovation also struggles to keep the market share, assuming there is still competition in the market. This is a balancing structure that explains how an increase in a firm's market share leads to less innovation, which in turn limits the market share itself (see the Competition and Pressure to Innovate Loop, B1). Such a causal structure exists as long as there is competition in the market, and ensures there is innovation adoption in the presence of competition.

Capacity to Innovate

Once again starting with market share; as firms gain market share and market power, they have the incentive to increase scope by integrating new products, and to amass scale by mergers and acquisitions. Both of these activities lead to further industry consolidation. As the industry consolidates the industry structure becomes less modular, on average. Less modular structures have lower capacity to innovate because fewer interfaces are standardized, so module level innovation is tougher, and integration increases the dimensional complexity, so those in control of it too struggle to introduce innovations. Such reduction in innovation capacity stifles the innovation adoption, hence adversely affecting the firm's market share. This too is a balancing structure (see Capacity to Innovate Loop, B2), that explains how increase in market share could lead to consolidation of the industry structure and hence the loss of capacity to innovate, thereby limiting the market share itself. There is never a complete loss of innovation capacity, not even when the industry structure fully integrates. However, structures B1 and B2 together explain that ultimate innovation adoption depends upon not just the capacity to innovate, but also the extant pressure to adopt them.

Ability to Comply and Coordination Cost

We saw above that an increase in firm-level market share ultimately results in the reduction of the modularity of the industry structure. With reduced modularity, firms need lower coordination, as they have less dependence on other firms, on average, when complying with regulation. The reduction in coordination necessary for regulatory compliance lowers the compliance cost and enables firms to achieve higher compliance. Further, as lower compliance cost lowers the price, the firm's service becomes more attractive and gains market share, forming a reinforcing structure (see Ability to Comply and Coordination Cost Loop, R1). This structure explains how increase in market share leads to more industry consolidation, which gives each firm more control to comply with regulation, and lowers their coordination cost, thereby reducing price and increasing the market share even further. When the market share reduces, the cycle reverses, taking us to the other end of the spectrum – modular industry structure, high coordination cost, and low achievable compliance. Of course, as discussed in chapter 2, even in a fully modular industry, some compliance is still achievable, but the level achievable may be far lower than required, and the cost and time required to achieve it may be inordinate.

Together, the three structures undergird the tradeoffs discussed in Table 15. An increase in industry modularity has the desirable effect of higher competition and innovation adoption, but the undesirable effect of lower compliance and higher coordination cost. Conversely, a decrease in industry modularity has the desirable effect of higher compliance at a lower compliance cost, but has the undesirable loss of competition and innovation.

Policy Levers

At the end of Research Stage II discussion, we setout three conditions for compliance, competition, innovation, and compliance cost. We can now use the above causal structure to identify policy levers that can help us meet the three conditions. We start with the third condition, which states that to balance the four attributes, "the modular structure must remain modular in the post-disruption period." Modularity is lost in the post-disruption period because modular firms gain market power and begin to consolidate. Policy lever 1, *Limiting Significant Market Power (SMP) Accumulation*, in a single firm or a collection of them, can keep the industry structure modular in the post-disruption period, and thereby minimize the undesirable loss of competition and innovation. The idea is that if regulation can limit the rapid and automatic translation of firm's market power into industry consolidation, the market would remain competitive with pressure to adopt innovation, and the modular structure will preserve the high capacity to innovate.

However, limiting SMP accumulation alone cannot be the solution to achieving the FB because keeping modularity high results in lower compliance because of high coordination cost. Hence, as stated in condition two, "the modular structure must have the ability to comply with regulations at low cost." If this can be achieved, we can also meet condition one ("the modular structure must enter and create competitive pressure") without using existing policy levers such as partial or delayed regulation, since both policies are aimed at lowering or delaying the impact of compliance cost. This discussion suggests that we must find another policy lever that achieves high compliance at low cost despite high modularity. Policy lever 2, *Building Broad-based Consensus* around regulatory issues, achieves this outcome.

Modular industries lose the ability to achieve high regulatory compliance because they lack consensus around regulatory issues. The lack of consensus imposes a high coordination cost, thereby lowering the achievable compliance. The idea behind policy lever 2 is that if regulators can build consensus among stakeholders around meeting critical regulatory objectives, the effort required for individual firms to build consensus for regulatory purposes reduces, thereby reducing their coordination cost and increasing their ability to comply with regulation. In the conclusion section, we will elaborate upon the ways to build consensus.

The above discussion shows that if both policy levers 1 and 2 are pulled the desired outcome (FB) may be achievable. We will now test on the systems model whether the two policy levers indeed work.

4.6.2 Stage III Results

4.6.2.1 Policy Lever 1: Limiting Significant Market Power

Figure 50-Figure 52 show the use of policy lever 1 with the aim of keeping the industry structure modular in the post-disruption period. Each figure shows outputs of three simulation runs, each with a different limit on SMP accumulation. Also, in each figure, sets of lines 4-5, 6-7, and 8-9 depict incumbent-entrant market share for the three simulations, and lines 1-3 show the parameter of interest.

Figure 49 shows how imposing higher limits on SMP accumulation renders increasingly modular industry structure in the post-disruption period. It shows how policy lever 1 achieves condition three of keeping the industry structure modular in the post-regulation period.

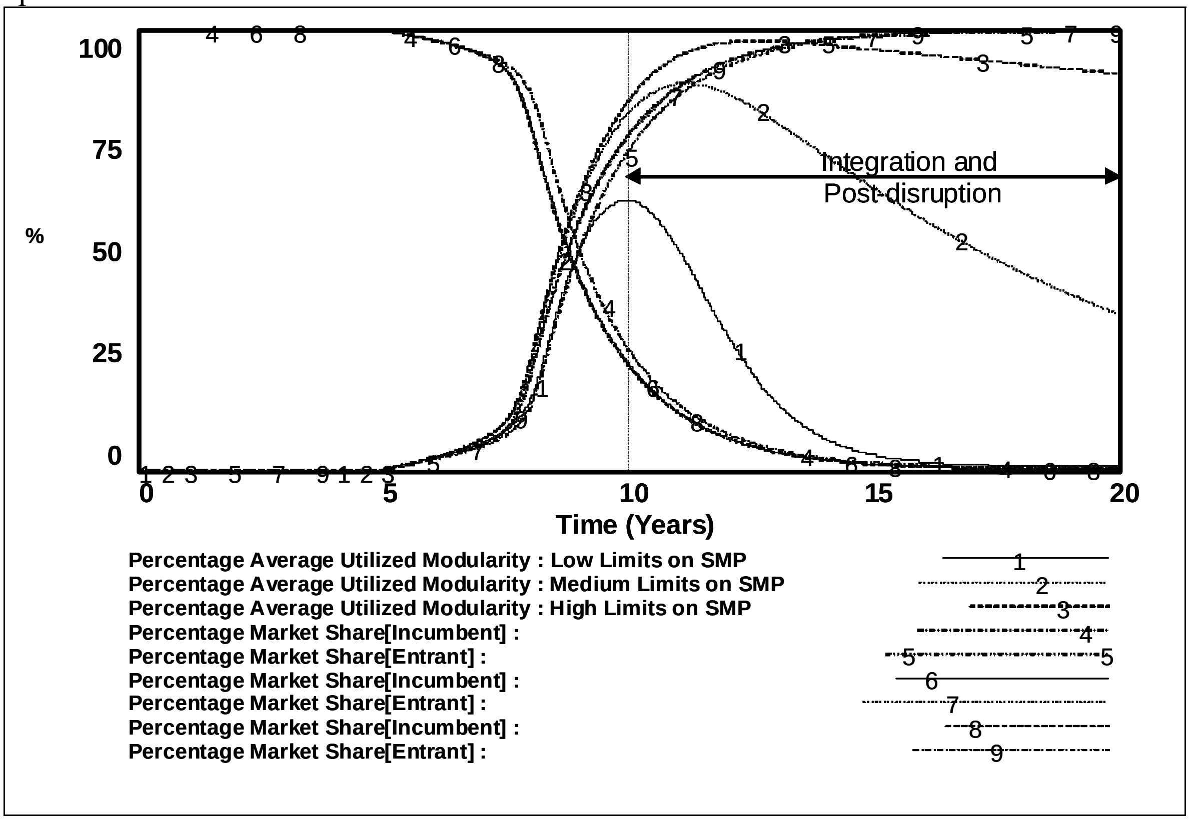


Figure 49: High Modularity under Limited Market Power in Post-disruption Period

We can now ask if the higher modularity in post-disruption period indeed yield higher competition and innovation.

Figure 50 shows that, as expected, imposing higher limits on SMP accumulation does render lower market power (i.e., higher competition) in the post-disruption period.

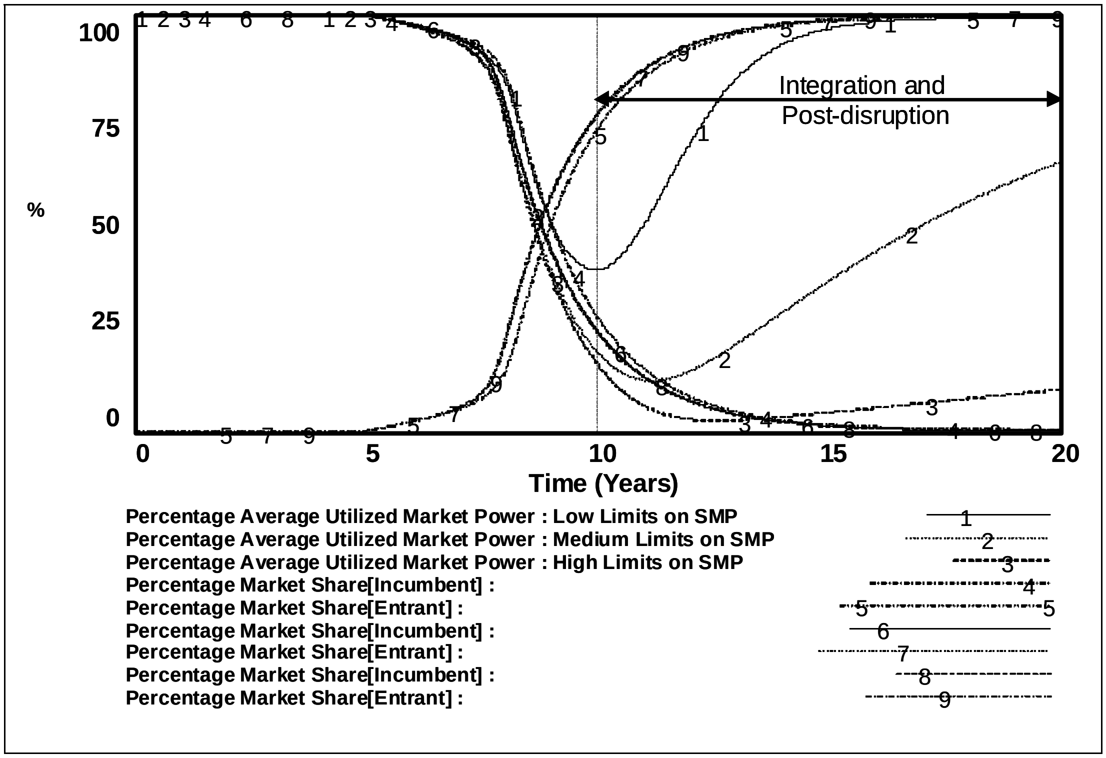


Figure 50: High Competition under Limited Market Power in Post-disruption

Similarly, as shown in Figure 51, imposing higher limits on SMP accumulation does render high innovation in the post-disruption period.

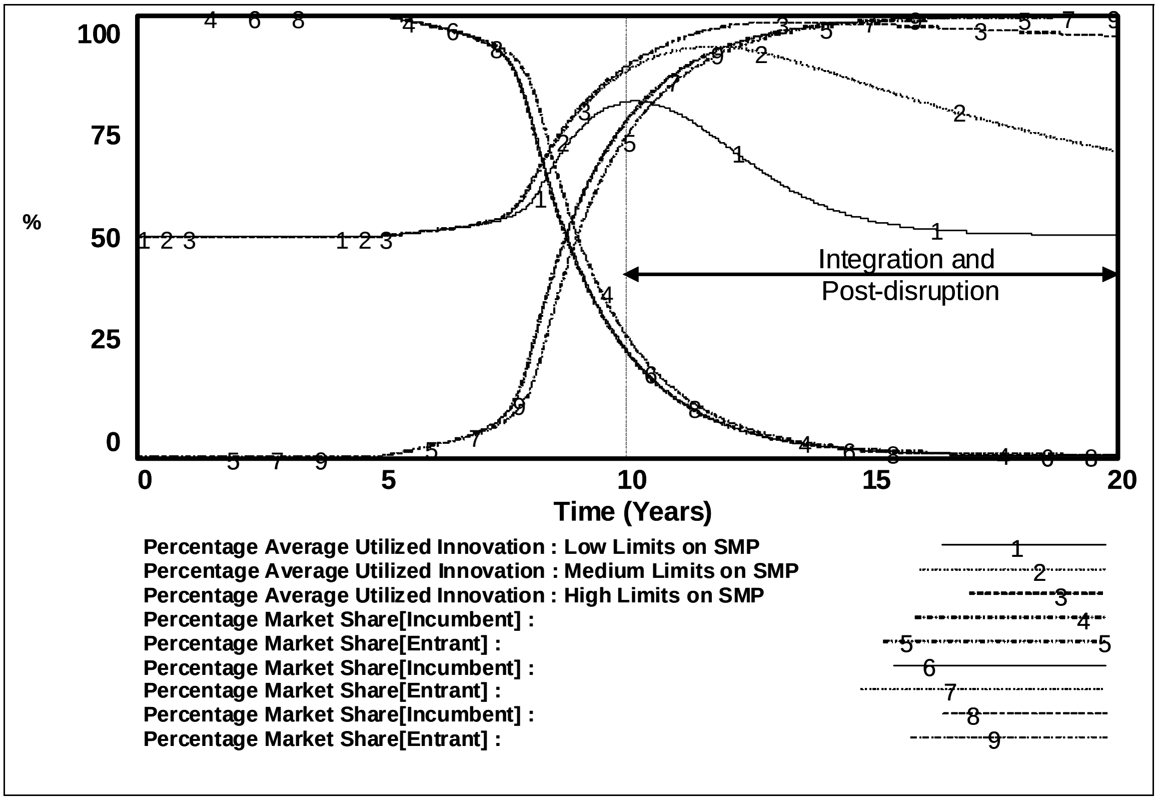
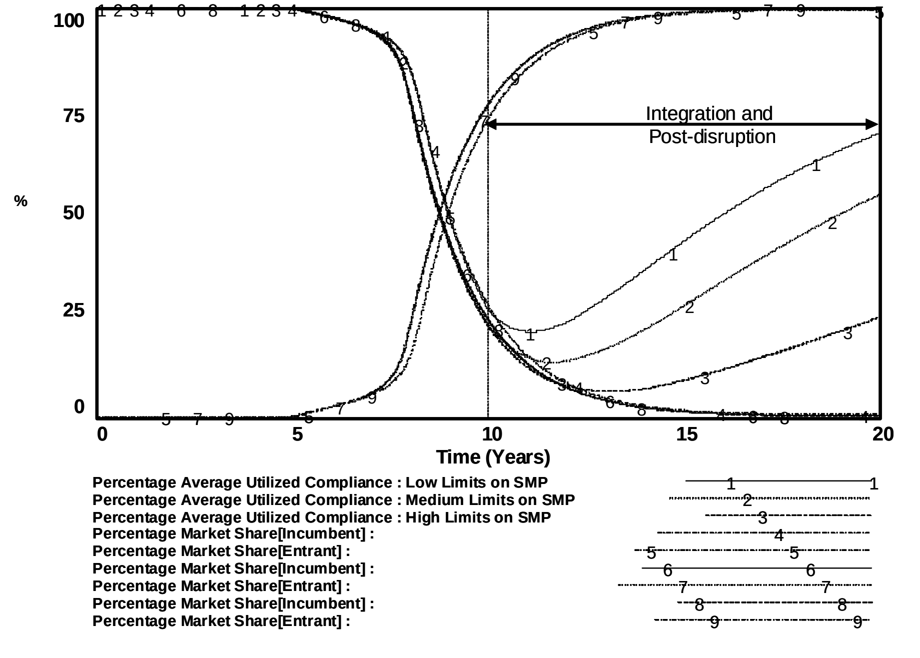


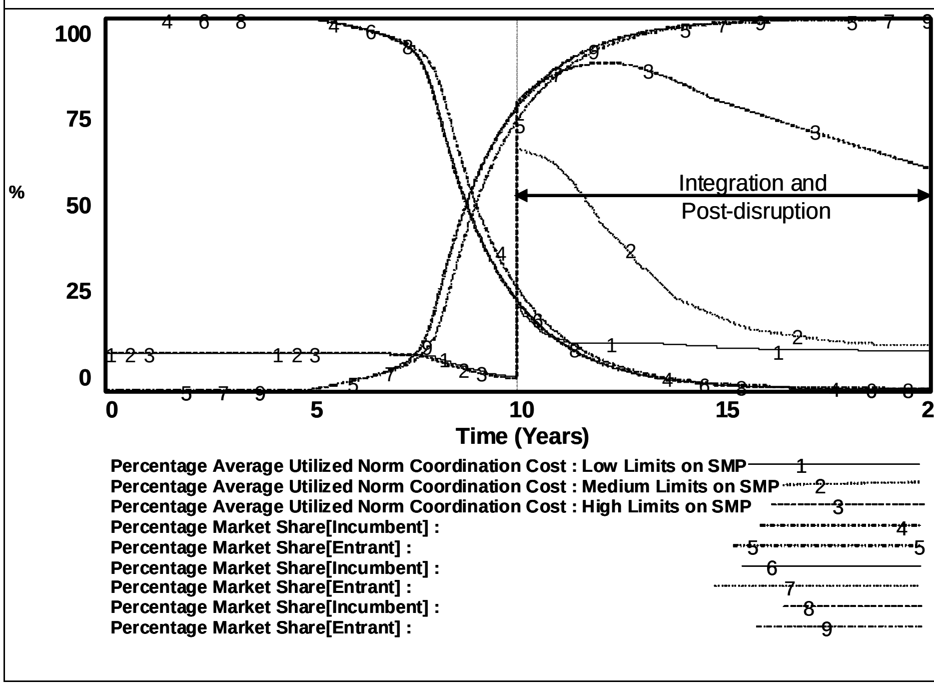
Figure 51: High Innovation under Limited Market Power in Post-disruption Period

Figure 50 and Figure 51 show that policy lever 1 facilitates achieving the innovation and competition portion of the FB outcome. As argued with the causal structure, however, policy lever 1 alone may not be sufficient for achieving the FB, since the increased modularity of the post-disruption period might lower compliance level and raise compliance cost. Figure 51 confirms this insight.

Figure 51(a) shows how imposing higher limits on SMP accumulation renders lower compliance in the post-disruption period. And Figure 51(b) shows how imposing higher limits on SMP accumulation renders high compliance cost in the post-disruption period.



(a) Compliance



(b) Coordination Cost

Figure 52: Lower Compliance and Higher Coordination Cost with Limiting Market Power in Post-disruption Period

The illustrations above confirm that limiting SMP accumulation increases competition and innovation, but exacerbates the loss of compliance and disproportionate coordination cost issues. Therefore, policy lever 1 alone is not sufficient for achieving the FB, from the systems perspective. We will not investigate what happens when policy levers 1 and 2 are combined.

4.6.2.2 Policy Lever 2: Building Broad-based Consensus

Figure 55-Figure 56 show the use of policy lever 1 and 2 with the aim of enabling modular structure to have the ability to comply with regulations at low cost. Each figure shows outputs of four simulation runs, each with a different relation ship between modularity and effort necessary to build consensus. Similar to the previous section, in each figure, sets of lines 5-6 and 7-8 depict incumbent-entrant market share for simulations 1 and 4, respectively. Lines 1-4 show the parameter of interest.

In the four simulations used, building consensus gets increasingly easy. In other words, in simulation 1, effort necessary to build consensus is positive and very convex in increasing modularity; meaning, the effort required to build consensus is low when the structure is integral, but increases exponentially with modularity. Highly modular structures required a very high effort to build consensus. Simulation 2, the relationship is less convex. In simulation 3, an increase in effort necessary to build consensus increases proportional to the modularity of industry structure and the effort necessary at any point is less than that in simulations 1 and 2. Finally, in simulation 4, the relationship between the two is convex. So, some structural intervention such as building broad-based consensus around regulatory issues, as suggested in policy lever 2, helps contain the effort required to build consensus.

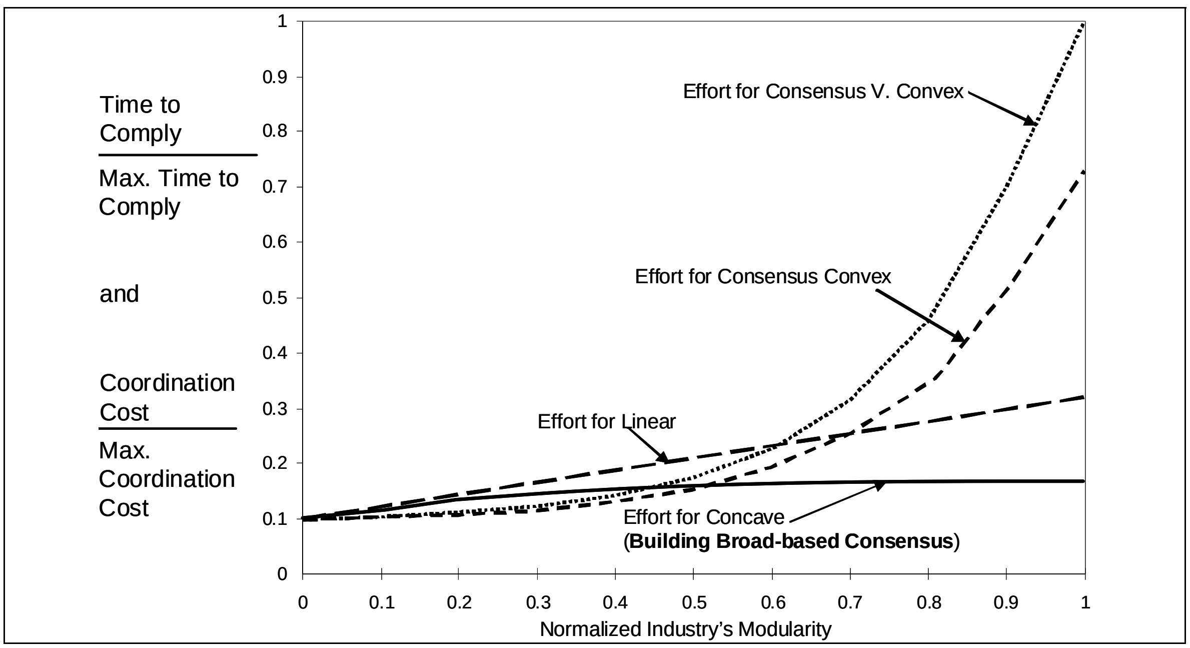


Figure 53: Relationship between Modularity of the Industry Structure and the Effort Necessary to Build Consensus

Figure 54 shows how building broad-based consensus around regulatory issues at increasingly high levels restores the modular structure's ability comply with regulation. Here, line 1 pertains to lowest consensus (i.e., maximum effort necessary to build consensus) and line 4 pertains to highest consensus.

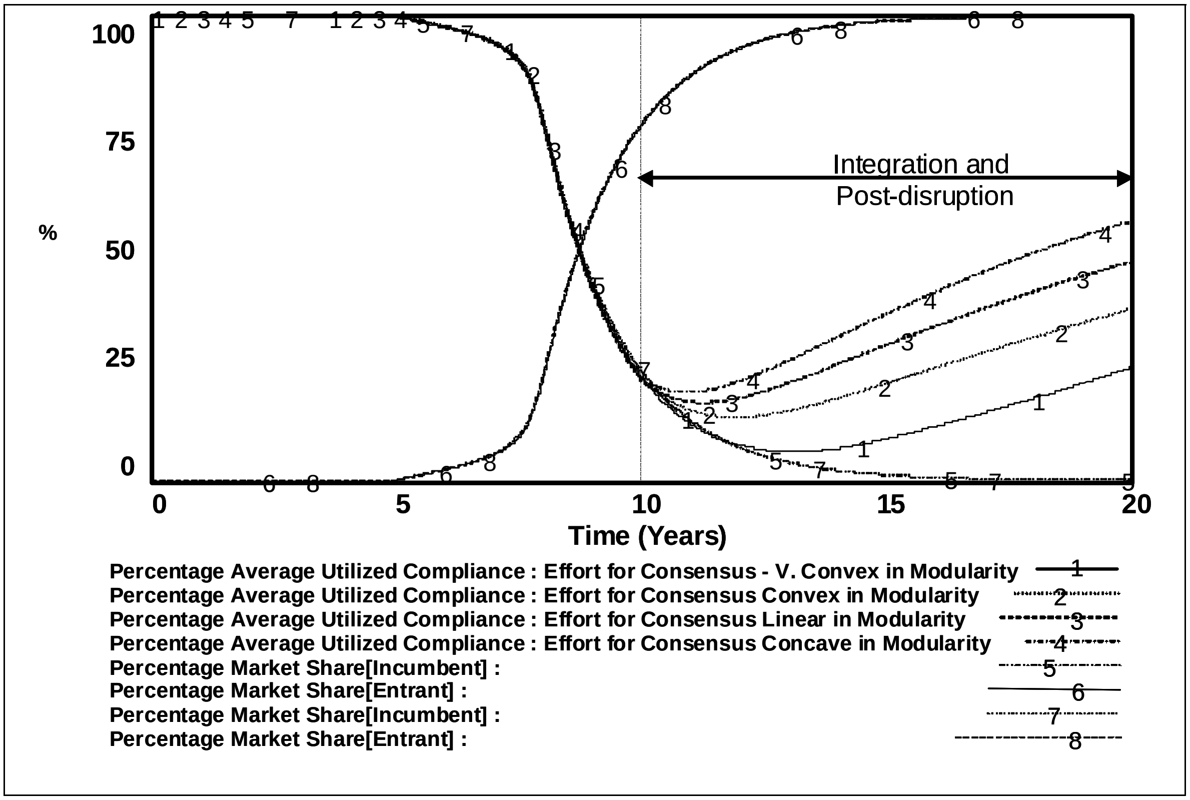


Figure 54: Higher Compliance under High Broad-based Consensus

Figure 55 shows how building broad-based consensus around regulatory issues at increasingly high levels reduces the compliance cost (coordination cost) in a modular structure. Here, line 1 pertains to lowest consensus, so maximum coordination cost, and line 4 pertains to highest consensus, so lowest coordination cost.

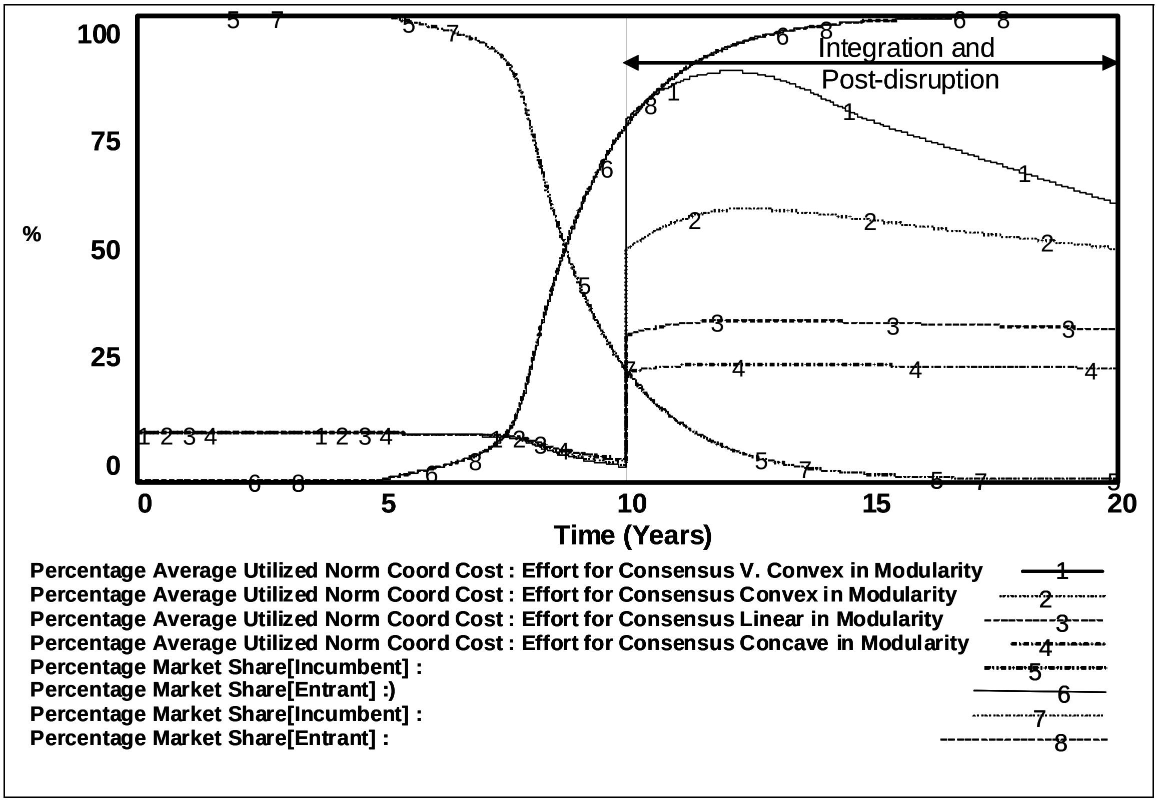
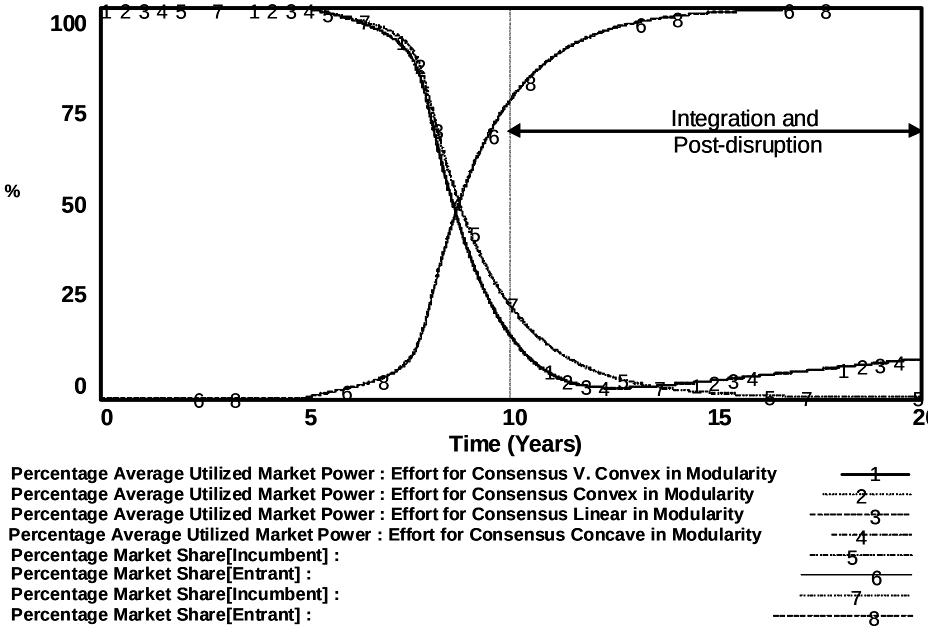


Figure 55: Lower Compliance Cost under High Broad-based Consensus

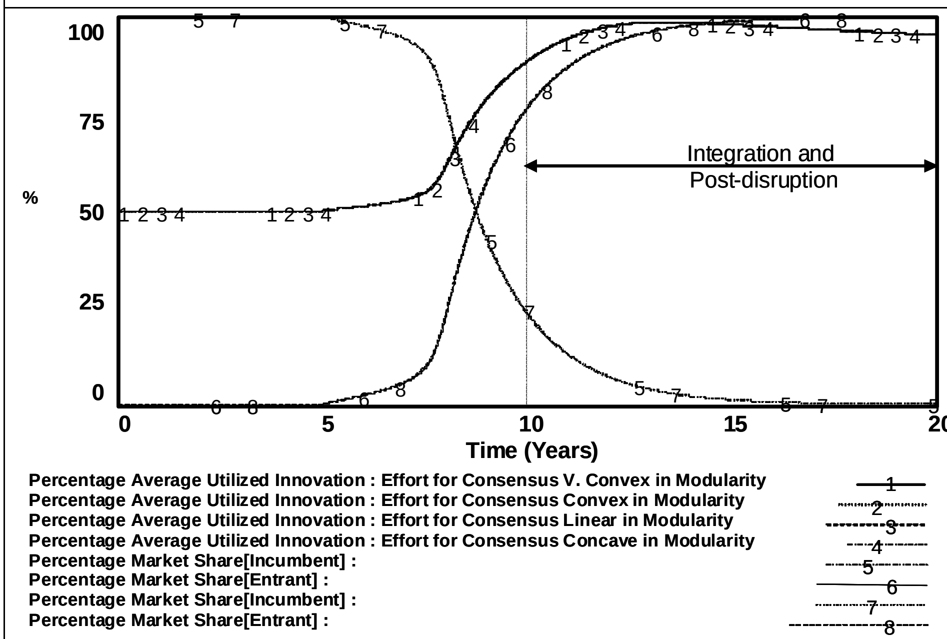
Together, Figure 54 and Figure 55 illustrate that pulling policy levers 1 and 2 meet condition two of increasing the ability of a modular structure to comply with regulation at low cost.

We must now ensure that the high competition and innovation benefits in the post-disruption period, obtained previously by policy lever 1 in the previously, are not lost when policy levers 1 and 2 both are pulled.

Figure 56 (a) and (b) show that pulling both policy levers 1 and 2, does not disturb the high competition and innovation, respectively, that by pulling policy lever 1 alone.



(a) Market Power



(b) Innovation

Figure 56: But the Innovation remains high and the market power remains low

The illustrations above confirm that the regulator both limits the accumulation of SMP and builds broad-based consensus in modular structure, the FB outcome to balance compliance, competition, innovation, and compliance cost can be achieved. We are now left with checking if the condition one, "the modular structure must enter and create competitive pressure," can be achieved without using partial and delayed regulation.

An experiment in Figure 57 shows that since the coordination costs that acted as a barrier to entry are lowered by consensus building; *when the policy levers 1 and 2 are pulled together, the FB can be achieved even without having to use partial or delayed regulation.* The outcome, where the entrant is fully regulated upon entry, is shown in Figure 57.

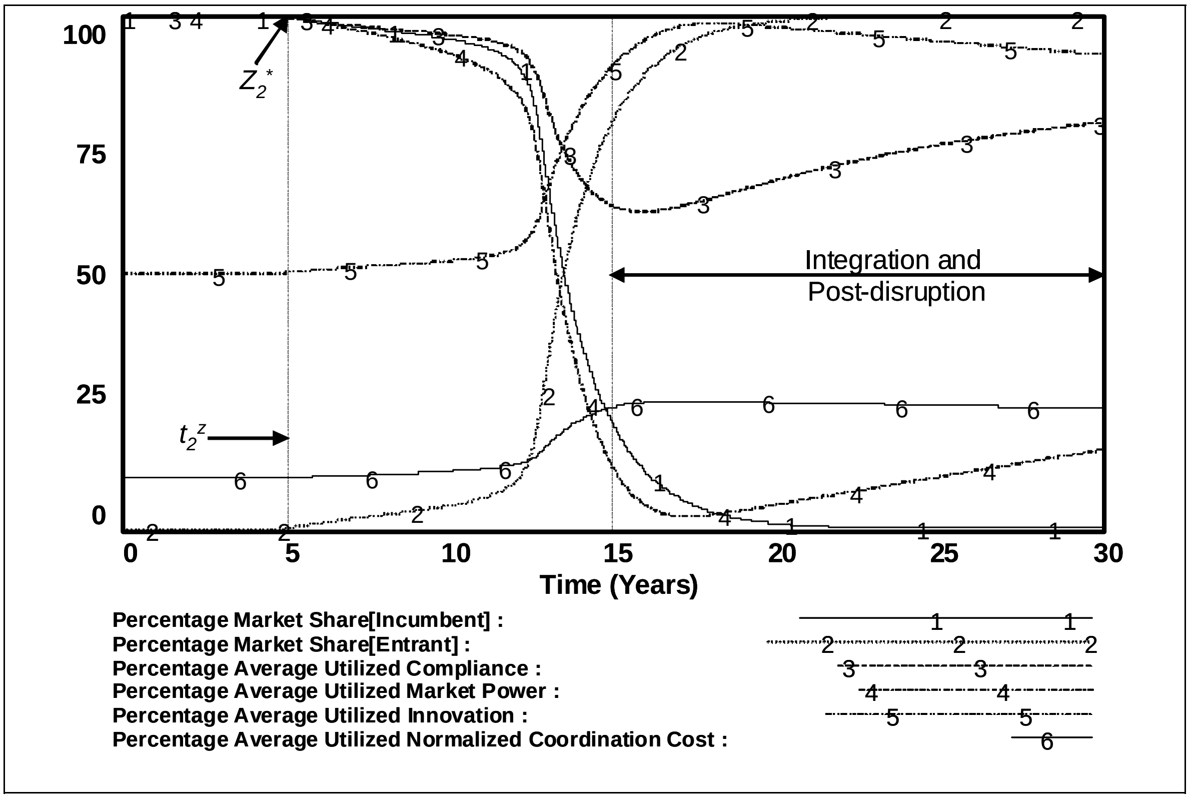


Figure 57: Policy Levers 1 and 2 can also Eliminate Incremental Regulation

4.7 Conclusion

We began this paper with the following broad question: *How can a desired balance of regulation, innovation, competition, and cost be achieved in the modular age of the Internet?* The question arose from an observation that the onset of the modular age naturally promotes economic objectives such as competition and innovation, but derails social ones such as law enforcement capability and public safety. Below are conclusions we can draw from the journey we have taken through the three research stages.

4.7.1 The Regulator's New Role in the Modular Age: Balance Compliance, Innovation, Competition, and Compliance Cost

The first stage of research began with a question: *What should be the regulators role in a system where a modular age disrupts an integral one?* To answer this question, we systematically studied emergent behavior in the systems model over three periods of disruption: pre-disruption, disruption, and post-disruption period.

The results showed that in each period of disruption, there are desirable and undesirable outcomes; also that transition from one period to the next reverses the tradeoffs. Evaluating this flip-flop of desirable and undesirable outcomes across different periods of disruption from the lens of two types of regulatory objectives (economic and social) illuminated that the regulator's new role ought to be to achieve the following vital combination across the different periods of disruption, which we define as the *first best* (FB) outcome:

1. The necessary regulatory compliance is achieved,
2. The high innovation and competition are preserved, and
3. The reasonable cost of compliance is maintained.

4.7.2 Existing Policy Levers are Inadequate for Achieving the FB Outcome

Defining the FB outcome motivated the question for the second stage of research: *Whether the FB can be achieved using the <u>currently-known policy levers</u> such as partial and delayed regulation?* For this investigation, we subjected the model to a set of optimization exercises.

The optimization exercises showed that existing policy levers cannot attain the FB outcome. In a sequential analysis, described below, it showed that even when both partial and delayed regulation are deployed, they may only achieve high innovation and competition while containing the coordination cost, but the necessary level of compliance cannot be ensured, and vice versa. Also, that the existing policies do not remedy the loss of innovation and competition in the post-disruption period. Hence the second stage of research concluded that the existing arrows in the regulatory quiver are blunt. They alone cannot achieve the desired outcome.

If regulatory compliance was all we cared about as a society, there would be no need to allow any other technology such as wireless, VoIP, or others to enter the market. PSTN is highly compliant with regulation and can do so at a cost structure that the firms and regulators have learned to deal with. However, since competition and innovation in communications industry is critical to stay ahead of competition, particularly in a rapidly globalizing world, regulation must not act as a barrier to entry for innovative technologies. The intuitive solution for letting innovative technologies enter is to delay their regulation. Delayed regulation of innovative technology increases competition and innovation in the short term, but compromises regulatory compliance in the long term. Such is the case with delayed regulation of either wireless technology or VoIP. The rationale behind delayed regulation is to not burden a nascent firm with heavy compliance cost until the firm matures. Partial regulation of a nascent industry is another way to abate the initial compliance cost. Partial regulation provides the desired short term benefit of removing the entry barrier, but it renders even lower compliance, exacerbating innovation-compliance tradeoff further in the long run.

Classic works on systems have acknowledged that "social systems usually exhibit fundamental conflict between the short-term and long-term consequences of a policy change."(Forrester 1969; Forrester 1973). In fact, these works go as far as to observe that, "a social system draws attention to the very points at which an attempt to intervene will fail." Choosing existing policy levers such as partial or delayed regulation exemplify these observations.

4.7.3 Three Conditions for Achieving the FB Outcome

Through the optimization exercises, we understood that the conditions for achieving the desired balance between compliance, competition, innovation and cost (i.e. the FB outcome) are as follows:

1. The modular structure must enter and create competitive pressure,
2. The modular structure must have the ability to comply with regulations at low cost, and
3. The modular structure must remain modular in the post-disruption period.

The first condition recognizes the fundamental urge to keep the market competitive and innovative that has been recognized ever since the formation of the FCC, and accentuated with the decision to leave the Internet ("information service") unregulated in the 1996 Telecommunications Act. The Acts of 1934 and 1996, however, were focused on market entry from the perspective of curbing the exploitation of monopolistic power. The concerns about market entry from the perspective of regulation posing entry barriers has also been around for a long time, but the regulator's position on this issue has changed radically. All the way until the breakup of AT&T, the regulators considered telecommunications a "natural monopoly," and devised entry restrictions to protect the monopoly. With the Internet, the regulatory sentiments are polar opposite. As stated in IP-Enabled Services NPRM of 2004, with Internet-based services, the regulatory sentiment is to "facilitate transudation to IP-enabled services." The first condition agrees with this sentiment of allowing market entry, but it does not agree with existing policy levers such as partial and delayed regulation for doing so.

Meeting the second condition of achieving high compliance at a low cost has fundamental difficulties in a modular structure. As conjectured by this research, increasing modularity can sharply increase the effort necessary to build consensus. The exact nature of the relationships between modularity and the time to build consensus or coordination cost are not well understood; still, a very long time to build consensus as well as a very high coordination cost for doing so in a highly modular industry may inferred from the many historical cases where modular industries have fought long-drawn battles over developing common standards.[82] The case research in chapter 2 has

---

[82] Regulators could look to historical cases in different industries, where a modular, hourglass-like architecture offered burgeoning growth, but led to long drawn battles over standard setting. Produced below are some examples of showing how time consuming and costly can the standard setting in a modular industry be.

From to be published draft payer by the author of the present research Vaishnav, C. (2009). The Internet: A Case of How Government's Involvement and Exit Influences Global Standards. Cambridge, MA.

As David Hounshell showed in his brilliant historical work, *From the American system to mass production, 1800-1932 : the development of manufacturing technology in the United States* , a great example of hourglass-like standardization at the center is the grain market in Chicago in mid 1800s. The new system of grain trade was a case of standardization at the center with the farms producing a variety of grains on one side, and the markets in Chicago selling them on the other. Just like the Internet hourglass separated the applications from the networks, standardization in grain trade abstracted the nature from the market, and transformed the level of productivity and creativity on both sides.

Despite these advantages, by the late 1860s there were widespread agitation throughout Illinois for legislation to regulate what many farmers and merchants regarded as a long list of abuses in the Chicago marketplace. Central to the dispute was the new grading system that affected both farmers and traders. Both doubted the honesty of a small number of grain elevator operators who mixed the grains and hence determined the profits and losses of both the parties. Also, the "elevator monopoly" made legal agreement with railroad operators to segment Chicago's grain handling market geographically. The dispute lasted until early 1970s, when the state intervened, and "Article 13 and Warehouse Act addressed each of the problems that had so concerned farmers, grain traders, and other elevator critics during the 1860s: grading, inspection, mixing, counterfeit receipts, public grain supply statistics, and the monopoly linkage between railroads and elevators."

The second example of hourglass-like standardization at the center is the standardization of shipping containers in the mid 1900s. The aluminum shipping containers were introduced in America in 1956. The advent of containers was a case of standardization at the center, with suppliers of products and raw materials on one side and buyers on the other. As pointed out by Mark Levinson in his business history book, *The Box: How the Shipping Container Made the World Smaller And The World Economy Bigger*, the introduction of shipping container transformed markets on both the supply and demand side.

The standardization of shipping containers was also very contentious and required government intervention to forge consensus among the various stakeholders nationally and internationally. By the late 1950s, the transportation world was using containers, but the "container" meant very different things to different people. This diversity threatened the large-scale adoption of containerization, since if one transportation company's containers did not fit other's ships, trucks, or railroads, they will have to maintain a fleet of many different containers.

In the United States, the United States Maritime Administration (Marad) decided in 1958 to put an end to this anarchy. Private competition to Marad's efforts came from the American Standards Association (ASA). After a few years of standards war, in 1961, at American urging, the International Standards Organization (ISO), which then had thirty-seven nations as members, agreed to study containers. The ISO project was meant to establish worldwide guidelines before firms made large financial commitments. By 1970s, the ISO was prepared to publish the first full draft of its "painstakingly negotiated" standards, "the bitter battles among competing economic interests were finally winding down."

reinforced the conjecture by showing how the nature of consensus is changing as the modular services disrupt the integrated ones. Thus, meeting the second condition is about fundamentally changing the relationship between modularity and the time and coordination cost of complying with regulation.

The third condition of keeping the industry structure modular in the post-disruption period rests upon how easily can firms gain and abuse market power. The American attitude to large corporations has always been somewhat ambivalent – we worry about the power that large corporations wield, and yet at the same time we appreciate the potential benefits associated with the economies of scale and scope that they command. Also, antitrust regulation in the US evaluates mergers only from the viewpoint of horizontal concentration within one industry, and not from the perspective of collective market power across multiple upstream and downstream industries. The flexibility offered by the modular age provides a fertile ground for firms to abuse market power in the environment of such narrow and ambivalent regulatory thinking. Thus, meeting the third condition requires fundamental changes to the antitrust regulation in America.

Meeting all three conditions simultaneously also has interesting issues. We have noted in this paper earlier that because of the structure of cause and effects, there is a fundamental tradeoff between conditions 1 (competition and innovation) and 2 (compliance and cost) in each period of disruption. Where compliance and costs are high competition and market power are low, and vice versa. Resolving these tradeoffs requires reversing some of the structural influences.

4.7.4 Two Unexplored Policy Levers—Limiting Significant Market Power and Building Broad-based Consensus—can Achieve the FB Outcome

The failure of existing policies in meeting the FB motivated the question for the third stage of research: *Are there policy levers that are capable of achieving the desired balance, but that have not been exploited by the policymakers yet?* To investigate this question, we carry out Policy Sensitivity Analysis on the systems model, which looked for policies that satisfy the three conditions for achieving the FB outcome above in the previous section.

The policy sensitivity analysis showed that a combination of two policy levers – *Limiting SMP Accumulation* and *Building Broad-based Consensus* around Regulatory Issues – can achieve the desired FB combination of high regulatory compliance, with high innovation and competition, but at low cost,.

Both policies are construed broadly. As for the first policy of limiting SMP accumulation; in the United States, antitrust regulations are used to curtail the accumulation of SMP. The antitrust concerns sometimes arise as a result of the conduct of a single firm, not because it possesses market power, but when it abuses it. When multiple firms are involved in a merger, one of two agencies – either the Federal Trade Commission (FTC), or the Department of Justice (DoJ) – takes the lead in investigating any merger (Marcus 2002). The DoJ/FTC Horizontal Merger Guidelines sets forth the methodology that these enforcement agencies will apply in analyzing horizontal mergers (mergers between participants in the same industry).[83] These guidelines provide a methodology that is purely economic. For example, a shorthand tool that is often used to assess the impact of a prospective merger is the *Herfindal-Hirschman Index (HHI)*. "The HHI is calculated by summing the squares of the individual market shares of all the participants."[84] In a perfectly monopolized market, the HHI would be 10,000; in a market with a vast number of tiny competitors, it would approach zero. The HHI is thus a measure of *relative concentration*. In a highly concentrated market (HHI greater than 1,800 after a merger), a merger that results in an increase in the HHI of 100 or more is felt *ceteris paribus* to "potentially raise significant competitive concerns"[85].

The spirit of Policy Lever 1 as construed by us is far broader. First, from the economic perspective, we construe limiting SMP as limiting market power horizontally (in the same industry), vertically (in upstream and downstream markets), and collectively (through various agreements across industries). Our thinking here is similar to that in the New Regulatory Framework for ICT under the European Union (EU), which states that, "[a]n undertaking shall be deemed to have significant market power if, either individually or jointly with others, it enjoys a position equivalent to dominance, that is to say a position of economic strength affording it the power to behave to an appreciable extent independently of competitors, customers and ultimately consumers." [86] As observed by Marcus when comparing the EU-US frameworks, this "concept of collective dominance has become well established in European case law, [but] by contrast, collective dominance is rarely raised as a concern in the U.S. unless there is actual evidence of collusion." (Marcus 2002)

Further, we advise regulators to evaluate SMP accumulation from the technological perspective, too. An evaluation of SMP from the technology perspective is critical for successfully managing the dynamic complexity of the Internet age. From the technology perspective, the SMP accumulation may be assessed by understanding how the accumulation of market power, in a single firm or a collection of them, results in standardized or proprietary nature of the product interfaces. A measure as quantitative as market share, used for the economic perspective, does not exist today to quantify the standardized or proprietary nature of service or product interfaces. Therefore, such an assessment will have to rely on independent expert judgment, at least initially. [87]

---

[83] U.S. Department of Justice and Federal Trade Commission, *Horizontal Merger Guidelines*, 57 Fed. Reg. 41557 (April 2, 1992, as revised April 8, 1997), http://www.ftc.gov/bc/docs/horizmer.htm.
[84] Ibid. §1.5, "Concentration and Market Shares".
[85] Ibid.
[86] Per Article 14, at 2, of the *Directive 2002/20.EC of the European Parliament and of the Council of 7 March 2002 on a common regulatory framework for electronic communications networks and services (Framework Directive)*, Official Journal of the European Communities, L 108, April 24, 2002.
[87] Effectively factoring in unbiased expert opinion in scientific or technological matter itself has been a conundrum for courts and agencies alike; however, despite the difficulties of doing so, such an understanding of interface standardization is important for preserving the highly innovative nature of the modular age.

As for the second policy lever of building broad-based consensus around regulatory issues; excepting a few very recent recommendations in the wireless spectrum allocation space (Bykowsky, Olson et al. 2008) that shift the FCC's position from merely adversarial to more cognizant of the highly competitive dynamics of the wireless market, much of FCC's enforcement has used command-and control as its primary mechanism. So a recommendation to build broad-based consensus may be received by regulators as counter-intuitive to the current thinking at the FCC.

Broad-based consensus is generally built in two ways: by bringing all stakeholders to the negotiation table, or via the process of standards. The FCC, today, is hesitant to participate in Internet standards work actively.[88] Also, they have not actively negotiated with players across the entire value chain the possibility of developing standard-based approaches to meeting the regulatory needs.

Following up on the recommendation of building broad-based consensus will require a radical change in the way the enforcement bureau works. It will require the enforcement bureau to acquire a whole new set of capabilities and processes. The bureau's enforcement paradigm has been command-and-control, which only uses fines and punishment as the enforcement mechanisms. Till now, the enforcement bureau has never included negotiators who systematically build consensus among diverse interests, nor have they participated in standard body meetings. To be able to follow upon on policy lever 2, it may need to acquire both of these skills.

4.8 From Animal Trainer to a Wildlife Conservationist

Metaphorically, we began this research in chapter 2 by arguing that the modular age has transformed the regulator's role from that of a shepherd herding sheep to one trying to control cats. This chapter suggests ways by which the regulator can hope to control cats. By way of the remedies suggested in this chapter, we argue that in the modular age, the role of the regulatory agency has gone from that of an animal trainer to a wildlife conservationist. The animal trainer cared only about compliance, but the wildlife conservationist cares also cares about the survival of species (biodiversity). The trainer, like a policeman, curtailed unwanted activity, whereas the conservationist, like a parent, is interest in a balance, where animals are playful but also grow into responsible citizens of the jungle.

[88] Such a bias can be deduced from comments such as the following: "I want to participate in IETF, at least once a year, but there is no recognition that standards work is connected to public safety," Richard Hovey, FCC Engineer, Public Safety and Homeland Security Bureu, FCC.

Chapter 5: Conclusion, Limitations, and Future Work

5.1 Conclusion

It is time now to draw the threads of discussion that was led in the three preceding chapters together. The fundamental premise behind the inquiry in these chapters was that as the modular age created by the Internet disrupts the integral age of the past, it is posing discontinuities in technology architecture, industry structure, and the environment of firms and consumers. So what should be the role of telecommunications regulators in this environment, and how can they fulfill it?

Asking such a question may seem to accept regulator's involvement in how Internet-based services develop. This research does take such a position. Voice communications market has traditionally endured regulation because of the fear of various market or institutional failures. Apprehensions about market failure arise from the fear of imperfect competition as firms exploit scale and direct network effect; whereas those about institutional failure arise because of the lack of collective action that may exclude marginalized populations from receiving affordable service. While the Internet may alleviate competition concerns, it introduces several new modes of possible market and institutional failures. The modular architecture of the Internet introduces unprecedented coordination issues among parties that provision the different functions of an end-to-end service. Such issues are apparent in complying with emergency service or lawful intercepts over the Internet. Additionally, the flexibility offered by the Internet architecture renders unstable the property rights, making it difficult to determine who should be responsible for such regulations. Finally, the Internet's separation of application/service from infrastructure exacerbates the free rider problem, as services can now be offered without owning any infrastructure. Thus, despite all its shortcomings the regulatory involvement in how Internet-based services develop seems inevitable.

Taking a case of voice communications regulation in the United States, this dissertation has shown what the regulator should discontinue, how can regulators and managers anticipate uncertainty in the modular age, what should be the new role of the telecommunications regulator, and how can they fulfill it. Summarized below are the findings.

5.1.1 What Does Not Work: The Existing Arrows in Regulatory Quiver are Blunt

Chapter 2 analyzed the appropriateness of present telecommunications regulation along three dimensions: the *objectives* it serves, the *obligations* it imposes to fulfill those objectives, and the *enforcement mechanisms* it uses to enforce those obligations. This three-part framework provides more comprehensive evaluation of regulation, as using any one dimension involves tradeoffs. Focusing solely on objectives eases legitimating policy but makes assigning responsibility difficult; focusing on obligations eases assigning responsibility but makes legitimating policy difficult; and focusing on enforcement mechanisms makes a policy more measurable and ostensibly objective but may suffer in terms of legitimacy and appropriate assignment of responsibility.

The research in this dissertation concludes that the current regulation of voice communications is inadequate on all three fronts. To be able to evaluate the objectives we must understand whether they are appropriate for the telecommunications system to fulfill. The telecommunications system continues to perform an important role in achieving social and economic objectives that were fulfilled by traditional technologies, but here is the problem: the current debate around regulations is focused on efficiency questions (i.e., questions of who should have the regulatory burden and when) rather questions about how to meet the objectives at the societal level first. At the societal level, the telecommunications system is one of many subsystems that facilitate social and economic objectives. If the telecommunications system as a whole shirks its duty in fulfilling these objectives because some technologies are regulated and others not, other subsystems—maybe more labor-intensive ones—will necessarily have to pick up the slack. But this fact has not been recognized. Only after we understand the objectives at the societal level can we correctly devise obligations for the communications system as a whole, or for the technologies or industries within it.

To be able to evaluate obligations we must understand whether they are appropriate for fulfilling the objective at hand, who should bear them, and when. Pro-market regulatory regimes have already responded to the "who" and "when" questions with partial and delayed regulation. Chapter 2 and 4 showed that considering the dynamic complexity that surrounds the Internet-based disruption, the use of these policy levers appears futile. Firstly, limiting regulatory scope in a modular architecture leads to inadequate provisioning of compliance and creates perverse incentives at two levels. At the industry level, it provides incentives to the regulated firms to flee to the unregulated technology segments. At the global level, it ignites competition in laxity between nation-states trying to lure both consumers and firms with less regulation.

Secondly, efficiently timing the delayed regulation of entrants is also nearly impossible given the far higher dynamic complexity of the modular age. The purpose of delayed regulation is to defer the regulatory costs until entrants mature, but the rate at which an unregulated segment might erode the existing regulatory compliance is difficult to predict as many competing factors mediate the rate of technology and industry disruption.

Finally, if we imagine that regulators got both the scope and the timing of regulation right, a major issue still remains. These policies alone cannot remedy the loss of innovation and competition in the post-disruption period; unless they can be skillfully combined with antitrust regulation, which, in the United States remain narrow an inadequate today for addressing the challenges posed by the Internet.

To be able to evaluate the current enforcement mechanisms we must understand whether they are effective for the system to be regulated. The enforcement mechanism for traditional telecommunications regulation has been command-and-control. Such an adversarial approach alone cannot possibly be adequate for the modular age. In the integral age, this mechanism worked because the industrial interests were concentrated, which made it possible for the regulator to know who to command and where to exert control. Also, as a firm possessed full functional control over a service, it could easily develop and deploy compliance mechanisms post regulation. The modular age has completely changed the rules of the game.

The modular forces blunt the mechanisms of command-and-control. In the modular age, the regulator finds it difficult to determine where a command-and-control mechanism ought to focus because the post-Internet era has multiple, equally capable interest groups that lack consensus over critical regulatory objectives. Ironically, these stakeholder factions that are in disagreement provision different functional components of a single voice communications service, so they must coordinate if regulatory compliance had to be provisioned. Naturally, the command-and-control mechanisms are completely ill-suited for building such consensus around regulatory issues.

For the above reasons, this research concludes that the existing arrows in the regulatory quiver are blunt. Socio-technical systems usually exhibit fundamental conflict between the short-term and long-term consequences of a policy. The failure of current regulatory response in considering the long-term consequences exemplifies this observation.

5.1.2 What Needs To Be Done: The New Role for Telecommunications Regulators

It should now be perfectly apparent that the regulator's new role is almost impossible to understand without grasping the dynamic complexity and emergent behavior of a system where regulators, firms, consumers, and technologists constantly interact. Dynamic complexity arises in such a system because of the strategic behaviors of these actors and the statistical nature of the various parameters. Therefore, the ultimate task of regulators and managers becomes that of managing the perpetual disequilibrium rather than hoping for an efficient equilibrium.

Once we understand the emergent behavior of a system where a modular technology and industry disrupts an integrated one, it becomes quite clear that the only role worth while for a telecommunications regulator in such a system is to sustain the following vital combination, which we defined as the *first best* (FB) outcome:

1. The necessary regulatory compliance is achieved,
2. The high innovation and competition are preserved, and
3. The reasonable cost of compliance is maintained.

The idea of "sustaining" (not just "attaining") such a combination arises because of the fundamental tradeoffs, between competition-innovation versus compliance-compliance cost, that occur across the different periods of disruption. In the pre-disruption period, just like the pre-AT&T break up period, compliance is high and compliance costs are well understood, but competition is low and there is little pressure to adopt innovation.

As the disruption occurs, just as with the first wave of competition to PSTN from wireless telecommunications service and now with VoIP, there is competitive pressure to adopt innovation, but regulatory compliance is compromised and incurring additional compliance cost is inevitable. In the post-disruption period, which we are yet to witness, entrants that triumph and incumbents that survive can be expected to deliver higher compliance at a relatively lower cost, but the competition and innovation adoption of the disruption phase will be lost. Thus, achieving the FB would require interventions that systematically reverse some of the structural influences that are natural to the system, and that inflict such tradeoffs across the different phase of disruption.

The optimization exercises in chapter 4 illuminated that to achieve the FB, the following set of conditions must be met:

1. The modular structure must enter the market and create competitive pressure,
2. The modular structure must have the ability to comply with regulations at low cost, and
3. The modular structure must remain modular in the post-disruption period.

The first condition agrees with the current regulatory sentiments of "facilitating transudation to IP-enabled services" as expressed in the IP-Enabled Services NPRM of 2004. However, as stated before, we disagree with the use of partial and delayed regulation for doing so, as these policies may meet the first condition in the short term but they have long-term consequences.

Meeting the second condition of achieving high compliance at a low cost requires changing the relationship between modularity and the time and cost of complying with regulation fundamentally. Historical cases suggest that in highly modular architectures and industries, the time to build consensus and the coordination costs can be inordinately large. As it is, despite being vertically integrated, it took telecommunications service providers approximately 30 years to meet traditional regulations such as E911 or Universal Services. Given the dispersion of stakeholder interest that was demonstrated by the case in chapter 2, one can only conjecture that the process for meeting critical regulatory objectives will take longer in the modular environment created by the Internet, if not facilitated by a somewhat trusted third-party such as the government.

Meeting the third condition of keeping the industry structure modular in the post-disruption period requires preventing firms from gaining and abusing market power. The most natural regulatory mechanism for achieving this objective is antitrust regulation. However, the current antitrust regulation in the United States is construed far too narrowly for addressing market power issues that can arise in the Internet realm. The flexibility offered by the modular age provides a fertile ground for firms to abuse market power in the environment of narrow and ambivalent regulatory thinking. Thus, meeting the third condition requires fundamental changes to the antitrust regulation in the United States.

The policy sensitivity analysis on the fully endogenous model showed that a combination of two policy levers – *Limiting Significant Market Power (SMP)*

Accumulation and *Building Broad-based Consensus around Regulatory Issues* – can achieve the desired FB combination by meeting its conditions. However, both policies must be construed broadly.

Limits to SMP accumulation must be construed broadly in two ways. First, from the economic perspective, it must be construed as limiting market power horizontally (in the same industry), vertically (in upstream and downstream markets), and collectively (through various agreements across industries). Doing so is critical because of the philosophy of the Internet architecture that hopes to promote any application on the top to run on any network at the bottom. Our recommendation hereis closer to that in the New Regulatory Framework for ICT under the European Union (EU) rather than the antitrust regulation in the United States. The US antitrust regulation evaluates mergers only from the viewpoint of horizontal concentration within one industry, and not from the perspective of collective market power across multiple upstream and downstream industries. While the concept of evaluating collective dominance has become well established in European case law, it is rarely invoked as a concern in the U.S. unless there is actual evidence of collusion. Hence, antitrust regulation is an area where the US might learn from the lessons learned by the EU regulators.

Second, regulators must also evaluate SMP accumulation from the technological perspective. From the technology perspective, the SMP accumulation may be assessed by understanding how the accumulation of market power, in a single firm or a collection of them, results in making product interfaces proprietary. A measure as quantitative as market share, used for the economic perspective, does not exist today to quantify the standardized or proprietary nature of service or product interfaces. Therefore, such an assessment will have to rely on independent expert judgment, at least initially.

The second policy lever of building broad-based consensus around regulatory issues may appear completely counter to the current thinking at the FCC. The FCC's enforcement paradigm has been mostly adversarial with command-and-control as its primary mechanism. Broad-based consensus is generally built in two ways: by bringing all stakeholders to the negotiation table, or via the process of standards. The FCC, today, is hesitant to participate in Internet standards work actively. Also, they have not actively negotiated with players across the entire value chain the possibility of developing standard-based approaches to meeting the regulatory needs. Hence, being able to build broad-based consensus among stakeholders requires different skills, organizational arrangement and processes than those the FCC has.

5.1.3 How To Do It: Balancing Regulation and Innovation in Telecommunications

Limiting the consolidation of market power and building broad based consensus may be a nice theoretical solution, but knowing the solution is different from implementing it. The factors that complicate the implementation are: first, the difficulties of *anticipation* amidst the bewildering array of uncertainties that surround a disruption phenomenon; and second, the institutional arrangements that may hinder *adaptation* necessary for implementing these solutions at the practical level.

Anticipation

Chapter 3 was dedicated to understanding anticipation uncertainty that surrounds disruption. With every emerging technology, the highest level uncertainty faced by regulators and mangers is whether there will be a disruption in the first place. The necessary and sufficient conditions for technology and industry disruption are not fully understood presently even at the theoretical level. Media and experts alike routinely misperceive the possibility of disruption, and such misperceptions lead to inefficient strategic decisions by managers and policymakers alike. Three such popular myths that arise due to misperceptions of feedback in complex systems and fog managerial decisions were shattered chapter 3.

Chapter 3 identified a framework of conditions under which technology and industry disruption may or many not take place because of various types of uncertainties. It showed that not every potentially disruptive technology can cause technology disruption (i.e., an entrant technology displaces an incumbent technology), and not every technology disruption turns into industry disruption (i.e., where entrant firms displace incumbent firms).The analysis of disruption under market, technological, organizational, and regulatory uncertainty ultimately imparted guidance on what can be anticipated about the various parameters that define competitive and regulatory dynamics if disruption were to take place.

Adaptation

The final challenge in implementing the solution is adaptation. Do the institutional arrangements permit the regulators adapt to new challenges and implement the solutions at the practical level? Between chapter 2 and chapter 4, we have learned that to design regulations that are appropriate for the modular age in a practical sense, the following combination must occur: the regulatory debate around objectives must be pursued at the societal level; the necessary obligations must follow from the objectives construed at the societal level; and a new policy mechanisms cognizant of the dynamic complexity of the modular age, such as limiting SMP accumulation and building broad-based consensus on regulatory issues, must be implemented.

This dissertation argues that to be able to address the objectives at the societal level, the FCC must be empowered to, and in fact must take a philosophical position on regulatory objectives, and thereby on the resulting obligations. While the dynamic complexity of the environment may complicate the enforcement of regulations, it does not obscure what the philosophical position on each objective ought to be. For example, the FCC must clearly state that objectives such as law enforcement and public safety cannot be compromised, and technologies that aspire to substitute existing channels of voice communications will be required to find a way to comply with the necessary obligations. Similarly, the FCC must clearly state that it considers promoting multi-modal competition and innovation to be of critical importance. Therefore, the interconnection obligations will be considered across any two technologies, not just within a single mode such as PSTN. Similarly, universal service obligations may be fulfilled by any acceptable substitute, not just PSTN.

Taking a clear philosophical stance on issues will help in several ways. First, it will prevent the entrenched interests from defocusing the regulatory debates. The analysis of the public comments in response to the 2004 IP-Enabled Services NPRM in chapter 2 showed how the absence of a clear position on the objectives allows the political economy of entrenched interests to hijack the regulatory debate away from being objective-centered. For example, the state vs. federal, or local vs. long-distance service interests currently overwhelm the debate about the access charges, which really ought to be centered around how to achieve the objective of high competition. Similarly, interests trying to preserve the compensations that currently benefit them monopolize the debate about universal service, which really ought to be centered on how socio-economic benefit may be brought to remote areas through new technologies. As a result, today, the regulatory proceedings spend enormous energy on appeasing the entrenched interests, which ultimately does not achieve the goal.

The second advantage of taking a clear position is that it reduces the regulatory uncertainty, and thereby makes both incumbents and entrants less risk averse. Firms do not risk investment in differentiating themselves from the competition when there is uncertainty about regulations that may neutralize the advantage. A clear position on the objectives makes it clear for the firm if they should expect to be regulated. And guaranteed regulation is often better than a threat of regulation.

The third advantage of taking a clear position is that the obligations that follow from a clear position on objectives will eliminate misalignment that currently exists between opportunities, objectives, obligations, and capabilities. The obligations that follow from public safety, equal opportunity, and universal service objectives would then more aggressively leverage the new technologies that offer improved ways to achieve these objectives. The obligations that follow from critical areas such as law enforcement would not be partial or delayed. And, the obligations would not burden only parts of the value chain when the capacity to meet the obligation has moved to the other parts as a result of the movement in the functional control.

Of course, simply taking a philosophical position will not be sufficient. To fulfill the objectives at the societal level, the government institutions, more broadly, and the FCC itself, more specifically, will have to organize differently. The fragmentation of government and the regulatory agency does not currently empower any party to be responsible for understanding and achieving the objectives at the societal level. While the full exploration of how to reorganize the government or the FCC is beyond the scope of this dissertation, here is an example.

We know from our analysis that a merger between two firms can potentially compromise two objectives: promoting multi-modal competition and innovation experienced by an average consumer. Yet, no merger in telecommunications industry to date has evaluated competition between multiple technologies, nor has any been viewed as a precursor to the impending loss of innovation. The reason clearly is the fragmented organizations sharing responsibility for evaluating a merger. The FCC is organized in technology-specific silos such as wireline, wireless, and media bureau. Despite that fact that large telecommunications firms today are invested in all technologies, every merger evaluation is assigned only to one of the FCC bureaus. Hence, the multimodal competition perspective is clearly lost. The FCC evaluates a merger from only the "public interest" perspective. It is the Department of Justice (DoJ) that assesses if the merger will "substantially lessen" the competition, but the DoJ does not have the technological perspective, let alone that of multi-modal technology. FCC's "public interest" analysis is also inadequate. It only involves the analysis of how the merger affects the consumer welfare, and does not recognize that with a merger, the industry integrates, product interfaces go from standardized to proprietary, and the industry turns from one that was innovation-focused to the one that is quality-focused.

Apart from taking a position on objectives and reorganizing the agency as appropriate, to be able to build broad-based consensus, a whole new set of capabilities and processes will have to be added to the enforcement bureau. Broad-based consensus may be built in two ways: by bringing all stakeholders to the negotiation table, or via the process of standards. The enforcement bureau has never included negotiators, nor have they participated in standard body meetings. It may need to acquire both of these skills. Their paradigm has been command-and-control, which only uses fines and punishment. Unfortunately, the modular age renders the current enforcement paradigm of command-and-control ineffective because of the enormous dynamic complexity. Today, the firms cannot easily comply with regulation because of the inordinate coordination cost due to the heterogeneity of architectures and competing interests. The regulator must focus on reducing effort required to a firm to comply with regulation, so the firm can focus on their core competencies. Being able to negotiate a broad-based consensus around regulatory issues will allow the FCC to reduce the burden of compliance on modular firms, so that these firms can comply with regulation and innovation at the same time.

From Herding Sheep to Herding Cats

Metaphorically, this is a tale of three animals – elephant, sheep, and cats. From the time the FCC was established (in 1934) until the break up of AT&T, the telecommunications regulator was a keeper of an elephant (AT&T). The elephant was monolithic and slow, but powerful and demanding because it faced no competition. It had negotiated with its keeper a suitable confinement in the form of the 1934 Telecommunications Act. With the break up of AT&T, the regulator became a shepherd herding a few sheep (the Baby Bells). The sheep were inherently less competitive, less innovative, and docile. They worked by consensus. To control a herd of sheep, the shepherd needed just a crook and a little guidance that came in the form the Telecommunications Act of 1996 and its enforcement. But the transition from an integral age to a modular age transforms the regulator's role from that of a shepherd who herded a few sheep to one who must now herd many cats. The cats are fiercely competitive, highly innovative, and agile. Most importantly, however, the cats lack consensus and are highly independent. To control cats requires a completely new mindset – maybe a net around them, or a set of incentives such as the mice, or something else. Neither the elephant's confinement, nor the crook used for the sheep will work for the cats. In other words, the effective control mechanisms for these species are radically different. Similar is the case of regulation in the integral versus the modular age: the effective control mechanisms for the two environments are starkly different.

5.2 Limitations

The limitations of this work may be thought of in two ways. One set of limitations stem from where we chose to, or had to, focus. If one thinks of this dissertation as challenges and solutions in regulating Internet-based services; this dissertation has had to focus more on problems than on solutions. The reason for such an imbalance in focus is that this dissertation does not have the luxury of standing on the shoulders of other works that apply systems principles to telecommunications regulation. Hence, we have had to devote a larger portion of time to researching and describing the problem vis-à-vis the solution. This fact introduces a limitation where the dissertation throws more light on anticipation under uncertainty, and less on adaptation once the solution is understood. That said, the research does offer a solution to the problem raised and discusses how it may be implemented.

Another set of limitations are those of the research design, which consisted of a case in chapter 2, a case in chapter 3, and the systems model that spanned chapters 2, 3, and 4.

Limitations of the Case on Pre- vs. Post-Internet Regulatory Environment

In this case, to understand stakeholder concentration along the value chain and their position on central issues of the two NPRMs analyzed, we designated each commenter a value chain position they represent. Once a position (e.g., equipment provider, access provider, etc.) was assigned to a commenter (e.g., a corporation like Verizon), it was not changed throughout the analysis. Such a decision introduces two limitations. First, it only captures the value chain position that most closely represents the corporation's central tendency and not the fact that the corporation may represent multiple value chain positions. Second, assigning a fixed value chain position to corporation does not capture shifts in its strategy over the period analyzed (1996-2009). Only correcting such a shortcoming, by recording the shifts in corporation's value chain position, can really speak to the impact of this limitation, but the following may be said about it at the outset. First, general understanding of the communications industry does not point out any glaring examples of firms changing their strategy from focusing solely on one value chain position to a completely different one (i.e., becoming an application provider from an equipment provider, or a device provider from access provider, etc.), so recording such shifts are not likely to change the lessons learned; though, it will certainly make our understanding richer. Second, a cursory glance at the shifts in value chain strategies suggests that with the advent of the Internet, most firms are more aware of the importance of the edge-based innovations, so if anything, recording such shifts in strategies might render a more pronounced demonstration of the discontinuities in technology and industry structure.

Limitations of the Case on Misperceptions of Disruption

In this case, after surveying the media for all technologies they proclaimed as disruptive, we restricted our analysis only to computer and communications industry. As described earlier, we made this choice consciously as these are fast clockspeed industries with higher likelihood of disruption, if any. However, such a choice imposes limitations on how generalizeable are the observations of the case study beyond the computer and communications industry. This is also the same generalization that applies to other case research based works on modularity, such as the Baldwyn and Clark's *Design Rules*.

Limitations of the Model

The systems model we built in this dissertation rests upon the following assumptions:

1. This is a behavioral model
2. The simulation runs are for 30 year period
3. This model only applies to cases where the modularity of technology and industry structure are positively correlated
4. Firms
   - 4.1. Only 2 Firms – Incumbent, Entrant
   - 4.2. Each firm represents a typical firm in their industry
   - 4.3. Each firm has one service type (total 2 types of service in the market)
   - 4.4. Each service has only the following attributes: Price, Primary Performance (Quality), Ancillary Performance (Innovation), Network Effect, and Switching Cost
   - 4.5. Firms take only two decisions each time period: resource allocation and outsourcing
   - 4.6. Resource Allocation
     - 4.6.1. Both firms endowed with equal total attention (resources)
     - 4.6.2. Each firm allocates resources only to achieving Regulatory Compliance, Primary Performance (Quality) and Ancillary Performance (Innovation)
   - 4.7. Outsourcing
     - 4.7.1. Each firm makes its interfaces more integrated or more proprietary
   - 4.8. Capacity formulation is excluded
5. Consumers
   - 5.1. Potential market size is constant
   - 5.2. Consumers are homogenous in their preferences, so the adoption process is simulated consumer segmentation only at the level of early adopters, mass market, and laggards are simulated
   - 5.3. Each consumer decides between the two services (to continue or to switch) every time period
   - 5.4. Consumer choice depends only on the service's compatibility (network effect), price, primary performance (quality), and ancillary performance (innovation)

6. Technology
    6.1. Features of each service are separable into (identifiable as) primary performance (quality) and ancillary performance (innovation)
    6.2. The primary performance (quality) of each service depends only upon its architectural limit, attention/resources the firm devotes to it, and time necessary for it to improve/deteriorate
    6.3. The ancillary performance (innovation) of each service depends only upon its architectural limit, attention/resources the firm devotes to it, and time necessary for it to improve/deteriorate
    6.4. The whole system becomes a natural selection environment for the innovations
7. Industry Structure
    7.1. A single attribute – Modularity – describes the state of each industry structure
    7.2. Modularity represents the level of integration/modularization in both technology and industry structure for that service
    7.3. Market Share, Time to Comply, Compliance Cost (and Resources), Enforcement Cost are industry-level properties
8. Regulation
    8.1. Desired level of compliance is possible to achieve under integrated technology and industry structure
    8.2. Regulated firms pass the Compliance Cost on to their consumer
    8.3. Regulated firm always provides resources necessary for regulatory compliance
    8.4. Firm devotes a finite maximum amount of resources to regulatory compliance

By nature every assumption is a simplification of reality, but a bad assumption is one that not only misrepresents reality but violating it reverses the outcome, thereby invalidating the lessons learned. Several of the above assumptions must be evaluated from this perspective.

Having only two firms and each representing a typical firm in their industry (assumptions 4.1 and 4.2) are assumptions that clearly misrepresent the reality. However, deploying them creates a useful tradeoff. Using a single firm to represent the industry does challenge us cognitively, since we must imagine the single firm to represent a cluster of firms when the industry is modular. But such a conceptual leap is worthwhile for several reasons. First, because using a single firm excludes from the model the dynamics of competition *among* modular firms, thereby greatly extending our ability to closely understand the competition *between* a modular and an integrated industry. Second, including the dynamics of multiple modular firms does not alter or enrich the insights for the issues we are interested in. If such a model were to be used for understanding competition between multiple incumbents or multiple entrants, including multiple firms would be a useful addition.

Excluding the capacity formulation (assumption 4.8) is also unrealistic and prevents us from studying the shorter-term boom-and-bust in communications market.

This may be acceptable for the present dissertation, but to study other emerging issues such as net-neutrality, it would be important to include the capacity formulation into the model.

From the consumer choice perspective, the assumptions of fixed market size and homogenous consumer preferences (assumptions 5.1 and 5.2, respectively) are not just unrealistic; they impact the understanding of limits to technology and industry disruption. The current formulation only simulates early adopters, mass market, and laggards. One might argue that this formulation is sufficient for studying the long term trends, but the communications market today shows additional peculiarities. Younger consumers have a dramatically different behavior from older consumers when it comes to using Internet-base services. Of course, with time, the younger consumers are displacing the older ones, the simulation of which would require including net birth rate into the model. More importantly, however, the consumer segmentation of young versus old seems lumpier than the smooth S-curve of adoption. And, if these segments are rather permanent, they have a potential to prevent winner-takes-all outcomes in the market. Hence, even when the network effects are strong, the incumbents may not be able to hold on to the entire market since what attracts younger consumers is drastically different from what it offers. Adding such consumer segmentation to the model is at least a Master's level thesis.

5.3 Directions for Future Work

This dissertation has begun answering *where* to focus attention and *what* to do as Internet-based services disrupt. The future work ought to answer, more deeply than did this dissertation, questions about *how* to respond. Listed below are four potential areas where substantial contributions can be made in this direction.

Building Consensus

Building consensus in modular structures is a very poorly understood area. Based on the analysis of the pre- and post-regulatory environments of the Internet, this research conjectured that increasing modularity may sharply increase the coordination cost and time to comply, limiting the achievable compliance in modular structures. But the exact nature of the relationship between modularity and the time to comply or coordination cost is far from being understood. One might retort to such assertion by saying that the hourglass architecture of the Internet, in some sense, has successfully done exactly that – it has built consensus among disparate application and network designers. We must not forget, however, that that architecture emerged with the support of government agencies and in times when major corporate interests were paying little attention to it. Today, all of that has changed. The key are of interest here are how time and cost of coordination changes with modularity, and what are the motivations and limits to coordination. These may be further understood with a modeling or qualitative frameworks that help us further understand behaviors in modular structures.

Institutional Arrangements

The organization of the regulatory agency (the FCC), the US government, and international institutions at large will have profound impact on how effectively regulatory compliance and innovation are balanced. This research concluded that to fulfill such higher level objectives, these institutions will have to organize differently, as the current fragmentation of government and the regulatory agency does not empower any party to be responsible for understanding and achieving the objectives at the societal level. We cannot offer a full agenda of what this area of research should look like, but here are a few possible starting points: what institutional arrangements would empower and enable the FCC (or a combination of agencies) to take on regulatory issues at the societal level? How can the FCC reorganize considering the onset of the modular age? How can antitrust regulatory be construed comprehensively considering the nature of the Internet?

Regulatory Capture

In 1971, in his seminal work, *The Theory of Economic Regulation*, George Stigler developed a theory of regulatory capture that, to paraphrase, said: an industry that is regulated can benefit from 'capturing' the regulatory agency involved. This can occur because of political influence; superior technical knowledge that forces the regulatory agency to depend on the industry; appointees being selected from the regulated industry or the possibility of future position in the industry; and the agency's need for recognition and informal cooperation from the industry.

Regulatory capture acquires an additional dimension in the modular age of the Internet. Movements such as Google, Wikipedia, Facebook, and others offer new platforms for collective action. It is not clear how much of such collective action provides the balance of power essential for a functioning democracy as against providing new ways for corporations, behind the veil of the consumers their platforms support, to capture regulation. The future work, therefore, must address the following question: what kinds of regulatory captures can occur in modular structures?

Variations in Regulatory Environments

Finally, the framework offered in this dissertation can be used for understanding the environments in different nations/regions in order to compare and contrast their regulatory policies and their impact. The model is currently formulated and estimated for the US environment. The author's post-doctoral research hopes to estimate the model to compare the telecommunications regulation in the United States and the European Union.

Appendix A - A Brief Evolutionary Outline of Statutory Definitions and FCC Jurisdiction

Several definitions set forth in the Communications Act and prior Commission orders are relevant for understanding the VoIP context.

First, the Act defines the terms "common carrier" and "carrier" to include "any person engaged as a common carrier for hire, in interstate or foreign communication by wire or radio." The Act specifically excludes persons "engaged in radio broadcasting" from this definition[89].

The Federal Communications Commission has long distinguished between "basic" and "enhanced" service offerings. In the *Computer Inquiry* line of decisions[90], the Commission specified that a "basic" service is a service offering transmission capacity for the delivery of information without net change in form or content. Providers of "basic" services were subjected to common carrier regulation under Title II of the Act. By contrast, an "enhanced" service contains a basic service component but also "employ[s] computer processing applications that act on the format, content, code, protocol or similar aspects of the subscriber's transmitted information; provide the subscriber additional, different, or restructured information; or involve subscriber interaction with stored information[91]."

The Commission concluded that enhanced services were subject to the Commission's jurisdiction[92]. It further found, however, that the enhanced service market was highly competitive with low barriers to entry; therefore, the Commission declined to treat providers of enhanced services as "common carriers" subject to regulation under Title II of the Act[93].

The 1996 Act defined "telecommunications" to mean "the transmission, between or among points specified by the user, of information of the user's choosing, without change in the form or content of the information as sent and received[94]."

---

[89] 47 U.S.C. § 153(10).

[90] *See Regulatory and Policy Problems Presented by the Interdependence of Computer and Communication Services and Facilities*, Docket No. 16979, Notice of Inquiry, 7 FCC 2d 11 (1966) (*Computer I NOI*); *Regulatory and Policy Problems Presented by the Interdependence of Computer and Communication Services and Facilities*, Docket No. 16979, Final Decision and Order, 28 FCC 2d 267 (1971) (*Computer I Final Decision*); *Amendment of Section 64.702 of the Commission's Rules and Regulations (Second Computer Inquiry)*, Docket No. 20828, Tentative Decision and Further Notice of Inquiry and Rulemaking, 72 FCC 2d 358 (1979) (*Computer II Tentative Decision*); *Amendment of Section 64.702 of the Commission's Rules and Regulations (Second Computer Inquiry)*, Docket No. 20828, Final Decision, 77 FCC 2d 384 (1980) (*Computer II Final Decision*); *Amendment of Section 64.702 of the Commission's Rules and Regulations (Third Computer Inquiry)*, CC Docket No. 85-229, Report and Order, 104 FCC 2d 958 (1986) (*Computer III*) (subsequent cites omitted) (collectively the *Computer Inquiries*).

[91] 47 C.F.R. § 64.702; *see also Computer II Final Decision*, 77 FCC 2d at 420-21, para. 97.

[92] *Computer II Final Decision*, 77 FCC 2d at 432, para. 125.

[93] *Id.* at 432-35, paras. 126-132.

[94] 47 U.S.C. § 153(43).

The 1996 Act also defined "telecommunications service" to mean "the offering of telecommunications for a fee directly to the public, or to such classes of users as to be effectively available to the public, regardless of facilities used[95]." The Commission has concluded, and courts have agreed, that the "telecommunications service" definition was "intended to clarify that telecommunications services are common carrier services[96]."

Various entitlements and obligations set forth in the Act – including, for example, the entitlement to access an incumbent's unbundled network elements for local service[97] and the obligation to render a network accessible to people with disabilities[98] – attach only to entities providing "telecommunications service."

By contrast, the 1996 Act defined "information service" to mean "the offering of a capability for generating, acquiring, storing, transforming, processing, retrieving, utilizing, or making available information via telecommunications, and includes electronic publishing, but does not include any use of any such capability for the management, control, or operation of a telecommunications network or the management of a telecommunications service[99]."

The Act did not establish any particular entitlements or requirements with regard to providers of information services, but the Commission has exercised its ancillary authority under Title I of the Act to apply requirements to information services[100].

In a 1998 Report to Congress known as the "Stevens Report[101],"the Commission considered the proper classification of IP telephony services under the 1996 Act. In that

---

[95] 47 U.S.C. § 153(46).

[96] *Cable & Wireless, PLC,* Order, 12 FCC Rcd 8516, 8521, para. 13 (1997); *see also Virgin Islands Tel. Corp. v. FCC*, 198 F.3d 921, 926-27 (D.C. Cir. 1999).

[97] *See* 47 U.S.C. § 251(c)(3).

[98] *See* 47 U.S.C. § 255(c).

[99] 47 U.S.C. § 153(20). "Information service" category includes all services that the Commission previously considered to be "enhanced services." *See Implementation of the Non-Accounting Safeguards of Sections 271 and 272 of the Communications Act of 1934, as Amended*, CC Docket No. 96-149.

[100] *See, e.g.*, *Implementation of Section 255 and 251(a)(2) of the Communications Act of 1934, as Enacted by the Telecommunications Act of 1996*, WT Docket No. 96-198, Report and Order and Further Notice of Inquiry, 16 FCC Rcd 6417, 6455-62, paras. 93-108 (1999) (*Disability Access Order*) (invoking ancillary authority to impose section 255-like obligations on providers of voicemail and interactive menu services); *see also Computer II Final Decision*; *Amendment of Section 64.702 of the Commission's Rules and Regulations (Second Computer Inquiry)*, Memorandum Opinion and Order, 84 FCC 2d 50 (1980) (*Computer II Reconsideration Decision*); *Amendment of Section 64.702 of the Commission's Rules and Regulations (Second Computer Inquiry)*, Memorandum Opinion and Order on Further Reconsideration, 88 FCC 2d 512 (1981) (*Computer II Further Reconsideration Decision*) (asserting ancillary jurisdiction over enhanced services, including voicemail and interactive menus, as well as over CPE).

[101] *Federal-State Joint Board on Universal Service*, CC Docket No. 96-45, Report to Congress, 13 FCC Rcd 11501 (1998) (*Stevens Report*).

Report, the Commission declined to render any conclusions regarding the proper legal and regulatory framework for addressing these services, stating "definitive pronouncements" would be inappropriate "in the absence of a more complete record focused on individual service offerings[102]."

The Commission did, however, observe that in the case of "computer-to-computer" IP telephony, where "individuals use software and hardware at their premises to place calls between two computers connected to the Internet," the Internet service provider did not appear to be "providing" telecommunications, and the service therefore appeared not to constitute "telecommunications service" under the Act's definition of that term. In contrast, a "phone-to-phone" IP telephony service relying on "dial-up or dedicated circuits … to originate or terminate Internet-based calls" appeared to "bear the characteristics of 'telecommunications services[103],'" so long as the particular service met four criteria: (1) it holds itself out as providing voice telephony or facsimile transmission service; (2) it does not require the customer to use CPE different from that CPE necessary to place an ordinary touchtone call (or facsimile transmission) over the public switched telephone network; (3) it allows the customer to call telephone numbers assigned in accordance with the North American Numbering Plan, and associated international agreements; and (4) it transmits customer information without net change in form or content[104].

[102] *See id.* at 11541, para. 83.
[103] Id. at 11544, para. 89.
[104] Id. at 11543-44, para. 88.

Appendix B - The Model

Presented in this appendix are four different views of the Systems Model of Regulation, Competition and Innovation in Telecommunications: causal loop diagrams (CLD), model-sectors diagram, parameter-input diagrams, and alphabetical list of model equations.

Causal Loop Diagrams

We start with causal loop diagrams (CLD), which are abstract representations of how cause and effects work in the model.

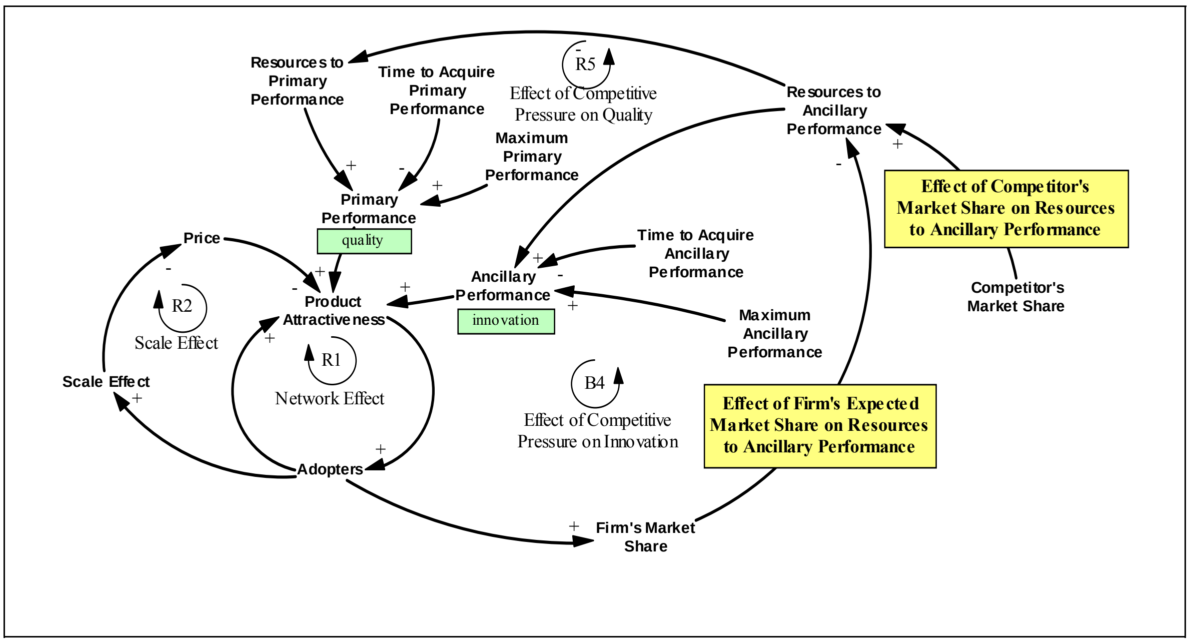


Figure 58: Consumer and Firm Dynamics

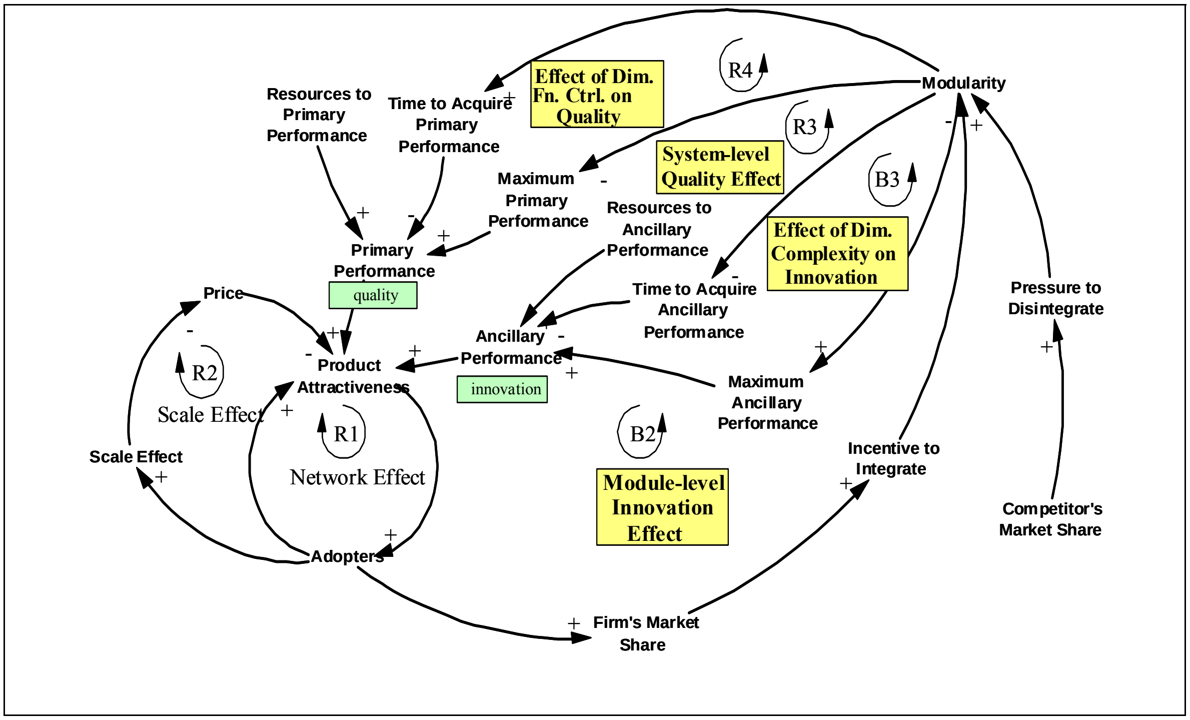


Figure 59: Technology, Firm, and Industry Dynamics

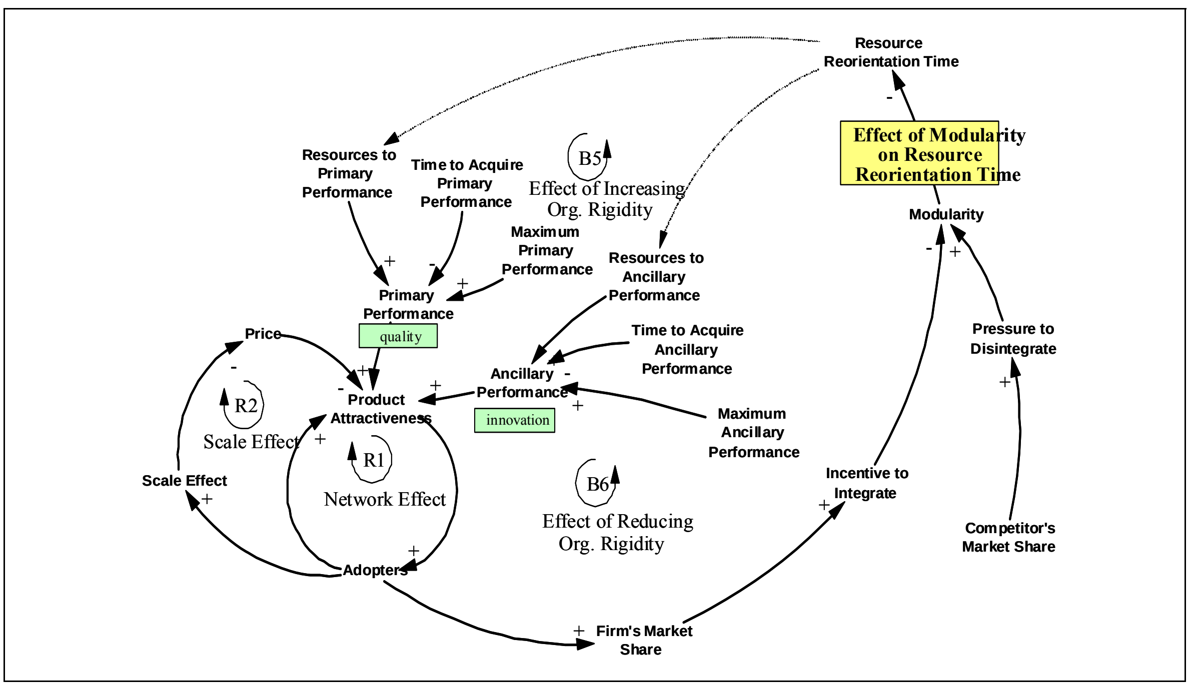


Figure 60: Firm and Industry Dynamics

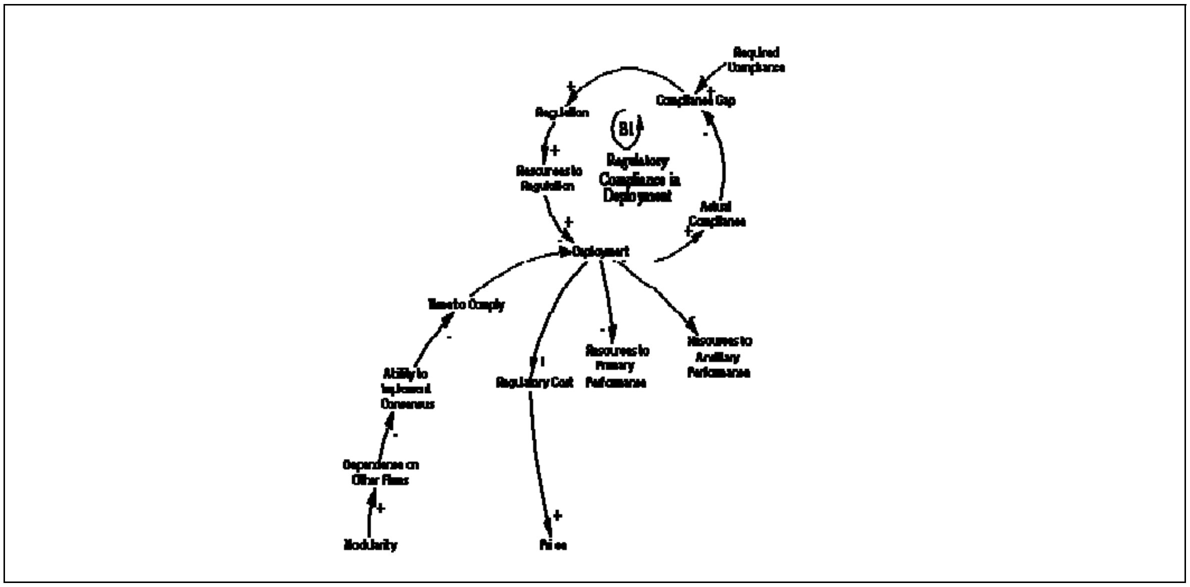


Figure 61: Regulation, Firm, and Industry Dynamics

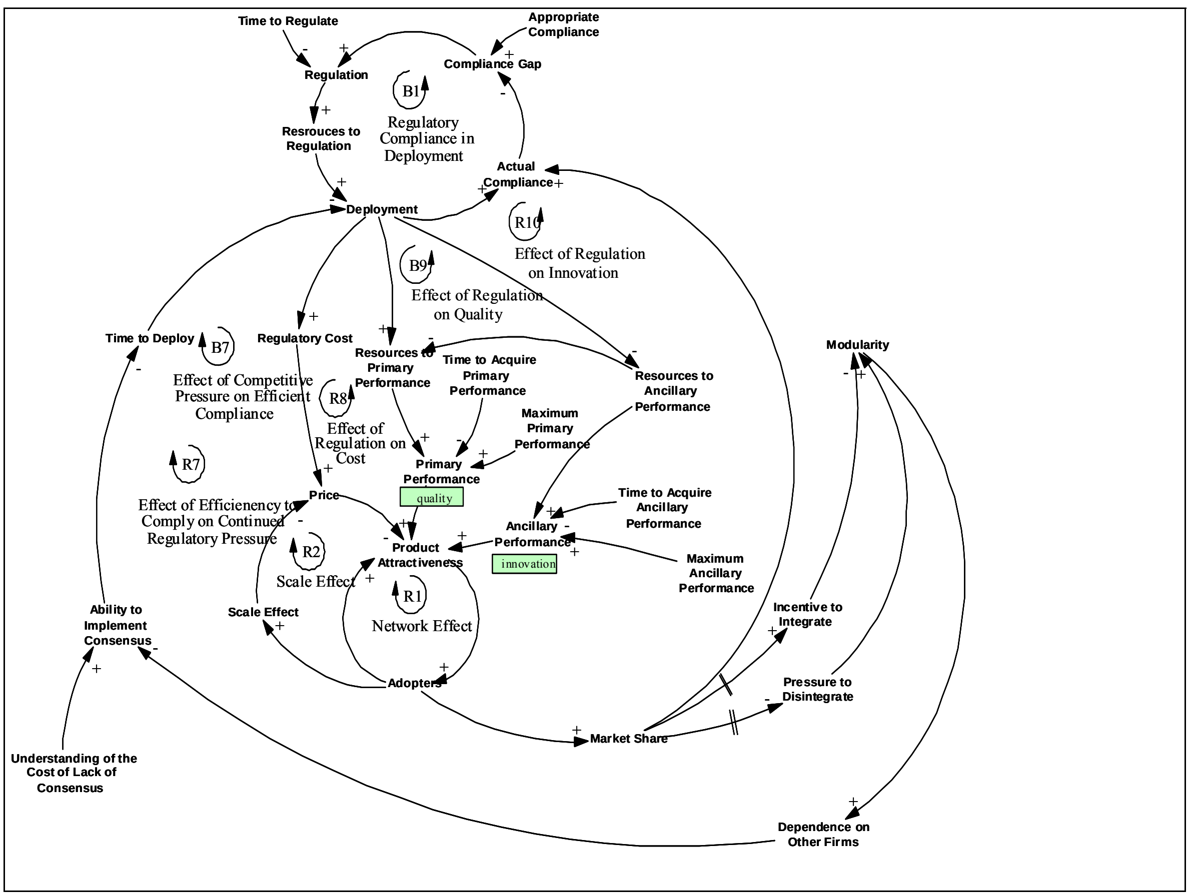


Figure 62: Complete Causal Structure

Model-Sectors Diagram

The next three representations—the model-sector diagram, parameter-input diagrams, and alphabetical listing of model equations—are meant to be read together. The model-sector diagram represents different sectors of the model and important variables in those sectors.

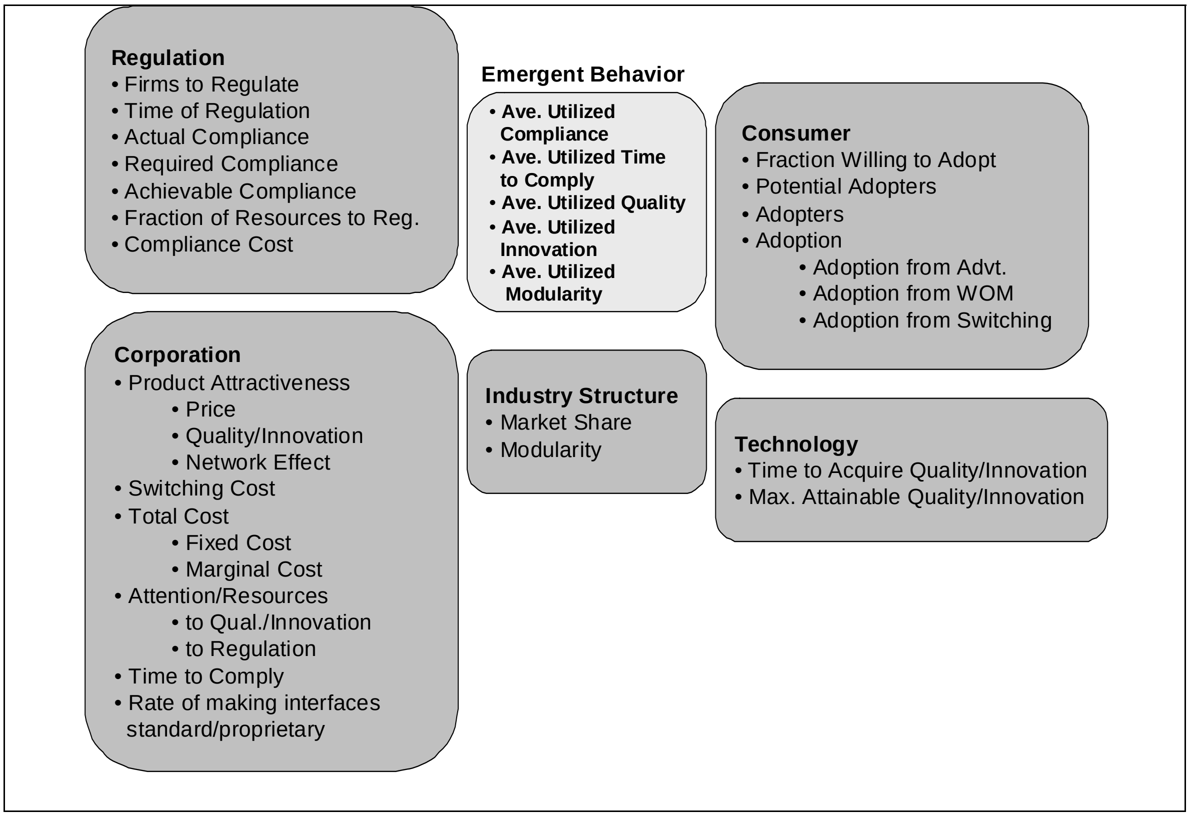
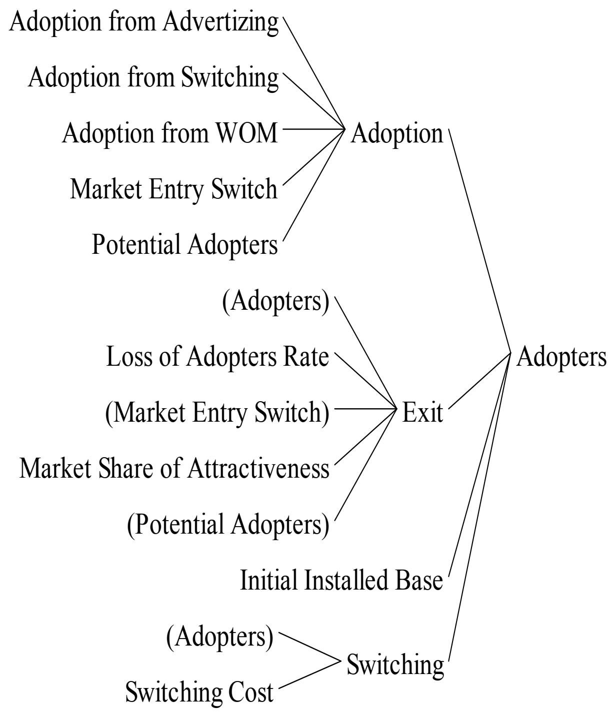
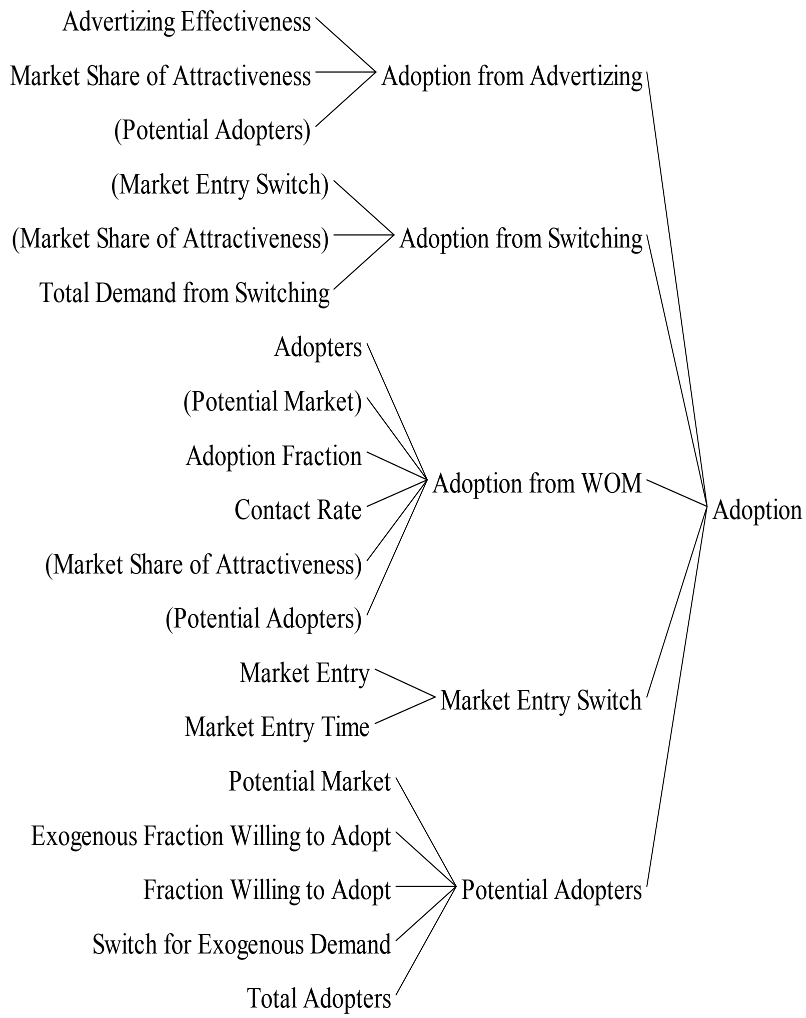


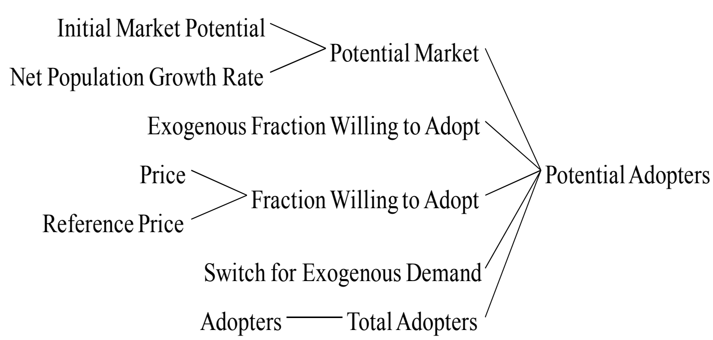
Figure 63: Model Sectors Diagram

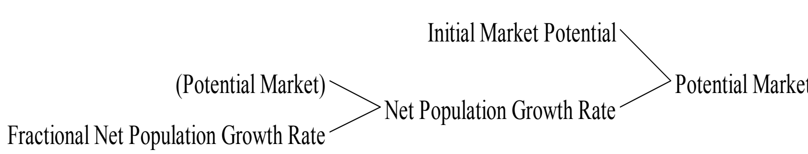
Parameter-input Diagrams

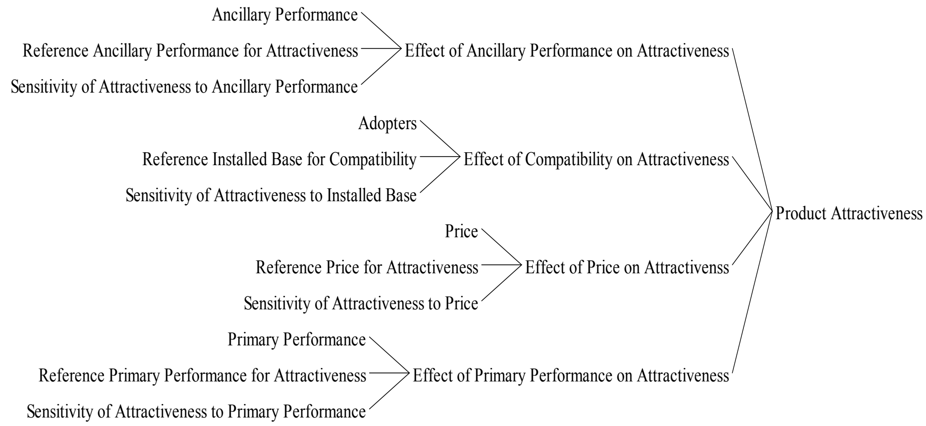
The parameter-input diagram below shows what goes into formulating each parameter in the model. These diagrams should be read in conjunction with the equations listed below to under how each parameter is formulated.

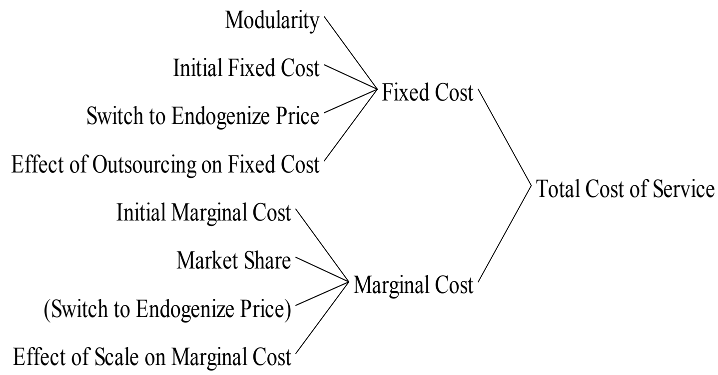

Adoption from Advertizing
Adoption from Switching
Adoption from WOM
Market Entry Switch
Potential Adopters
Adoption
(Adopters)
Loss of Adopters Rate
(Market Entry Switch)
Market Share of Attractiveness
(Potential Adopters)
Exit
Adopters
Initial Installed Base
(Adopters)
Switching Cost
Switching

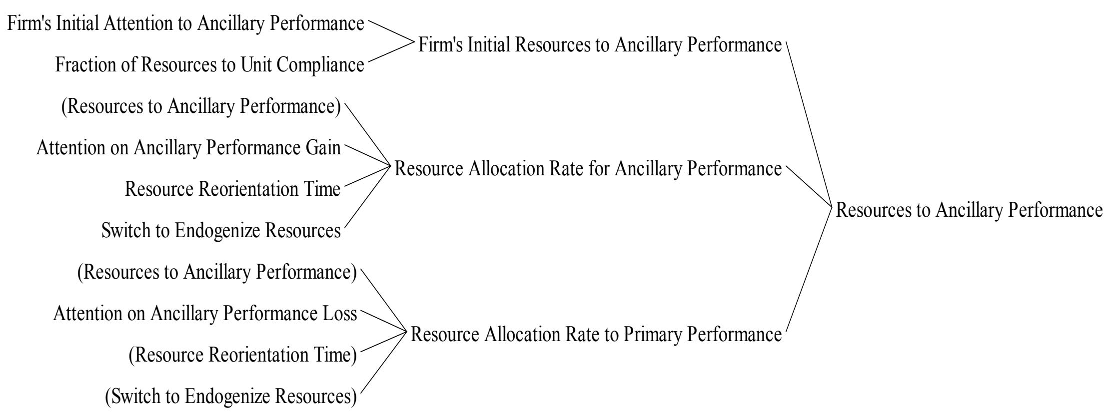

Advertizing Effectiveness
Market Share of Attractiveness
(Potential Adopters)
Adoption from Advertizing
(Market Entry Switch)
(Market Share of Attractiveness)
Total Demand from Switching
Adoption from Switching
Adopters
(Potential Market)
Adoption Fraction
Contact Rate
(Market Share of Attractiveness)
(Potential Adopters)
Adoption from WOM
Adoption
Market Entry
Market Entry Time
Market Entry Switch
Potential Market
Exogenous Fraction Willing to Adopt
Fraction Willing to Adopt
Switch for Exogenous Demand
Total Adopters
Potential Adopters

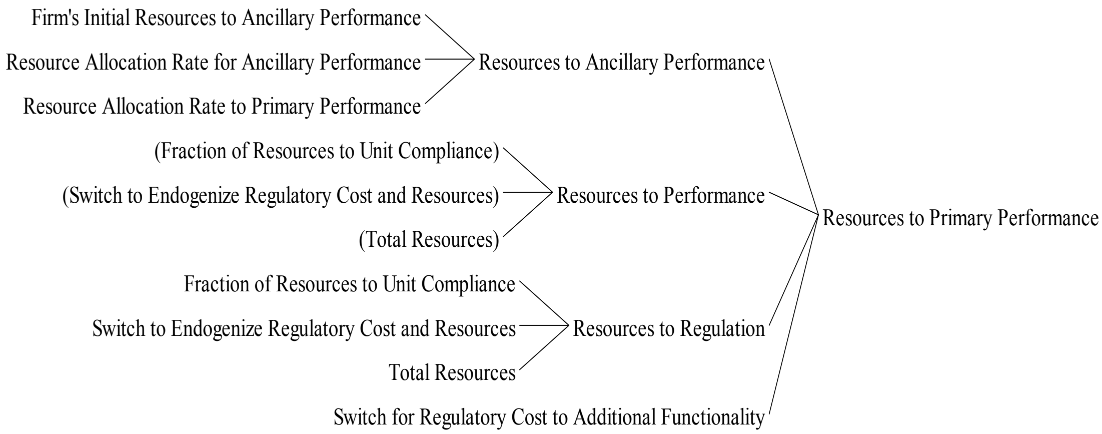

Initial Market Potential
Net Population Growth Rate
Potential Market
Exogenous Fraction Willing to Adopt
Price
Reference Price
Fraction Willing to Adopt
Potential Adopters
Switch for Exogenous Demand
Adopters
Total Adopters

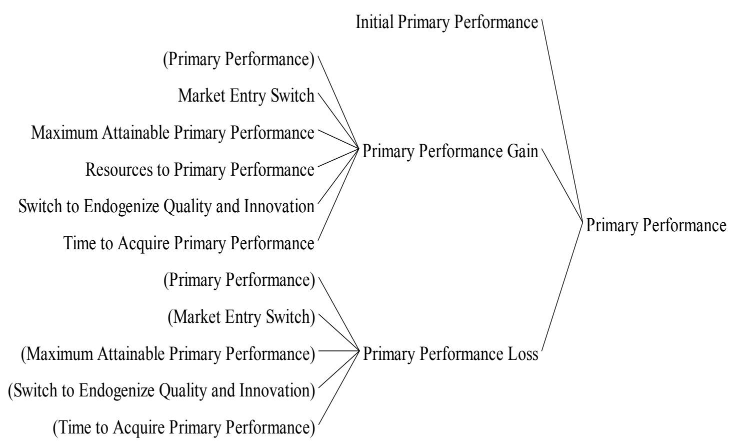

Initial Market Potential
(Potential Market)
Fractional Net Population Growth Rate
Net Population Growth Rate
Potential Market

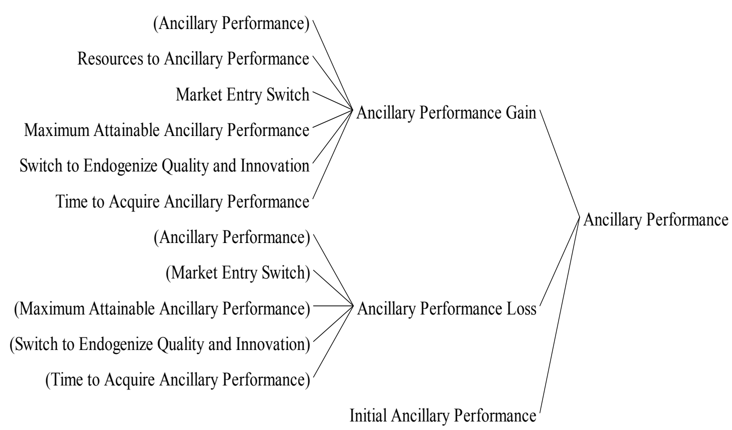

Ancillary Performance
Reference Ancillary Performance for Attractiveness
Sensitivity of Attractiveness to Ancillary Performance
Effect of Ancillary Performance on Attractiveness
Adopters
Reference Installed Base for Compatibility
Sensitivity of Attractiveness to Installed Base
Effect of Compatibility on Attractiveness
Price
Reference Price for Attractiveness
Sensitivity of Attractiveness to Price
Effect of Price on Attractivenss
Primary Performance
Reference Primary Performance for Attractiveness
Sensitivity of Attractiveness to Primary Performance
Effect of Primary Performance on Attractiveness
Product Attractiveness

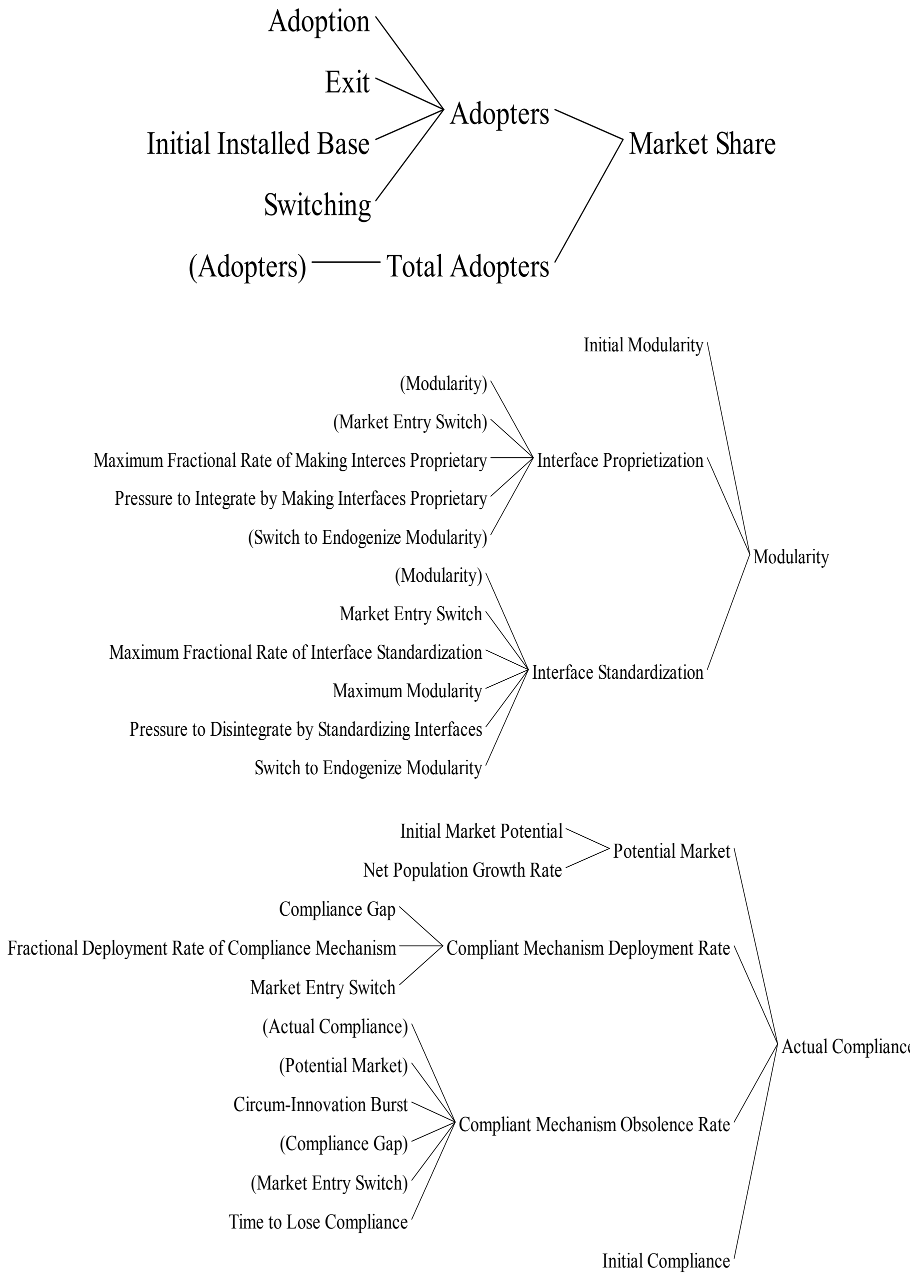

Modularity
Initial Fixed Cost
Switch to Endogenize Price
Effect of Outsourcing on Fixed Cost
Fixed Cost
Initial Marginal Cost
Market Share
(Switch to Endogenize Price)
Effect of Scale on Marginal Cost
Marginal Cost
Total Cost of Service

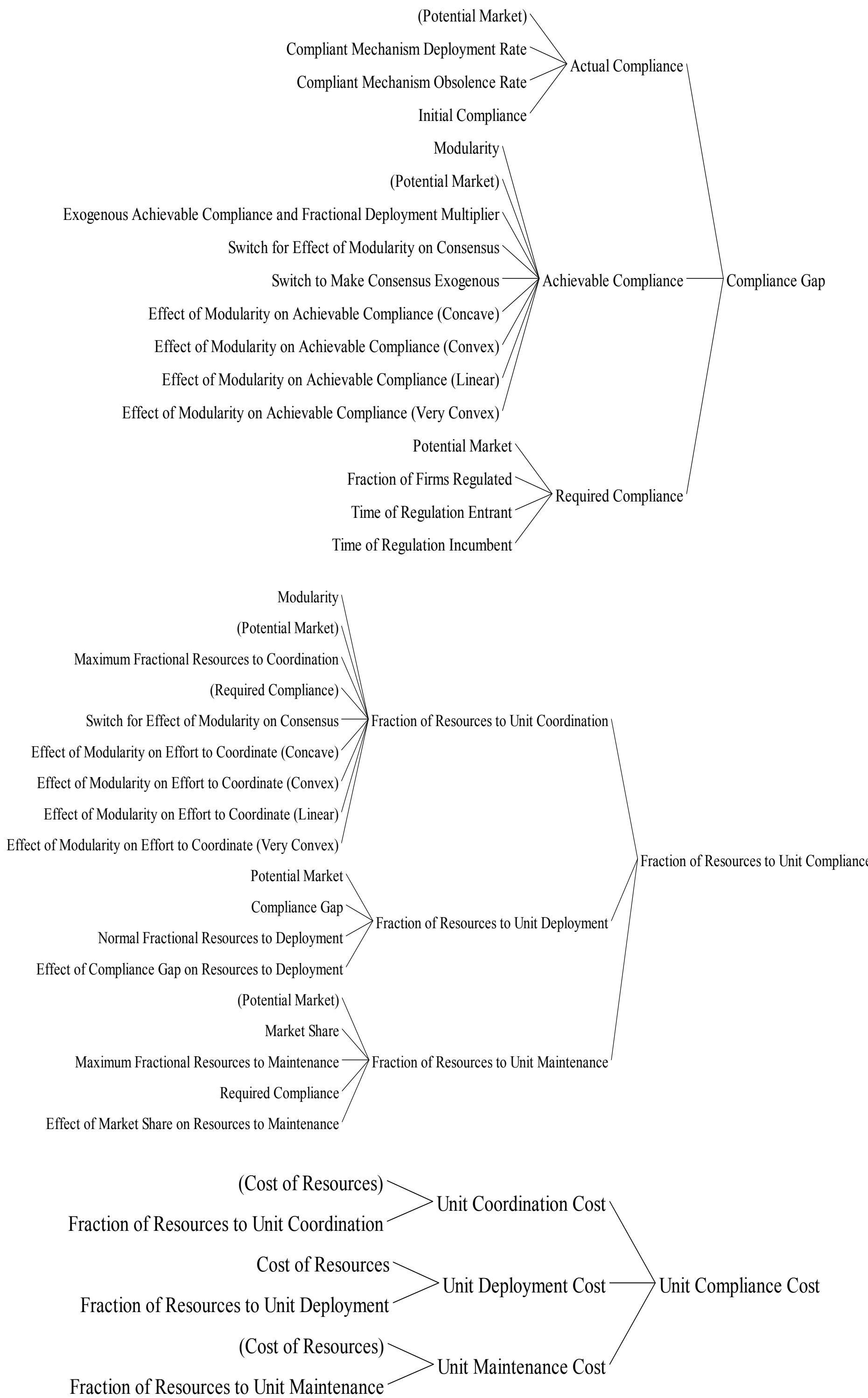

Firm's Initial Attention to Ancillary Performance
Fraction of Resources to Unit Compliance
Firm's Initial Resources to Ancillary Performance
(Resources to Ancillary Performance)
Attention on Ancillary Performance Gain
Resource Reorientation Time
Switch to Endogenize Resources
Resource Allocation Rate for Ancillary Performance
(Resources to Ancillary Performance)
Attention on Ancillary Performance Loss
(Resource Reorientation Time)
(Switch to Endogenize Resources)
Resource Allocation Rate to Primary Performance
Resources to Ancillary Performance


Firm's Initial Resources to Ancillary Performance
Resource Allocation Rate for Ancillary Performance
Resource Allocation Rate to Primary Performance
Resources to Ancillary Performance
(Fraction of Resources to Unit Compliance)
(Switch to Endogenize Regulatory Cost and Resources)
(Total Resources)
Resources to Performance
Resources to Primary Performance
Fraction of Resources to Unit Compliance
Switch to Endogenize Regulatory Cost and Resources
Total Resources
Resources to Regulation
Switch for Regulatory Cost to Additional Functionality


Initial Primary Performance
(Primary Performance)
Market Entry Switch
Maximum Attainable Primary Performance
Resources to Primary Performance
Switch to Endogenize Quality and Innovation
Time to Acquire Primary Performance
Primary Performance Gain
Primary Performance
(Primary Performance)
(Market Entry Switch)
(Maximum Attainable Primary Performance)
(Switch to Endogenize Quality and Innovation)
(Time to Acquire Primary Performance)
Primary Performance Loss


(Ancillary Performance)
Resources to Ancillary Performance
Market Entry Switch
Maximum Attainable Ancillary Performance
Switch to Endogenize Quality and Innovation
Time to Acquire Ancillary Performance
Ancillary Performance Gain
Ancillary Performance
(Ancillary Performance)
(Market Entry Switch)
(Maximum Attainable Ancillary Performance)
(Switch to Endogenize Quality and Innovation)
(Time to Acquire Ancillary Performance)
Ancillary Performance Loss
Initial Ancillary Performance


Adoption
Exit
Initial Installed Base
Switching
Adopters
Market Share
(Adopters)
Total Adopters
Initial Modularity
(Modularity)
(Market Entry Switch)
Maximum Fractional Rate of Making Interces Proprietary
Pressure to Integrate by Making Interfaces Proprietary
(Switch to Endogenize Modularity)
Interface Proprietization
Modularity
(Modularity)
Market Entry Switch
Maximum Fractional Rate of Interface Standardization
Maximum Modularity
Pressure to Disintegrate by Standardizing Interfaces
Switch to Endogenize Modularity
Interface Standardization
Initial Market Potential
Net Population Growth Rate
Potential Market
Compliance Gap
Fractional Deployment Rate of Compliance Mechanism
Market Entry Switch
Compliant Mechanism Deployment Rate
(Actual Compliance)
(Potential Market)
Circum-Innovation Burst
(Compliance Gap)
(Market Entry Switch)
Time to Lose Compliance
Compliant Mechanism Obsolence Rate
Actual Compliance
Initial Compliance



(Potential Market)
Compliant Mechanism Deployment Rate
Compliant Mechanism Obsolence Rate
Initial Compliance
Actual Compliance
Modularity
(Potential Market)
Exogenous Achievable Compliance and Fractional Deployment Multiplier
Switch for Effect of Modularity on Consensus
Switch to Make Consensus Exogenous
Effect of Modularity on Achievable Compliance (Concave)
Effect of Modularity on Achievable Compliance (Convex)
Effect of Modularity on Achievable Compliance (Linear)
Effect of Modularity on Achievable Compliance (Very Convex)
Achievable Compliance
Compliance Gap
Potential Market
Fraction of Firms Regulated
Time of Regulation Entrant
Time of Regulation Incumbent
Required Compliance
Modularity
(Potential Market)
Maximum Fractional Resources to Coordination
(Required Compliance)
Switch for Effect of Modularity on Consensus
Effect of Modularity on Effort to Coordinate (Concave)
Effect of Modularity on Effort to Coordinate (Convex)
Effect of Modularity on Effort to Coordinate (Linear)
Effect of Modularity on Effort to Coordinate (Very Convex)
Fraction of Resources to Unit Coordination
Fraction of Resources to Unit Compliance
Potential Market
Compliance Gap
Normal Fractional Resources to Deployment
Effect of Compliance Gap on Resources to Deployment
Fraction of Resources to Unit Deployment
(Potential Market)
Market Share
Maximum Fractional Resources to Maintenance
Required Compliance
Effect of Market Share on Resources to Maintenance
Fraction of Resources to Unit Maintenance
(Cost of Resources)
Fraction of Resources to Unit Coordination
Unit Coordination Cost
Cost of Resources
Fraction of Resources to Unit Deployment
Unit Deployment Cost
Unit Compliance Cost
(Cost of Resources)
Fraction of Resources to Unit Maintenance
Unit Maintenance Cost

Alphabetical Listing of Model Equations

Equation	Variables

1 **Achievable Compliance[Firm]=**
Potential Market * ((Switch to Make Consensus Exogenous * Exogenous Achievable Compliance and Fractional Deployment Multiplier\
[Firm]) + (1 - Switch to Make Consensus Exogenous) * (IF THEN ELSE(Switch for Effect of Modularity on Consensus
=1, "Effect of Modularity on Achievable Compliance (Very Convex)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=2\
, "Effect of Modularity on Achievable Compliance (Convex)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=3\
, "Effect of Modularity on Achievable Compliance (Linear)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=4\
, "Effect of Modularity on Achievable Compliance (Concave)"
(Modularity[Firm]), 0)))
~ Unit
~ Number of adopters for each firm's (industry's) network that can be \
covered given the level of consensus among firms.

2 **Actual Compliance[Firm]= INTEG (**
Compliant Mechanism Deployment Rate[Firm]-Compliant Mechanism Obsolence Rate[Firm],
Initial Compliance[Firm] * Potential Market)
~ Unit
~ Number of adopters of each firm's (industry's) network currently compliant.

3 **Adjustment for Month=**
12
~ Month/Year
~ Year to Month Adjustment

4 **Adopters[Firm]= INTEG (**
Adoption[Firm]-Exit[Firm]-Switching[Firm]-Exit[Firm],
Initial Installed Base[Firm])
~ Unit
~ Adopters for each firm

5 **Adoption Fraction=**
0.3
~ Unit/Contact
~ 1/Number of Contacts it takes to convert a potential adopter to an adopter

6 **Adoption from Advertizing[Firm]=**

Potential Adopters * Advertizing Effectiveness * Market Share of Attractiveness[Firm\
]
~ Unit/Month
~

7 **Adoption from Switching[Incumbent]=**
Market Entry Switch[Incumbent] * Total Demand from Switching * Market Share of Attractiveness\
[Incumbent] + (1 - Market Entry Switch[Entrant]) * Total Demand from Switching * Market Share of Attractiveness\
[Entrant] ~~
Adoption from Switching[Entrant]=
Market Entry Switch[Entrant] * Total Demand from Switching * Market Share of Attractiveness\
[Entrant] + (1 - Market Entry Switch[Incumbent]) * Total Demand from Switching * Market Share of Attractiveness\
[Incumbent]
~ Unit/Month
~ When both firms are in the market, the firm gains consumers based on its \
market share of attractiveness. When only one firm is in the market, that \
firms gains all the consumers that decide to switch.

8 **Adoption from WOM[Firm]=**
Adoption Fraction * Contact Rate * ((Adopters[Firm] * Potential Adopters)/Potential Market\
) * Market Share of Attractiveness[Firm]
~ Unit/Month
~

10 **Adoption[Incumbent]=**
IF THEN ELSE(Potential Adopters>=0, Market Entry Switch[Incumbent] * (Adoption from Advertizing
[Incumbent] + Adoption from WOM
[Incumbent] + Adoption from Switching[Incumbent]), 0) ~~

9 Adoption[Entrant]=
IF THEN ELSE(Potential Adopters>=0, (Market Entry Switch[Entrant] * (Adoption from Advertizing
[Entrant] + Adoption from WOM
[Entrant] + Adoption from Switching[Entrant])), 0)
~ Unit/Month
~ Formulates total gain of adopters for a firm. The gain part of equation \
(when there are Potential Adopters left) is simple. A firm gains adopters \
due to advertizing, word of mouth, or switching from the other firm.

11 **Advertizing Effectiveness=**
0.4
~ 1/Month
~ Fraction that Adopts due to advertizing every month

12 **Ancillary Performance Gain[Firm]=**
MAX(0, Switch to Endogenize Quality and Innovation * Market Entry Switch[Firm] * Resources to Ancillary Performance\
[Firm

] * ((Maximum Attainable Ancillary Performance
[Firm]
- Ancillary Performance[Firm])/Time to Acquire Ancillary Performance[Firm]))
~ 1/Month
~ Performance change given the gap between Maximum and the current ancillary \
performance, as weighted by the current resource allocation.

13 **Ancillary Performance Loss[Firm]=**
MAX(0, Switch to Endogenize Quality and Innovation * Market Entry Switch[Firm] * ((Ancillary Performance\
[Firm] - Maximum Attainable Ancillary Performance
[Firm])/Time to Acquire Ancillary Performance[Firm]))
~ Dimensionless/Month
~

14 **Ancillary Performance[Firm]= INTEG (**
Ancillary Performance Gain[Firm]-Ancillary Performance Loss[Firm],
Initial Ancillary Performance[Firm])
~ Dimensionless
~ Firm's (or represented industry's) current ancillary performance.

15 **Appropriate Level of Compliance=**
1
~ Dimensionless
~ Assumption: Socially, it is desirable that all the traffic complies with \
regulation

16 **Attention on Ancillary Performance Gain[Incumbent]=**
Resources to Performance[Incumbent] * (Switch for Highly Reactive Reallocation of Attention and Resources
*Effect of Highly Reactive Reallocation of Attention(
Expected Market Share[Entrant]) + (1-Switch for Highly Reactive Reallocation of Attention and Resources\
)*Effect of Competitor's Expected Market Share on Attention to Ancillary Performance
(Expected Market Share[Entrant])) ~~
Attention on Ancillary Performance Gain[Entrant]=
Resources to Performance[Entrant] * (Switch for Highly Reactive Reallocation of Attention and Resources
*Effect of Highly Reactive Reallocation of Attention(
Expected Market Share[Incumbent]) + (1-Switch for Highly Reactive Reallocation of Attention and Resources\
)*Effect of Competitor's Expected Market Share on Attention to Ancillary Performance
(Expected Market Share[Incumbent]))
~ Dimensionless
~ Fraction of total attention on innovation.

17 **Attention on Ancillary Performance Loss[Firm]=**
Resources to Performance[Firm] * (1 - (Switch for Highly Reactive Reallocation of Attention and Resources
*Effect of Highly Reactive Reallocation of Attention

(Expected Market Share[Firm])+(1-Switch for Highly Reactive Reallocation of Attention and Resources\
)*Effect of Competitor's Expected Market Share on Attention to Ancillary Performance
(Expected Market Share[Firm])))
~ Dimensionless
~ Fraction of total attention on quality.

18 **Average Required Compliance=**
Required Compliance[Incumbent] * Market Share[Incumbent] + Required Compliance[Entrant\
] * Market Share[Entrant]
~ Unit
~ Emergent Behavior: market share weighted current level of compliance \
required by the regulator across all firms.

19 **Average Utilized Compliance=**
Actual Compliance[Incumbent] * Market Share[Incumbent] + Actual Compliance[Entrant] \
* Market Share[Entrant]
~ Unit
~ Emergent Behavior: market share weighted current level of compliance \
considering all services.

20 **Average Utilized Innovation=**
SUM(Weighted Firm Innovation[Firm!])
~ Dimensionless
~ Emergent Behavior: market share weighted innovation of both industries.

21 **Average Utilized Market Power=**
1 - Average Utilized Modularity
~ Dimensionless
~ Inverse of the Modularity. The less the average modularity the more the \
market power, and vice versa.

22 **Average Utilized Modularity=**
SUM(Weighted Firm Modularity[Firm!])
~ Dmnl
~ Emergent Behavior: Market share weighted modularity of each industry \
(firm).

23 **Average Utilized Normalized Coordination Cost=**
SUM(Weighted Normalized Coordination Cost[Firm!])
~ Dimensionless
~ Market share weighted Normalized Coordination Cost

24 **Average Utilized Quality=**

SUM(Weighted Firm Quality[Firm!])

~ Dimensionless

~ Emergent Behavior: market share weighted quality of both industries.

25 **Circum-Innovation Burst[Firm]=**

0 * (STEP(0.1, 50) + STEP(-0.1, 60))

~ Dmnl/Month

~ This parameter allows the modeler to simulate loss of compliance due to \

innovation bursts. It represents loss of compliance in an already \

compliance network, as opposed to the rise of new technologies that are \

non-compliant and unregulated.

26 **Compliance Gap[Firm]=**

MIN(Required Compliance[Firm], Achievable Compliance[Firm]) - Actual Compliance[Firm\

]

~ Unit

~ Gap between the required or achievable and current compliance level for \

each firm.

27 **Compliant Mechanism Deployment Rate[Firm]=**

Market Entry Switch[Firm] * (IF THEN ELSE(Compliance Gap[Firm]>0, Fractional Deployment Rate of Compliance Mechanism\

[Firm]*Compliance Gap[Firm], 0))

~ Unit/Month

~ Rate at which the compliant technology is deployed.

29 **Compliant Mechanism Obsolence Rate[Firm]=**

Market Entry Switch[Firm] * (IF THEN ELSE(Compliance Gap[Firm]<0, Actual Compliance[\

Firm]/Time to Lose Compliance, 0) + "Circum-Innovation Burst"[Firm

] * Potential Market)

~ Unit/Month

~ Percentage of network in which the compliance becomes obsolete in the face \

of innovation.

30 **Contact Rate=**

20

~ Contact/Unit/Month

~ Contacts every user makes in a month

31 **Cost of Resources[Firm]=**

1

~ Dollar/(Month*Unit)

~

32 **Demand Side Average Time to Deploy=**

(1/Fractional Deployment Rate of Compliance Mechanism[Incumbent]) * Market Share[Incumbent\
] * (MIN(Required Compliance[Incumbent], Achievable Compliance[Incumbent])/Potential Market
) + (1/Fractional Deployment Rate of Compliance Mechanism[Entrant]) * Market Share
[Entrant] * (MIN(Required Compliance[Entrant], Achievable Compliance[Entrant])/Potential Market\
)

~ Month

~

33 **Effect of Ancillary Performance on Attractiveness[Firm]=**

EXP(Sensitivity of Attractiveness to Ancillary Performance * Ancillary Performance[Firm\
]/Reference Ancillary Performance for Attractiveness
)

~ Dmnl

~ Effect of Ancillary Performance on Attractiveness: The service is more \
attractive when the ancillary performance (innovation) is higher than the \
reference.

34 **Effect of Compatibility on Attractiveness[Firm]=**

EXP(Sensitivity of Attractiveness to Installed Base * Adopters[Firm]/Reference Installed Base for Compatibility\
)

~ Dmnl

~ The effect of compatibility on attractiveness captures the network and \
compatibility effects: the larger the installed base, the greater the \
attractiveness of that product. There are a number of plausible shapes for \
the relationship between installed base and attractiveness. The \
exponential function is used here to be consistent with the standard logit \
choice model.

35 **Effect of Competitor's Expected Market Share on Attention to Ancillary Performance(**

[(0,0)-(1,1)],(0,0),(0.176259,0.016092),(0.352518,0.0390805),(0.53777,0.0735632),(0.696043\
,0.156322),(0.816547,0.255172),(0.890288,0.367816),(0.917266,0.448276),(0.942446,0.556322\
),(1,1))

~ Dimensionless

~ This function represents how the firm reacts to competitor firm's market \
share. The Incumbent firm takes a wait-and-see approach in diverting \
resources towards innovation. Initially, when Entrant's market share is \
low, the Incumbent is tries to ascertain if this is a price-based \
competition or innovation-based competition, and keeps most of its \
resources focused on the current activity. When the Entrant's expected \
market share crosses a certain limit, it becomes clear that the future \
belongs to the Entrant-like innovations, so the Incumbent diverts \
resources to innovation (i.e. Ancillary Performance). The inverse is true \
for the Entrant. The Entrant initially focuses its attention on \

innovation, but as it gains more market share, it diverts attention to \
quality (i.e. Primary Performance) that its increasing customer base \
demands.

36 **Effect of Competitors Market Share on Interface Standardization(**
[(0,0)-(1,1)],(0,0),(0.477064,0.105263),(0.706422,0.214912),(0.83792,0.421053),(0.908257\
,0.618421),(1,1))
~ Dmnl
~ This function represents how competitor's market share creates pressure to \
disintegrate. The pressure to disintegrate is increasing and convex as the \
competitor gains market share. The output of the function acts as \
multiplier for the Maximum Fractional Rate of Interface Standardization.

37 **Effect of Compliance Gap on Resources to Deployment(**
[(-1,0)-(1,1)],(-1,0),(0.001,0),(0.0011,1),(1,1))
~ Dimensionless
~

38 **Effect of Highly Reactive Reallocation of Attention(**
[(0,0)-(1,1)],(0,0),(1,1))
~ Dimensionless
~ This function represents how an agressive firm would react to competitor's \
market share. This function is used for sensitivity tests.

39 **Effect of Market Share on Resources to Maintenance(**
[(0,0)-(1,1)],(0,0),(1,1))
~ Dimensionless
~

40 **Effect of Modularity on Achievable Compliance (Concave)(**
[(0,0)-(1,1)],(0,1),(0.201835,0.960526),(0.379205,0.925439),(0.58104,0.890351),(0.715596\
,0.868421),(0.82263,0.859649),(0.911315,0.850877),(0.993884,0.85))
~ Dimensionless
~ This function "conjectures" how achievable compliance drops in a concave \
fashion with increasing modularity due to the lack of consensus among \
industry players. This one of four conjectured relationships between \
modularity and consensus that is selected wtih a switch for sensitivity \
analysis.

41 **Effect of Modularity on Achievable Compliance (Convex)(**
[(0,0)-(1,1)],(0,1),(0.211009,0.969298),(0.406728,0.925439),(0.626911,0.855263),(0.788991\
,0.785088),(0.883792,0.719298),(0.963303,0.644737),(1,0.6))
~ Dimensionless
~ This function "conjectures" how achievable compliance drops in a convex \
fashion with increasing modularity due to the lack of consensus among \

industry players. This one of four conjectured relationships between \
modularity and consensus that is selected wtih a switch for sensitivity \
analysis.

42 **Effect of Modularity on Achievable Compliance (Linear)(**
[(0,0)-(1,1)],(0,1),(1,0.75))
~ Dimensionless
~ This function "conjectures" how achievable compliance drops in a linear \
fashion with increasing modularity due to the lack of consensus among \
industry players. This one of four conjectured relationships between \
modularity and consensus that is selected wtih a switch for sensitivity \
analysis.

43 **Effect of Modularity on Achievable Compliance (Very Convex)(**
[(0,0)-(1,1)],(0,1),(0.211009,0.969298),(0.406728,0.925439),(0.626911,0.855263),(0.847095\
,0.741228),(0.905199,0.653509),(0.963303,0.486842),(1,0.25))
~ Dimensionless
~ This function "conjectures" how achievable compliance drops in a very \
convex fashion with increasing modularity due to the lack of consensus \
among industry players. This one of four conjectured relationships between \
modularity and consensus that is selected wtih a switch for sensitivity \
analysis.

44 **Effect of Modularity on Deployment Rate Due to Consensus (Concave)(**
[(0,0)-(1,1)],(0,1),(0.201835,0.960526),(0.379205,0.925439),(0.58104,0.890351),(0.715596\
,0.868421),(0.82263,0.859649),(0.911315,0.850877),(0.993884,0.85))
~ Dimensionless
~ This function "conjectures" how deployment rate of compliant technology \
drops in a concave fashion with increasing modularity due to the lack of \
consensus among industry players. This one of four conjectured \
relationships between modularity and consensus that is selected wtih a \
switch for sensitivity analysis.

45 **Effect of Modularity on Deployment Rate Due to Consensus (Convex)(**
[(0,0)-(1,1)],(0,1),(0.211009,0.969298),(0.406728,0.925439),(0.626911,0.855263),(0.788991\
,0.785088),(0.883792,0.719298),(0.963303,0.644737),(1,0.6))
~ Dimensionless
~ This function "conjectures" how deployment rate of compliant technology \
drops in a convex fashion with increasing modularity due to the lack of \
consensus among industry players. This one of four conjectured \
relationships between modularity and consensus that is selected wtih a \
switch for sensitivity analysis.

46 **Effect of Modularity on Deployment Rate Due to Consensus (Linear)(**

[(0,0)-(1,1)],(0,1),(1,0.75))

~ Dimensionless

~ This function "conjectures" how deployment rate of compliant technology \
drops in a linear fashion with increasing modularity due to the lack of \
consensus among industry players. This one of four conjectured \
relationships between modularity and consensus that is selected wtih a \
switch for sensitivity analysis.

47 **Effect of Modularity on Deployment Rate Due to Consensus (Very Convex)(**

[(0,0)-(1,1)],(0,1),(0.211009,0.969298),(0.406728,0.925439),(0.626911,0.855263),(0.847095\
,0.741228),(0.905199,0.653509),(0.963303,0.486842),(1,0.25))

~ Dimensionless

~ This function "conjectures" how deployment rate of compliant technology \
drops in a very convex fashion with increasing modularity due to the lack \
of consensus among industry players. This one of four conjectured \
relationships between modularity and consensus that is selected wtih a \
switch for sensitivity analysis.

48 **Effect of Modularity on Effort to Coordinate (Concave)(**

[(0,0)-(1,1)],(0,0.1),(0.333333,0.171053),(0.541284,0.20614),(0.746177,0.22807),(0.865443\
,0.236842),(0.993884,0.25))

~ Dimensionless

~ This function "conjectures" how effort required to build consensus for \
regulatory purposes increases in a concave fashion with increasing \
modularity due to the lack of consensus among industry players. This one \
of four conjectured relationships between modularity and consensus that is \
selected wtih a switch for sensitivity analysis.

49 **Effect of Modularity on Effort to Coordinate (Convex)(**

[(0,0)-(1,1)],(0,0.1),(0.409786,0.144737),(0.654434,0.267544),(0.82263,0.416667),(0.93578\
,0.535088),(0.996942,0.609649))

~ Dimensionless

~ This function "conjectures" how effort required to build consensus for \
regulatory purposes increases in a convex fashion with increasing \
modularity due to the lack of consensus among industry players. This one \
of four conjectured relationships between modularity and consensus that is \
selected wtih a switch for sensitivity analysis.

50 **Effect of Modularity on Effort to Coordinate (Linear)(**

[(0,0)-(1,1)],(0,0.1),(1,0.35))

~ Dimensionless

~ This function "conjectures" how effort required to build consensus for \

regulatory purposes increases in a linear fashion with increasing \
modularity due to the lack of consensus among industry players. This one \
of four conjectured relationships between modularity and consensus that is \
selected wtih a switch for sensitivity analysis.

51 **Effect of Modularity on Effort to Coordinate (Very Convex)(**

[(0,0)-(1,1)],(0,0.1),(0.440367,0.122807),(0.59633,0.157895),(0.721713,0.232456),(0.792049\
,0.328947),(0.859327,0.460526),(0.908257,0.618421),(0.957187,0.776316),(1,1))

~ Dimensionless

~ This function "conjectures" how effort required to build consensus for \
regulatory purposes increases in a very convex fashion with increasing \
modularity due to the lack of consensus among industry players. This one \
of four conjectured relationships between modularity and consensus that is \
selected wtih a switch for sensitivity analysis.

52 **Effect of Modularity on Enforcement Cost(**

[(0,0)-(1,1)],(0,0),(0.477064,0.105263),(0.706422,0.214912),(0.83792,0.421053),(0.908257\
,0.618421),(1,1))

~ Dimensionless

~ This function "conjectures" how enforcement cost for regulators increase \
in a convex fashion with increasing modularity.

53 **Effect of Modularity on Maximum Attainable Ancillary Performance(**

[(0,0)-(1,1)],(0,0.5),(1,1))

~ Dmnl

~ This function represents how modularity affects the achievable level of \
innovation. More innovation is possible to achieve in more modular \
structures.

54 **Effect of Modularity on Maximum Attainable Primary Performance(**

[(0,0)-(1,1)],(0,1),(1,0.5))

~ Dimensionless

~ This function represents how modularity affects the achievable level of \
quality. More quality is possible to achieve in more integrated (i.e. less \
modular) structures.

55 **Effect of Modularity on Resource Reorientation Time(**

[(0,0)-(1,1)],(0,0.67),(1,0.33))

~ Dimensionless

~ This function represents the effect of modularity on organizational \
rigidity. Firms in more modular industries are more nible in reallocating \
resources and vice versa.

56 **Effect of Modularity on Time to Acquire Ancillary Performance(**

[(0,0)-(1,1)],(0,0.67),(1,0.33))

~ Dmnl

~ This function represents how modularity affects dimensional complexity, \
and therefore the time to innovate. More modular product has less \
dimensional complexity and requires less time to innovate. Highy \
integrated products become dimensionally complex, requiring more time.

57 **Effect of Modularity on Time to Acquire Primary Performance(**

[(0,0)-(1,1)],(0,0.33),(1,0.67))

~ Dimensionless

~ This function represents how modularity affects functional control over \
components, and therefore the time to build in quality. The functional \
control is higher in more integrated products, requiring less time to \
acquire quality. Highy modular products create more dependencies when \
developing system-level quality, requiring more more time to develope \
quality.

58 **Effect of Outsourcing on Fixed Cost(**

[(0,0)-(1,1)],(0,1),(1,0))

~ Dimensionless

~ This function represents how a firm reduces its fixed cost by outsourcing \
(or becoming modular). In reality, the fixed costs never go to zero, but \
it become small enough compared to that for the fully integrated structure

59 **Effect of Own Market Share on Interface Proprietization(**

[(0,0)-(1,1)],(0,0),(0.477064,0.105263),(0.706422,0.214912),(0.83792,0.421053),(0.908257\
,0.618421),(1,1))

~ Dmnl

~ This function represents how firm's own market share (i.e. market power) \
creates incentive to integrate. The incentive to integrate is increasing \
and convex as the firm gains market share. The output of the function acts \
as multiplier for the Maximum Fractional Rate of Making Interfaces \
Proprietary.

60 **Effect of Price on Attractivenss[Firm]=**

EXP(Sensitivity of Attractiveness to Price * Price[Firm]/Reference Price for Attractiveness\
)

~ Dmnl

~ Effect of Price on Attractiveness: The service becomes more attractive \
when the price is lower than the reference, and less attractive when it is \
higher.

61 **Effect of Primary Performance on Attractiveness[Firm]=**

EXP(Sensitivity of Attractiveness to Primary Performance * Primary Performance[Firm]\
/Reference Primary Performance for Attractiveness
)
~ Dmnl
~ Effect of Primary Performance on Attractiveness: The service is more \
attractive when the primary performance (quality) is higher than the \
reference.

62 **Effect of Scale on Marginal Cost(**

[(0,0)-(1,1)],(0,1),(1,0))
~ Dimensionless
~ This function represents the economies of scale a firm enjoyes with \
growing number of adopters.

62 **Exit[Incumbent]=**

IF THEN ELSE(Potential Adopters<0, (IF THEN ELSE(Adopters[Incumbent]>0, (Market Entry Switch\
[Incumbent] * Loss of Adopters Rate
* (- Potential Adopters) * (1-
Market Share of Attractiveness[Incumbent])) , 0)) + (IF THEN ELSE(Adopters[Entrant]>\
0, 0, (Market Entry Switch[Entrant]
* Loss of Adopters Rate * (- Potential Adopters) * (1-
Market Share of Attractiveness[Entrant])))), 0) ~~
Exit[Entrant]=
IF THEN ELSE(Potential Adopters<0, (IF THEN ELSE(Adopters[Entrant]>0, (Market Entry Switch\
[Entrant] * Loss of Adopters Rate
* Potential Adopters * (1-
Market Share of Attractiveness[Entrant])) , 0)) + (IF THEN ELSE(Adopters[Incumbent]>\
0, 0, (Market Entry Switch[Incumbent
] * Loss of Adopters Rate * Potential Adopters * (1-
Market Share of Attractiveness[Incumbent])))), 0)
~ Unit/Month
~ Formulates the loss of adopters for a firm. The shrinking of the market is \
slighly involved. When market shrinks, firms lose adopters according to \
their Market Share of Product Attractiveness. The more attractive the \
product, the smaller is the firm's loss of adopters. When the market \
shrinks, the adjustment some times can be such that a firm may lose all of \
its adopters and would have lost more if it had them. So, when there is a \
situation that a firm loses all its adopters but the market continues to \
shrink, the remaining adopters come from the other firm. In other words, \
the the less popular firm first goes out of business, while the more \
popular one services but with a few adopters.

63 **Exogenous Fraction Willing to Adopt=**

1

~ Dimensionless [0,1]

~ This parameter is used a scenario when the effect of demand curve needs to \
be excluded to simplify the analysis. Range [0,1]

63 **Entrants Adopters from Market Expansion=**

(Fraction Willing to Adopt After Entrant - Fraction Willing to Adopt beore Entrant) \
* Initial Market Potential * Initial Adopter Adjustment Pulse

~ Unit*Month

~

64 **Expected Adopters[Firm]=**

Adopters[Firm] * EXP(Forecast Horizon[Firm] * Expected Growth Rate of Adopters[Firm]\
)

~ Unit

~ Expected Adopters after the forecast horizon.

65 **Expected Growth Rate of Adopters[Firm]=**

MIN(Indicated Growth Rate of Adopters[Firm], Maximum Expected Growth Rate/Adjustment for Month\
)

~ 1/Month

~ Behavioral parameter to cap the Trend function output. When the Input to \
the Trand function (in this case, the Indicated Growth Rate of Adopters) \
is initially 0, the first time this input becomes non-zero the Indicated \
Growth Rate is a large value. In practice, people don't react to unusually \
large forecast values, and so this MIN function provides that expected \
growth rate below which people consider the forecasts more believable.

66 **Expected Market Share[Firm]=**

ZIDZ(Expected Adopters[Firm],Total Expected Adopters[Firm])

~ Dimensionless

~ Expected Market Share

67 **Firm:**

Incumbent, Entrant

~ Dmnl

~ In this model there is a single incumbent and multiple entrants. The \
entrants are combined as a single player.

68 **Firm's Initial Attention to Ancillary Performance[Firm]=**

0,1

~ Dimensionless [0,1]

~ Attention firms pay to innovation (Ancillary Performance) at time 0. \

Typically, a dominant incumbent pays little attention to innovation, while \
the entrant pays most of its attention to innovation.

69 **Firm's Initial Resources to Ancillary Performance[Firm]=**

(1-Fraction of Resources to Unit Compliance[Firm]) * Firm's Initial Attention to Ancillary Performance\
[Firm
]

~ Dimensionless

~ Adjusting for regulatory compliance, as the current assumption requires \
firms to allocate necessary resources for regulatory compliance and use \
the remaining for performance.

70 **Fixed Cost[Firm]=**

Switch to Endogenize Price * Initial Fixed Cost[Firm] * Effect of Outsourcing on Fixed Cost\
(Modularity[Firm]) + (1-Switch to Endogenize Price) * Initial Fixed Cost[Firm]

~ Dollar/(Month*Unit)

~ Fraction of total cost that is fixed cost.

71 **Fixed Maximum Attainable Ancillary Performance[Firm]=**

1,1

~ Dimensionless

~ Fixed and exgonenous limit on innovation (ancillary performance). Maximum \
attainable innovation normalized to 1. When used, this constant means that \
there is no architectural constraint on how much ancillary performance can \
be achieved in integrated structures.

72 **Fixed Maximum Attainable Primary Performance[Firm]=**

1,1

~ Dimensionless [0,1]

~ Fixed and exogenous limit on quality (primary performance. Maximum \
possible quality (primary performance) normalized to 1. When used, it \
means that modular structures are capable of attaining the same primary \
performance as the integrated structures.

73 **Forecast Horizon[Firm]=**

6

~ Month

~ Number of months over which to forecast.

74 **Fraction of Firms Regulated[Incumbent]=**

1 ~~

Fraction of Firms Regulated[Entrant]=

1

~ Dimensionless [0,1,1]
~ This parameter allows the modeler to create scenarios of full or parial \
regulation or deregulation of the industry. FCC's philosophy of regulating \
narrowly can be simulated with this parameter.

75 **Fraction of Resources to Unit Compliance[Firm]=**
(Fraction of Resources to Unit Deployment[Firm] + Fraction of Resources to Unit Maintenance\
[Firm] + Fraction of Resources to Unit Coordination
[Firm])
~ Dimensionless
~

76 **Fraction of Resources to Unit Coordination[Firm]=**
Maximum Fractional Resources to Coordination[Firm] * (IF THEN ELSE(Switch for Effect of Modularity on Consensus
=1, "Effect of Modularity on Effort to Coordinate (Very Convex)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=2\
, "Effect of Modularity on Effort to Coordinate (Convex)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=3\
, "Effect of Modularity on Effort to Coordinate (Linear)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=4\
, "Effect of Modularity on Effort to Coordinate (Concave)"
(Modularity[Firm]), 0)) * (Required Compliance[Firm]/Potential Market)
~ Dimensionless
~

77 **Fraction of Resources to Unit Deployment[Firm]=**
Normal Fractional Resources to Deployment[Firm] * Effect of Compliance Gap on Resources to Deployment\
(Compliance Gap
[Firm]/Potential Market)
~ Dimensionless
~

78 **Fraction of Resources to Unit Maintenance[Firm]=**
Maximum Fractional Resources to Maintenance[Firm] * Effect of Market Share on Resources to Maintenance\
(MIN(Required Compliance[Firm]/Potential Market, Market Share[Firm]))
~ Dimensionless
~

79 **Fraction Willing to Adopt=**
MAX(0, MIN(1, (1 - MIN(Price[Incumbent], Price[Entrant])/Reference Price)))
~ Dimensionless
~ Fraction of the potential market willing to adopt as determined by minimum \
price

80 **Fractional Deployment Rate of Compliance Mechanism[Firm]=**
Maximum Fractional Deployment Rate Under Maximum Consensus[Firm] * ((Switch to Make Consensus Exogenous\
* Exogenous Achievable Compliance and Fractional Deployment Multiplier[Firm]) + (1\

- Switch to Make Consensus Exogenous) * (IF THEN ELSE(Switch for Effect of Modularity on Consensus
=1, "Effect of Modularity on Deployment Rate Due to Consensus (Very Convex)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=2\
, "Effect of Modularity on Deployment Rate Due to Consensus (Convex)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=3\
, "Effect of Modularity on Deployment Rate Due to Consensus (Linear)"
(Modularity[Firm]), 0) + IF THEN ELSE(Switch for Effect of Modularity on Consensus=4\
, "Effect of Modularity on Deployment Rate Due to Consensus (Concave)"
(Modularity[Firm]), 0)))
~ Dmnl/Month
~ Fraction of non-compliant users that can be made compliant in a month.

81 **Fractional Net Population Growth Rate=**
0
~ 1/Month
~ Net of Birth-Death Rate

82 **Indicated Growth Rate of Adopters[Firm]=**
TREND(Adopters[Firm], Time to Perceive Trend[Firm], Minimum Initial Annual Growth/Adjustment for Month\
)
~ 1/Month
~ Indicated growth rate in adopter base. Output of the Trend function.

83 **Initial Ancillary Performance[Firm]=**
0.5,1
~ Dimensionless [0,1]
~ Firm's service innovation (ancillary performance) when entering the market.

84 **Initial Compliance[Firm]=**
1,0
~ Dimensionless
~ Compliance for each firm at time 0.

85 **Initial Fixed Cost[Firm]=**
0.5,0.5
~ Dollar/(Unit*Month)
~ Fraction of Total Cost that is Fixed Cost in the absence of Outsourcing \
(i.e. in a completely integrated structure)

86 **Initial Installed Base[Firm]=**
3e+008,0
~ Unit [0,1]
~ This parameter lets the modeler start the model at different points on the \

timeline along which the disruption occurs (imagine two S-curves of \
disruption along the time axis). If set to [0,0], the model starts with no \
firm having any market share. If set to [1,0], the model starts with the \
incumbent having the whole market and the entrant having none.

87 **Initial Marginal Cost[Firm]=**

0.25,0.25

~ Dollar/(Month*Unit)

~ Fraction of total cost that is marginal cost in the absence of economies \
of scale.

88 **Initial Market Potential=**

3e+008

~ Unit

~

89 **Initial Modularity[Firm]=**

0,1

~ Dmnl

~ Modularity of each industry (firm) at time 0.

90 **Initial Primary Performance[Firm]=**

1,0.5

~ Dimensionless [0,1]

~ Firm's service quality (primary performance) when entering the market.

91 **Interface Proprietization[Firm]=**
MAX(0, Market Entry Switch[Firm] * Switch to Endogenize Modularity * Pressure to Integrate by Making Interfaces Proprietary\

[Firm] * Maximum Fractional Rate of Making Interces Proprietary

*

Modularity[Firm])

~ Dmnl/Month

~ Fraction of interfaces made proprietary every month.

92 **Interface Standardization[Firm]=**

Market Entry Switch[Firm] * Switch to Endogenize Modularity * Pressure to Disintegrate by Standardizing Interfaces\

[Firm] * (Maximum Fractional Rate of Interface Standardization

* (Maximum Modularity

- Modularity[Firm]))

~ Dmnl/Month

~ Fraction of interfaces standardized every month.

93 **Loss of Adopters Rate=**

1

~ 1/Month

~ Used when the market demand shrinks due to regulation.

94 **Marginal Cost[Firm]=**

Switch to Endogenize Price * Initial Marginal Cost[Firm] * Effect of Scale on Marginal Cost\

(Market Share[Firm]) + (1 - Switch to Endogenize Price) * Initial Marginal Cost[Firm\

]

~ Dollar/(Month*Unit)

~

95 **Market Entry Switch[Firm]=**

STEP(Market Entry[Firm], Market Entry Time[Firm])

~ Dmnl

~

96 **Market Entry Time[Firm]=**

0,60

~ Month

~ Time at which the first entrant enters the market

97 **Market Entry[Firm]=**

1,1

~ Dmnl [0,1,1]

~ When set to ON, the firm enters the market; otherwise, it does not

98 **Market Share of Attractiveness[Firm]=**

Product Attractiveness[Firm]/Total Attractiveness of all Products

~ Dmnl

~ Market share is determined by the attractiveness of each firm's products \

relative to the attractiveness of the other firms' products.

99 **Market Share[Firm]=**

ZIDZ(Adopters[Firm], Total Adopters)

~ Dimensionless

~ Market share of each firm.

100 **Maximum Attainable Ancillary Performance[Firm]=**

Switch to Endogenize Modularity * Variable Maximum Attainable Ancillary Performance[\

Firm] + (1-Switch to Endogenize Modularity

)*Fixed Maximum Attainable Ancillary Performance[Firm]

~ Dimensionless

~

101 **Maximum Attainable Innovation in a Fully Modular Technology and Industry=**

1

~ Dmnl

~ Maximum attainable innovation, normalized to 1.

102 **Maximum Attainable Primary Performance[Firm]=**

Switch to Endogenize Modularity * Variable Maximum Attainable Primary Performance[Firm\

] + (1-Switch to Endogenize Modularity

)*Fixed Maximum Attainable Primary Performance[Firm]

~ Dimensionless

~

103 **Maximum Attainable Quality in a Fully Integrated Technology and Industry=**

1

~ Dimensionless

~ Maximum attainable quality, normalized to 1.

104 **Maximum Expected Growth Rate=**

0.1

~ 1/Year [0,1]

~ Annual Maximum Growth Rate below which people pay attention to forecasts.

105 **Maximum Fractional Deployment Rate Under Maximum Consensus[Firm]=**

1/Time to Comply[Firm]

~ Dmnl/Month

~ Maximum fraction of non-compliant users that can be made compliant in a \
month.

106 **Maximum Fractional Rate of Interface Standardization=**

0.01

~ Dmnl/Month

~ This parameter represents the rate at which the remaining fraction of \
integrated structure (architecture or industry structure) is being \
standardized. This parameter has a flavor of clockspeed thinking. The \
higher value represents faster clock speed.

107 **Maximum Fractional Rate of Making Interces Proprietary=**

0.01

~ Dmnl/Month

~ This parameter represents the rate at which the remaining fraction of \
modular structure (architecture or industry structure) is being \
integrated. This parameter has a flavor of clockspeed thinking. The higher \
value represents faster clock speed.

108 **Maximum Fractional Resources to Coordination[Firm]=**

0.25,0.25

~ Dimensionless

~ Fraction of resources the firm allocates for coordination with other firms \
inorder to comply with regulation. This parameter allows the modeler to \
change the coordination cost.

109 **Maximum Fractional Resources to Maintenance[Firm]=**

0

~ Dimensionless

~ Fraction of resources the firm allocates to maintaining compliance if it \
had the whole market. This parameter allows the modeler to change the \
maintenance cost.

110 **Maximum Modularity=**

1

~ Dmnl

~ Normalized to 1.

111 **Maximum Unit Coordination Cost[Firm]=**

Maximum Fractional Resources to Coordination[Firm] * Cost of Resources[Firm]

~ Dollar/(Unit*Month)

~ Maximum per unit cost of coordination required for regulatory compliance

112 **Minimum Initial Annual Growth=**

0.02

~ 1/Year

~ Minimum annual growth rate of adopters.

113 **Modularity[Firm]= INTEG (**

Interface Standardization[Firm]-Interface Proprietization[Firm],

Initial Modularity[Firm])

~ Dmnl

~ Current level of modularity of the technology and industry structure for \
each industry structure (as manifested in their representative firm).

114 **Net Population Growth Rate=**

Fractional Net Population Growth Rate * Potential Market

~ Unit/Month

~

115 **Normal Fractional Resources to Deployment[Firm]=**

0

~ Dimensionless

~ Fraction of resources th firm allocates to compliance as long as there is \
compliance gap. This parameter allows the modeler to change the deployment \

cost.

116 **Normal Resource Reorientation Time=**

15

~ Month

~ This parameter allows the modeler to vary the time it takes the firm to \
resources its resources as desired for sensitivity tests.

117 **Normal Time to Acquire Innovation=**

15

~ Month

~ This parameter allows the modeler to vary the time it takes to innovate in \
a sensitivity test. Currently set such that a modular firm takes 1/3rd of \
the time whereas the integrated firm takes 2/3 of this time.

118 **Normal Time to Acquire Quality=**

15

~ Month

~ This parameter allows the modeler to vary the time it takes to acquire \
quality in a sensitivity test. Currently set such that a modular firm \
takes 2/3rd of the time whereas the integrated firm takes 1/3 of this time.

119 **Normalized Coordination Cost[Firm]=**

Unit Coordination Cost[Firm]/Maximum Unit Coordination Cost[Firm]

~ Dimensionless

~ Normalized Coordination Cost

120 **Percentage Attractiveness from Compatibility[Firm]=**

Effect of Compatibility on Attractiveness[Firm]/Product Attractiveness[Firm]

~ Dimensionless

~

121 **Percentage Attractiveness from Price[Firm]=**

-Effect of Price on Attractivenss[Firm]/Product Attractiveness[Firm]

~ Dimensionless

~

122 **Percentage Required Compliance[Firm]=**

100*Required Compliance[Firm]/Potential Market

~ Dimensionless

~ Percentage of Total Market that is required to be compliant if the firm \
owned complete market share

123 **Potential Adopters=**

(Switch for Exogenous Demand * Exogenous Fraction Willing to Adopt +(1 - Switch for Exogenous Demand\

) * Fraction Willing to Adopt) * Potential Market- Total Adopters

~ Unit

~ Ramaining Market Potential

124 **Potential Market= INTEG (**

Net Population Growth Rate,

Initial Market Potential)

~ Unit

~ Population Eligible to become Potential Adopters

125 **Pressure to Disintegrate by Standardizing Interfaces[Incumbent]=**

Effect of Competitors Market Share on Interface Standardization(Market Share[Entrant\

]) ~~

Pressure to Disintegrate by Standardizing Interfaces[Entrant]=

Effect of Competitors Market Share on Interface Standardization(Market Share[Incumbent\

])

~ Dmnl

~

126 **Pressure to Integrate by Making Interfaces Proprietary[Incumbent]=**

Effect of Own Market Share on Interface Proprietization(Market Share[Incumbent]) ~~

Pressure to Integrate by Making Interfaces Proprietary[Entrant]=

Effect of Own Market Share on Interface Proprietization(Market Share[Entrant])

~ Dmnl

~

127 **Price[Firm]=**

((1 - Switch for Subsidy[Firm]) * Switch to Endogenize Regulatory Cost and Resources\

* Unit Compliance Cost[Firm]) + Total Cost of Service[Firm]

~ Dollar/(Month*Unit)

~ Price of the service.

128 **Primary Performance Gain[Firm]=**

MAX(0, Switch to Endogenize Quality and Innovation * Market Entry Switch[Firm] * Resources to Primary Performance\

[Firm]

* ((Maximum Attainable Primary Performance[Firm

] - Primary Performance

[Firm])/Time to Acquire Primary Performance[Firm]))

~ 1/Month

~ Performance change given the gap between Maximum and the current primary \

performance, as weighted by the current resource allocation.

129 **Primary Performance Loss[Firm]=**

MAX(0, Switch to Endogenize Quality and Innovation * Market Entry Switch[Firm] * ((Primary Performance\

[Firm] - Maximum Attainable Primary Performance

[Firm])/Time to Acquire Primary Performance[Firm]))

~ Dimensionless/Month

~

130 **Primary Performance[Firm]= INTEG (Primary Performance Gain[Firm]-Primary Performance Loss**

[Firm],

Initial Primary Performance[Firm])

~ Dimensionless

~ Firm's (or represented industry's) current primary performance.

131 **Product Attractiveness[Firm]=**

Effect of Compatibility on Attractiveness[Firm] * Effect of Price on Attractivenss[Firm\

] * Effect of Primary Performance on Attractiveness[Firm] * Effect of Ancillary Performance on Attractiveness\

[Firm]

~ Dmnl

~ Combined Effect of Price and Installed Base

132 **Reference Ancillary Performance for Attractiveness=**

0.5

~ Dmnl [0,1]

~ The reference is a scaling factor representing the reference beyond which \

ancillary performance effects become important. Ancillary performance is \

synonymous with "Innovation".

133 **Reference Installed Base for Compatibility=**

3e+007

~ Unit

~ The reference is a scaling factor representing the size of the installed \

base above which network effects become important.

134 **Reference Price for Attractiveness=**

0.5

~ Dollar/(Unit*Month)

~ Price Customer Expects to pay for Incumbent's Service. The reference is a \

scaling factor representing the price below which price effects become \

important.

135 **Reference Price=**

1

~ Dollar/(Month*Unit)

~ Calibration point for the demand curve

136 **Reference Primary Performance for Attractiveness=**

0.5

~ Dmnl [0,1]

~ The reference is a scaling factor representing the level beyond which \
primar performance effects become important. Ancillary performance is \
synonymous with "Quality".

137 **Required Compliance[Incumbent]=**

0 +STEP(Fraction of Firms Regulated[Incumbent]*Potential Market,Time of Regulation Incumbent\
) ~~

Required Compliance[Entrant]=

0 +STEP(Fraction of Firms Regulated[Entrant]*Potential Market, Time of Regulation Entrant\
)

~ Unit

~ Number of adopters for each firm's (industry's) network that is required \
to be compliant.

138 **Resource Allocation Rate for Ancillary Performance[Firm]=**

Switch to Endogenize Resources[Firm] * (MAX(0, (Attention on Ancillary Performance Gain\
[Firm] - Resources to Ancillary Performance[Firm])/Resource Reorientation Time
[Firm]))

~ Dimensionless/Month

~

139 **Resource Allocation Rate to Primary Performance[Firm]=**

Switch to Endogenize Resources[Firm] * (MAX(0, (Resources to Ancillary Performance[Firm\
] - Attention on Ancillary Performance Loss[Firm])/Resource Reorientation Time
[Firm
]))

~ Dimensionless/Month

~

140 **Resource Reorientation Time[Incumbent]=**

Normal Resource Reorientation Time * Effect of Modularity on Resource Reorientation Time\
(Modularity[Incumbent]) * Test Parameter to Make Incumbent Inherently Agile or Sluggish\
~~

Resource Reorientation Time[Entrant]=

Normal Resource Reorientation Time * Effect of Modularity on Resource Reorientation Time\
(Modularity[Entrant]) * Test Parameter to Make Entrant Inherently Agile or Sluggish

~ Month

~ Time to reorient resources. This includes writing a report, convincing the \
management, and convincing your best people to move from their current \
activity to the new focus.

141 **Resources to Ancillary Performance[Firm]= INTEG (**

Resource Allocation Rate for Ancillary Performance[Firm]-Resource Allocation Rate to Primary Performance\
[Firm],

Firm's Initial Resources to Ancillary Performance[Firm])

~ Dimensionless

~ Fraction of total resources to innovation.

142 **Resources to Performance[Firm]=**

(1 - (Fraction of Resources to Unit Compliance[Firm]*Switch to Endogenize Regulatory Cost and Resources\
)) * Total Resources[Firm]

~ Dimensionless

~ Fraction of firm's (or represented industry's) total resources to quality \
and innovation.

143 **Resources to Primary Performance[Firm]=**

(1 - Switch for Regulatory Cost to Additional Functionality) * Resources to Regulation\
[Firm] + MAX (0, (Resources to Performance[Firm] - Resources to Ancillary Performance\
[Firm]))

~ Dimensionless

~ Fraction of total resources to quality.

144 **Resources to Regulation[Firm]=**

Fraction of Resources to Unit Compliance[Firm] * Switch to Endogenize Regulatory Cost and Resources\
* Total Resources[Firm]

~ Dimensionless

~ Fraction of firm's (or represented industry's) total resources to \
regulatory compliance.

145 **Sensitivity of Attractiveness to Ancillary Performance=**

13.5

~ Dimensionless [0,100]

~ This parameter allows the modeler to vary the effect of ancillary \
performance on product attractiveness in sensitivity tests.

146 **Sensitivity of Attractiveness to Installed Base=**

1

~ Dmnl [0,100]

~ The parameter allows the modeler to vary the strength of the effect of \
compatiblity (i.e. network effect) on product attractiveness in \
sensitivity tests.

147 **Sensitivity of Attractiveness to Price=**

-5

~ Dmnl [-100,0]

~ The parameter allows the modeler to vary the strength of the effect of \
price on product attractiveness in sensitivity tests. It is price \

elasticity of product attractiveness. A value of 100 means, 1% increase in \
price causes 100% change in attractiveness.

148 **Sensitivity of Attractiveness to Primary Performance=**

5

~ Dimensionless [0,100]

~ This parameter allows the modeler to vary the effect of primary \
performance on product attractiveness in sensitivity tests

149 **Supply Side Average Time to Deploy=**

(1/Fractional Deployment Rate of Compliance Mechanism[Incumbent]) * (MIN(Required Compliance\
[Incumbent], Achievable Compliance[Entrant])/Potential Market
) + (1/Fractional Deployment Rate of Compliance Mechanism[Entrant]) * (MIN(Required Compliance\
[Entrant], Achievable Compliance[Entrant])/Potential Market)

~ Month

~

150 **Switch for Effect of Modularity on Consensus=**

1

~ Dimensionless [1,4,1]

~ When 1, achievable compliance is decreasing and very convex with \
increasing modularity. When 2, achievable compliance is decreasing and \
convex with increasing modularity. When 3, achievable compliance is \
decreasing and linear with increasing modularity. When 4, achievable \
compliance is decreasing and concave with increasing modularity.

151 **Switch for Exogenous Demand=**

1

~ Dimensionless [0,1,1]

~ When set to 1, exogenous demand of 1 (i.e. the entire potential market) is \
used. When set to 0, the demand curve is used.

152 **Switch for Highly Reactive Reallocation of Attention and Resources=**

0

~ Dimensionless [0,1,1]

~ When set to 0 (OFF), a real-life-like policy for resource allocation is \
used. This policy of wait-and-watch is deduced from interviews with \
incumbents and entrant firms. When set to 1 (ON), a highly reactive \
policy, where resources,commensurate with the expected market share of the \
competitor is used.

153 **Switch for Regulatory Cost to Additional Functionality=**

1

~ Dimensionless [0,1,1]

~ When set to 1 all of the regulatory cost is allocated to functionality \
additional to the primary and ancillary features that the firm markets \
(i.e. to neither primary or ancillary performance). For example, \
wiretapping (CALEA compliance), emergency calling (911) will require \
additional functionality, whereas supporting universal service obligations \
does not require new functionality but only needs more of the same. When \
set to 0, all of the regulatory cost is provided to maintain certain \
minimum primary performance.

154 **Switch to Endogenize Modularity=**

0

~ Dimensionless [0,1,1]

~ When ON, industry level modularity is endogenous and reacts to competitive \
pressures. When OFF, industry level modularity stays at the initial level.

155 **Switch to Endogenize Price=**

0

~ Dimensionless [0,1,1]

~ When ON, there is economies of scale. When OFF, the price remains constant \
at the initial value.

156 **Switch to Endogenize Quality and Innovation=**

1

~ Dimensionless [0,1,1]

~ When ON, it limits the attinable ancillary performance as a function of \
modularity.

157 **Switch to Endogenize Regulatory Cost and Resources=**

1

~ Dimensionless [0,1,1]

~ When ON, the regulation affects firm's cost (hence the price) and resources

158 **Switch to Endogenize Resources[Firm]=**

1

~ Dimensionless [0,1,1]

~ When ON, firms reallocate resources. When OFF, the firms keep their \
initial resource allocation.

159 **Switch to Make Consensus Exogenous=**

0

~ Dimensionless [0,1]

~ When ON, exogenous function of modularity is used to calculate the effort \
required to bulid consensus, fractional deployment of compliance, and the \

coordination costs. This parameter is turned on only for sensitivity test. \
For example, for a result of Paper 1.

160 **Switching Cost[Firm]=**
0.95, 0.95
~ 1/Month [0,1]
~ Percentage customers that make a decision about switching every year

161 **Switching[Firm]=**
Adopters[Firm] * (1 - Switching Cost[Firm])
~ Unit/Month
~ Number of customers that make a switching decision every month

162 **Test Parameter to Change Entrants Time to Acquire Innovation=**
1
~ Dimensionless [0,3]
~ This variable can be used to change the Time to Acquire Innovation for the \
entrant. When = 1, it has no effect on the Time to Acquire Innovaion as \
calculated by other variables. When >1, it increases the time taken to \
acquire innovation above normal. The value of <1 reduces it below normal.

163 **Test Parameter to Change Entrants Time to Acquire Quality=**
1
~ Dimensionless
~ This variable can be used to change the Time to Acquire Quality for the \
entrant. When = 1, it has no effect on the Time to Acquire Performance as \
calculated by other variables. When >1, it increases the time taken to \
acquire quality above normal. The value of <1 reduces it below normal.

164 **Test Parameter to Change Incumbents Time to Acquire Innovation=**
1
~ Dimensionless
~ This variable can be used to change the Time to Acquire Innovation for the \
incumbent. When = 1, it has no effect on the Time to Acquire Performance \
as calculated by other variables. When >1, it increases the time taken to \
acquire innovation above what it would otherwise be. The value of <1 \
reduces it below its value otherwise.

165 **Test Parameter to Make Entrant Inherently Agile or Sluggish=**
1
~ Dimensionless [0,3]
~ This factor simulates conditions where the Entrant is inherrently agile or \
slugish. A value = 1 means Entrant has the same Normal Resource \

Reorientation Time. A value< 1 means the Entrant is more agile and takes \
less time to reorient resources. A value > 1 means the Entant is more \
slugish and takes longer to reorient resources.

166 **Test Parameter to Make Incumbent Inherently Agile or Sluggish=**
1
~ Dimensionless
~ This factor simulates conditions where the incumbent is inherrently agile \
or slugish. A value = 1 means Incumbent has the same Normal Resource \
Reorientation Time. A value< 1 means the Incumbent is more agile and takes \
less time to reorient resources. A value > 1 means the Incumbent is more \
slugish and takes longer to reorient resources.

167 **Time (Years)=**
Time/Adjustment for Month
~ Year
~

168 **Time of Regulation Entrant=**
96
~ Month [0,240]
~ Time at which Entant is regulated. This parameter allows the modeler to \
create the different timing-related scenarios of when the Incumbent and \
Entrant are regulated or deregulated.

169 **Time of Regulation Incumbent=**
0
~ Month [0,10]
~ Time at which the Incumbent is regulated. This parameter allows the \
modeler to create the different timing-related scenarios of when the \
Incumbent and Entrant are regulated or deregulated.

170 **Time to Acquire Ancillary Performance[Incumbent]=**
Normal Time to Acquire Innovation * Effect of Modularity on Time to Acquire Ancillary Performance\
(Modularity[Incumbent]
) * Test Parameter to Change Incumbents Time to Acquire Innovation ~~
Time to Acquire Ancillary Performance[Entrant]=
Normal Time to Acquire Innovation * Effect of Modularity on Time to Acquire Ancillary Performance\
(Modularity[Entrant])
* Test Parameter to Change Entrants Time to Acquire Innovation
~ Month
~ Total time required to attain the desired innovation.

171 **Time to Acquire Primary Performance[Incumbent]=**

Normal Time to Acquire Quality * Effect of Modularity on Time to Acquire Primary Performance\
(Modularity[Incumbent]) ~~
Time to Acquire Primary Performance[Entrant]=
Normal Time to Acquire Quality * Effect of Modularity on Time to Acquire Primary Performance\
(Modularity[Entrant]) * Test Parameter to Change Entrants Time to Acquire Quality
~ Month
~ Total time required to attain the desired quality.

172 **Time to Comply[Firm]=**
96,96
~ Month
~ Total Time to Deploy the lower of the achievable or maximum compliance.

173 **Time to Lose Compliance=**
3
~ Month
~ Time it takes for innovation that erode compliance to be adopted.

174 **Time to Perceive Trend[Firm]=**
12
~ Month
~ Period for accumulating observations before deducing the trend.

175 **Total Adopters=**
SUM(Adopters[Firm!])
~ Unit
~ Installed base of Incumbent and Entrants

176 **Total Attractiveness of all Products=**
SUM(Product Attractiveness[Firm!])
~ Dmnl
~ Total attractiveness is the sum of the attractiveness levels of all \
products in the marketplace.

177 **Total Cost of Service[Firm]=**
Fixed Cost[Firm] + Marginal Cost[Firm]
~ Dollar/(Month*Unit)
~

178 **Total Demand from Switching=**
SUM(Switching[Firm!])
~ Unit/Month
~ Customers from Incumbent and Entrant that make a switching decision every \
month

179 **Total Expected Adopters[Firm]=**

SUM(Expected Adopters[Firm!])

~ Unit

~

180 **Total Resources[Firm]=**

1,1

~ Dimensionless

~ Total resources with each firm, normalized to 1. Both firms endowed with \
equal and constant resources.

181 **Unit Compliance Cost[Firm]=**

Unit Deployment Cost[Firm] + Unit Maintenance Cost[Firm] + Unit Coordination Cost[Firm\
]

~ Dollar/(Month*Unit)

~ The fraction of total cost of making the service to a single adopter \
compliant. This cost is passed on to the adopter when the regulator does \
not subsidize the firm.

182 **Unit Coordination Cost[Firm]=**

Fraction of Resources to Unit Coordination[Firm] * Cost of Resources[Firm]

~ Dollar/(Month*Unit)

~ Fraction of total cost towards coordination for regulatory compliance for \
a single user.

183 **Unit Deployment Cost[Firm]=**

Fraction of Resources to Unit Deployment[Firm] * Cost of Resources[Firm]

~ Dollar/(Month*Unit)

~ Fraction of total cost towards deploying regulatory compliance for a \
single user.

184 **Unit Enforcement Cost[Firm]=**

Base Enforcement Cost * Effect of Modularity on Enforcement Cost(Modularity[Firm]) *\
(Required Compliance[Firm]/Potential Market)

~ Dollar/(Month*Unit)

~ Marginal enforcement cost.

185 **Unit Maintenance Cost[Firm]=**

Fraction of Resources to Unit Maintenance[Firm] * Cost of Resources[Firm]

~ Dollar/(Month*Unit)

~ Fraction of total cost towards maintaining regulatory compliance for a \
single user.

186 **Unit Regulatory Cost[Firm]=**

Unit Compliance Cost[Firm]+ Unit Enforcement Cost[Firm]

~ Dollar/(Month*Unit)

~ Such summing of the two regulatory costs is notional. The real costs are \

difficult to assess here.

187 **Variable Maximum Attainable Ancillary Performance[Firm]=**
Maximum Attainable Innovation in a Fully Modular Technology and Industry * Effect of Modularity on Maximum Attainable Ancillary Performance

(Modularity[Firm])

~ Dmnl

~

188 **Variable Maximum Attainable Primary Performance[Firm]=**
Maximum Attainable Quality in a Fully Integrated Technology and Industry * Effect of Modularity on Maximum Attainable Primary Performance\

(Modularity[Firm])

~ Dimensionless

~

189 **Weighted Firm Innovation[Firm]=**

Ancillary Performance[Firm] * Market Share[Firm]

~ Dimensionless

~

190 **Weighted Firm Modularity[Firm]=**

Modularity[Firm] * Market Share[Firm]

~ Dimensionless

~

191 **Weighted Firm Quality[Firm]=**

Primary Performance[Firm] * Market Share[Firm]

~ Dimensionless

~

Appendix C – Instructions for Reproducing Experiments

Reproducing Chapter 2 Figures

Required vs. Actual Compliance (Figure 7(a))

Variable	Value	Notes
Market Entry	1,0	Only incumbent in the market
Initial Installed Base	3.0e+08,0	Incumbent owns the entire market
Switching Cost	1,0	Incumbent retains the entire market
Initial Compliance	0,0	

Required vs. Achievable vs. Actual Compliance (Figure 7(b))

Variable	Value	Notes
Market Entry	1,1	Both firms in the market
Initial Installed Base	0,3.0e+08	Entrant owns the entire market
Switching Cost	0,1	Entrant retains the entire market
Initial Compliance	0,0	

Partial Regulation (Figure 8(a))

Variable	Value	Notes
Market Entry	1,0	Only incumbent in the market
Initial Installed Base	3.0e+08,0	Incumbent owns the entire market
Switching Cost	1,0	Incumbent retains the entire market
Initial Compliance	0,0	
Fraction of Firms Regulated	1,0 (Run 1) 0.8,0 (Run 2) 0.6,0 (Run 3)	All, 80%, and 60% of the Incumbent firms are regulated

Delayed Regulation (Figure 8(b))

Variable	Value	Notes
Market Entry	1,0	Only incumbent in the market
Initial Installed Base	3.0e+08,0	Incumbent owns the entire market
Switching Cost	1,0	Incumbent retains the entire market

Initial Compliance	0,0	
Time of Regulation Incumbent	0 (Run 1) 60 (Run 2) 120 (Run 3)	Incumbent regulated at time 0, month 60 (year 5), and month 120 (year 10)

Disruption Base Case (Figure 9)

Variable	Value	Notes
Switch to Endogenize Regulatory Cost and Resources	0	Regulation does not affect competition
Market Entry Time	0,60	Entrant enters at year 5
Initial Installed Base	3.0e+08,0	Incumbent owns the entire market
Fixed Cost	0.5, 0.25	Entrant has half the fixed cost compared to that of the incumbent
Quality	1,0.5	Entrant has half the quality compared to that of the incumbent
Innovation	0.5,1	Entrant has double the innovation compared to that of the incumbent
Switching Cost	0.95,0.95	5% consumers consider switching, and *may* switch products based on attractiveness
Sensitivity of Attractiveness to Ancillary Performance	9	To create disruption because of entrant's high innovation

Average Utilized Compliance Sensitivity (Figure 14)

Variable	Value	Notes
Switch to Endogenize Regulatory Cost and Resources	0	Regulation does not affect competition
Market Entry Time	0,60	Entrant enters at year 5
Fraction of Firms Regulated	1,1	Both fully regulated
Time of Regulation Entrant	60	Entrant regulated upon entry
Switch to Make Consensus Exogenous	1	Consensus in the industry structure is exogenous
Exogenous Achievable Compliance and Fractional	1, 0.25-0.85	Sensitivity test. The integral structure can achieve full compliance. The modular

Deployment Multiplier		structure's compliance level and time to deploy compliance varies.

Average Utilized Compliance (Market Share: 80% incumbent, 20% entrant)

(Figure 15(a))

Variable	Value	Notes
Fraction of Firms Regulated	1,0.5	100% incumbent firms regulated, 50% entrant firms regulated
Initial Compliance	1,0.5	Incumbent 100% compliant, entrant 50% compliant
Initial Installed Base	2.4e+08,0.6e+08	Market share: 80% incumbent, 20% entrant
Switching Cost	1,1	No switching in between services

Average Utilized Compliance (Market Share: 20% incumbent, 80% entrant)

(Figure 15(b))

Variable	Value	Notes
Fraction of Firms Regulated	1,0.5	100% incumbent firms regulated, 50% entrant firms regulated
Initial Compliance	1,0.5	Incumbent 100% compliant, entrant 50% compliant
Initial Installed Base	0.6e+08,2.4e+08	Market share: 20% incumbent, 80% entrant
Switching Cost	1,1	No switching in between services

Timing of Delayed Regulation (Figure 17)

Variable	Value	Notes
Time of Regulation Incumbent	60 (Run 1) 60 (Run 2) 120 (Run 3)	Entrant regulated at month 60 (i.e., upon entry), months, 72, 84, 90, 92, 94, 96, 108, 120. The close together runs near months 90-96 is show the high degree of sensitivity due to nonlinear forces.

Price Sensitivity (Changes additional to Disruption Base Run) (Figure 18 (a))

Variable	Value	Notes
Initial Marginal Cost	0.25, 0.27	Entrant price higher than the base

		run
Initial Marginal Cost	0.25, 0.23	Entrant price lower than the base run

Innovation Sensitivity (Changes additional to Disruption Base Run) (Figure 18 (b))

Variable	Value	Notes
Initial Ancillary Performance	0.5,1.01	Entrant more innovative than the base run
Initial Ancillary Performance	0.5,0.99	Entrant less innovative than the base run

Quality Sensitivity (Changes additional to Disruption Base Run) (Figure 18c)

Variable	Value	Notes
Initial Primary Performance	1.0, 0.51	Entrant has higher quality than the base run
Initial Primary Performance	1.0,0.49	Entrant has lower quality than the base run

Reproducing Chapter 3 Figures

Network Effect Phase Plot (Changes additional to Disruption Base Run)

Variable	Value	Notes
Sensitivity of Attractiveness to Installed Base	0, 0.1, 0.2…1.9, 2.0	In total, 21 runs with different values of Sensitivities.

Switching Cost Phase Plot (Changes additional to Disruption Base Run)

Variable	Value	Notes
Switching Cost	0.91, 0.95 (incumbent, entrant) 0.92, 0.95 0.93, 0.95 … 0.99, 9.95	In total, 9 runs with different values of incumbent's switching cost.

Comparative Effect Phase Plot (Changes additional to Disruption Base Run)

Variable	Value	Notes

Base Sensitivities	1 (Sens. Inst. Base) -5 (Sens. Price) 5 (Sens. Quality) 5 (Sens. Innovation)	Set such that maximum attractiveness due to each parameter is equal.
Sensitivity of Attractiveness to Installed Base	0, 0.2, 0.4…2.8, 3.0	In total,15 runs with different values of Sensitivities.
Sensitivity of Attractiveness to Price	0, -1, -2…-14, -15	In total,15 runs with different values of Sensitivities.
Sensitivity of Attractiveness to Innovation	0, 1, 2…14, 15	In total,15 runs with different values of Sensitivities.
Sensitivity of Attractiveness to Quality	0, 1, 2…14, 15	In total,15 runs with different values of Sensitivities.

Multiple Disruptions (Changes additional to Disruption Base Run)

Variable	**Value**	**Notes**
Base Sensitivities	1 (Sens. Inst. Base) -5 (Sens. Price) 5 (Sens. Quality) 13.5 (Sens. Innovation)	

Technological Uncertainty Incumbent's Superior Quality Myth (Changes additional to Disruption Base Run)

Variable	**Value**	**Notes**
Base Sensitivities	0 (Sens. Inst. Base) 9 (Sens. Innovation)	
Switch to Endogenize Regulatory Cost and Resources	0	No regulatory effects to study the dynamics of only the industry structure
Initial Fixed Cost	0.5,0.5	
Initial Marginal Cost	0.25,0.25	
Test Parameter to Change Entrants Time to Acquire Quality	4	
Switch to Endogenize Modularity	0 (Open MM) 1 (Closed MM)	

Switch to Endogenize Price	0 (Open MM) 1 (Closed MM)	

Technological Uncertainty Entrant's Superior Innovation Myth (Changes additional to Disruption Base Run)

Variable	**Value**	**Notes**
Base Sensitivities	0 (Sens. Inst. Base) 9 (Sens. Innovation)	
Switch to Endogenize Regulatory Cost and Resources	0	No regulatory effects to study the dynamics of only the industry structure
Initial Fixed Cost	0.5,0.5	
Initial Marginal Cost	0.25,0.25	
Test Parameter to Change Incumbents Time to Acquire Innovation	4	
Switch to Endogenize Modularity	0 (Open MM) 1 (Closed MM)	
Switch to Endogenize Price	0 (Open MM) 1 (Closed MM)	

Organizational Uncertainty Agility Myth (Changes additional to Disruption Base Run)

Variable	**Value**	**Notes**
Base Sensitivities	0 (Sens. Inst. Base) 9 (Sens. Innovation)	
Switch to Endogenize Regulatory Cost and Resources	0	No regulatory effects to study the dynamics of only the industry structure
Initial Fixed Cost	0.5,0.5	
Initial Marginal Cost	0.25,0.25	
Test Parameter to Make incumbent Inherently Agile or Sluggish	4	
Switch to Endogenize Modularity	0 (Open MM) 1 (Closed MM)	
Switch to Endogenize Price	0 (Open MM)	

	1 (Closed MM)	

Technological Uncertainty Functional Control and Quality (Changes additional to Disruption Base Run)

Variable	**Value**	**Notes**
Base Sensitivities	0 (Sens. Inst. Base) 9 (Sens. Innovation)	
Switch to Endogenize Regulatory Cost and Resources	0	No regulatory effects to study the dynamics of only the industry structure
Initial Fixed Cost	0.5,0.5	
Initial Marginal Cost	0.25,0.25	
Test Parameter to Change Entrants Time to Acquire Quality	4	
Switch to Endogenize Modularity	0 (Open MM) 1 (Closed MM)	
Switch to Endogenize Price	0 (Open MM) 1 (Closed MM)	

Regulatory Uncertainty (Changes additional to Disruption Base Run)

Variable	**Value**	**Notes**
Base Sensitivities	0 (Sens. Inst. Base) 9 (Sens. Innovation)	
Switch to Endogenize Regulatory Cost and Resources	0	No regulatory effects to study the dynamics of only the industry structure
Initial Fixed Cost	0.5,0.5	
Initial Marginal Cost	0.25,0.25	
Maximum Fractional Rate of Making Interfaces Proprietary	0.1, 0.01, 0.001	Corresponds to High, Medium, and Low Limits on SMP, respectively

Reproducing Chapter 4 Figures

Emergent Behaviors (Figure 38-Figure 42(a), Figure 43-Figure 47)

Base Run (Initial Conditions)									
Regulatory Choice		**Corporate Strategy Choice**		**Consumer Choice**		**Technology**		**Industry Structure**	
Variable	**Value**	**Variable**	**Value**	**Variable**	**Value**	**Variable**	**Value**	**Variable**	**Value**
Initial Compliance	1.0	Initial Primary Perform-ance	1,0.5	Initial Installed Base	3e+8, 0			Initial Modul-arity	0,1
Fraction of Firms Regulated	1,1	Initial ancillary Perform-ance	0.5,1						
Normal Fract. Resources to Deployment	0	Fixed Cost	0.5, 0.25						
Max. Fract. Resources to Maintenance	0	Initial Marginal Cost	0.25, 0.25						
Max. Fract. Resources to Coordination	0.25	Firm's Initial Attention to Ancillary Perform-ance	0,1						
ON OFF Switches									
Switch to Endogenize Regulatory Cost and Resources	1	Switch to Endogenize Price	1	Switch for Exo-genous Demand	1	Switch to Endo-genize Quality and Innovation	1	Switch to Endo-genize Modul-arity	1
		Switch to Endogenize Resources	1						
Decision/Choice Parameters									
Time for Regulation Incumbent	0	Switching Cost		Sens. Of Attractive-ness to Installed Base	1				
Time for Regulation Entrant	120	Market Entry	1,1	Sens. Of Attractive-ness to Price	-5				
		Market	0,60	Sens. Of	-5				

		Entry Time		Attractive-ness to Primary Perf.					
				Sens. Of Attractive-ness to Ancillary Perf.	11.5				

Average Compliance Cost (Figure 42(b))

Variable	**Value**	**Notes**
Time for Regulation Entrant	120	
Sens. Of Attractiveness to Ancillary Performance	11.5	

Policy Lever I (Figure 49-Figure 52)

Variable	**Value**	**Notes**
Maximum Fractional Rate of Interfaces Proprietary	0.1 (Low Limits on SMP) 0.01 (Medium Limits on SMP) 0.001 (High Limits on SMP)	

Policy Lever I-II (Figure 54-Figure 57)

Variable	**Value**	**Notes**
Maximum Fractional Rate of Interfaces Proprietary	0.1 (Low Limits on SMP) 0.01 (Medium Limits on SMP) 0.001 (High Limits on SMP)	
Switch for Effect of Modularity on Consensus	4 (Very Convex) 3 (Convex) 2 (Linear) 1 (Convex)	

Appendix D – Notes on Model Validation and Testing

Validation

The following steps were taken for model validation as well as building confidence in model:

1. The model in this dissertation uses, where possible, standard/proven System Dynamics formulations such as the Bass Model of Diffusion, Logit Choice Model, etc.
2. The formulations are grounded in theory such as theories of technology and industry disruption, etc., where possible.
3. Unstructured interviews with appropriate stakeholders were used for the formulations where the theory is not well-developed.
4. This model as been shared with a number of stakeholder audiences over the past two years. The most prominent among them were author's presentation of the model to:
    a. Multiple presentations to The Communications Futures Program (http://cfp.mit.edu) participants. This group consists of a number of experienced architects and managers from the communications industry in the United States and Europe as well as some leading academics researching various aspects of communications technology and industry.
    b. Two presentations to regulatory agencies with audiences that consisted of lawyers, economists, and technologists; first, at the Federal Communications Commission (FCC) on December 10, 2007; and second, at the Ministry of Internal Affairs and Communications, Tokyo, Japan on January 16, 2008.
5. The analysis was carried out in two phases:
    a. Analysis of a unit (moralized model) model to understand structural forces and incentives
    b. Analysis of calibrated model (shared in chapter 3) to understand timing and magnitude of the forces

Testing

The following steps outline the model testing strategy:

1. Partial Model Testing: this model has several switches (see model variable with names starting with "Switch for…" in the alphabetical listing of equations provided in Appendix B) that can be used to isolate parts of the model to be tested with exogenous inputs.
2. Sensitivity of each exogenous parameter (including those that were made endogenous later) was done to test for intendedly rational behavior and behavior under extreme conditions.
3. The model outcome was analyzed under the following Industry Structure Scenarios (at all steps of model expansion and for the whole model):
    a. Integrated Incumbent Remains Dominant

    b. Niche Entrant, modular in technology and industry structure, displaces the Incumbent
    c. Erstwhile Entrant (new Incumbent in the modular structure) remains dominant with a new modular entrant present
4. The model outcome was analyzed under the following regulatory scenarios (at all steps of model expansion and for the whole model):
    a. Only Incumbent is Regulated
    b. Both Incumbent and Entrant are Regulated
    c. Delayed Regulation of the Entrant
    d. Delayed Deregulation of the Incumbent

REFERENCES

(2005). E911 Requirement for IP-Enabled Service Providers. WC Docket No. **05-196**.

(2008). High-Cost Universal Service Support NPRM. WC Docket No. **08-22**.

Ackoff, R. L. (1999). Ackoff's best : his classic writings on management. New York, Wiley.

Anderson, P. and M. L. Tushman (1990). "Technological Discontinuities and Dominant Designs - a Cyclical Model of Technological-Change." Administrative Science Quarterly **35**(4): 604-633.

Armstrong, M. and R. Porter (2007). Handbook of Industrial Organization, Volume 3, Elsevier B. V.

Bajaj, V. (2006). The Future of Futures? The New York Times. **C; Business/Financial Desk; STREET SCENE:** 5.

Bass, F. M., T. V. Krishnan, et al. (1994). "Why the Bass Model Fits without Decision Variables." Marketing Science **13**(3): 203-223.

Benjamin, S. M., D. G. Lichtman, et al. (2006). Telecommunications Law and Policy, Carolina Academic Press.

Bensinger, A. (2008). Industry Surveys: Communications Equipment, Standards & Poor's.

Bertalanffy, L. v. (1968). General system theory; foundations, development, applications. New York,, G. Braziller.

Brooke, L. (2007). That New Shine? It's Not From Buffing. The New York Times. **SPG; Pg. 28**.

Bykowsky, M. M., M. A. Olson, et al. (2008). A Market-based Approach to Establishing Licensing Rules: Licensed Versus Unlicensed Use of Spectrum. OSP Working Paper Series, FCC**:** 27.

Cammaerts, B. and J.-C. Burgelman (2000). Beyond competition : broadening the scope of telecommunications policy, Brussels, VUB University Press.

Carr, D. (2006). Online Player In the Game Of Politics. The New York Times. **C; Business/Financial Desk; THE MEDIA EQUATION:** 1.

Christensen, C. M. (1992). "Exploring the limits of technology S-curve: Architecture Technologies." Production and Operations Management **1**(4).

Christensen, C. M. (1992). "Exploring the limits of technology S-curve: Component Technologies." Production and Operations Management **1**(4).

Christensen, C. M. (1997). The innovator's dilemma : when new technologies cause great firms to fail. Boston, Mass., Harvard Business School Press.

Christensen, C. M. and M. E. Raynor (2003). The innovator's solution : creating and sustaining successful growth. Boston, Mass., Harvard Business School Press.

Christensen, C. M. and R. S. Rosenbloom (1995). "Explaining the Attackers Advantage - Technological Paradigms, Organizational Dynamics, and the Value Network." Research Policy **24**(2): 233-257.

Christensen, C. M., F. F. Suárez, et al. (1996). Strategies for survival in fast-changing industries. Cambridge, MA, International Center for Research on the Management of Technology, Sloan School of Management, Massachusetts Institute of Technology.

Cortese, A. (2003). Business; Can Energy Ventures Pick Up Where Tech Left Off? The New York Times. **3; Money and Business/Financial Desk:** 4.

Cusumano, M. A. and D. B. Yoffie (2000). Competing on Internet time : lessons from Netscape and its battle with Microsoft. New York, NY, Simon & Schuster.

de Bijl, P. and J. Huigen (2008). "The future of telecommunications regulation." Telecommunications Policy
Future Telecommunications Regulation: A Dutch Perspective - Future Telecommunications Regulation **32**(11): 699-700.

De Vries, P. (2008). "Internet Governance as Forestry: Deriving Policy Principles from Managed Complex Adaptive Systems." SSRN eLibrary.

Eisenberg, A. (1999). WHAT'S NEXT; Vivid Colors in the Palm of Your Hand. Section G;Page 13;Column 1;Circuits
The New York Times.

(ESD), E. S. D. (2004). ESD Symposium Committee Overview. MIT Engineering Systems Symposium, Cambridge, MA.

Fallows, J. F. J. (2004). In Internet Calling, Skype Is Living Up to the Hype. The New York Times. **3; SundayBusiness; TECHNO FILES:** 5.

Fine, C. H. (1998). Clockspeed : winning industry control in the age of temporary advantage. Reading, Mass., Perseus Books.

Fisher, F. M. and Massachusetts Institute of Technology. Dept. of Economics. (1990). Organizing industrial organization : reflections on parts 2 and 3 of the Handbook of Industrial Organization. Cambridge, Mass., Dept. of Economics, Massachusetts Institute of Technology.

Forrester, J. W. (1969). Urban dynamics. Cambridge, Mass.,, M.I.T. Press.

Forrester, J. W. (1971). Principles of systems. Cambridge, Mass., Productivity Press.

Forrester, J. W. (1973). World dynamics. Cambridge, Mass., Wright-Allen Press.

Forrester, J. W. (1999). Industrial dynamics. Waltham, MA, Pegasus Communications.

Furchtgott-Roth, H. W. (2006). A tough act to follow? : the Telecommunications Act of 1996 and the separation of powers. Washington, D.C., AEI Press.

Gary, M. S. (2005). "Implementation strategy and performance outcomes in related diversification." Strategic Management Journal **26**(7): 643.

Gibbons, R. and National Bureau of Economic Research. (1996). An introduction to applicable game theory. Cambridge, MA, National Bureau of Economic Research.

Gould, C. (2000). INVESTING WITH: Robert A. Loest; IPS Millennium. Money and Business/Financial Desk
The New York Times**:** 10.

Graham-Hackett, M. (1999). Industry Surveys: Computers-Networking, Standards & Poor's.

Hecht, J. (2007). Bell Labs: Over and Out. New Scientist.

Henderson, R. M. and K. B. Clark (1990). "Architectural Innovation - the Reconfiguration of Existing Product Technologies and the Failure of Established Firms." Administrative Science Quarterly **35**(1): 9-30.

Hounshell, D. A. (1984). From the American system to mass production, 1800-1932 : the development of manufacturing technology in the United States. Baltimore, Johns Hopkins University Press.

Hughes, T. P. (2000). Rescuing Prometheus. New York, Vintage Books.

Huigen, J. and M. Cave (2008). "Regulation and the promotion of investment in next generation networks--A European dilemma." Telecommunications Policy
Future Telecommunications Regulation: A Dutch Perspective - Future Telecommunications Regulation **32**(11): 713-721.

Kachigan, S. K. (1986). Statistical analysis : an interdisciplinary introduction to univariate & multivariate methods. New York, Radius Press.

Kahneman, D., P. Slovic, et al. (1982). Judgment under uncertainty : heuristics and biases. Cambridge ; New York, Cambridge University Press.

Kane, C. (2000). THE MEDIA BUSINESS: ADVERTISING; Want to get yourself some opera tickets? Just go down to the soda machine and swipe your card. Section C;Page 8;Column 3;Business/Financial Desk
The New York Times.

Kennedy, C. H. and M. V. Pastor (1996). An introduction to international telecommunications law. Boston, Artech House.

Kessler, S. and K. Kawagauchi (2008). Industry Surveys: Computers-Consumer Services & the Internet, Standards & Poor's.

Kitano, H. (2001). Foundations of systems biology. Cambridge, Mass., MIT Press.

Krattenmaker, T. G. and L. A. Powe (1994). Regulating broadcast programming. Cambridge, Mass.
Washington, D.C., MIT Press ;
American Enterprise Institute for Public Policy Research.

Krippendorff, K. (1980). Content analysis : an introduction to its methodology. Beverly Hills, Sage Publications.

Laffont, J.-J. and J. Tirole (2000). Competition in telecommunications. Cambridge, Mass., MIT Press.

Legomsky, J. (2000). INVESTING; Kodak Is Reloading, But Its Stock Is Jammed. Section 3;Page 10;Column 5;Money and Business/Financial Desk
The New York Times.

Levinson, M. (2006). The box : how the shipping container made the world smaller and the world economy bigger. Princeton, N.J., Princeton University Press.

Li, F. and J. Whalley "Deconstruction of the telecommunications industry: from value chains to value networks." Telecommunications Policy **26**(9-10): 451-472.

Lipsey, R. G. and K. Lancaster (1956-1957). "The General Theory of Second Best." The Review of Economic Studies **24**(11): 11-32.

Lohr, S. (2000). I.B.M. to Use Linux System In Software ForInternet. Section C;Page 1;Column 5;Business/Financial Desk

The New York Times.

Lohr, S. (2000). Ideas & Trends: Net Americana; Welcome to the Internet, The First Global Colony. Week in Review Desk
The New York Times**:** 1.

Lohr, S. (2005). Just Googling It Is Striking Fear Into Companies. The New York Times. **1; National Desk:** 1.

Magee, C. L. and O. L. de Weck (2004). Complex System Classification. 14th Annual INCOSE, Toulouse, France.

Marcus, S. (2006). "Beyond Layers." SSRN eLibrary.

Marcus, S. J. (2002). The Potential Relevance to the United States of the European Union's Newly Adopted Regulatory Framework for Telecommunications. OSP Working Paper Series, FCC**:** 29.

Markoff, J. (1999). TECHNOLOGY; Computer Scientists Are Poised For Revolution on a Tiny Scale. Section C;Page 1;Column 2;Business/Financial Desk
The New York Times.

Markoff, J. (2000). Ethernet Finds a New Level; Souped-Up Versions of Familiar Networking Format Promise Swift Improvements in Communications. Section C;Page 1;Column 2;Business/Financial Desk
The New York Times.

Markoff, J. (2002). The Corner Internet Network vs. the Cellular Giants. The New York Times. **C; Business/Financial Desk:** 1.

McGEEHAN, P. and D. Hakim (2000). Online Funds, Built To Order. Money and Business/Financial Desk
The New York Times**:** 1.

Mendelson, H. and R. R. Pillai (1999). "Industry Clockspeed: Measurement and Operational Implications." Manufacturing & Service Operations Management **1**(1): 1.

Murphy, D. (2002). The Business Dynamics of Global Regulatory Competition. UCLA International and Area Studies. Los Angeles.

Nagourney, E. (2001). For Medical Journals, A New World Online. The New York Times. **F; Science Desk:** 1.

Norton, J. A. and F. M. Bass "A Diffusion Theory Model of Adoption and Substitution for Successive Generations of High-Technology Products." Management Science **33**(9): 1069.

Nuechterlein, J. E. and P. J. Weiser (2005). Digital crossroads : American telecommunications policy in the Internet age. Cambridge, Mass., MIT Press.

Paich, M. and J. D. Sterman (1993). "Boom, Bust, and Failures to Learn in Experimental Markets." Management Science **39**(12): 1439-1458.

Peck, S. (2006). Scan This Book! The New York Times. **6; Magazine:** 10.

Pouwelse, J. A., P. Garbacki, et al. (2008). "Pirates and Samaritans: A decade of measurements on peer production and their implications for net neutrality and copyright." Telecommunications Policy
Future Telecommunications Regulation: A Dutch Perspective - Future Telecommunications Regulation **32**(11): 701-712.

Reiner, D. M. (2002). Casual reasoning and goal setting : a comparative study of air pollution, antitrust and climate change policies.

Richardson, G. P. (1991). Feedback thought in social science and systems theory. Philadelphia, University of Pennsylvania Press.

Riordan, T. (2002). Patents; A publicity success, the futuristic Segway scooter may be celebrated for its engine. The New York Times. **C; Business/Financial Desk:** 2.

Rosenbluth, T. (2008). Industry Surveys: Telecommunications-Wireline, Standards & Poor's.

Rosenbluth, T. and K. Kawagauchi (2008). Industry Surveys: Telecommunications-Wireless, Standards & Poor's.

S&P (2000). Industry Surveys - Computers: Software, Standards and Poor's, The McGraw-Hill Companies.

S&P (2000). Industry Surveys - Telecommunications: Wireless, Standards and Poor's, The McGraw-Hill Companies.

S&P (2000). Industry Surveys - Telecommunications: Wireline, Standards and Poor's, The McGraw-Hill Companies.

S&P (2007). Industry Surveys - Computers: Software, Standards and Poor's, The McGraw-Hill Companies.

S&P (2007). Industry Surveys - Telecommunications: Wireless, Standards and Poor's, The McGraw-Hill Companies.

S&P (2007). Industry Surveys - Telecommunications: Wireline, Standards and Poor's, The McGraw-Hill Companies.

Saltzer, J. H., D. P. Reed, et al. (1984). "End-to-end arguments in system design." ACM Trans. Comput. Syst. **2**(4): 277-288.

Sapolsky, H. M. (1992). The Telecommunications revolution : past, present, and future. London; New York, Routledge.

Simon, H. A. (1981). The sciences of the artificial. Cambridge, Mass., MIT Press.

Simon, H. A. (1982). Models of bounded rationality. Cambridge, Mass., MIT Press.

Stanbury, W. T. and Institute for Research on Public Policy. (1986). Telecommunications policy and regulation : the impact of competition and technological change, Montreal, Institute for Research on Public Policy = Institut de recherches politiques.

Stelter, B. (2008). From MySpace To YourSpace. The New York Times. **C; Business/Financial Desk:** 1.

Sterman, J. (2000). Business dynamics : systems thinking and modeling for a complex world. Boston, Irwin/McGraw-Hill.

Sterman, J. (c2000). Business dynamics: systems thinking and modeling for a complex world. Boston, Irwin/McGraw-Hill.

Sterman, J. D. (1989). "Modeling Managerial Behavior - Misperceptions of Feedback in a Dynamic Decision-Making Experiment." Management Science **35**(3): 321-339.

Sterman, J. D., R. Henderson, et al. (2007). "Getting Big Too Fast: Strategic Dynamics with Increasing Returns and Bounded Rationality." Management Science **53**(4): 683-696.

Telecommunications Policy Research Conference, G. W. Brock, et al. (1996). The internet and telecommunications policy : selected papers from the 1995 Telecommunications Policy Research Conference, Mahwah, N.J., Lawrence Erlbaum Associates.

Telecommunications Policy Research Conference, S. E. Gillett, et al. (1999). Competition, regulation, and convergence : current trends in telecommunications policy research, Mahwah, N.J., Lawrence Erlbaum.

Tunstall, J. (1986). Communications deregulation : the unleashing of America's communications industry. Oxford, OX, UK; New York, NY, USA, B. Blackwell.

Vaishnav, C. (2005). Voice over Internet Protocol (VoIP): The Dynamics of Technology and Regulation. Technology and Policy Program. Cambridge, Massachusetts Institute of Technology**:** 166.

Vaishnav, C. (2009). The Internet: A Case of How Government's Involvement and Exit Influences Global Standards. Cambridge, MA.

Vaishnav, C. and C. H. Fine (2006). A dynamic assessment of VoIP innovation, adoption and their interaction with CALEA regulation. Technology Policy Research Conference, Arlington, VA.

Varian, H. R. V. H. R. (2005). In the clash of technology and copyright, file sharing is only the latest battleground. The New York Times. **C; Business/Financial Desk; Economic Scene:** 2.

Whitney, D. E. and C. H. Fine (1996). Is the make-buy decision process a core competence.

Wiener, N. (1948). Cybernetics; or, Control and communication in the animal and the machine. Cambridge, Mass., Technology press.

Wilson, K. G. (2000). Deregulating telecommunications : U.S. and Canadian telecommunications, 1840-1997. Lanham, Md., Rowman & Littlefield Publishers.

Wireless Competition Bureau, F. (2000). Fifth Annual Commercial Mobile Radio Services Competition Report, Federal Communications Commission.

Wireless Competition Bureau, F. (2006). Eleventh Annual Commercial Mobile Radio Services Competition Report, Federal Communications Commission.

Wireless Competition Bureau, F. (2009). Thirteenth Annual Commercial Mobile Radio Services Competition Report, Federal Communications Commission.

Wireline Competition Bureau, F. (2008). High-Speed Services for Internet Access: Status as of December 31, 2007, Federal Communications Commission.

Wireline Competition Bureau, F. (2008). Local Telephone Competition: Status as of December 31, 2007, Federal Communications Commission.

Wireline Competition Bureau, F. (2008). Telephone Subscribership in the United States, Federal Communications Commission.

Wohl, P. (1999). Industry Surveys: Telecommunications-Wireline, Standards & Poor's.

Wooldridge, J. M. (2006). Introductory econometrics : a modern approach. Mason, OH, Thomson/South-Western.