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Hippocratic Paradox:
Co-evolution of Medical Ethics, Health Law, and Social Practice

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Mathematical Behavioral Sciences

by

Junying Zhao

Dissertation Committee:
Professor Donald G. Saari, Chair
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2020

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DEDICATION

To my parents, and my advisor Don Saari who helps me grow.

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I am deeply grateful to Don Saari for inspiring and advising me this dissertation. It is based on a novel approach discovered by Don, who inspires me to explore its application to medical ethics. His advice coincides with Poncare's insight a century ago, and still, has never been done before until now. His advice also shapes a unique direction of my career — to integrate mathematics and medicine to solve problems that matter. Thank you, Don.

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ABSTRACT OF THE DISSERTATION

Hippocratic Paradox:
Co-evolution of Medical Ethics, Health Law, and Social Practice

By

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Doctor of Philosophy in Mathematical Behavioral Sciences

University of California, Irvine, 2020

Professor Donald G. Saari, Chair

This research is motivated by the Hippocratic Paradox and associated hard cases that have been heard by the U.S. Supreme Court. The Hippocratic Paradox refers to ethical dilemmas caused by the conflict of some of the four principles in medical ethics — nonmaleficence, beneficence, autonomy, and justice. Studies in medicine, law, sociology, and philosophy have contributed considerable expertise and narrative insights on an *ad hoc* basis. This research aims to discover general patterns. It appears to be the first mathematical analysis of the co-evolution of the three domains — ethics, law, and society — in the context of medicine. Previously there has been no research in this direction.

This interdisciplinary research makes several contributions. First, I establish a coordinate system for each of the three domains to understand issues that occur in each domain driven by underlying principles. Second, I apply a novel mathematical approach developed by Saari (2018) to capture the qualitative features of unknown dynamics among the three domains, including the existence, number, and nature of unexpected interior equilibria. Third, I predict and update bifurcations when dynamics evolve from one state to another. Fourth, I identify root causes of bifurcations, i.e., variations in endogenous or exogenous parameters that change the weighing of underlying principles of each domain and hence alter the dy-

namic outcomes. Fifth, I discover the existence of equivalence classes in which seemingly different issues have similar configurations and hence similar evolutions. Sixth, I conduct policy analyses for contemporary issues such as abortion, the opioid epidemic, healthcare artificial intelligence, stem cell and genome editing research, and find unexpected and undesired outcomes. I also propose effective policies. In sum, I apply a general theory created by Saari (2018) to explain what has happened for existing cases in medical ethics and law, and to predict what can and probably will happen for new cases and what can be done. This research can serve as a prediction and policy tool to assist the ethical and legal aspects of medical decision-making.

Chapter 1

Introduction

Medical ethics consists of four general principles — nonmaleficence, beneficence, autonomy, and justice — as well as rules subordinate to each principle [76, 7]. Some of the four principles may conflict in a particular case and hence invoke ethical dilemmas. Such an inconsistency problem of the medical ethics system, which I name as *Hippocratic Paradox*, relates to both conceptual and practical problems across medicine, law, philosophy, and social sciences. It results in moral dilemmas for physicians, some of which turn into hard legal cases that have been heard by the U.S. Supreme Court and challenged the fundamentality of human rights and the U.S. Constitution.

For instance, on the issue of withdrawing life-sustaining support, families of patients in persistent vegetative state requested physicians and hospitals to remove respirators or nutrition tubes, but their requests were refused. They sued, succeeded at trials, lost appeals, and finally had their cases heard by the Supreme Court — *Quinlan v. New Jersey* (1976) and *Cruzan v. Director, Missouri Department of Health* (1990). On one side, care providers defended using the ethical principle of *nonmaleficence* and the legal obligations of *duty of care* in *tort* law and *physician-patient relationship* in *contract* law [76]. On the other side,

plaintiffs argued for both the *right to die* and *right to privacy*. The former was not upheld by the Court as constitutional but the latter, which was free from states' interventions. The cases further triggered delicate distinctions between legal concepts — *competence* and *incompetence*; and medical definitions — *cardiac death* and *brain death*, and the latter's varied standards such as *irreversibility*, *cognitive criterion*, and *Harvard criteria* [76]. Therefore, society, ethics, law are conceptually intertwined.

The three domains are also economically entwined. Every step of the process, from trial, to appeal, to petition, to hearing by the Supreme Court, costs an enormous amount of time, human and monetary resources, both public and private of taxpayers, patients, clinicians, hospitals, insurers, lawyers, judges, and jury members. To take a recent example: Texas passed *House Bill No.* 2 in 2013 requiring all clinics performing abortions to meet hospital-like standards and doctors to have admitting privileges at local hospitals [35]. The issue was whether the state law was constitutional. The answer was no. In *Whole Woman's Health v. Hellerstedt* (2016), the Court ruled in a 5 : 3 vote that Texas cannot place restrictions on the delivery of abortion services that create an undue burden for women seeking an abortion. The legal defense costs associated with the case totaled $768,722, including salary, overhead, and travel expenses incurred by the Texas Attorney General's Office. Similarly, the price tag for *Planned Parenthood, et al. v. Abbott, et al.* (2014) decided by the 5th Circuit Court that targeted the admitting privileges was $311,355, adding public spending on legal defense up to more than $1 million [99], not to mention the $4.5 million legal costs on the plaintiffs' side [90].

In 2017 alone, the violation of one ethical principle — do no harm — resulted in malpractice compensations of approximately $2.5 billion [39]. Given estimates that insurance claims are one-tenth of true malpractice events, and that compensation decided both inside and outside the court system is paid in less than half of these claims, the violation of one medical ethical principle in 2017 incurred an estimated $50 billion social welfare loss.

The three domains — ethics, law, and society — guide human conduct in general, and behaviors of patients, interest groups, medical and legal practitioners in particular. They interact and co-evolve throughout history. But how? Case studies in medicine, law, sociology, and philosophy have contributed deep insights into critical cases in history [76, 22].

More importantly, how might we avoid these challenging, costly dilemmas? To address this problem, we need to answer questions below: What elements are common to the co-evolutionary processes of all cases? How does an ethical dilemma occur, mobilize interest groups, escalate to the legal system, and yield social welfare losses? How are some cases essentially the same while being seemingly different? Did past policies succeed or fail due to unexpected and undesired outcomes? What outcomes are likely for new and future cases? And what can be done to prevent ethical dilemmas and legal disputes from occurring? One cannot do all these case by case. Instead, one can analyze old cases, discover patterns, generate mechanisms behind phenomena, predict new cases, evaluate existing policies, and propose effective new ones. All these require a systematic method, rather than handling them on an *ad hoc* basis.

A general approach, therefore, is needed that is complementary to existing literature. Mathematics was proposed a century ago as a means to better understanding ethics by one of France's greatest mathematicians known as "the Last Universalist," Henri Poincaré. While respecting philosophers' expertise in the contents of ethics, he encouraged from a fruitful perspective how mathematics (science) can contribute to the study and practice of ethics:

"Science alone builds firmly; it has constructed astronomy and physics; today it is constructing biology; by the same processes tomorrow it shall construct ethics. Its ordinances shall reign uncontested; no one shall be able to oppose them, and shall no more think of rebelling against the moral law than we think today of rebelling against the theorem of the three perpendiculars of the law of gravitation."

"And therein is a difficulty which the moralists have encountered for a long time. They strive to prove the moral law; we must forgive them since this is their trade. They wish to base ethics on something, as if it could be based on anything but itself. Science shows us that man can only debase himself by living in such or such a manner. And what if I care little about debasing myself and what if, what you call degradation, I call progress? Metaphysics obliges us to conform to the general law of being which it claims to have discovered. It is possible to reply: I prefer to obey my own particular law. I do not know what metaphysics will reply, but I can assure you that it will not have the last word. Submission of the heart cannot be dictated."

"Morality is based on what one's heart imagines and feels. Science cannot therefore of itself create morality; nor can it of itself and directly weaken or destroy traditional morality. But can it not exercise an indirect influence? Science, as Aristotle said, has the universal as the object. In the presence of a particular fact, it will want to know the universal law; it will aspire to a more and more extensive generalization...It will have performed useful work; it will have rendered valuable assistance to the moralists. Morality has nothing to fear from science which is motivated by a true experimental spirit; such science is respectful of the past (the reality)." — Poincaré, 1913 [77]

Motivated both practically and intellectually, I develop a mathematical theory for the co-evolution of ethics, law, and society in the context of medicine, by creating a coordinate system for each domain and by exploiting a novel approach developed by Saari (2018) [83] and based on the well-established index theory in algebraic topology. I overview the history and medical ethical dilemmas in Chapter 2. I introduce the general theory in Chapter 3 and apply it to particular cases in historical and contemporary times, together with policy analysis, in Chapters 4 and 5. I then discuss findings and policies that are universal across all cases and conclude in Chapter 6.

Chapter 2

History and Problems

This Chapter overviews classic cases in medical ethics and associated legal suits that partially shape the history. These cases are chosen from a variety of sources, especially the work of the most comprehensive case studies [76], and are organized into two main categories where ethical dilemmas occur at two critical times of life — death, and birth.

2.1 Death: Physician-assisted death

2.1.1 The Netherlands

Physician-assisted death leads to a conflict between doing no harm and respecting patients' autonomy. It started in the Netherlands. In 1971, Dr. Geertruida Postma mercifully killed her terminally-ill mother using morphine. She was prosecuted after she informed the authority. In 1973, the Dutch Medical Association reached an agreement with the prosecutors that doctors would not be prosecuted if the following conditions were satisfied: 1) the patient who makes the request is competent; 2) the request is repeated, unambiguous, unpres-

sured, and documented; 3) a consultant physician offers a second opinion and agrees on physician-assisted death, and 4) the patient experiences unbearable pain with no likelihood of improvement. Eventually, Dr. Postma was found guilty of murder with a suspended sentence.

Under the mutually-agreed regulation, Dutch physicians continued providing assisted death in the following two decades. Such a practice divided the society into two groups. The critics made a slippery slope argument that it may unnecessarily harm patients and the integrity of medical practice. Whereas, the advocates cited results of social experiments and clarified that almost all the killed were terminally-ill patients contracted with cancer or AIDS; and that doctors turned down two-thirds of the requests from competent patients. Thirty years later, in 2001, surveys showed that 90% of Dutch citizens supported physician-assisted death, [76], and both branches of the legislature passed its legalization.

2.1.2 U.S. Oregon – Death with Dignity Act

In 1994, citizens in Oregon initiated and passed the *Oregon Death with Dignity Act* with 51% v. 49% winning votes to legalize assisted death with prescription drugs. Nonetheless, in 1997, the U.S. Supreme Court held that no basic right to physician-assisted suicide could be inferred from either *"equal protection"* or *"due process"* clause of the U.S. Constitution, but indicated that a state could grant the right if it wished. A survey in 1996 of about $2,700$ doctors found that around 60% of doctors were not morally opposed to it.

Reacted to the Court decision, the Oregon state legislature repealed the Act, which irritated the citizens who then reacted to pass the Act, again, with more winner votes 60% v. 40%. Even 50% Catholics voted for it, as revealed from a survey. Similarly, the Oregon Medical Association publicly opposed the Act. Currently, the Act still has implementation issues.

2.1.3 U.S. Michigan – People v. Kevorkian

In 1986, Retired pathologist Dr. Jack Kevorkian started publicizing support for the Dutch decriminalization of physician-assisted death. In 1990, his assistance for death was requested by patient Janet Adkins, who had contracted with Alzheimer's disease for years. After interviewing and receiving agreement from Janet, and her husband and son, Dr. Kevorkian left her with three bottles of drugs for intravenous therapy. She turned on the switch and became unconscious and dead. The local district attorney prosecuted him for murder. The local judge, however, dismissed the case because there was no law against assisted suicide in Michigan but ordered Dr. Kevorkian to stop his service. Since then, many patients contacted him and made the requests. His assistance was free but required donations to the suicide center "Obitorium", which was one of many popular suicide organizations such as the Hemlock Society [76]. In 1991, again, Dr. Kevorkian was indicted for murder and was acquitted since his behavior did not violate any Michigan law. Nevertheless, his medical license was suspended.

In 1991, states such as California and Washington tried to legalize physician-assisted death but defeated due to the opposition from the Catholic Church. Whereas, Michigan banned it in 1993, but the Michigan Supreme Court threw it out in 1994. In the same year, Washington and New York banned it, but federal judges struck them down; and later in 1996, the $2nd$ and $9th$ Circuit Courts of Appeals held that laws banning physician-assisted death were unconstitutional.

Up to 1997, Dr. Kevorkian had assisted more than 100 patients and acquitted in three trials charged with five death. Nevertheless, the U.S. Supreme Court made a watershed decision in 1997. The Court recognized the AMA's claim that *"legalization of physician-assisted dying would hurt the disable and poor, and possibly start a slippery slope."* The Court held that *"a fundamental 'right to die' does not exist in the Constitution. Interpretation of 'liberty'*

in the "equal protection" and "due process" clauses of the 14*th Amendment should only be expanded if the rights and interests in question are deeply rooted in this nation's history and tradition. States could, but need not pass a law banning physician-assisted death".* Notice how different the law can be depends on which country (e.g., the Netherlands and the U.S.) and which state one locates! The Court decision opened the door for states to pass such criminal laws.

In 1999, Dr. Kevorkian publicized a videotape recording assisted death on popular television program *60 minutes*. It stirred social repugnance and criticism on ethics in medicine and media. During 2001–2002, Michigan state courts at all three levels — trial, appeal, and supreme (with a 6 : 1 vote) — confirmed that Dr. Kevorkian was guilty of second-degree murder.

2.1.4 U.S. New York – Vacco v. Quill

Similar to *People v. Kevorkian*, all three domains — ethics, law, and society — agreed in *Vacco v. Quill* (1997). The main difference is their attitudes were completely reversed. "Diane" had been Dr. Timothy Quill's patient for more than three years. Dr. Quill informed her that her chronic leukemia turned into acute and patiently explained to her the benefits and side effects of chemotherapy. Nevertheless, she declined the chemotherapy and requested Dr. Quill to prescribe barbiturates to help her sleep and then suicide when needed several months later. Both her husband and son supported her competent decision. Dr. Quill also wrote her farewell messages and published her death in a respected medical journal. Although he was later prosecuted for murder, he was acquitted because the grand jury refused to indict him. Moreover, many doctors who strongly opposed Dr. Kevorkian praised Dr. Quill.

Vacco v. Quill is an exception. In general, AMA strongly opposed physician-assisted death.

The society's attitude overall was neutral, although the Catholic Church and the billionaire Georgy Soros, respectively, spent million dollars on media against and for this issue.

2.2 Death: Withdrawal of life-sustaining support

Rather than *actively* assisting patients' suicide, withdrawing life-sustaining support removes respirators or feeding tubes to *passively* let patients die. When requested by patients, it causes a conflict between principles of respecting the patient's autonomy and doing no harm.

2.2.1 1970s, Quinlan v. New Jersey

In *Quinlan v. New Jersey* (1975), Karen Quinlan had been in a persistent vegetative state in a Catholic hospital. Her parents requested withdrawal of a respirator. Physicians rejected it. Her parents sued and lost at both the lower and appellate courts which held that there was no *"constitutional right to die"*. Eventually, they won unanimously at the New Jersey Supreme Court by arguing the *"constitutional right to privacy"*. That is, how to die is individuals' private decision and should not be intervened by the state. The AMA, however, strongly opposed it equating it to active euthanasia. After the Court decision, the Catholic hospital transferred Quinlan to public nursing home under the pressure from the New Jersey Medicaid office. More than a decade later, when she contracted with pneumonia, her family legally declined antibiotics, and then she died.

2.2.2 1980s, Cruzan v. Director, Missouri Department of Health

In 1983, Nancy Cruzan had been in persistent vegetative state for years in a state-run hospital. Her parents and sister requested physicians to withdraw the feeding tube. The

hospital refused. Her family sued and won at the probate court. The Missouri Supreme Court, however, reversed the decision because there was no living will of Nancy, there was no *"clear and convincing evidence"* that she would have made this decision if she was competent. The U.S. Supreme Court further distinguished incompetence from competence. In particular, Justice O'Connor wrote that *"the Constitution gives Americans a liberty interest to be free of unwanted medical support."* Nevertheless, the Court decision was weaker for incompetent patients — *"state could, but need not" pass such a statute."*

Reacted to the U.S. Supreme Court decision, society was divided especially between legal and medical practitioners [76]. Medical experts started to redefine the criteria of death. The AMA further affirmed in 1986 that *"it is ethically possible for a physician, after consulting with patient's family, to withdraw life-sustaining support from an irreversibly comatose patient."* Several months after the Court decision, physicians legally removed Cruzan's feeding tube, and then she died.

2.2.3 1990s, Medical Futility Movement, Gilgunn v. Massachusetts General Hospital

Beginning in the late 1980s, doctors behaved excessively liberally by removing support or not providing services that they believed futile. In *Gilgunn v. Massachusetts General Hospital* (1995), emergency care physicians were sued for not providing resuscitation to a $71-$ year-old comatose woman. The physicians, however, were found not guilty since the grand jury did not find a causal inference from not providing resuscitation to the woman's death. Nevertheless, medical futility caused too many ethical dilemmas and emotional pains, and hence eventually waned. Nowadays, patients admitted to hospital are asked to sign "Advanced Directives" and patients often decline treatments when being advised by their physicians that there is no realistic chance to recover.

2.3 Birth: Assisted reproduction

Assisted reproduction consists of sexual and asexual reproductions. The former contains Artificial Insemination of Husband/Donor's sperm, In vitro fertilization, paid egg donation, paid sperm donation, paid surrogacy, and paid adoption. The latter includes reproductive cloning, reproductive research using embryos and stem cells.

2.3.1 Artificial Insemination of Husband/Donor's Sperm (AIH/D)

In the 1850s, physician J. Marion Sims in Alabama artificially inseminated more than 50 infertile wives with the sperm of their husbands [76]. He produced one pregnancy but was forced to stop due to harsh criticism. Similarly, in the 1890s, another American doctor Robert Latou Dickinson practiced AIH but was accused of abetting adultery. A century later, society accepted artificial insemination of not only husbands' but also donors' sperm.

2.3.2 In vitro fertilization (IVF)

The IVF technology fertilizes an egg and sperm in a tube, incubates the fertilized egg into an 8−cell embryo, and injects the embryo back to the mother's fallopian tubes to induce pregnancy. It is an operation at the cellular, rather than genetic, level, and hence is not genetic manipulation. An *embryo* is neither a *baby* nor a person (Table 2.1, [76]). However, an embryo may be conceptualized as a baby or a potential person by some interest groups from a certain point of view. Therefore, although IVF gives hope to those who are infertile, it technically destroys an embryo and, thus, kills a baby or a person. IVF faces an ethical dilemma where the principle of doing no harm to a baby conflicts the principle of doing good to the infertile.

In 1978, the first IVF baby Louise Brown was born in the U.K. Later; the U.S. banned IVF services at federal facilities, in particular, and federal funds on human embryo experiments, in general. The risk of abnormal babies concerned social groups such as the Catholics and conservative Christians. Whereas, the liberals and pro-choice Christians claim that no reasonable approach to life can avoid all risks. In fact, harming is a relative concept depending on which baseline one chooses — *wrongful life or wrongful birth*. The former leads to a conclusion that IVF does not harm, because otherwise, the baby would not even exist. Whereas, the latter reasons that IVF can harm if it causes defects that a normal baby does not have.

Nevertheless, private clinics that provide IVF services have been increasing. During 2017, around 78,052 IVF infants, accounting for 1.7% of all U.S. infants, have been born at 448 reporting clinics in the U.S. [30] By 2016, 15 (not majority) states mandate private insurance companies to pay for Artificial Reproductive Technology (ART) including IVF for infertile people who argue that infertility is a disease, whereas the insurance companies argue that it is a lifestyle [20]. Meanwhile, the American Society of Reproductive Medicine (ASRM) provides technical suggestions to multiple births for patients.

Table 2.1: Distinctions in Medical Definitions, Cite from [76]

Term	What, When, Where
Zygote	a successful union of egg and sperm in a tube or a fallopian tube
Embryo	an 8-cell organism that travels down the fallopian tube to the uterus
Fetus	an organism from 9 weeks of gestation in the uterus until birth
Baby	a newborn human being, alive outside the womb

2.3.3 Paid Surrogacy

Paid surrogacy puts the embryo obtained from IVF to the uterus of another woman hired by the intended mother (and father). In *William Stern vs. Mary Beth Whitehead* (1980),

the Stern's used their own sperm and egg of the hired surrogate mother to produce a baby. The surrogate mother felt she developed bonding with the baby and refused to give back the baby. The Stern's sued. In 1987, a local trial court upheld the concept of *contract* and ordered the surrogate mother to return the baby to the Stern's. The New Jersey Supreme Court, however, unanimously reversed the decision by invalidating the surrogacy contract. Later, some states, such as New York, Michigan, Washington, Utah, Arizona, New Mexico, criminalized commercial surrogacy. Others, such as California, Alaska, Florida, Ohio, Virginia, Nevada, New Hampshire, legally recognized the paid surrogacy contract.

The case divided the feminists into two opposite subgroups. The merit feminists respected the obligation of a contract; whereas, the social feminists supported the surrogate. During the 2010s, around 750 babies were born each year using gestational surrogacy in the U.S. [76]

2.3.4 Human Cloning

Asexual reproduction produces the same genes of one human being or animal. It includes four different types of technology. *Embryo twinning* divides an 8-cell embryo into 16 cells and then puts them back to a human uterus. *Cellular* cloning produces copies of one cell. *Molecular cloning* duplicates strings of DNA that contain genes in a host bacterium such as yeast. *Fusion* puts a donor's adult cell next to an enucleated egg, fuses the two with a tiny electric current which activates the egg to develop into a *blastocyst* that is more than 100 cells and already differentiated, and then injects the blastocyst to the female uterus.

Fusion produced the first cloned sheep "Dolly" in 1997 Scotland. This concerned the Clinton administration because of its implication on humans which took advice from the National Bioethics Advisory Committee (NBAC), banned funding human embryo research, and made human cloning a crime at the federal level. Although the House of Representatives passed

the *"Human Cloning Prohibition Act of 2001"*, the Senate did not pass it. Meanwhile, society universally repulsed those who publicly claimed that they wanted to clone their own genes and produce children.

2.3.5 Research Using Embryos and Stem Cells

The destruction of embryo cells annoys pro-life groups since it causes harm to those who are potential persons. In 1977, the Ethics Advisory Board (EAB) suggested that continuing federal funding for some research was morally possible, and hence weakly supported human embryo research. The suggestion, however, was never taken by Congress due to anti-abortion group's reaction. Both the Reagan and Bush administrations during 1981–1989 and 1989–1993 were pro-life, and equated the destruction of embryos to the destruction of fetuses in the issue of abortion, and hence did not renew EAB charter.

Beginning in 1993, the Clinton administration was more sympathetic about this issue. The Congress revoked the discussion, requiring EAB approval of human embryo research and allowing federal funds for research using tissues derived from an aborted fetuses. The National Health Institute held an oversight committee — Human Embryo Research Panel (HERP) which supported federal funding, allowed *research embryo*, and rejected using *spare embryo*. The increasingly conservative Congress, however, rejected HERP's advice and passed the *Partial-Birth Abortion Act* in 1995. Since then, no Congressperson wanted to initiate legalizing human embryo research again.

Nevertheless, the status quo was interrupted by medical breakthroughs. In 1998, two American researchers supported by private funding (e.g., Planned Parenthood) discovered immortal human stem cell lines from spare embryos and aborted fetuses, respectively. Thus, artificial reproduction could be possible by using less controversial stem cells rather than embryos and fetuses. The NBAC concluded that the government should fund stem cell research. The

conservative Congress, however, still did not accept the suggestion.

Further, in 2001, adult stem cells were discovered in the bone marrow, which can be used to eradicate a variety of genetic diseases and cancers. Such a scientific breakthrough alleviated ethical concerns and implied a national interest in the global competition in this new area. In the same year, the Bush administration allowed federal funds for research using around 60 stem cell lines that had already been derived from spare embryos.

2.4 Birth: Abortion

Abortion faces an ethical dilemma in which the principle of doing no harm to the fetus conflicts with that of respecting the mother's autonomous choice or doing good to the mother. It was documented in the $12th$ century that Catholic and Christian Churches heavily punished abortion. Whereas the law was quite lenient during the colonial times and the $17-19$th century [76] Around the 1860s U.S. Civil War, the medical profession evolved and founded AMA which heavily lobbied the law to oppose abortion.

The Civil Rights Movement starting from the 1960s reshaped the issue of abortion. The U.S. Supreme Court held that individuals have the *right to privacy* regarding contraception in *Griswold v. Conneticut* (1965) and regarding abortion before viability in *Roe v. Wade* (1973).

Nevertheless these firm pro-choice decisions irritated pro-life groups who then initiated the Anti-abortion Movement during the 1980s. In the next two decades, many states passed laws requiring minors to obtain parents' consent for abortion, which resonated with the U.S. Supreme Court decision in *Planned Parenthood v. Casey* (1992). Legislatively, Congress passed *Partial-Birth Abortion Ban Acts of 1995* and *2003*.

The pendulum, again, swung back to pro-people during the $2009-2017$ Obama administration, which appointed two liberal Justices to the Supreme Court. Although state laws were passed requiring abortion providers to obtain admitting privileges from local hospitals in 2013 Texas [96] and costly facilities in 2014 Louisiana [97], the Supreme Court struck the Texas law in *Whole Woman's Health v. Hellerstedt* (2017). Although President Trump later appointed two conservative Justices, the Court still struck down the Louisana law in *June Medical Services v. Gee* (2019) reaffirming its respect for *Roe v. Wade*.

Chapter 3

General Theory

I create the general theory by five steps to systematically understand how the three domains —medical ethics, health law, and social practice — co-evolve.

- First, I set up a coordinate system — a set of underlying principles — a basis that generates and drives all activities in each domain. When conflicting within a domain, the principles that outweigh determine the overall *characteristic* of the domain. Which principle outweighs comes from observational, aggregate-level data in each domain.
- Second, the characteristic of each domain decides the pairwise interaction — *edge flow*— between two domains.
- Third, for each pairwise interaction, I examine how the third domain plays with the existing interaction — *interior flow*. Taken together, the characteristics, edge flows, and interior flows compose a *configuration* — a representation of limited known information about all three domains.
- Fourth, I build a map of configurations from the initial state, through intermediate states, to all possible final states. Which configuration at the final state will happen

requires one to detect the right *path* in the map using contextual and longitudinal data of a particular issue in question.

- Fifth, after arriving at the final state, I sort out alternative *characterizations* of the configuration in order to make a sound *prediction*.
- Finally, I update the configuration and prediction for policy analysis.

3.1 Step 1: Coordinate System

For each domain, I construct a *basis* of key underlying principles on which actions are driven and evaluated, just like a mathematical *basis* on which all vectors in a vector space are spanned and decomposed.

Within our framework, ethics is a set of universal common moralities shared by most cultures, groups, and individuals, as well as a collection of particular ethics including professional ethics [7, 43]. Medical ethics, specifically, consists of four obligatory principles:

1. *nonmaleficence* (do no harm)
2. *beneficence* (do good)
3. *autonomy* (respect patient's autonomous choice)
4. *justice* (fairly distributing benefits, risks, and costs)

Nonmaleficent and beneficent obligations, together with virtues of physicians, appeared in both the *Hippocratic Oath* dated back to the 5th century B.C.E. and the first comprehensive modern *Medical Ethics* (1903) [7]. Virtues, however, were de-emphasized in the first version of the American Medical Association (AMA) *Code of Ethics* (1847) and were eliminated,

with the exception of honesty, in its 1980 version [7]. Moreover, the notion of *informed consent* was raised against the 1940s unethical conduct of Nazi physicians, and was adopted by the AMA since 1957 and the British Medical Association since 1959 [54]. Further, swayed by the 1960s−1970s Civil Rights Movement, patients' *rights*, together with the subordinate confidentiality rule, were incorporated into the principle of autonomy.

The formal principle of *justice* has a long history since Aristotle. It requires treating equal people (e.g., patients) equally. In modern medicine, the notion of fairness appears while distributing benefits (e.g., scarce kidneys during the 1970s and hearts 1980s for transplantation patients) and risks (e.g., treatments inside and outside clinical trials during the 1990s for HIV/AIDS patients) [7]. Justice involves other members in society, and hence causes dilemmas usually in public health and healthcare policy. Nonetheless, various justice theories define "equal" differently and hence offer differential guidances. For instance, scarce medical resources are argued to be distributed in many ways — 1) completely equally by the egalitarian theory, 2) to maximize the communal good by the communitarian theory, 3) to prioritize the most disadvantaged by the Rawl's rule, 4) to guarantee equal access to care by the fair-opportunity rule, 5) to maximize the sum of utilities by the utilitarian theory, and 6) to prioritize freedom to choose hence ability to pay by the libertarian theory.

The Anglo-American common law consists of two main branches — legislative and judicial law. The former codifies the law, and the latter interprets the law and decides cases accordingly [41]. Together, they form a legal institution that operates based on general principles:

1. *self-reference*
2. *external reference*
3. *self-interest*

Self-reference, also called *consistency*, means the requirement that a new legislation fits in

the existing legal structure or a judge's decision respects precedents set by courts of the same or superior level [50]. Nevertheless, when there does not exist a relevant law or the old interpretation of an existing law no longer suits new contexts, judges may refer to external needs and values to innovate their own interpretation and make a decision accordingly which serves as a new precedent [51]. Finally, lawmakers and legal practitioners have their own self-interests. They concern themselves with reelections if applicable [91] and the existence and credibility of the legal institution *per se*. For instance, the English court Star Chamber that ensures fair law enforcement against socially and politically prominent suspects was abolished by the Long Parliament with the *Habeas Corpus Act* (1640) [41]. Whereas in the 2018 election year, State Supreme Court and Appellate Court campaigns in the U.S., on average, raised more than $6 million and $1 million respectively, while the U.S. House and Senate, on average, raised more than $15 million each [42].

Social practice, according to [8] is guided by:

1. *values*
2. *mores and taboos*
3. *customs and conventions*
4. *needs* that are root causes of social activities

In particular, values, mores, and taboos are social norms about what is important, right, and wrong. Whereas, there are many kinds of needs including but not limited to economic, physical, and psychological needs. Take two examples of economic need: before the Industrial Revolution, farming required traditional families to function as economic production units that resisted abortion to promote labor. Similarly, infanticide has been practiced in various societies when families did not have the resources to support another mouth to feed. Similarly, the infertile population has a physical need for babies, and hence an inelastic demand

for assisted reproduction such as in vitro fertilization (IVF). The new technology, however, is a double-edged sword. In a general population, it also raises fear of unknown harm to IVF babies, and hence a psychological need for certainty.

Notice that I do not cover religion, ideology, politics, culture, and concepts alike, because their arguments can be decomposed into underlying principles such as fear of unknown harm, values, or conventions. Also, the non-exhaustiveness of the principles does not affect the analysis. After all, it is the weighing of particular principles in conflict at a particular time that decides the dominant attitude of a domain toward an issue.

3.2 Step 2: Unknown Dynamics & Index

When conflicting, the principle that outweighs others determines the characteristic of a domain at a time. The characteristics of the two domains decide their interaction. But how? In natural sciences, the process for understanding how an object evolves with another is to take its first derivative with respect to another object — an *ordinary differential equation*. And vice versa. Take an example of the logistic population model where $x(t)$ is the population of some species at time t, N is the carrying capacity, and assume the parameter $a > 0$ [56]:

$$x' = ax(1 - \frac{x}{N}).$$

Assume N=1, then the ODE becomes:

$$x' = f_a(x) = ax(1 - x).$$

Take the second derivative, I have:

$$x'' = f'_a(x) = a - 2ax.$$

Solve the ODE by integration:

$$\int \frac{dx}{x(1-x)} = \int a dt,$$
$$\int \Big(\frac{1}{x} + \frac{1}{1-x}\Big) dx = \int a dt.$$

The solution is:

$$x(t) = \frac{Ke^{at}}{1 + Ke^{at}},$$

with the initial condition:

$$K = \frac{x(0)}{1 - x(0)}.$$

That is:

$$x(t) = \frac{x(0)e^{at}}{1 - x(0) + x(0)e^{at}}$$

This ODE has two equilibria. One occurs at $x(t) = 1$, when $x(0) = 1$; the other appears at $x(t) = 0$, when $x(0) = 0$. Their distinctive behaviors can be found by derivative tests. When $x(t) > 1$, the slope $x' < 0$, hence $x(t)$ decreases to the equilibrium $x = 1$. Meanwhile, when $0 < x(t) < 1$, it implies that the slope $x' > 0$. So $x(t)$ increases to $x = 1$. Taken together, it implies that $x = 1$ is an attractor. Whereas, when $x(t) < 0$, the slope reverses sign $x' < 0$, and hence $x(t)$ decreases even more moving away from $x = 0$, which is a repeller.

The nature of the two equilibria can also be shown by the second derivative tests. At $x = 0$,

the accelerator $f_a'(x) = a > 0$. It means that the slope f_a increase as $x(t)$ passes through 0. Therefore, $x = 0$ is a repeller. Whereas, at $x = 1$, the accelerator $f_a'(x) = -a < 0$. It implies that the slope f_a decreases forcing $x(t)$ toward 1 . Thus, $x = 1$ is an attractor (Figure 3.1). In this 1-dimensional example, if the parameter a changed its sign, a bifurcation will occur.

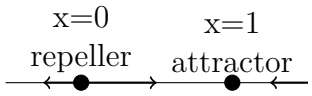


Figure 3.1: Logistic Growth Model Equilibria

If there are two (and more) objects, then (more than) two such equations compose a *system of ordinary differential equations*, called a *dynamic system*. In a lower dimension, $\mathbb{R}^2$, consider a general, linear, planar system:

$$X' = AX, \tag{3.1a}$$

$$A = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in \mathbb{R}^{2\times 2}, \tag{3.1b}$$

$$X = \begin{pmatrix} x \\ y \end{pmatrix} \in \mathbb{R}^2. \tag{3.1c}$$

The characteristic equation is: (3.1d)

$$(A - \lambda I)V = 0, \tag{3.1e}$$

$$\text{where } A = \begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix}. \tag{3.1f}$$

Then the solution is: (3.1g)

$$X(t) = c_1 e^{\lambda_1 t} V_1 + c_2 e^{\lambda_2 t} V_2. \tag{3.1h}$$

Given different ranges of real eigenvalues, different outcomes can occur. If both eigenvalues are negative, the dynamic system has an attractor (i.e., a sink). If both are positive, a repeller (i.e., a source). If one is positive, the other negative, then the system has a saddle.

When the matrix features differently:

$$A = \begin{pmatrix} 0 & \beta \\ \beta & 0 \end{pmatrix}, \tag{3.2a}$$

the solution becomes: (3.2b)

$$X(t) = e^{i\beta t} \begin{pmatrix} 1 \\ i \end{pmatrix}, \tag{3.2c}$$

$$\text{where } \lambda = i\beta, V = \begin{pmatrix} 1 \\ i \end{pmatrix}. \tag{3.2d}$$

Using the Euler's formula: (3.2e)

$$e^{i\beta t} = cos\beta t + i\ sin\beta t, \tag{3.2f}$$

The solution can be rewritten as: (3.2g)

$$X(t) = \begin{pmatrix} cos\beta t + i\ sin\beta t \\ -sin\beta t + i\ cos\beta t \end{pmatrix} \tag{3.2h}$$

The eigenvalues $\lambda = i\beta$ allow the solution flow to be a center, clockwise if $\beta > 0$ and counterclockwise if $\beta < 0$.

Furthermore, when the matrix features:

$$A = \begin{pmatrix} \alpha & \beta \\ \beta & \alpha \end{pmatrix}, \tag{3.3a}$$

the solution becomes: (3.3b)

$$X(t) = e^{\alpha + i\beta t} \begin{pmatrix} 1 \\ i \end{pmatrix}, \tag{3.3c}$$

Hence, the solution becomes: (3.3d)

$$X(t) = e^{\alpha t} \begin{pmatrix} cos\beta t \\ -sin\beta t \end{pmatrix} + ie^{\alpha t} \begin{pmatrix} sin\beta t \\ cos\beta t \end{pmatrix} \tag{3.3e}$$

The α component in eigenvalues $\lambda = \alpha + i\beta$ allow the solution flow to be a spiral — spiral source if $\alpha > 0$ and spiral sink if $\alpha < 0$. Therefore, the eigenvalues suggest analytical solutions to and equivalence classes of a dynamic system.

In this system, however, one must precisely specify every equation. It is possible to do so in natural sciences, where ideally one can repeat an experiment infinitely many times, record values of variables, fit data into relationships among variables from time to time, and hope these disparate specifications eventually converge to one numerical form of each ODE.

Nevertheless, such an approach is impractical and complex, hence impossible, in social sciences and in medical and legal practices. Therefore, I choose the qualitative version of dynamic systems, called *index theory*. It is a mathematical field that is well-developed and has been successfully applied to physics and biology [10]. It models a dynamic system topologically and predicts nonnumerical outcomes such as the existence, number, and nature of equilibria.

More importantly, in social sciences we have topological spaces where the metric is no longer Euclidean, the properties of the slope field of and solutions to a dynamic system can still be

understood via the topological properties of curves in the slope field using the indexy theory. According to [26], for a vector field $V = (F(x, y), G(x, y))$, the quantity

$$\frac{G(x, y)}{F(x, y)}$$

is the slope of a field vector in the xy plane. Define angle ϕ that corresponds to the slope vector field as:

$$d\phi = d\Big(\arctan\frac{G}{F}\Big).$$

Hence,

$$d\phi = \frac{GdF - FdG}{F^2 + G^2}, \quad (G \neq 0).$$

Define the index of a closed curve ind γ by the following line integral

$$\text{ind } \gamma = \frac{1}{2\pi}\int_\gamma d\phi.$$

Therefore, the index ind of a curve γ is the *number of revolutions*, when one traces the path of a single point on the curve following the continuous rotation of a field vector attached to the point, until the point returns to its initial position and the field vector returns to its original orientation. This process can be interrupted by singular points at which $F = G = 0$. Both the *number of revolutions* and the *direction of rotation* executed by the filed vector depend on the flow patterns. The sign of the index indicates whether the rotation of the field vector is in the same or opposite sense to the orientation of the curve.

Recall Green's Theorem:

THEOREM 3.1. Over a region D in the plane with boundary ∂D,

$$\oint_{\partial D} P(x, y)dx + Q(x, y)dy = \iint_D \Big(\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y}\Big)dxdy,$$

where the left side is a line integral and the right side is a surface integral.

Together with Green's Theorem, the definition of index implies that

THEOREM 3.2. The index of a curve is equal to the sum of the indices of all singular points in the region D bounded by the curve.

Indices are powerful topological properties because they are invariant:

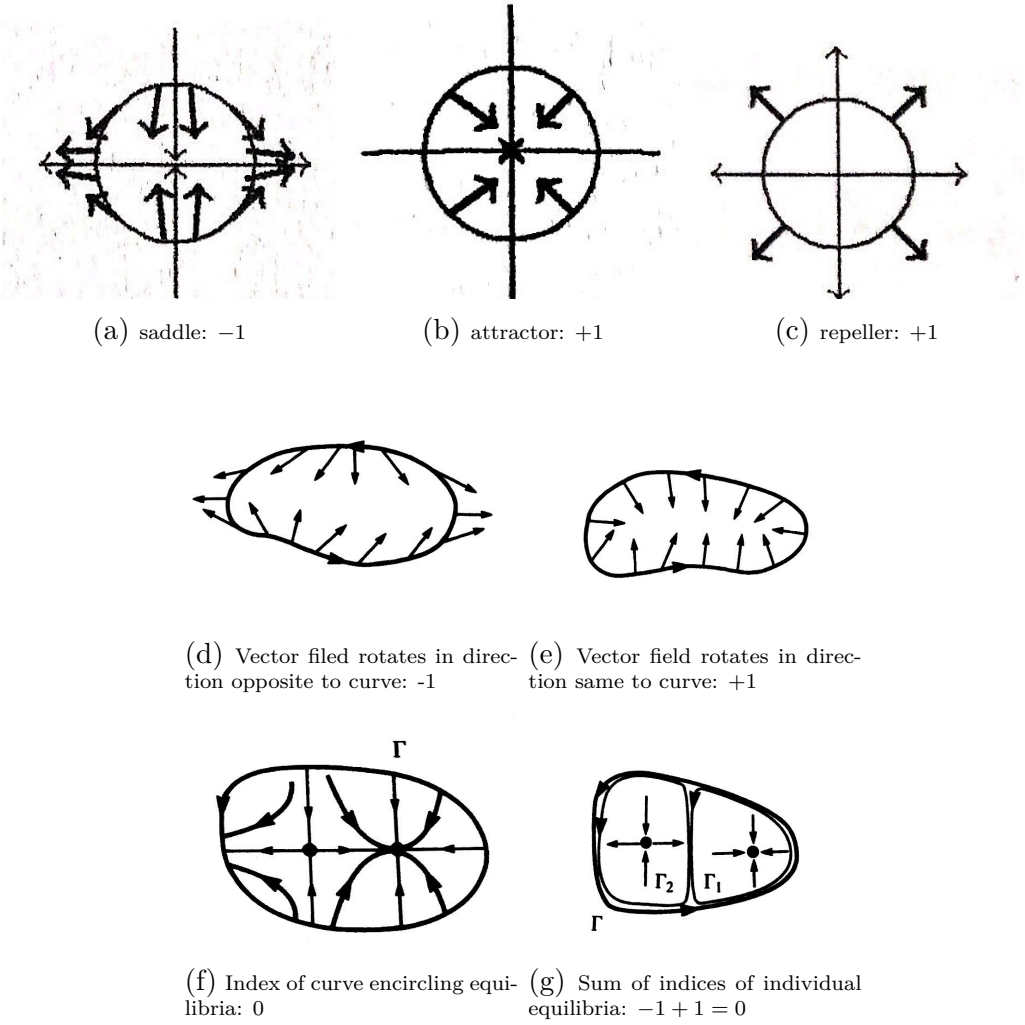
THEOREM 3.3. The index does not change if the curve or the vector field is distorted, provided that during the process of change no singular points cross or are on the curve.

Applying index theory to social sciences is a new approach developed by Saari (2018) [83] that suits social sciences in general, and this research in particular, where precise, numerical specifications of the interactions among ethics, law, and medicine are impossible to know. Below I introduce the intuition of key definitions — *equilibrium*, *index*, *bifurcation*, and *equivalence class*— and two theorems that are crucial for prediction and policy analysis. Readers who are interested in a more rigorous mathematical version should refer to [56, 26] for index theory and [83] for its applications to social sciences.

Given two variables, how one variable changes with respect to the other can be measured by the magnitude and direction of the slope, called a *slope vector*, or equivalently by the angle corresponding to the slope vector at a given point. A point where the relative change is absent, i.e., the slope is zero, is called an *equilibrium (point)*. Such a *steady state* can be as stable as an *attractor*, or unstable as an *attracting limit cycle*, *repeller*, and *saddle* [26]. I explain these concepts in Theorem 3.5 below.

Over a region of many points, the relative change between two variables can be captured by the slope vector at every point in this region, called *slope vector field*. To know overall how the angles corresponding to all slope vectors rotate, one can put a closed curve in the region, and trace the path of a single point on the curve following the continuous rotation of a slope vector attached to the point, until the point returns to its original position, and the slope vector returns to its original orientation. This process can only be interrupted by equilibria

at which slopes are zero; hence, variables stop change relative to each other. The number of revolutions of the slope vector defines the index of the curve, which I call the *global index*. The sign of the global index indicates whether the rotation of the slope vector is in the same or opposite sense to the orientation of the curve. For instance, in Figure 3.2d, tracing the path along the curve counterclockwise, the slope vector encounters one clockwise revolution; hence, the global index is -1. However, if it completes one counterclockwise revolution, then the global index is $+1$ (Figure 3.2e). Figures 3.2a, 3.2b, and 3.2c show that the index of a saddle, an attractor (or an attracting limit cycle), and a repeller (or a repelling limit cycle) is -1, $+1$, and $+1$, respectively.



(a) saddle: -1 (b) attractor: $+1$ (c) repeller: $+1$

(d) Vector filed rotates in direction opposite to curve: -1 (e) Vector field rotates in direction same to curve: $+1$

(f) Index of curve encircling equilibria: 0 (g) Sum of indices of individual equilibria: $-1+1=0$

Figure 3.2: Indices of Equilibria & Curve, Cited from [26]

Theorem 3.2 that connects the indices of equilibria and the curve and is crucial for prediction states: The index of a curve is equal to the sum of the indices of all equilibria in the region bounded by the curve [83]. I call the sum of indices of equilibria on the boundary the *partial sum of local indices*. Equivalently, I have:

THEOREM 3.4. The global index is equal to the partial sum of local indices plus the indices of interior equilibria.

To illustrate, Figure 3.2f indicates that the global index of the curve that surrounds two interior equilibria is 0. The nonexistence of boundary equilibria gives a 0 partial sum of local indices, together with the interior attractor and saddle, totaled a sum of 0 (Figure 3.2g), which is equal to the global index.

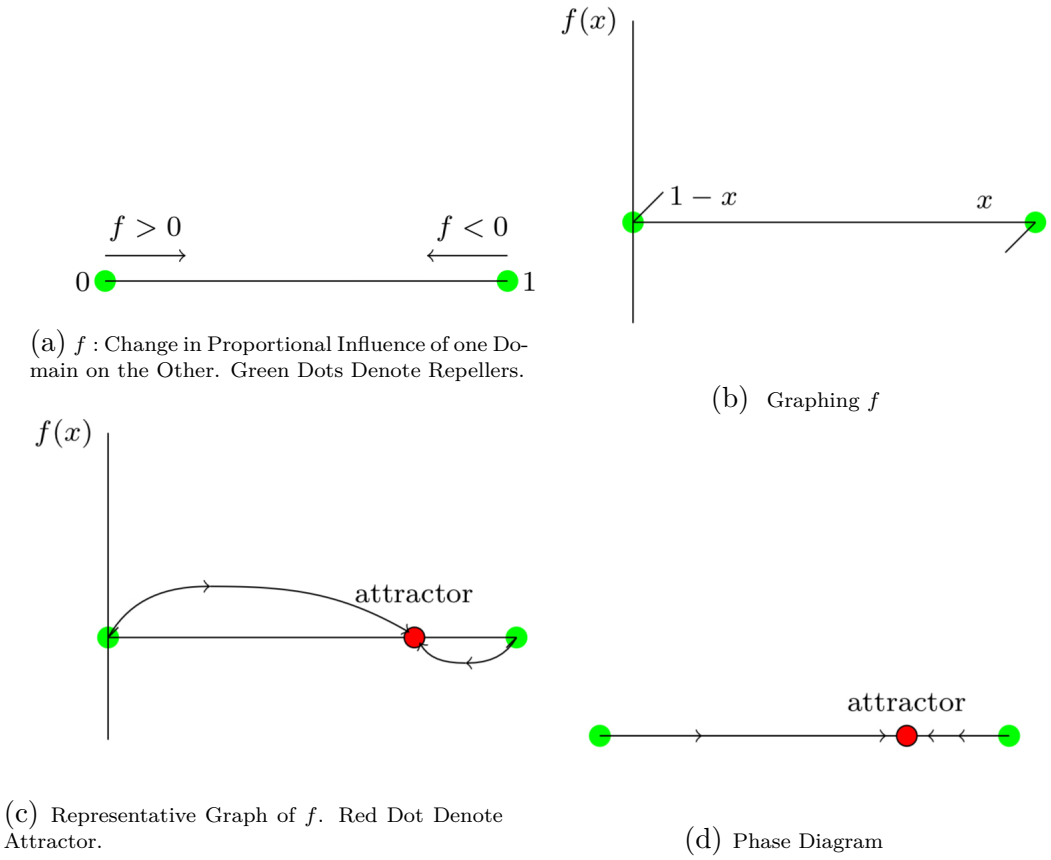
3.3 Step 3: Configuration

Applying concepts in the steps above, I construct a configuration of the relationship of the three domains. For each domain, there are two main characteristics, i.e., attitudes — for or against — toward an action that invokes an ethical dilemma. When lacking of an attitude, a domain is temporarily neutral and can be readily perturbed to develop an attitude. Moreover, the strength of an attitude can be intuitively (topologically) categorized into two degrees — strong and weak. Admittedly, there can be more than two categories. The point is that the strength is a matter of degree. In this research, I use characteristics, attitudes, and types interchangeably.

When two domains interact, I denote them as two vertices and their mutual influence as the distance in between (Figures 3.3, 3.4, and 3.5). I call this an *edge flow*. Normalize the distance to 1. Let x be the proportional influence gained by one domain, and $1 - x$ by the other. Define $f(x)$ to be the first derivative of the proportional influence one domain has,

with respect to the other. Assume $f(x)$ is continuous.

There are four general cases for each pairwise interaction: Two domains have either the same (Figure 3.3) or opposite (Figure 3.4) attitudes, or one neutral domain is completely dominated by the other (Figures 3.5). In the case of cooperation, I have $f(x) < 0$ near the right vertex (Figure 3.3a). By definition of f, it means in this region the value of x



(a) f : Change in Proportional Influence of one Domain on the Other. Green Dots Denote Repellers.

(b) Graphing f

(c) Representative Graph of f. Red Dot Denote Attractor.

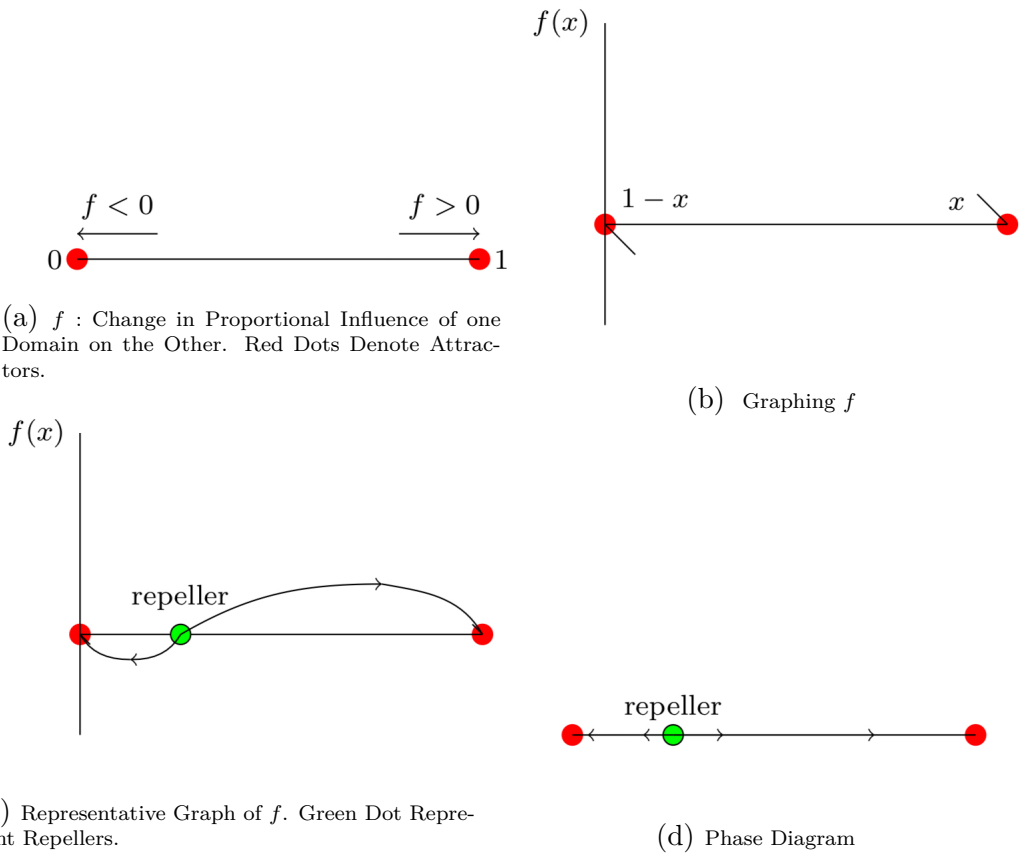
(d) Phase Diagram

Figure 3.3: Pairwise Interaction Case 1 Cooperation, Cited from [83]

will decrease (Figure 3.3b), hence the proportional influence of the right domain shrinks and moves to the left where the left domain is relatively dominant, denoted as a left-pointed arrow in the right region (Figure 3.3c). Correspondingly, there exits $f(x) > 0$ around the left vertex, which means in the left region the value of x will increase. Thus, the proportional influence of the left domain grows and moves to the right where the right domain is relatively dominant, denoted as a right-pointed arrow in the left region. The interaction continues evolving, until

both arrows meet at a point in between where the proportional dominance over each other is balanced, hence the relative change of the proportional dominance becomes zero — an *attractor* is born, depicted as the red circle in between in the *phase diagram* (Figure 3.3d). The interpretation is that if both domains share the same attitude, i.e., they agree on an issue in hand, then both prosper from mutual dominance, i.e., they cooperate.

In the case of competition, I have $f(x) > 0$ near the right vertex (Figure 3.4a). By definition



(a) f : Change in Proportional Influence of one Domain on the Other. Red Dots Denote Attractors.

(b) Graphing f

(c) Representative Graph of f. Green Dot Represent Repellers.

(d) Phase Diagram

Figure 3.4: Pairwise Interaction Case 2 Competition, Cited from [83]

of f, it means in this region the value of x will increase (Figure 3.4b), hence the proportional influence of the right domain expands and moves to the right where the right domain itself is even more dominant, denoted as a right-pointed arrow in the right region (Figure 3.4c). Correspondingly, there exits $f(x) < 0$ around the left vertex, which means in the left region the value of x will decrease, that is, the value of $1 - x$ increases. Thus, the proportional

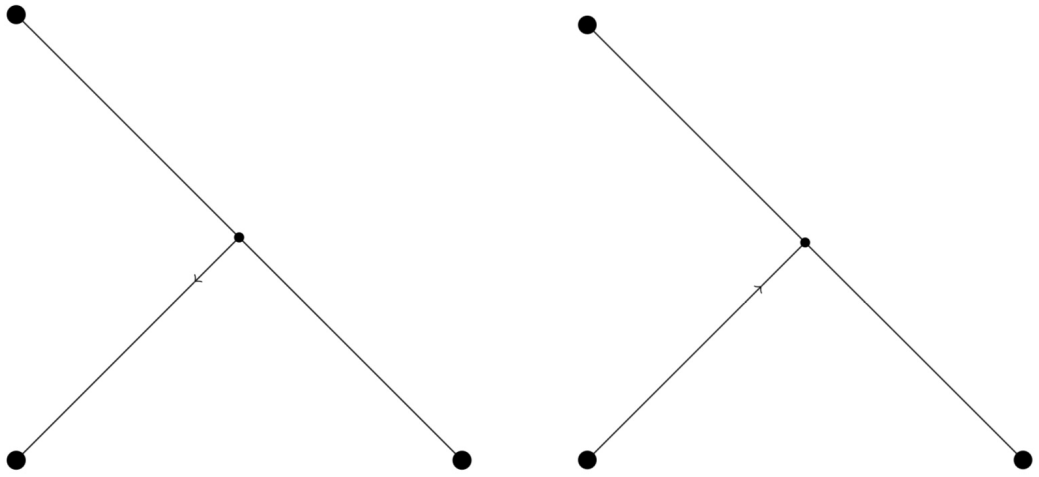
influence of the left domain boosts and moves to the left where the left domain is even more dominant, denoted as a left-pointed arrow in the left region. The dynamic lasts, until either arrow first reaches a vertex where one domain's proportional dominance over the other is 100%. Thus, the relative change of the proportional dominance becomes zero — an *attractor* is born at either domain, depicted as the red circle at either vertex hence a *repeller* in between in the *phase diagram* (Figure 3.4d). The interpretation is that if two domains disagree, then each gains influence from its own dominance, i.e., they compete.

(a) Phase Diagram

(b) Phase Diagram

Figure 3.5: Pairwise Interaction Cases 3 and 4 with Neutrality

Together, all three pairwise interactions form a triangular relationship among the three domains, represented as a triangular curve connecting law at the top vertex, and social practice and medical ethics at the left and right bottom vertices (Figure 3.7 first row). Given an edge flow, the third domain may (Figure 3.6a) or may not (Figure 3.6b) join in the



(a) join

(b) not join

Figure 3.6: Third Domain Participation

interaction between former two. If the third domain involves, it exerts additional influence hence generates an *interior flow*, represented as an arrow pointed away from the edge toward the third vertex (Figure 3.6a). Otherwise, its influence dies out producing an interior flow depicted as an arrow pointed toward the edge and away from the third vertex (Figure 3.6b). Given the data of a particular issue at a particular time, vertices, edge flows, and interior flows compose a configuration at that time.

3.4 Step 4: Map from Initial Configuration to 64 Possible Final Configurations

Over time, how many possible configurations are there at the lowest level of complexity? Recall that along each of the three edges, there are two main interactions, not to mention cases of neutral characteristics; and toward or away from each of the three edges, there are two further possible involvements of the third vertex. In total, there are $2^6 = 64$ possible configurations at the lowest level of complexity. In other words, there are 64 simplest cases. One can lay out a map from the configuration of the initial state where an event occurs in one domain to all 64 possible configurations of the final state.

Figure 3.7 illustrates a map of this kind. Consider an initial state appears in the domain of social practice (e.g., false advertisement of OxyContin by Purdue Pharma), while the other two domains are neutral. The first row shows that the vertex of social practice attracts all internal dynamics and dynamics on the boundary. The activity either irritates or resonates with medical ethics, which either competes or cooperates with social practice and hence generates $2^1 = 2$ cases in the second row. In each case, the third player, law, may (e.g., regulate) or may not (e.g., leave Purdue Pharma alone) engage the existing interaction, which leads to two further situations; hence, $2^2 = 4$ scenarios in the third row.

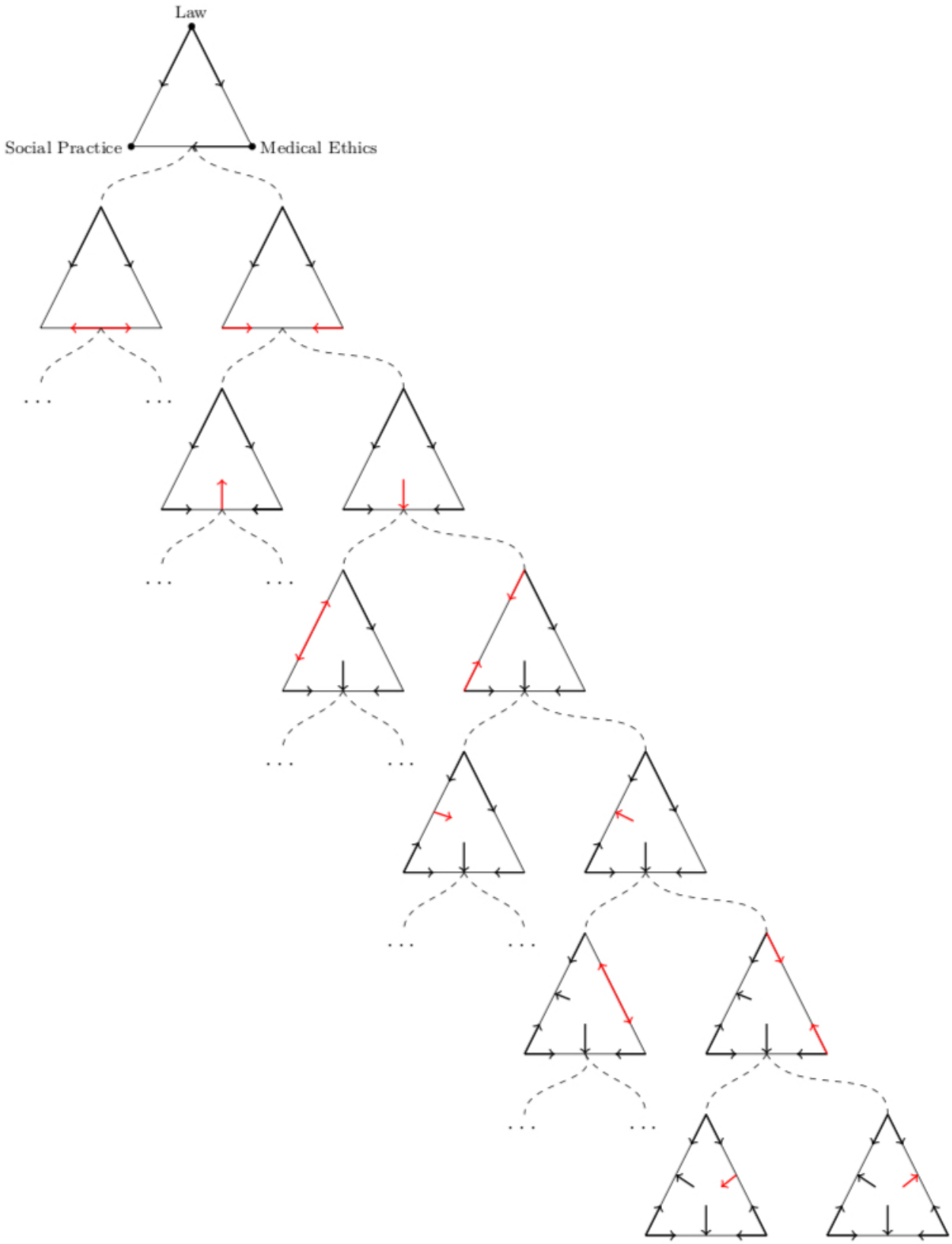


Figure 3.7: Map from Initial Configuration to 64 Possible Final Configurations

Moreover, it takes time for the law to weigh relevant principles and develop an attitude toward the issue, which determines its interaction with social practice — competition or cooperation — and adds up to $2^3 = 8$ configurations in the fourth row. Further, regarding the newly-formed interaction between law and social practice, the third player, medical ethics, may or may not influence, which amounts to $2^4 = 16$ possibilities in the fifth row.

Similarly, the interaction between law and medical ethics cumulatively leads to $2^5 = 32$ cases in the sixth row. Besides, social practice may (e.g., lobby lawmakers and medical groups) or may not (e.g., let the legal and medical experts decide the destiny of its product OxyContin) decide to influence. Exhaustively, there are $2^6 = 64$ possible configurations of the final state in the seventh row. Which one will result relies on the contextual data of a particular issue at each intermediate state. One can put together configurations of all intermediate states to detect along which path in the map the issue evolves, so that one can reach the configuration of the final state. Notice that an event can occur in any of the three domains, hence there are $64 \times 3 = 192$ possible configurations of a final state.

3.5 Step 5: Characterization of a Configuration

For each configuration, especially that of the final state, I use Theorem 3.4 to predict the outcome — the index of interior equilibria. It indicates the existence, number, and nature of interior equilibria. The same index, however, may be alternatively characterized as a different number and nature of interior equilibria; this is where the complications arise.

Specifically, alternative characterizations of a fixed configuration are contingent on 1) the pair of interior equilibria summing to the same index, and 2) the nature of interior equilibria with the same index. Theoretically speaking, when the index of interior equilibria is 0, there could be infinitely many pairs of interior equilibria with indices -1 and $+1$ offsetting each

other. How many pairs are there depends on the contextual data (e.g., the directions of interior flows). The least number of pairs as the simplest case often give sufficient insights into the issue. Moreover, an equilibrium with index +1 could be a repeller, an attractor, or an attracting or repelling limit cycle. Which one is correct also depends on the contextual data of a particular issue. Upon arrival at the final state, after careful characterizing its configuration, one is ready to predict its outcome.

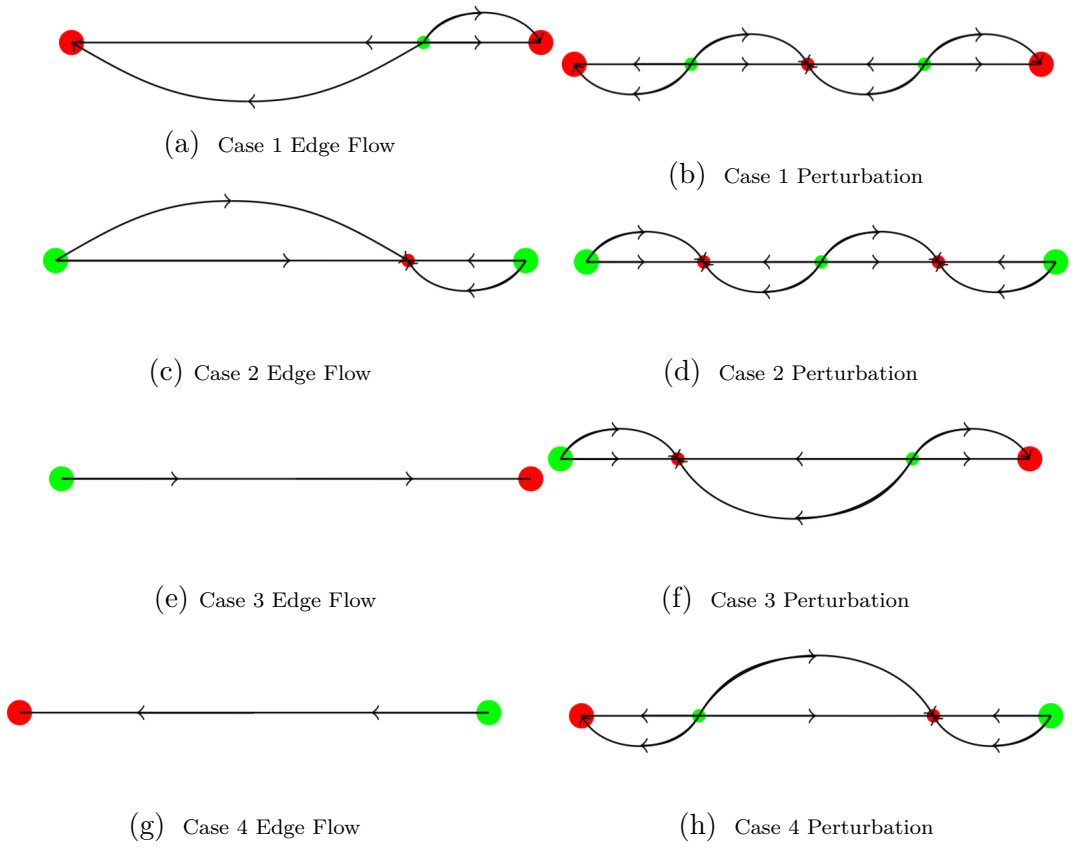
3.6 Step 6: Bifurcation & Policy

An outcome of a dynamic system, however, can suddenly shift into a distinct outcome as some parameter varies. Such a phenomenon is called a *bifurcation*. Two dynamic systems that share similar configurations hence have similar outcomes are called *conjugate* or *equivalent* to each other. In other words, if the flows of two dynamic systems are topologically equivalent and result in the same outcome of dynamics, such as the same number and nature of equilibria, then the two dynamic systems belong to an *equivalence class*.

Bifurcations may be caused by 1) mutations of vertices, 2) perturbations of edge flows, and 3) insertions of interior flows, as resulted from natural evolutions or policy interventions. Firstly, each vertex may mutate owing to variations in weighing its inherent principles. Secondly, each edge flow may be perturbed by exogenous shocks such as policies, wars, and economic crises. A theorem below that is generically true categorizes four perturbations of an edge flow, and hence is crucial for policy analysis [83].

THEOREM 3.5. If the edge flow moves toward each vertex (Figure 3.8a), then any robust continuous model has an odd number of equilibria in-between. These equilibria alternate from being a repeller, where motion moves away from the equilibrium, to an attractor, where motion starting at points near the equilibrium moves toward the equilibrium, and then to another repeller (Figure 3.8b). Similarly, if the edge flow moves away from each vertex

(Figure 3.8c), then the odd number of in-between equilibria alternate from an attractor to a repeller and then to another attractor (Figure 3.8d). If the motion near both vertices move to the right (Figure 3.8e), then there is an even number of in-between equilibria in the attractor, repeller order (Figure 3.8f). Whereas, if the motion near both vertices moves to the left (Figure 3.8g), then an even number of in-between equilibria alternate from repeller to attractor (Figure 3.8h).



(a) Case 1 Edge Flow

(b) Case 1 Perturbation

(c) Case 2 Edge Flow

(d) Case 2 Perturbation

(e) Case 3 Edge Flow

(f) Case 3 Perturbation

(g) Case 4 Edge Flow

(h) Case 4 Perturbation

Figure 3.8: Theorem 3.5 for Policy Analysis

Lastly, the directions of interior flows may also be diverted by the strategic decisions of each third player. Given ever-changing contextual and longitudinal data, one needs to update configurations to make updated and sound predictions. Below I show how to do so in case studies ranging from historical to contemporary times.

Chapter 4

Application of General Theory to Particular Cases

In this Chapter, I show how to apply the general theory to particular issues that have already completed or have almost completed evolutions in history. The purpose is to validate the general theory whose predictions are evidence-based, reliable, and robust using past data of fully-evolved cases.

For each issue, I start with key concepts and ethical dilemmas. To construct a configuration of the initial state, I describe the early observational data to examine underlying principles and determine the characteristic of each domain (i.e., vertex), as well as interactions (i.e., edge flows and interior flows) among domains. I then use Theorem 3.4 and compare with the reality to predict the dynamic outcome at the final state. With new observations available over time, I update the configuration and prediction (hence bifurcations) and compare updated projection with the newly-evolved reality. I also conduct cross-country comparisons for global issues, and policy analyses to detect unexpected and undesired outcomes.

4.1 Birth: In Vitro Fertilization (IVF)

4.1.1 IVF Prediction

Assisted reproduction IVF is a process of fertilizing an egg with sperm outside the body and transplanting the zygote in the fallopian tube to initiate a pregnancy. It faces an ethical dilemma in which the principle of doing no harm to babies conflicts with the principles of doing good to infertile patients and respecting patients' autonomous choices.

The first IVF baby, Louise Brown, was born in 1978 as requested by her parents, who were accused of being unethical by the majority of society and the medical community [76]. The fear of unknown harm in the general public dominated the need for fertility in the infertile population. According to the coordinate system, it was the *psychological need* that prevailed over the *physical need*. Overall, society strongly opposed IVF. Similarly, since the harm to an IVF baby and its possible heredity to future generations were much more uncertain than the benefit of having the baby, *nonmaleficence* outranked *beneficence*. Medical ethics also denounced IVF, while the law was indifferent.

The characteristics of the three vertices decide their interrelationships (Figure 4.1). Both the society and medical community resist IVF, so they cooperate, denoted as the bottom edge flow where two arrows are drawn toward each other from the domains of social practice and medical ethics. Meanwhile, the neutrality of law is readily affected by the other two domains, displayed as arrows sending from the top vertex along the lateral edges to the two bottom vertices.

As a result, the edge flows yield equilibria on the boundary: one repeller with index $+1$ at the law vertex, two saddles with the same index -1 at the vertices of social practice and medical ethics between which an attractor with index $+1$ is born. Adding them all gives a 0 partial sum of local indices. Meanwhile, proceeding along the boundary counterclockwise,

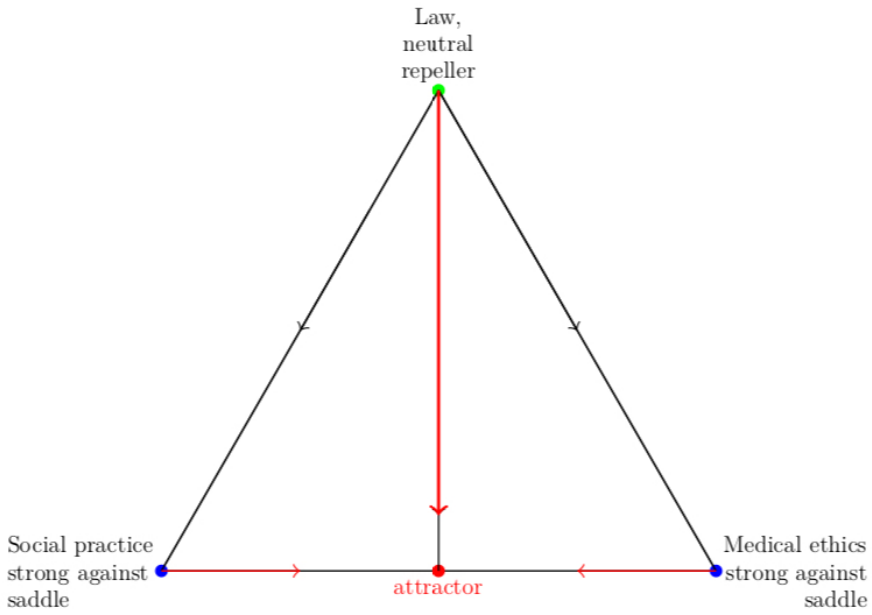


Figure 4.1: IVF Dynamics: 1978 Resistance to First IVF Baby

one encounters zero counterclockwise revolutions; hence, the global index is 0. By Theorem 3.4, subtracting the partial sum of local indices from the global index gives a 0 index of interior equilibria. It implies that, in the simplest case, there exists no interior equilibria; so all dynamics converge to the attractor on the bottom edge. Therefore, the theory predicts that when both society and medicine share ethical concerns while the law being indifferent, IVF will continuously encounter social and professional resistance.

A bifurcation, however, can easily occur when the neutrality of law is perturbed. Perhaps constituents or lobbyists bring their worries to lawmakers. Legislative deliberations draw dynamics away from the bottom edge, hence turns the attractor into a saddle (Figure 4.2). Consequently, the global index and partial sum of local indices change to -1 and -2, respectively. By Theorem 3.4, the index of interior equilibria becomes $+1$. Given the directions of existing flows where the arrow at the bottom saddle points upward, and the arrow from the repelling law vertex points downward, it is consistent with characterizing the interior equilibria as an attractor or attracting limit cycle. The attractor suggests a permanent peace among society, medicine, and law (Figure 4.3). .

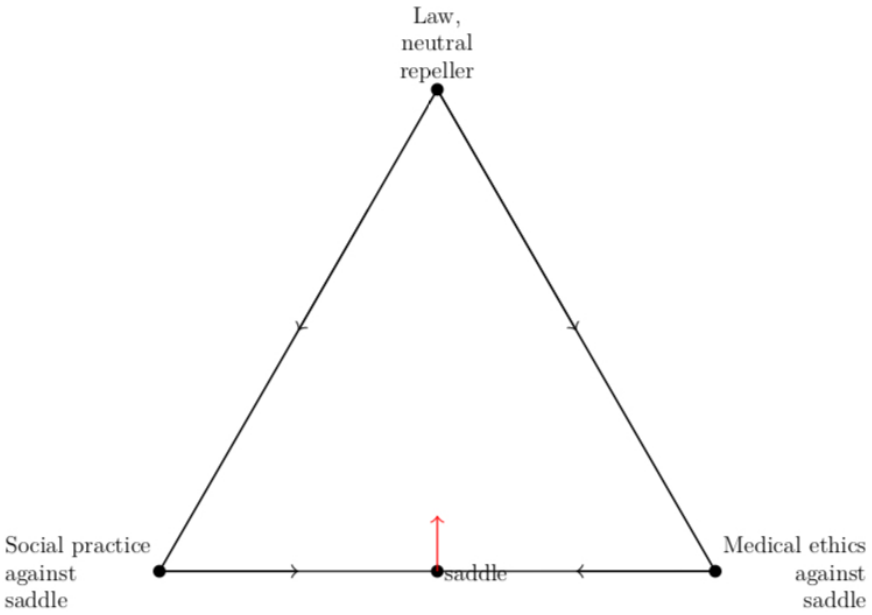


Figure 4.2: IVF Dynamics: Law Action

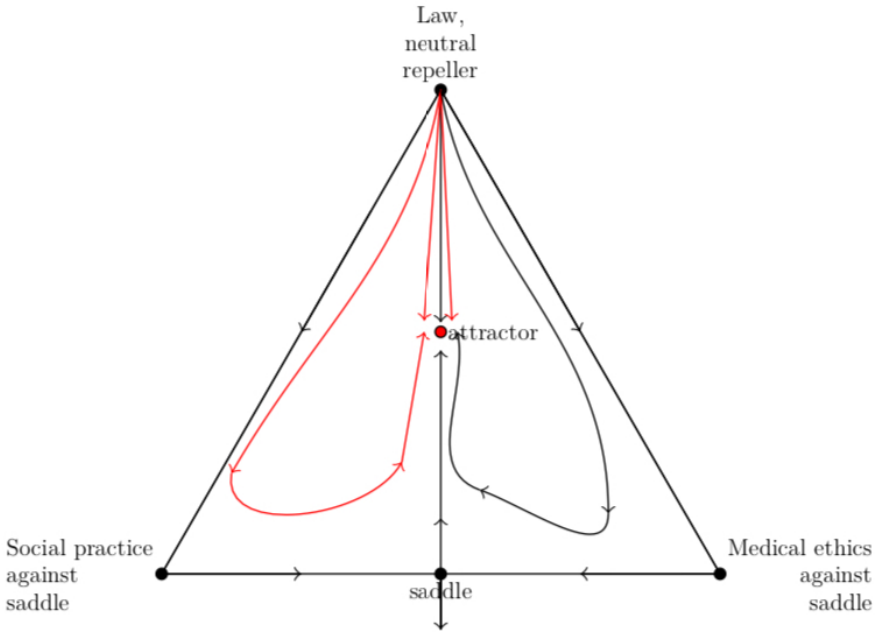


Figure 4.3: IVF Dynamics: Law Action Outcome Case 1

Alternatively, an attracting limit cycle has internal dynamics repelling while external dynamics converging to it (Figure 4.4). The interpretation is that whenever a coalition of two domains, for example, society and law, seems to dominate the situation (i.e., flows approach the left edge), the force of medical ethics will drag the dynamics back to a compromising

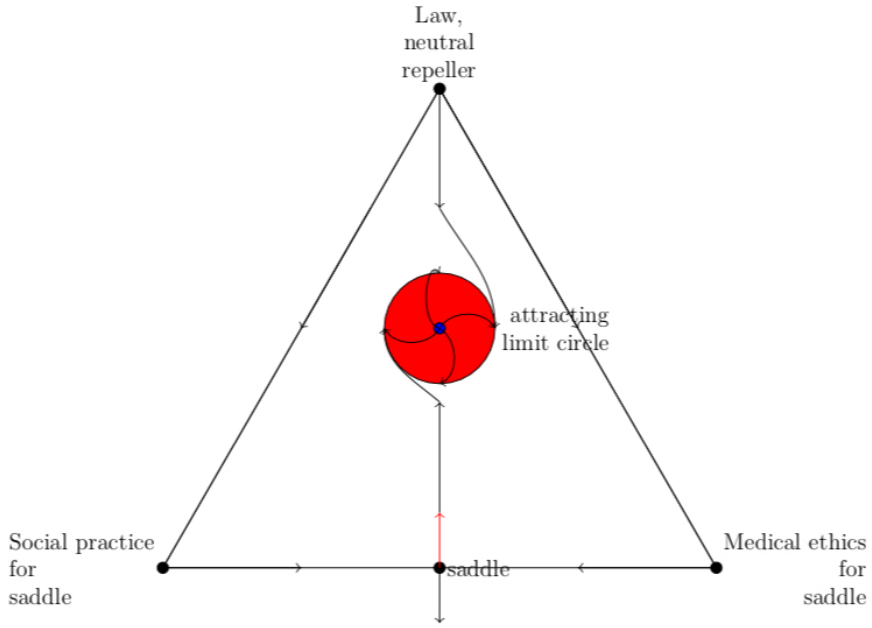


Figure 4.4: IVF Dynamics: Law Action Outcome Case 2

zone. Such an oscillation never ends; hence, as long as the law's attitude remains neutral, the IVF issue will never be settled.

Over time, a bifurcation gradually develops as the law sufficiently consults and reflects *external values* in the other two domains [57]. In Figure 4.5, on the left edge, the law

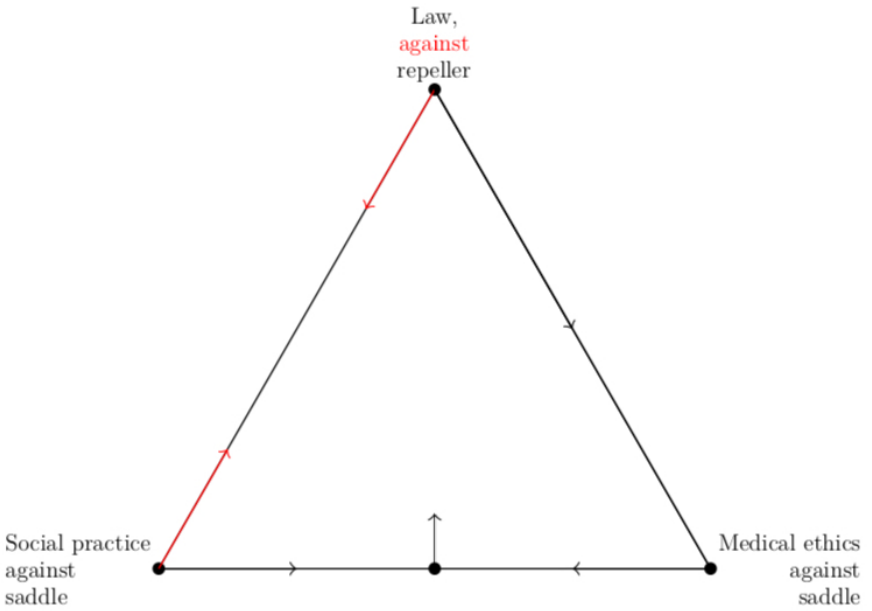


Figure 4.5: IVF Dynamics: Law Cooperates with Society

cooperates with social practice, displayed as two arrows sending from the two vertices toward each other and producing an attractor in between. Medical ethics may or may not participate in this cooperation. If it does not join in, then the interior flow points away from its vertex toward the left edge; and all dynamics converge to the attractor on the edge. In that scenario, medical ethics lets the issue be resolved entirely by the alliance of law and society against IVF (Figure 4.6). Otherwise, the attractor on the left edge will be pulled to the interior

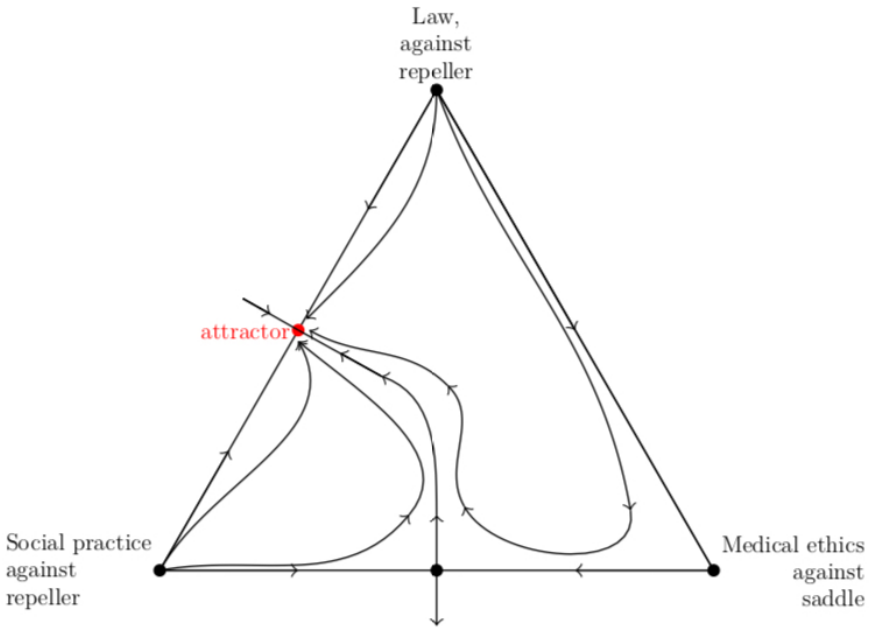


Figure 4.6: IVF Dynamics: Outcome Case 1:
Medical Ethics Inaction

(Figure 4.7), forming a more balanced power among the three. Similarly, on the right edge, the law also collaborates with medical ethics. Additional social resistance leads to an interior attractor suggesting a perpetual rejection of IVF among the three (Figure 4.8).

Vertices mutate as evidence accumulates; hence, a further bifurcation rises. In the intervening decades since her birth, the general public observed that Louise Brown grew to adulthood and eventually gave birth to two healthy babies [24, 12]. The fear of unknown harm to IVF babies disappeared, while the demand for IVF services increased among fertility-challenged couples and among singles and same-sex couples [20]. In terms of underlying principles,

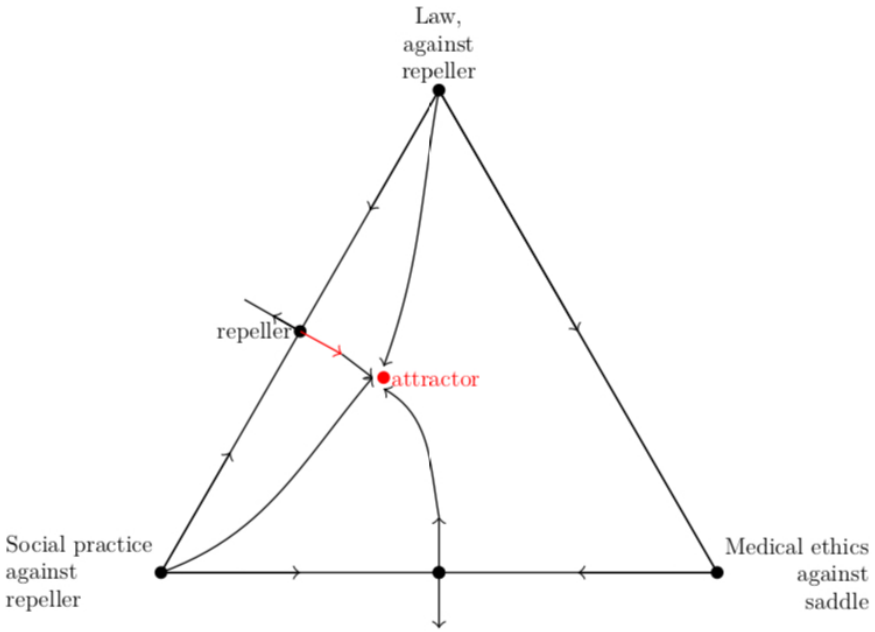


Figure 4.7: IVF Dynamics: Outcome Case 2:
Medical Ethics Action

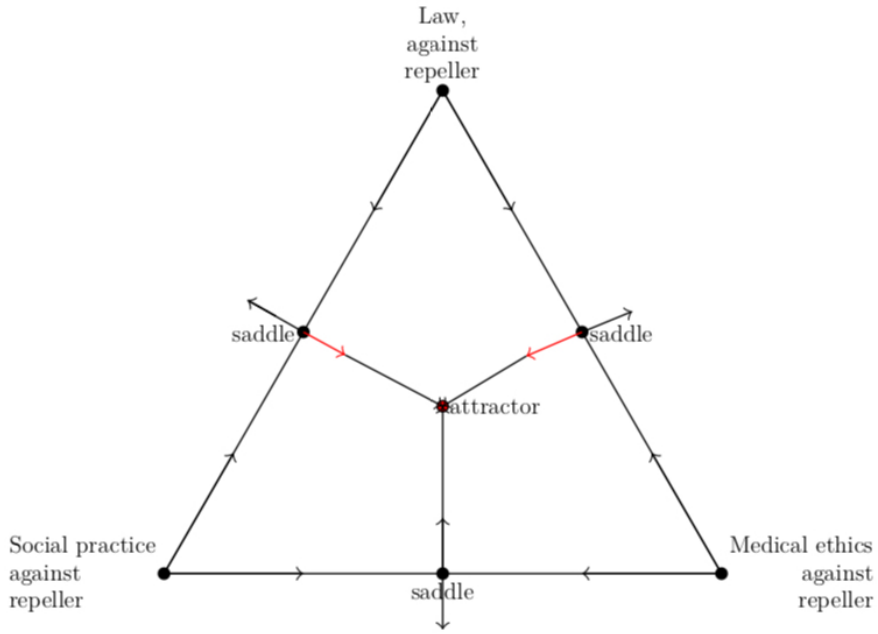


Figure 4.8: IVF Dynamics: Law Cooperates with Medical Ethics & Society Action

psychological needs became overridden by *physical needs*; hence, the prevailing social attitude shifted from negative to positive. Similarly, *nonmaleficence* was overpowered by *beneficence* and *autonomy*. Therefore, both vertices of social practice and medical ethics mutate from

resistance to acceptance while staying cooperative. Thus, the updated directions of the bottom edge flows remain unchanged.

Whether the overall dynamics alter depends on whether the law mutates. Given the fact that both the law and society actively entangle themselves with the IVF issue (e.g., states mandated insurance coverage of IVF services, same-sex couples sued clinics for refusing IVF requests [20]) while medical ethics does not [76], if the law also flips to acceptive (Figure 4.9), then there will exist a saddle on the right edge and an attractor on the left edge, which

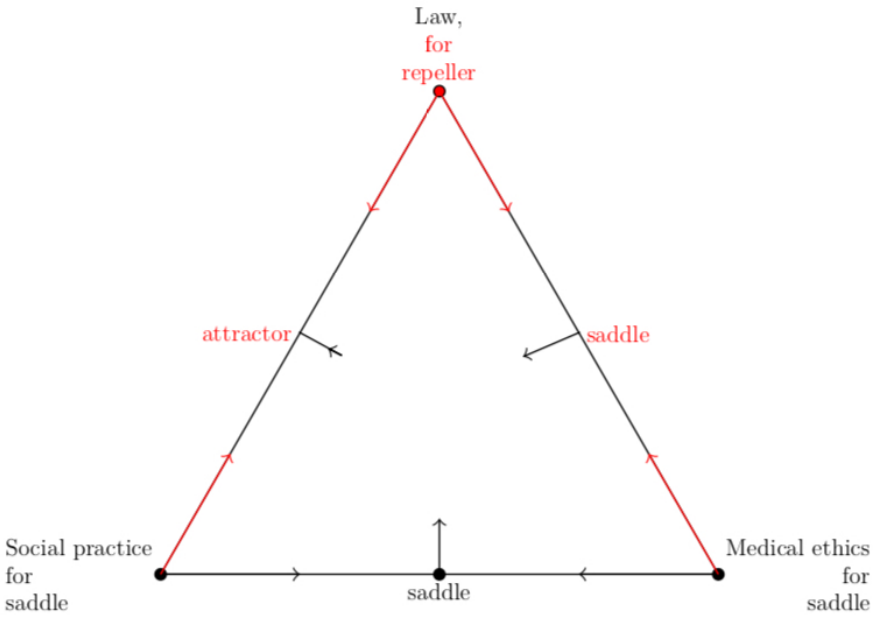


Figure 4.9: IVF Dynamics: Mid-1990s– Society & Medical Ethics Mutate, Case 1: Law Mutates

results in a prevailing acceptive agreement between law and society.

Otherwise, the law continues prohibition. Then instead there will occur a saddle and a repeller on the lateral edges, respectively (Figure 4.10), which generates a -2 partial sum of local indices and a -1 global index, hence a $+1$ index of interior equilibria (Figure 4.11). Given the directions of existing flows, it is impossible to have only one attractor or one repeller in the interior. Moving to the next level of complexity, it is consistent with having three equilibria — a saddle, a repeller, and an attractor — whose net index is still $+1$. The

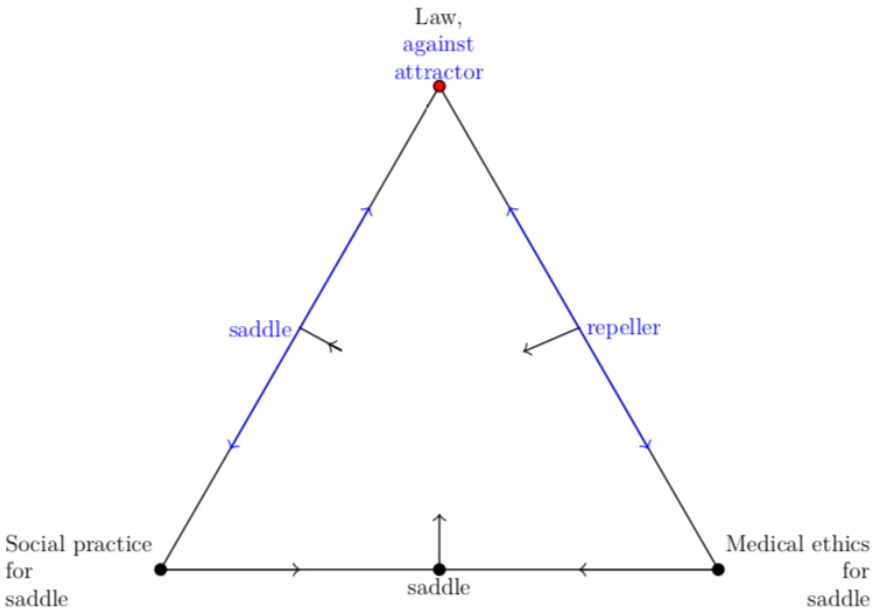


Figure 4.10: IVF Dynamics: Mid-1990s– Society & Medical Ethics Mutate, Case 2: Law Reserves

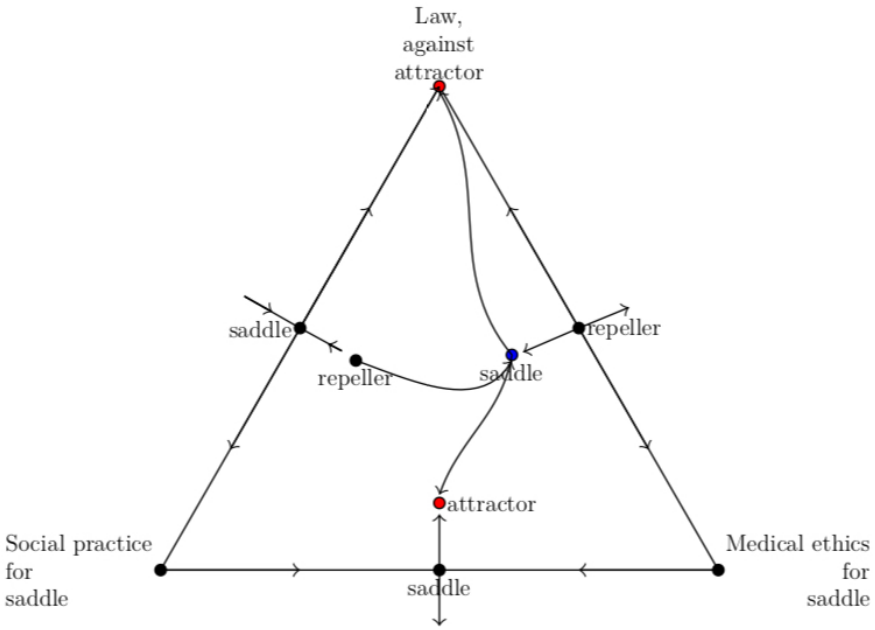


Figure 4.11: IVF Dynamics: Case 2 Outcome

attractor, in particular, locates in the lower region and is bounded by the flows above that connect interior saddle and repeller to equilibria on lateral edges. The characterization of the final state predicts that even though the law keeps illegalizing IVF, ultimately, the issue will evolve into an acceptive union between society and medicine with some but relatively

little impact of the prohibitive law.

The prediction is proven by reality. Although the federal law bans IVF services at any federal-funded facility and only a minority (18 out of 50) of states mandate its insurance coverage for infertility, from the mid-1990s to the mid-2000s, there was a dramatic increase in IVF usage by 114% and success by more than 30% live births [20]. During 2017, about 78,052 IVF infants, accounting for 1.7% of all infants, were born at 448 reporting clinics in the U.S. [30].

4.1.2 IVF Policy

Policies could be examined and excluded if the projection of the outcome is unsatisfactory. Interventions can aim to endogenously mutate a vertex, say, the law. For instance, IVF lobby groups such as the National Infertility Association may convince Congress to abolish the federal ban or expand the state mandate. As a result, the law inverts from resistant to benignant (Figure 4.12). It transforms edge flows accordingly and generates a +2 partial

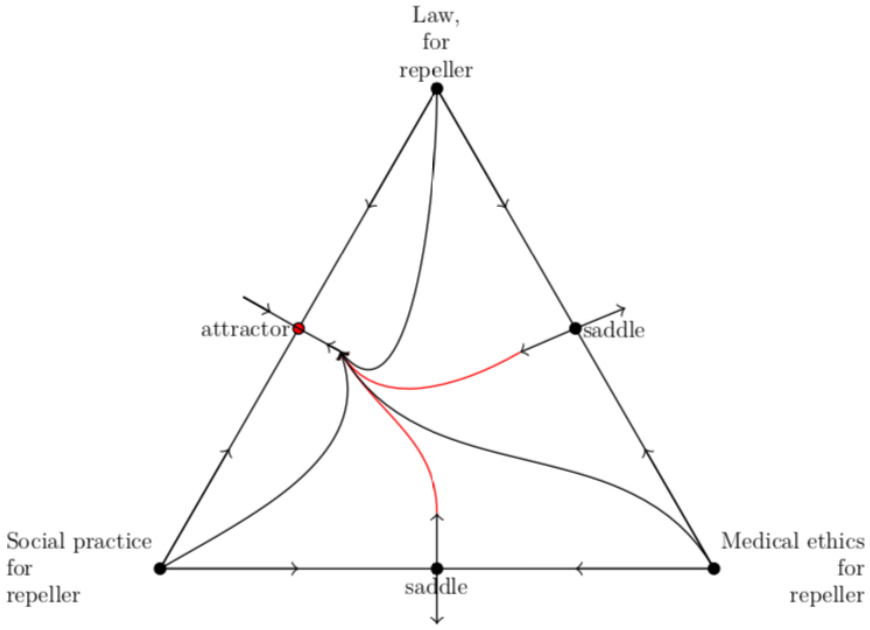


Figure 4.12: IVF Policy: AHRQ Regulation Case 1 Social Action

sum of local indices and a +2 global index, which implies a 0 index of interior equilibria. Given directions of existing flows, it is consistent with having zero interior equilibria; hence, all dynamics converge to the attractor on the left edge. The policy strengthens a mutual agreement between society and law to support IVF.

Policies can also target at perturbing an edge flow. For example, the Agency for Healthcare Research & Quality (AHRQ) may require private IVF clinics to install higher-standard facilities. It intervenes the competitive relationship between medicine and law hence, by Theorem 3.5, breeds three equilibria on the right edge (Figures 4.13 and 4.14). Its evolutionary outcome depends on the societal reaction. It may agitate the infertile and same-sex population over a threshold and stir up protests, represented as the interior flows sending from the three newly-formed edge equilibria to the vertex of social practice. The updated configuration then anticipates a +1 index of interior equilibria, which is consistently characterized as an attractor in the confined right lower region. With efforts of the general public, there is a small chance that tolerant medical ethics dominates resistant law, and people can still get access to private IVF services (Figure 4.13). Otherwise, social groups remain silent and

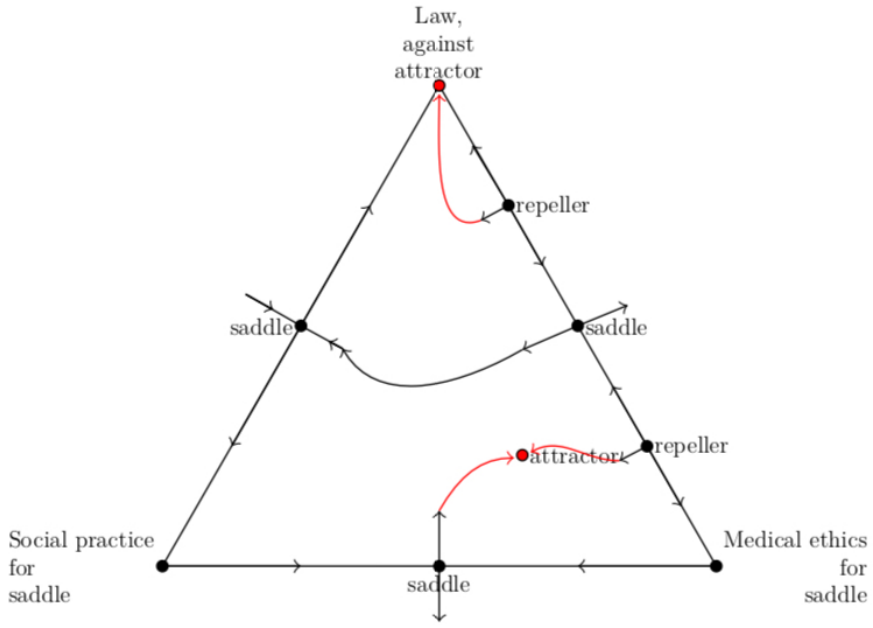


Figure 4.13: IVF Policy: AHRQ Regulation Case 1 Social Action

inactive, depicted as interior flows pointed toward the right edge and away from the bottom left vertex, and there will be little hope for any compromise between law and medical ethics — an undesired outcome for a seemingly mild policy (Figure 4.14).

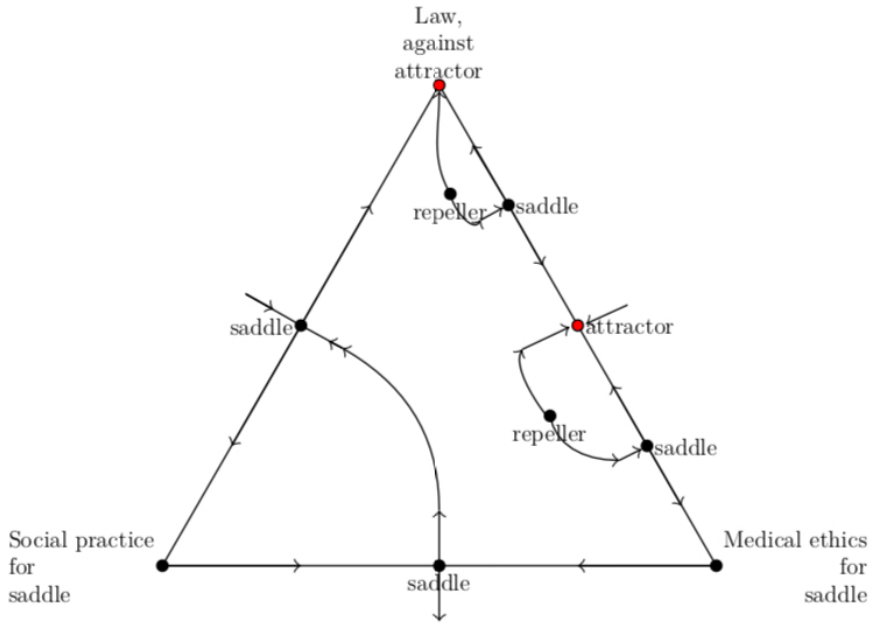


Figure 4.14: IVF Policy: AHRQ Regulation Case 2 Social Inaction

4.2 Death: Medical Futility

4.2.1 Medical Futility Prediction

Beginning in the 1980s, physicians reduced support for, or stopped providing, services that were judged to be futile [76]. As a result, the then new trend of Medical Futility Movement gave rise to an ethical dilemma in which the double negation of *do good — do not do if not good* — paternalistically overrode *respect patients' autonomy*. In its early stages, society and law failed to notice the trend, let alone responded. So all dynamics converged to medical ethics at the right corner (Figure 4.15).

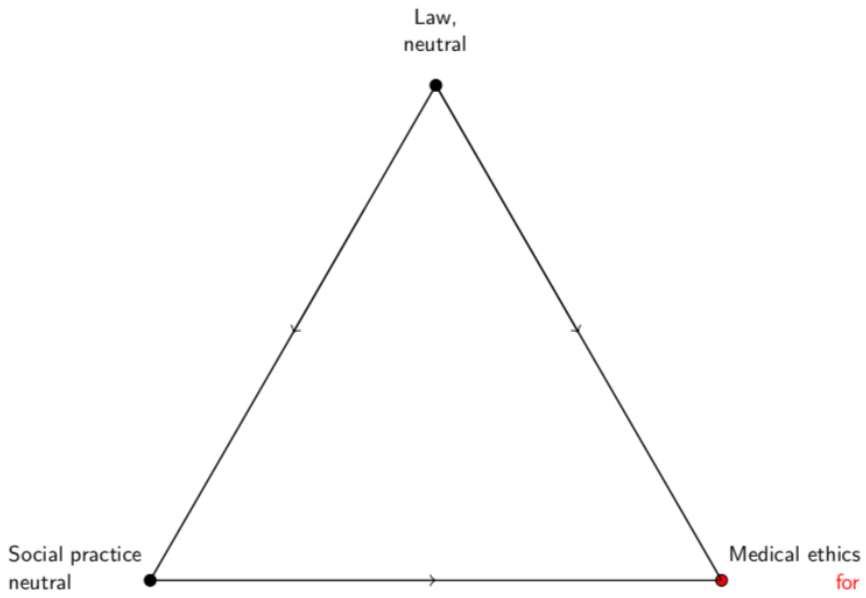


Figure 4.15: U.S. Medical Futility Dynamics: 1980s Rise

A bifurcation arose, as more patients and families rejected physicians' inaction and societal disfavor developed [84], which competed for power with predominant medical ethics resulting in a repeller near the bottom right vertex. As social repugnance grew, it dragged the repeller closer to the bottom left vertex (Figure 4.16). At the early stage, disputes had not escalated

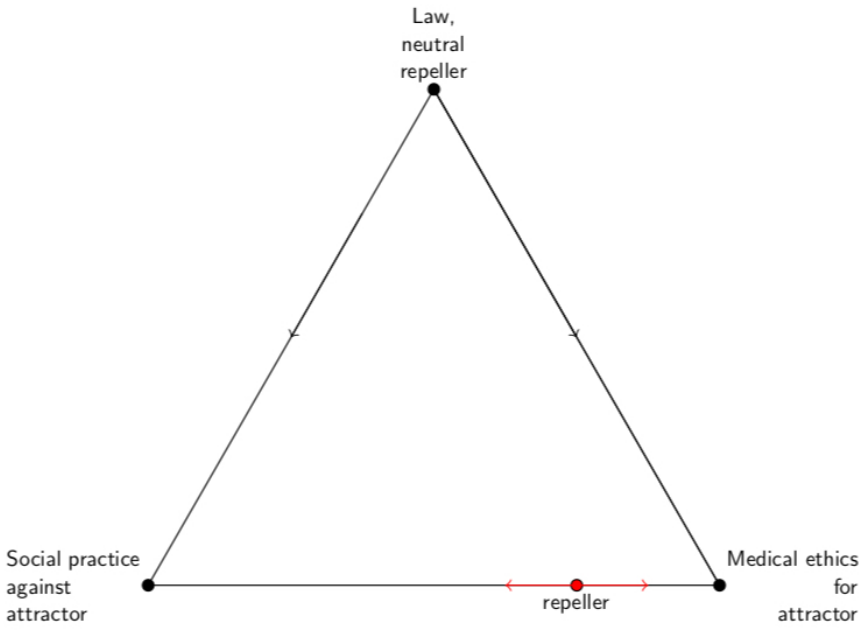


Figure 4.16: U.S. Medical Futility Dynamics: 1980s Social Resistance Continued

to courts and often been ended by either physicians or patients contingent on which side was more powerful, denoted as dynamics converging to two attractors at the two bottom vertices (Figure 4.17).

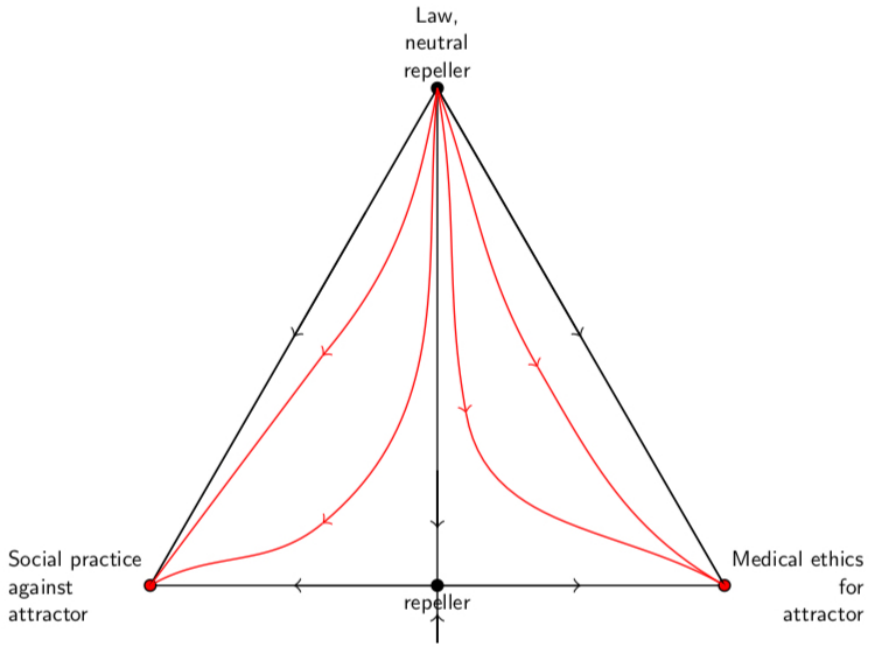


Figure 4.17: U.S. Medical Futility Dynamics: 1980s Law Inaction

Another bifurcation occurred when the irritation of patients aggravated over a threshold and they sought legal resolution. Such an involvement of the law is displayed as an arrow stemming from the bottom edge upward to the top vertex (Figure 4.18). For example, in *Gilgunn v. Massachusetts General Hospital* (1995), emergency physicians refused to provide a 70-year old comatose woman resuscitation that was believed to be futile. They were sued by the woman's daughter. According to the principle of *external reference*, the law has two sources or sub-principles to which it can refer. One is the *external need*; the patient's need to be alive justifies the use of resuscitation regardless of whether it is futile or not. The other is the *external value*; the physicians believe that resuscitation is futile for the patient, which justifies physicians' rejection of the patient's need. Thus, how this case will evolve relies on which sub-principle the grand jury will prioritize. Given the strong consensus on futility among physicians at the early development of the Futility Movement, it is more likely

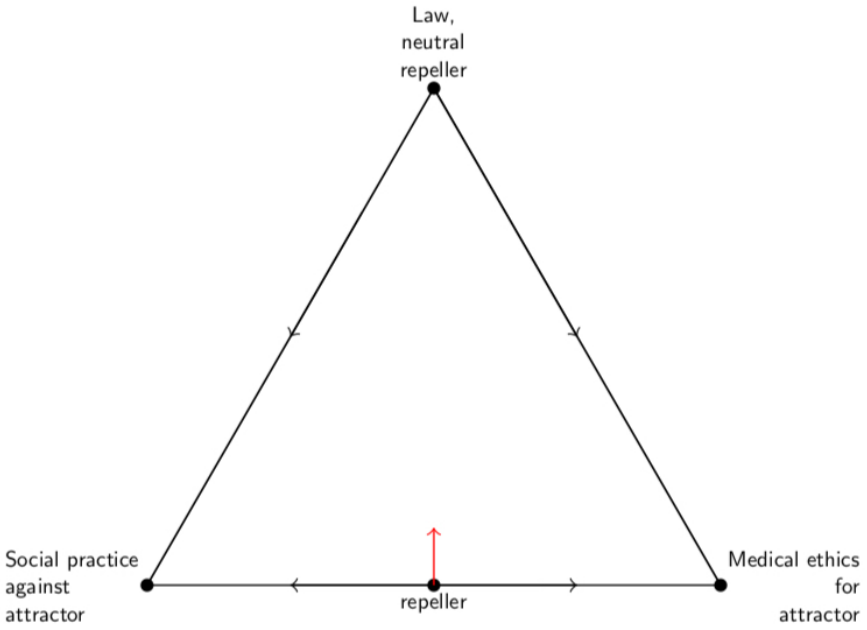


Figure 4.18: U.S. Medical Futility Dynamics: 1995 Law Action Began

that the jury weighs the opinion of medical experts more, and hence agrees with medical ethics. Such an agreement between law and medicine is depicted as two arrows sent from the top and right vertices toward each other (Figure 4.19). The cooperation between law and

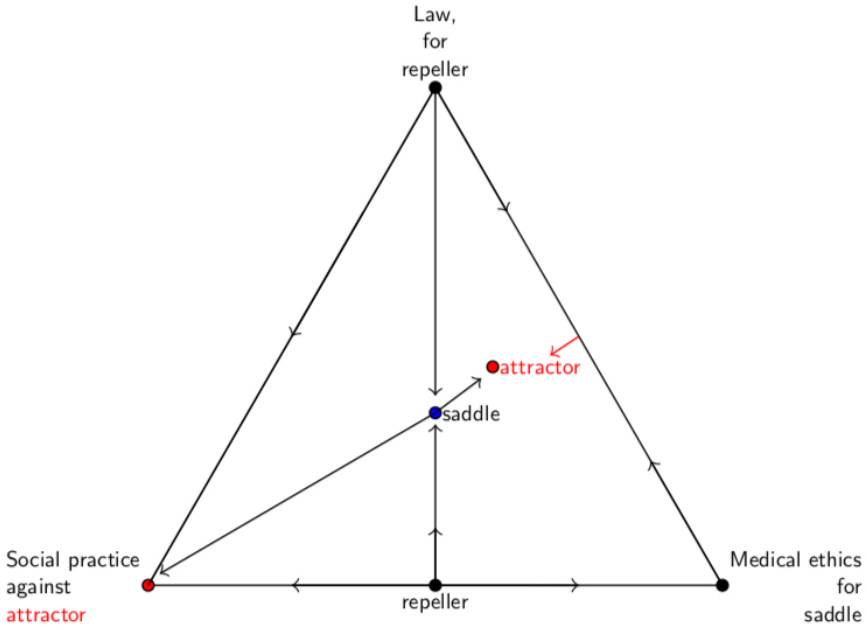


Figure 4.19: U.S. Medical Futility Dynamics: 1995 Law Action Outcome

medicine likely stirs social resistance [36, 37, 3], which justifies an arrow pointed away from

the right edge to the bottom left vertex. In Figure 4.20, on the left edge, the law and society

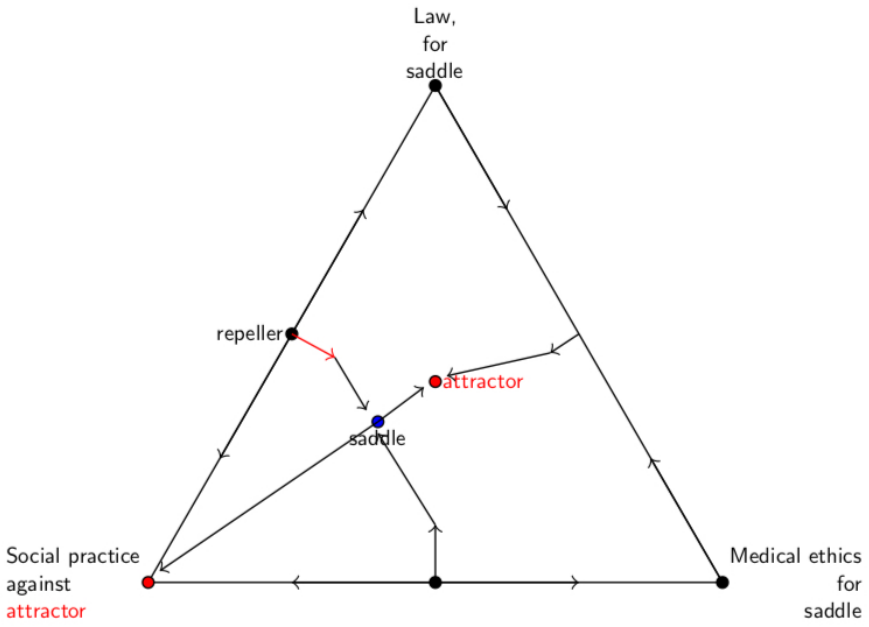


Figure 4.20: U.S. Medical Futility Dynamics: 1995 Medical Ethics Action; Peak

disagree on futility, represented as two arrows pulled against each other. Also, the Movement was argued as physicians' competition for power, a backlash of the 1970s Patients' Rights Movement [76], which rationalizes an arrow away from the left edge toward the bottom right vertex.

This configuration, by Theorem 3.4, predicts a 0 index of interior equilibria, which in the simplest case is characterized as a pair — a saddle, and an attractor locating in the large right region. Therefore, with the strategic involvement of medical ethics, it is largely likely that the Futility Movement will reach a stable, excessively liberal agreement between medicine and law dominating society.

The prediction matches reality. The grand jury consulted with medical experts and decided that physicians were not guilty [76]. Meanwhile, more than 130 journal articles of original research on futility were published in 1995, while the Movement was reaching its peak [40].

Following the rise of medical futility, a further bifurcation emerged. Dissenting voices within

the medical profession were expressed and spread emphasizing autonomy: "No one is better than the patient herself to judge what is best for her." [40] Over time, *autonomy* overweighed the double negation of *beneficence*. Hence, medical ethics switched to be cautious about futility. The lacking of a consensus on the concept, measurement, and value of futility in medicine turned the law to more consistent *need* of patients and families in society. Thus, the law also reversed against futility. Consequently, altered characteristics of both vertices changed the outcome resulting in a resonance among all three domains against futility (Figure 4.21).

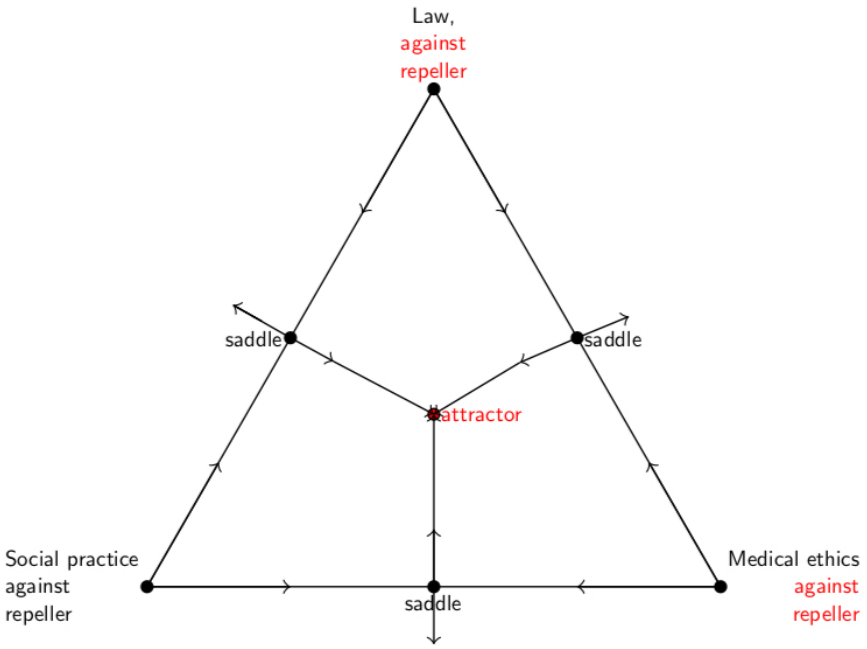


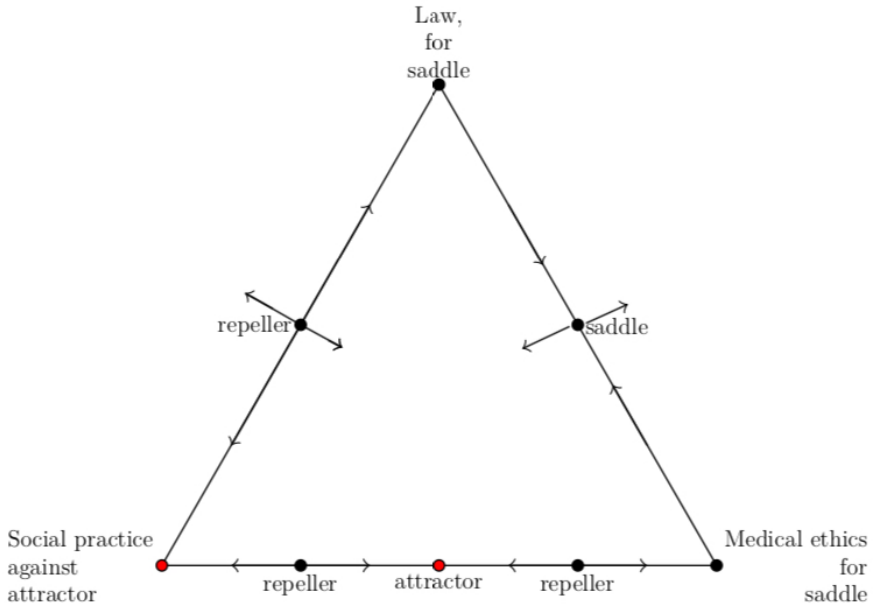
Figure 4.21: U.S. Medical Futility Dynamics: Late 1990s– Fall

The updated prediction is proved by observations — the fall of the Medical Futility Movement. In 1999, only 31 articles on futility were published. Medical ethicists reflected that "the courts have not upheld futility because there does not exist a consensus on its definition and the underlying principles." [40] Today, norms have formed, although AMA still states in *Code of Ethics* (2012) section 2.035 that "physicians are not ethically obligated to deliver care that, in their best professional judgment, will not have a reasonable chance of benefiting their patients," and "patients should not be given treatments simply because they demand

them." [5] In fact, patients are often given advanced directives to sign upon admission. Patients also usually decline treatments when they are advised by physicians that there is no realistic chance to recover [76].

4.2.2 Medical Futility Policy

Policies could have been introduced at an early stage to redirect dynamics and prevent unnecessary legal suits and emotional pains. Suppose hypothetically that in the early 1990s, patient groups signed a White House petition or lobbied the Agency for Healthcare Research and Quality (AHRQ) to regulate the trending practice of futility. Such a regulation, according to Theorem 3.5, splits the equilibrium on the bottom edge between society and medical ethics into three equilibria — one attractor and two repellers (Figure 4.22a). Although there



(a)

Figure 4.22: U.S. Medical Futility Policy: Early 1990s Option

are $2^3 = 6$ possibilities regarding how the law engages, two extreme cases offer a simple comparison of good and bad policies.

In one case, the law remains inactive, denoted as the interior flows sending from the top vertex to all three newly-formed equilibria. Since the policy *per se* limits the practice of futility and acts as a gatekeeper to reduce lawsuits, there is no need for the law to influence. Then, the theory predicts a +1 index of interior equilibria, characterized as a repelling limit cycle that directs nearby frustrating dynamics to the new stable attractor on the bottom edge. Hence, in addition to the attracting social practice, dynamics partly converge to the in-between attractor on the bottom edge — a new compromise between the autonomous society and paternalistic medical ethics: A policy would be welcomed by both sides (Figure 4.23).

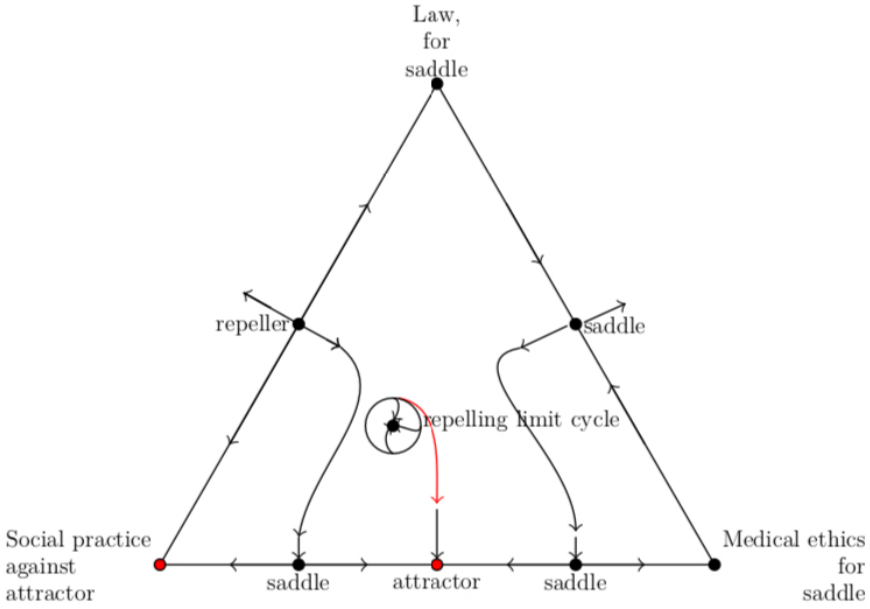


Figure 4.23: U.S. Medical Futility Policy: Case 1 Law Inaction

In the other case, where the law entangles completely, the attractor on the bottom edge suddenly disappears. Theoretically speaking, *ceteris paribus*, there will never be any room for compromise — an unexpected and, from physicians' perspective in that era when no one knew what was right to do, an undesired outcome (Figure 4.24): A policy could be bad, and the law may make things worse.

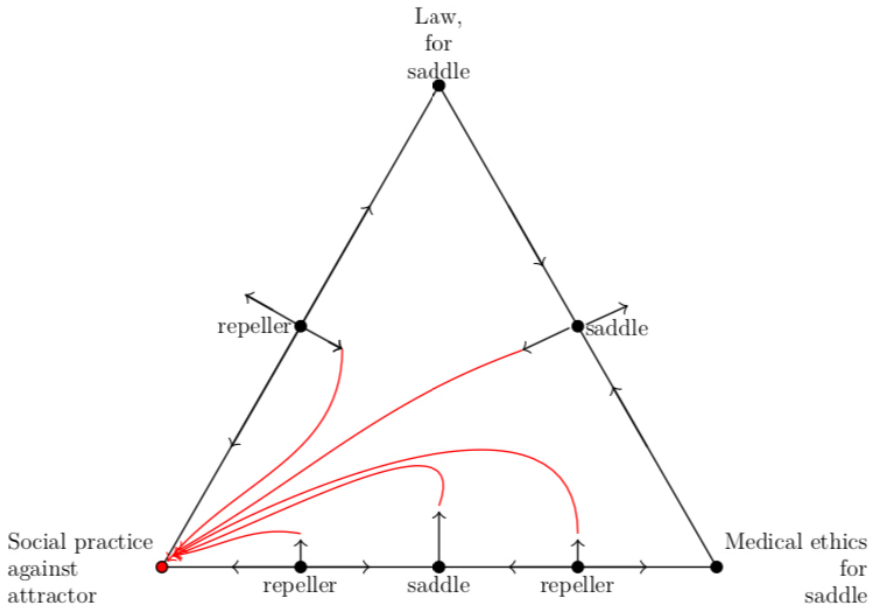


Figure 4.24: U.S. Medical Futility Policy: Case 2 Law Action

Chapter 5

Prediction of Contemporary Issues

In this Chapter, I apply the general theory to contemporary issues, including stem cell research, genome editing, abortion, the opioid epidemic, and healthcare artificial intelligence. Issues alike are ongoing, puzzling, and awaiting predictions about what can and probably will happen and what needs to be done.

5.1 Birth: Stem cell research

The evolution of the IVF issue in the Chapter above shed light upon the research in human embryo, stem cell, and genome editing because they are similar in the sense that they all can be used for assisted reproduction and disease eradication, but are also different in the sense that they may intervene at distinct levels of germline cells, non-germline cells, and genes. The IVF projection suggests that medical, legal, and social attitudes may mutate, as more evidence of the unknown harm is accumulated; and that if the harm is known to be significantly smaller than the benefit, then a technology would eventually be accepted. Below I examine whether this is the case for stem cells.

5.1.1 Japan pluripotent stem cells (iPSCs) Prediction & Policy

There are three primary sources of stem cells — human embryo (hESCs), somatic cell nuclear transfer (SCNT), and induced pluripotent stem cells (iPSCs). In 1998, John D. Gearhart at Johns Hopkins University in the U.S. first identified and isolated hESCs, which however are often derived from spare embryos or aborted fetuses; hence are controversial. SCNT inserts the nuclear of an adult cell into an enucleated egg and then stimulates it to develop into an embryo for stem cell harvest. SCNT is cloning, which produced Dolly the Sheep in 1996, Scotland. It copies the same DNA of the adult cell hence is asexual reproduction and threatens traditional sexual reproduction of the human species hence is the most controversial and prohibited. In 2006, Shinya Yamanaka at Kyoto University in Japan invented iPSCs by reprogramming adult cells back into a pluripotent state. Essentially, he transduced four exogenous stem cell-associated genes into adult skin cells by viral vectors, and grew them in the ESCs culture into embryonic-like colonies. The iPSCs alleviated ethical concerns of the former two and were awarded the 2012 Nobel Prize in Physiology or Medicine for clinical potentials.

How the event of iPSCs will evolve depends on the purpose — reproduction or therapy — and geography. Despite the lack of law and medical ethics, depicted as the neutrality of the two domains, the Japanese Ministry of Science implemented a policy that forbade iPSCs to be used to produce germline cells and human [74]. Given the noninvolvement of the law, such a restraining policy breaks the complete dominance of emboldened scientific practice over medical ethics, creating an attractor — a stable equilibrium — on the bottom edge. The theory predicts that the policy effectively adds a stable, mutual balance between social practice and medical ethics, which matches the reality (Figure 5.1).

Nevertheless, Japan administers a progressive policy for iPSCs use in disease eradication. The first iPSCs clinical trial was approved for a patient with macular degeneration in 2014

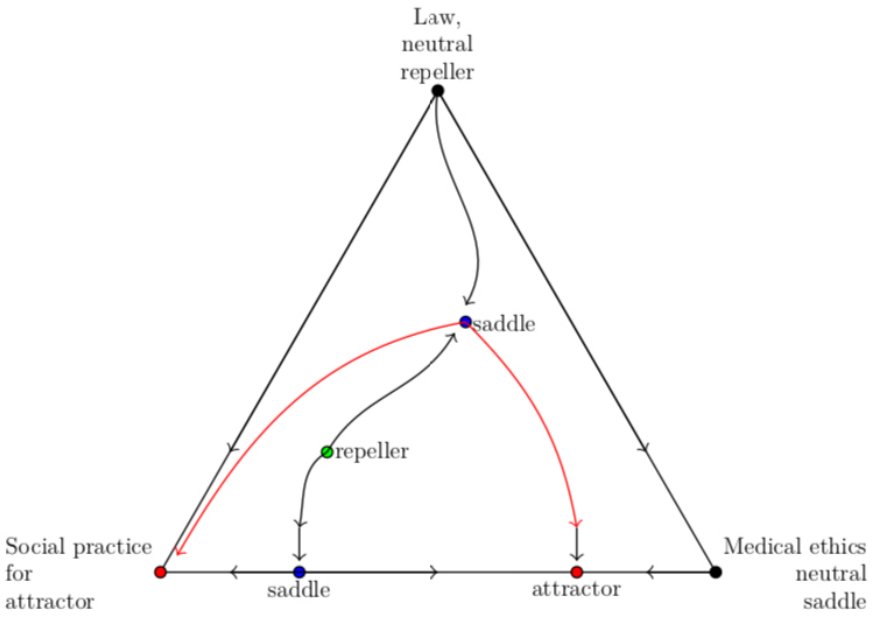


Figure 5.1: Japan iPSCs Reproduction Policy

and the second trial in 2015. The latter was suspended due to a side effect of genetic mutation [45]. Later that year, Japan passed a new law stating that regenerative medical products can be approved for marketing if safe [74]. In other words, the law mutated its attitude toward iPSCs for therapy purposes from being neutral to supportive and cooperates with the social practice. The cooperation generates an attractor on the left edge, according to the theory. A stable agreement between audacious science and lenient law was found in both theory and observation (Figure 5.2).

5.1.2 U.S. iPSCs Prediction & Policy

Similarly, in 2016, the U.S. FDA drafted standards of *clinical grade* in addition to *lab grade* to culture iPSCs for trials. The NIH regenerative medical program successfully cultured iPSCs and aimed to *"remove barriers in the development of cell-based therapies."* [67] If the law further supports the therapeutic use of iPSCs, then the American dynamics and the Japanese counterpart above will fall in an **equivalence class**, which awaits further observation.

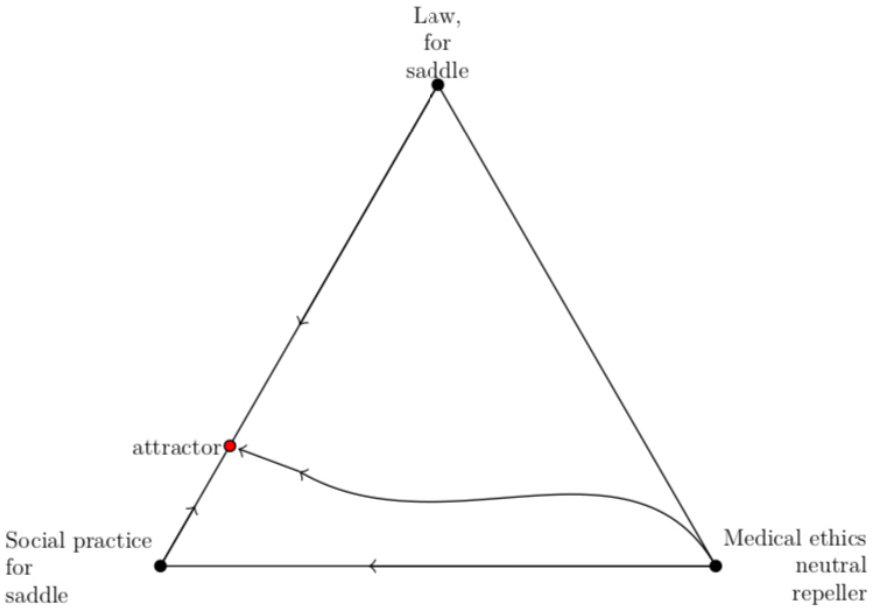


Figure 5.2: Japan iPSCs Therapy Dynamics

5.1.3 E.U. Human Embryos (hEs) and Human Embryo Stem Cells (hESCs) Research Prediction & Policy

Different from iPSCs, the evolution of hESCs issue features a kaleidoscopic map of the globe, especially the E.U. and the U.S. In Europe, Germany passed the *Embryo Protection Act* in 1991 and the *Stem Cell Act* in 2002 after the E.U. originated, both of which greatly impacted the E.U. statutes. According to the law's principle of *self reference* and the fact that it is statutory law, more than case law, that guides judges' reasoning in Continental Europe, the theory anticipates a convergence to the prohibitive law (Figure 5.3). The prediction is supported by the subsequent observation of judicial decisions. In 2011, the European Court of Justice used patent law to ban patenting innovations derived from embryos, human eggs, and related commercial exploitations that were immoral [21]. In *Parrillo v. Italy* (2015), in a vote of 16 : 1, the Court firmly held against individuals' donating hESCs derived from IVF spare embryos to scientific research as basic human *rights to life, property, and privacy.* The Court, however, did not clarify the personhood status of an embryo. In sum, the theory projects that hESCs research and commercialization will be permanently banned by the

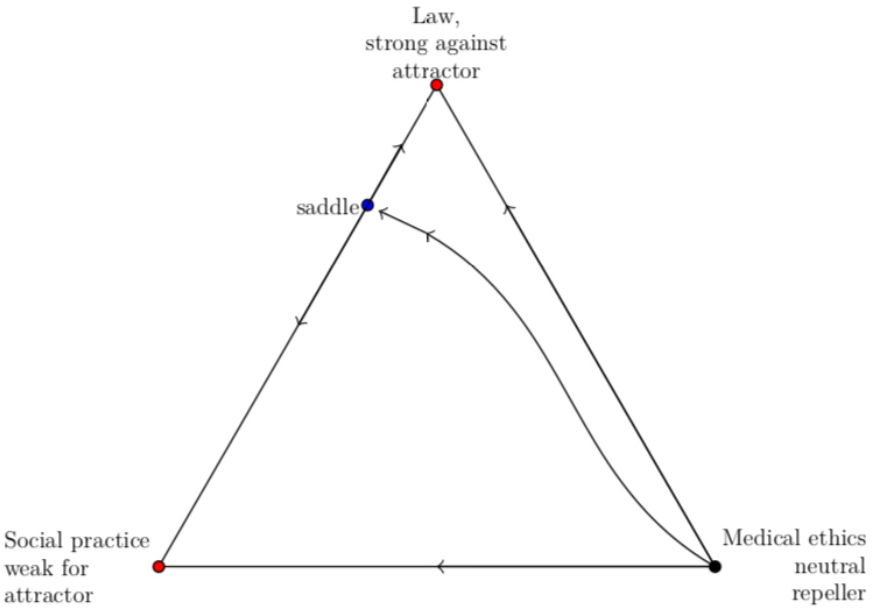


Figure 5.3: E.U. Human embryo & hESCs Dynamics

E.U.'s statutes, *ceteris paribus*, which matches the current reality [69, 52].

5.1.4 U.S. hEs and hESCs Research Prediction & Policy

The U.S. has experienced decades of ethical debate over research using embryos and stem cells — two highly related but distinct areas. After abortion prior to viability was legalized in *Roe v. Wade* (1973), research experiments using live-born fetuses stirred social repugnance [79] (Figure 5.4). Although the Ethics Advisory Board (EAB) suggested in 1977 that some research on embryos and fetuses were morally possible for federal funds [73], its advice was never taken by Congress. Thus, the dynamics respectively converged to two stable equilibria — the weak ethical support and the strong social resistance (Figure 5.5).

During $1981 - 1993$, the Reagan and Bush administrations did not renew EAB's charter so that there was a lack of ethicists' opinion and legislation. Both banned federal funds for research using embryos. The regulations brought about two equilibria on the left edge between science and law, where the saddle in the lower part was attracted to the stable social

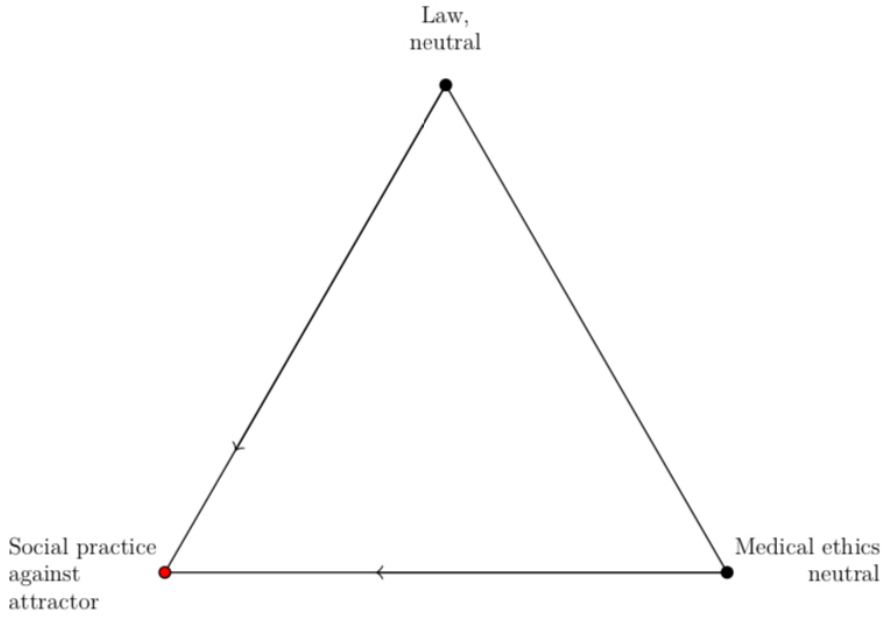


Figure 5.4: U.S. Human Embryo Research Dynamics: Early 1970s

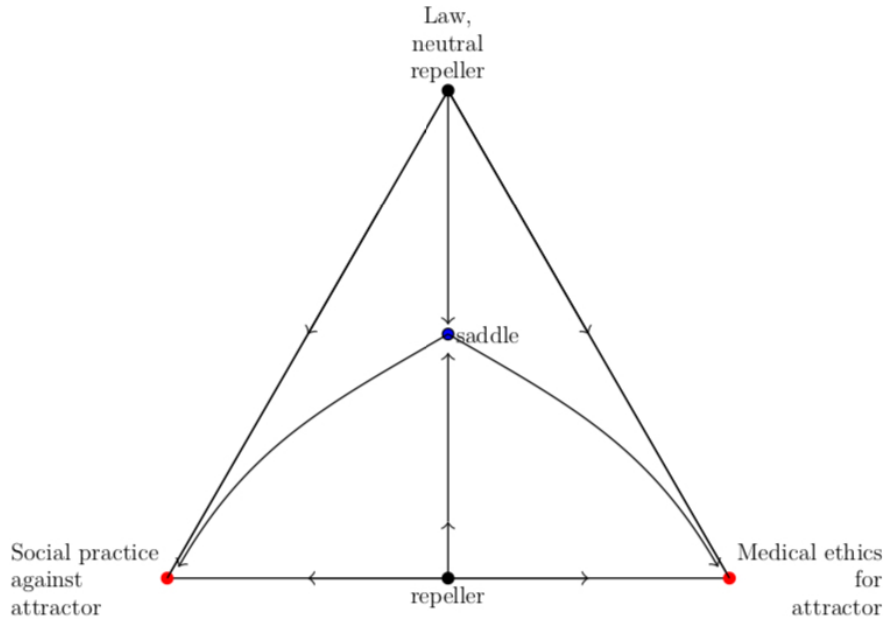


Figure 5.5: U.S. Human Embryo Research Dynamics: Late 1970s

resistance, and the attractor in the upper part was associated with a repelling limit cycle, implying the surprisingly never-ending battle that occurred during the 1980s (Figure 5.6).

Conversely in 1993, the sympathetic Clinton administration removed the federal ban; and the renewed EAB made encouraging ethical recommendations. Both the newly neutral law and

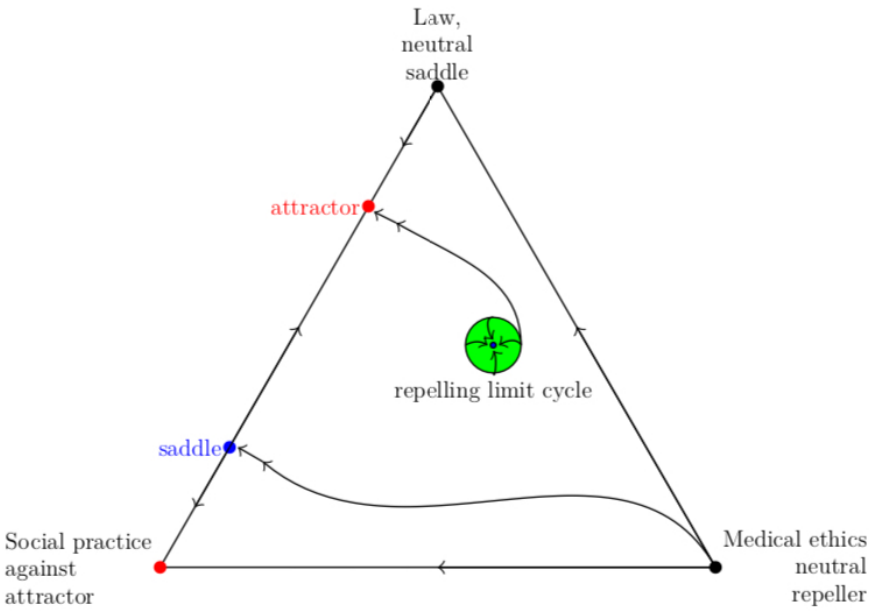


Figure 5.6: U.S. Human Embryo Research Dynamics: 1980s

supportive ethics forced the attractor at the opposing scientific practice from the previous state to the supporting partnership between society and medical ethics at this stage (Figure 5.7). The sudden disappearance of the interior equilibrium removed the constant struggle and suggested that the policy of the Clinton administration was effective.

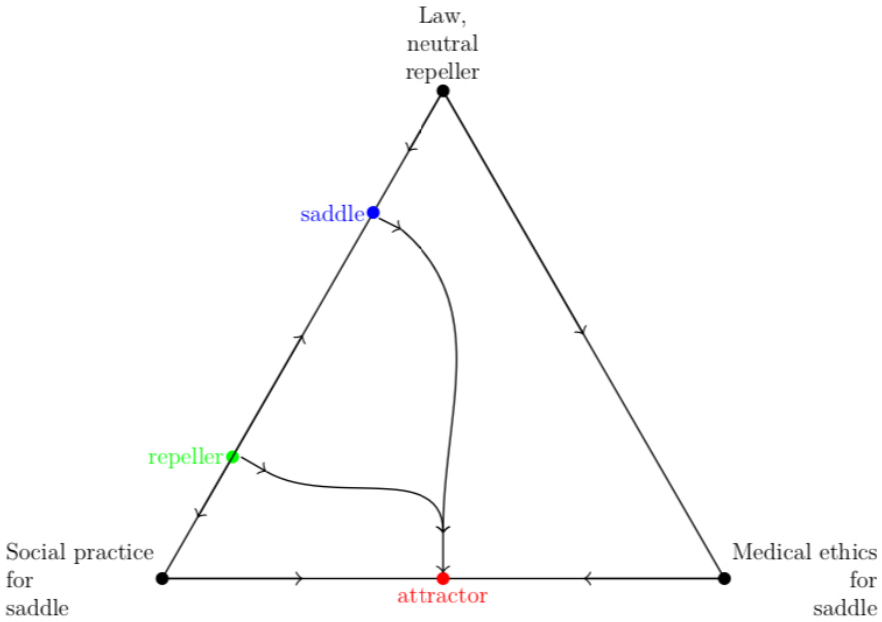


Figure 5.7: U.S. Human Embryo Research Dynamics: Early 1990s

However, anti-abortionists increasingly took seats in Congress and successfully added the *Dickey-Warner Amendment* to the NIH appropriations bills in 1996 prohibiting the use of federal funds for creating, destroying, or knowingly injuring human embryos. That is, the law mutated its attitude. Together, the resistant legislation and tolerant policy yielded an interior attracting limit cycle — an unending frustration among the three domains, which reversed the peace in the early 1990s (Figure 5.7) to the struggle in the late 1990s (Figure 5.8).

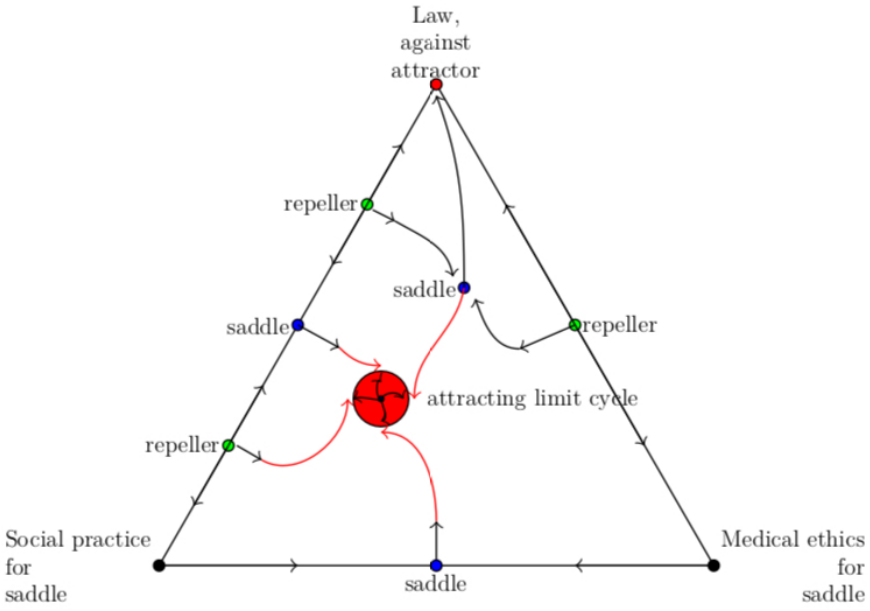


Figure 5.8: U.S. Human Embryo Research Dynamics: Late 1990s

The discovery of hESCs in 1998 changed the game. Its indirect relation to embryos gained support from the U.S. National Bioethics Advisory Commission [28]. Its potential in reproduction and disease eradication may also advance the U.S. national interest. Thus, the George W. Bush administration allowed stem cell lines for research that had already been derived from embryos by 2001, while the *Dickey-Warner Amendment* was in effect. According to the theory, the permissive policy created three new equilibria on the left edge and, in particular, pulled the unstable attracting limit cycle in the interior back to the stable attractor on the left edge. In other words, the relaxed policy forced the dynamic outcome from a

relentless struggle to a peaceful compromise between the adventurous scientific practice and the prohibitionary law (Figure 5.9).

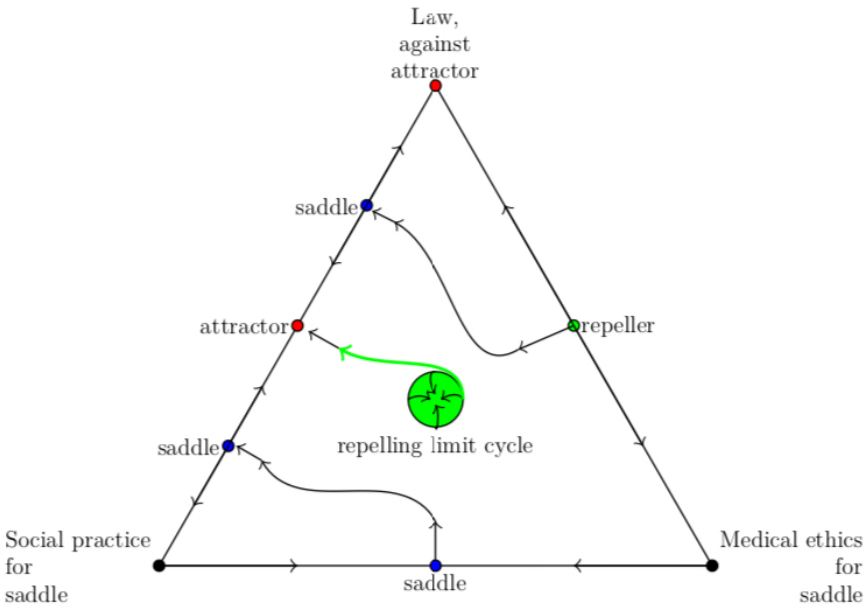


Figure 5.9: U.S. Human Embryo Stem Cell (hESCs) Research Dynamics: 2000s & 2010s

Further, in 2009, the Obama administration removed barriers to federal funding research using hESCs and human embryos *per se*; and as of 2016 the FDA has approved and registered 14 hESCs clinical trials for eye diseases [13]. Surprisingly, the dynamics during the Bush and Obama administrations reside in the same **equivalence class** because of the similar configurations — both feature resistant law but benignant medical ethics and scientific practice as well as permissive policy — resulting in a stable compromise between law and science. They differ only in policies by a matter of degree. Bush's policy only allowed research using a few stem cell lines derived by a specific time, whereas Obama's intervention supported research using not only most stem cell lines but also human embryos and aborted fetuses [89].

5.2 Birth: Genome editing research

The DNAs of stem cells can further be modified by genome editing, which uses two methods with or without virus DNAs. The former introduces virus DNAs to the human genome and hence increases the risk of genetic mutation and magnifies the harm to generations if applied to germ lines. How ethically controversial genome editing is, therefore, depends on the method, purpose, and also geography.

The clustered regularly interspaced short palindromic repeats (CRISPR) is a family of DNA sequences in prokaryote derived from virus DNA fragments. The CRISPR system is a technique that relies on an enzyme that recognizes and cleaves specific strands of DNA that are complementary to CRISPR [80]. It is more precise, efficient, but riskier than other methods — meganucleases, zinc finger nucleases (ZFNs) [46], and transcription activator-like effector-based nucleases (TALEN) [55]. These methods also use enzymes to modify DNAs without matching nucleobases using virus DNAs, and hence are less precise and efficient but safer.

5.2.1 China CRISPR Prediction & Policy

Genome editing is more controversial when applied to germline cells for reproduction rather than to adult cells infected by viruses or tumors for therapy. So far, China has no law to regulate risk-taking scientific practice using CRISPR. In 2014, a study approved by the local ethical board was conducted at Sun Yat-Sen University. It concerned the β-globin gene (HBB) which, if mutated, causes anemia. It applied CRISPR to human embryos and tested the effectiveness of cleaving the endogenous HBB and efficiency of homologous recombination directed repair of HBB. Although it used tripronuclear (i.e., nonviable) human zygotes, it still generated mixed reactions [48]. In 2016, a clinical trial that applied CRISPR to non-

small lung cancer patients was approved by the ethical board at a local hospital affiliated to Sichuan University [58, 59]. Both studies involved no viable human embryos and pregnancies. Taken together, the lack of legal involvement and the cooperation between scientific practice and medical ethics generate dynamic flows toward each other along the bottom edge; thus, there must be an attractor somewhere in between, according to the theory. In other words, in the absence of law, there exists a stable unregulated coalition between aggressive scientific practice and lax medical ethics, which matches reality (Figure 5.10).

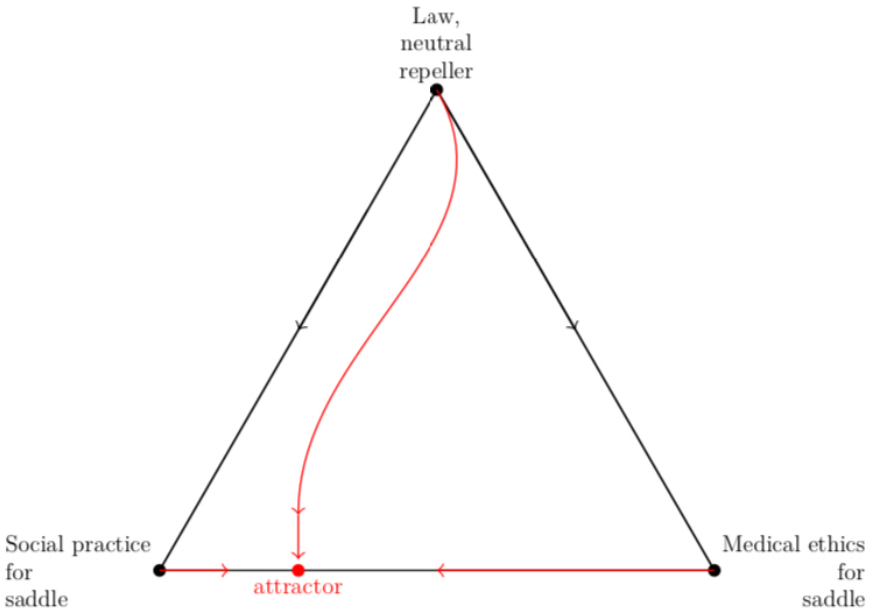


Figure 5.10: China CRISPR Therapy Dynamics: 2014–2017

The forecast explains the observation that in China CRISPR has been continually applied for therapeutical purposes, including the controversial case in 2018, in which Dr. Jiankui He used CRISPR to knock out the gene of a receptor of the HIV [86].

Dr. He did so, however, in germline cells and produced babies. What is permitted by tolerant domestic ethical standards may be denounced by strict international ethical consensus [87]. So the same case may lead to entirely different outcomes domestically versus internationally. Witness the 2015 international summit on CRISPR co-hosted by the Chinese Academy of Sciences, the U.S. National Academy of Sciences, and the U.K.'s Royal Society,

at which scientists and ethicists on the international platform reached an agreement that genome editing is less controversial for research as long as no pregnancy is produced [16]. It was this consensus that Dr. He's research broke by producing twin girls, despite the therapeutic purpose — they were claimed to be insusceptible to HIV whose parents were infected. The competition between audacious scientific practice and strict ethics, together with non-involvement of law, creates a saddle on the bottom edge, which directs the flows converging to the scientific practice and ethics, respectively. The latter is supported by observation — international dynamics are overpowered by medical ethics (Figure 5.11).

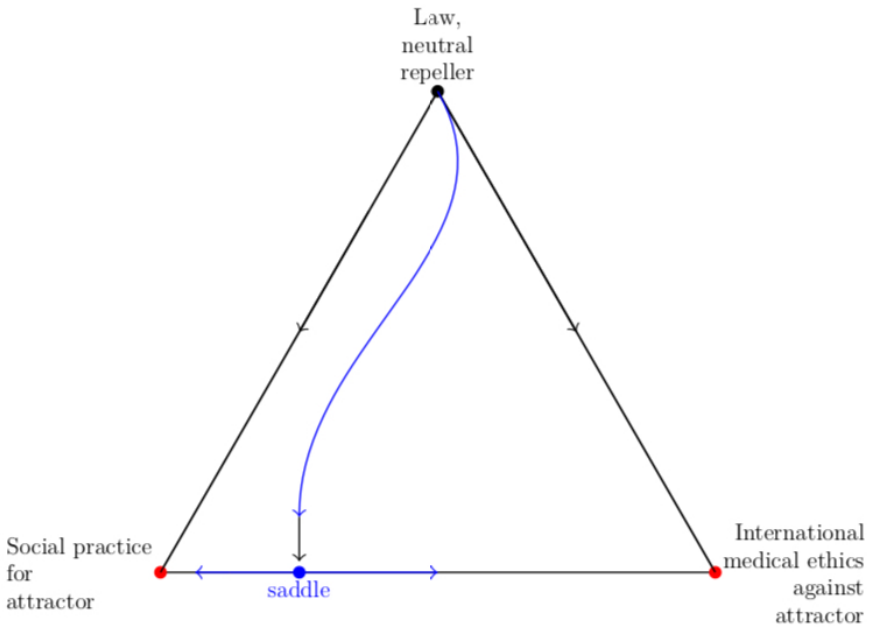


Figure 5.11: China CRISPR Reproduction Dynamics: 2018 Before

For example, in the international community, Dr. He's work had been criticized mainly as unethical [86]. Under international pressure, China may not soon pass a law, but instead take expedient measures to return a compromise with the international medical ethics, depicted as a newly-created attractor subtly positioned between two unstable equilibria on the bottom edge (Figure 5.12). That is what occurred. Three days after the announcement of the scientific result, Dr. He's research activities were suspended, and he was placed under some level of surveillance [14]. In 2019, lawyers in China reported the drafting of CRISPR

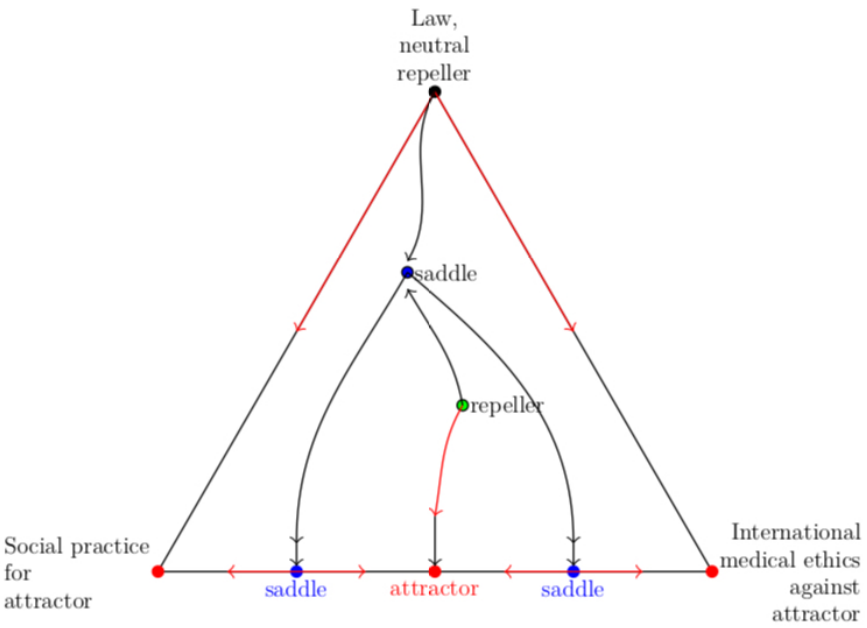


Figure 5.12: China CRISPR Reproduction Dynamics: 2018 After

regulations for related adverse consequences [61].

5.2.2 U.S. Genome Editing Prediction & Policy

In contrast, genome-editing methods were applied to adult cells in clinical trials, including CRISPR for patients with several types of cancers in the U.S. in 2014 [60] and TALENS for children patients with leukemia in the U.K. in 2016 [88]. Despite the lack of law, the fact that ethical boards and government agencies (e.g., the FDA) approved these trials (Figure 5.13) shows that supporting government policies increase the number of attractors hence possibilities of agreements between science and ethics, compared to the only one attractor without encouraging policies. These dynamics remain in the same **equivalent class** that is distinguished from the CRISPR counterpart for reproduction.

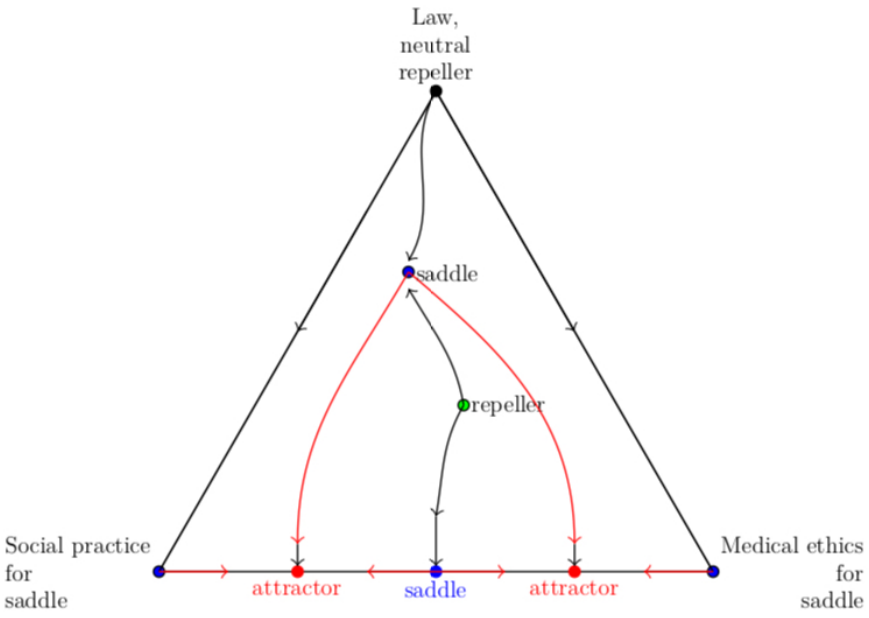


Figure 5.13: U.S. ZFN & U.K. TALENS Therapy Dynamics

5.2.3 U.K. Genome Editing Prediction & Policy

In particular, the U.K. has experienced three bifurcations in the evolution of the genome editing issue. The *Human Fertilization and Embryology Act* (1990) prohibits clinical use of oocytes, sperm cells, or embryos that have had their nuclear DNA modified and treats such uses as criminal offenses. Such a prohibitive law competes with the scientific practice of genome editing (Figure 5.14). However, in 2015, the British Medical Research Council urged a lenient environment for mitochondrial DNA replacement therapy (MRT) which yielded an interior attractor in Figure 5.15 — a stable compromise between resistant statutes, and tolerant medical ethics and scientific practice. Entering into 2016, more encouraging policy intervened. For the first time in the world, the Human Fertilization and Embryo Authority approved the mitochondrial DNA replacement therapy in spare embryos donated by IVF parents for research purpose [102]. Although this merciful policy adds a repeller and a saddle on the left edge, the theory predicts that the number and nature of interior equilibria remain the same in Figure 5.16 as in Figure 5.15. Thus, it is still unclear how effective the policy is.

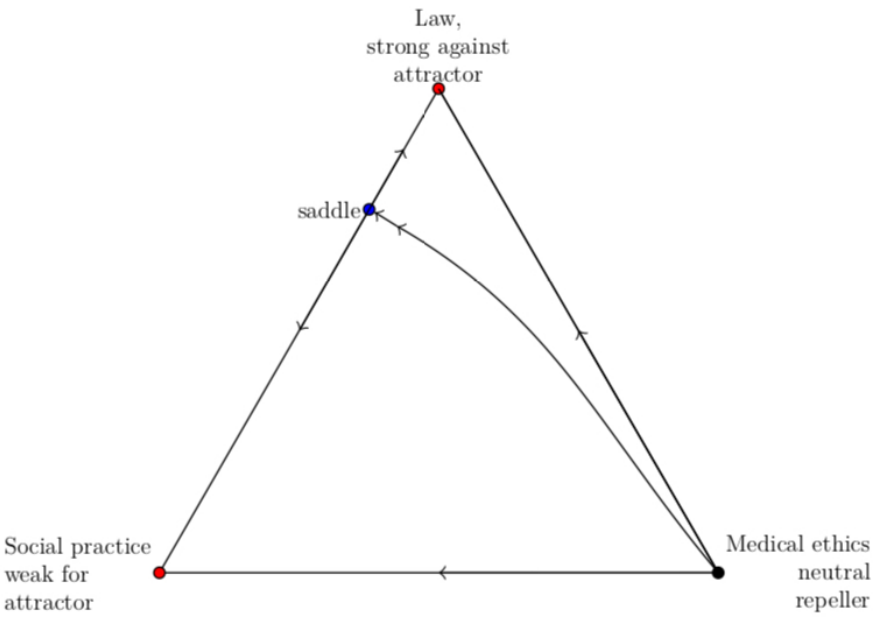


Figure 5.14: U.K. Genome Editing Research Dynamics 1990s

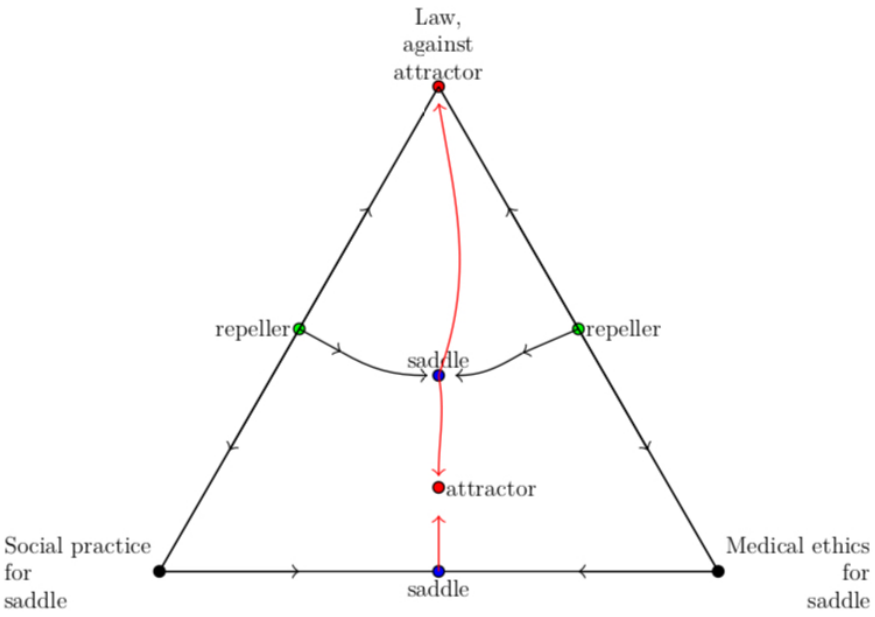


Figure 5.15: U.K. MRT Therapy Dynamics 2015

5.3 Birth: Abortion

Unlike other issues, abortion seems constantly oscillating between pro-life and pro-choice extremes. Abortion is the ending of a pregnancy by removal or expulsion of an embryo or fetus [38]. It confronts an ethical dilemma because doing no harm to a fetus — a potential person

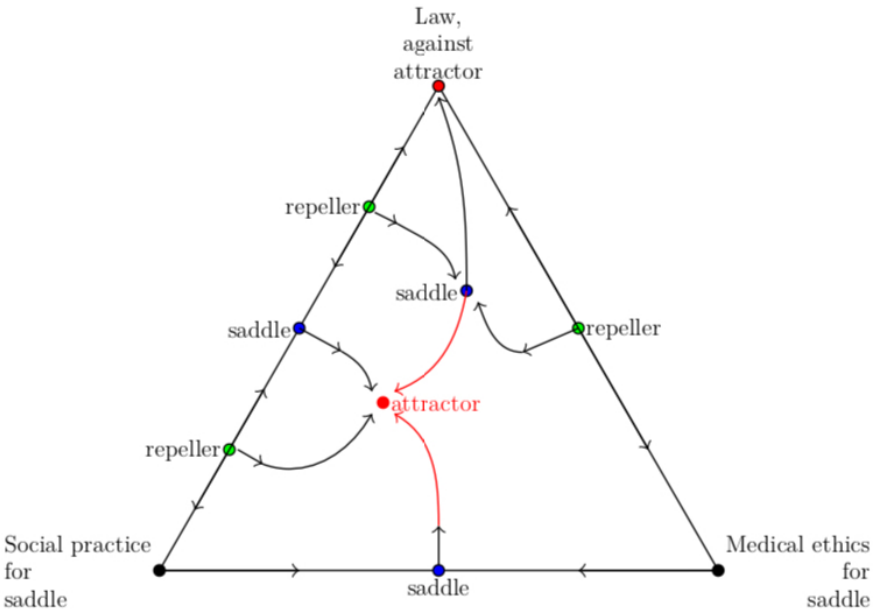


Figure 5.16: U.K. MRT Therapy Dynamics 2016

— conflicts with respecting the mother's autonomous choice or doing good to the mother.

5.3.1 Abortion before 1850s Prediction

Documented back to the 12th century, Catholic and Christian Churches severely punished abortion. In the 1850s, the Catholic Church officially denounced abortion by teaching that personhood starts from conception [17]. While the social resistance was strong, the law was quite merciful. In 1803, the English statute made abortion of a quickened fetus a capital crime, but under American law, abortion before quickening was merely a misdemeanor or even legal if it was delivered for therapeutic reasons and recommended by two practitioners [9]. Given the indifference of medical ethics, all dynamics converged to the resistant union between society and law, which matched historical reality (Figure 5.17).

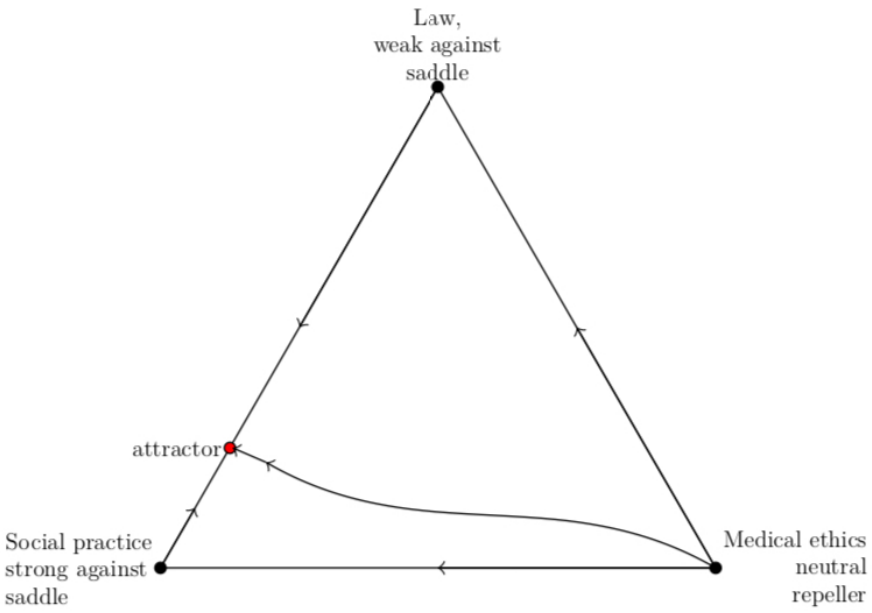


Figure 5.17: U.S. Abortion Dynamics: Before 1850s

5.3.2 Abortion Before and After Civil War Prediction & Policy

The U.S. Civil War ($1861 - 1865$) proved to be a watershed in the evolution of the abortion issue. Before then, most babies were delivered by midwives [27]. Nevertheless, in 1847, physicians founded the American Medical Association (AMA), which standardized medical practice and regulated medical profession, and hence endeavored to reduce harms caused by lay midwives. The AMA, therefore, strongly opposed abortion and successfully lobbied for anti-abortion legislation [25]. Most states consequently made abortion illegal after the War [76]. The theory predicts a 0 index of interior equilibria when the AMA had not engaged yet, and all dynamics converge to the opposing concordance between law and society (Figure 5.18). As the AMA lobbied more heavily, depicted as interior flow sending from the left edge toward the bottom right vertex, its influence pulled the left-edge attractor in Figure 5.18. to the interior in Figure 5.19 The theoretical prediction is supported by the historical consensus among all three domains strongly against abortion since the 1860s.

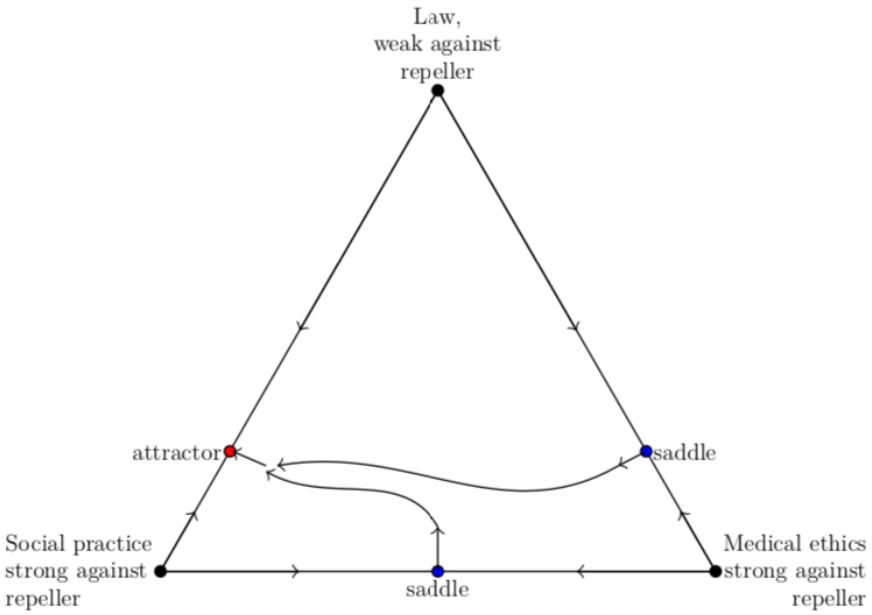


Figure 5.18: U.S. Abortion Dynamics: 1850s AMA Establishment

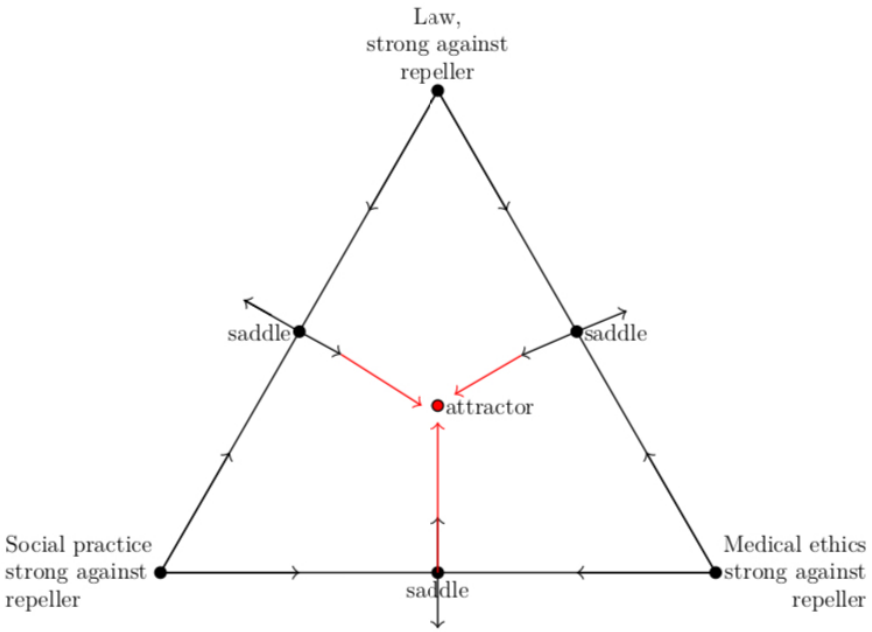


Figure 5.19: U.S. Abortion Dynamics: 1860s Civil War

5.3.3 Abortion 1960s Prediction

A bifurcation occurred during the 1960s Civil Rights Movement. Although Pope Paul VI issued the encyclical *Humanae Vitae* in 1968, which insisted that the Church would not

accept any artificial birth control, about 90% American Catholics disagreed with the Church's position [95]. *Griswold v. Conneticutt* (1965) involved a couple who were denied the ability to refill birth control pills under state law. The issue was: Does a state have the constitutional right to forbid contraception? The answer was no, and the U.S. Supreme Court upheld individuals' right to contraception under the *right to privacy*. The AMA continued its formal position against abortion. Together, the inverted, liberal social practice led to a bifurcation with a +1 index of interior equilibria: a repeller and a saddle in the left region, and an attractor in the right area near the conservative coalition between law and medical ethics. Given the greater strengths of law and medical ethics than the emerging social liberty, there was a higher probability (a larger grey area in Figure 5.20) that dynamics would be drawn

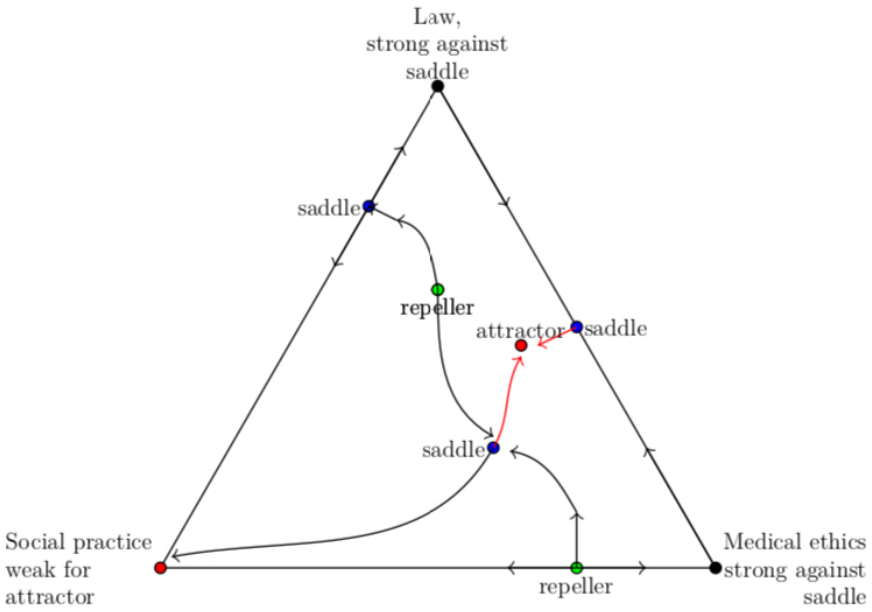


Figure 5.20: U.S. Abortion Dynamics: 1960s Civil Rights Movement

toward the liberal society, which was the case in the subsequent decade.

5.3.4 Abortion 1970s Prediction

Referring internally to *Griswold v. Conneticutt* (1965) and externally to the social value of liberty, the Supreme Court established its landmark precedent in *Roe v. Wade* (1973). In

Roe, the state district attorney Henry Wade prosecuted Jane Roe under Texas criminal law for undergoing an abortion in Dallas. The issue was: Does a state have the constitutional right to criminalize all abortions? The answer was: It depends. The U.S. Supreme Court introduced the concept of *viability — the potential to live outside the mother's womb even though with artificial aid* — and held that before viability, states could not make abortion illegal; and after viability, a state may forbid abortion but it need not [9]. In *Planned Parenthood of Central Missouri v. Danforth* (1976), the Court further invalidated a state law that required a woman to obtain consent from the fetus's father and, if a minor, to obtain consent from her parents. It also overthrew Ohio and Pennsylvania laws requiring a 24-hour wait period before an abortion. Physicians respect patients' autonomy hence provide abortion services when requested but did, depicted as the interior flow away from the bottom right vertex and toward the left edge. The theory projects 0-indexed interior equilibria; hence, all dynamics converged to the liberal collaboration between society and law, which resonated with the historical observation (Figure 5.21).

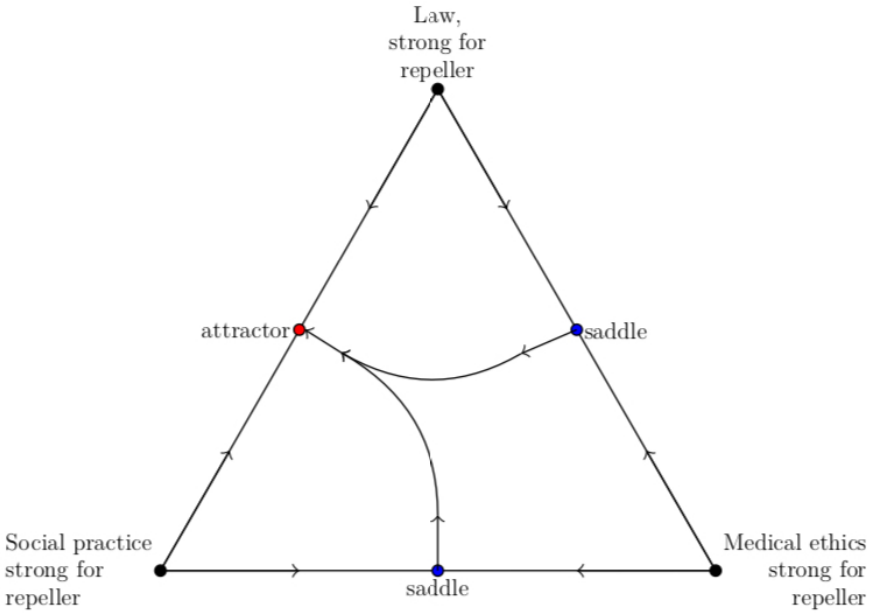


Figure 5.21: U.S. Abortion Dynamics: 1970s;
2009 – 2016 Liberal States & Federal

5.3.5 Abortion 1980s – early 1990s Prediction

The strong liberal resonance among the three domains irritated pro-life groups, who then reacted and initiated the Anti-Abortion Movement during the 1980s−early 1990s. The elections of Presidents Reagan and Bush also signaled a flip of prevailing social values from liberal to conservative. The law weighed conflicting principles — *self reference* to seminal pro-choice *Roe v. Wade* versus *external reference* to prevalent pro-life values in society. Two outcomes could happen contingent on the context of a particular case in hand. Sometimes self-reference overruled external reference, the law supported abortion. Then the theory anticipated a +1-indexed interior equilibria: an interior attracting limit cycle in a larger interior away from the smaller bounded neighborhood of the conservative society. It foretold a never-ending struggle between the conservative society and the liberal law and medical ethics would be more likely to occur (Figure 5.22), which matched majority of observations in re-

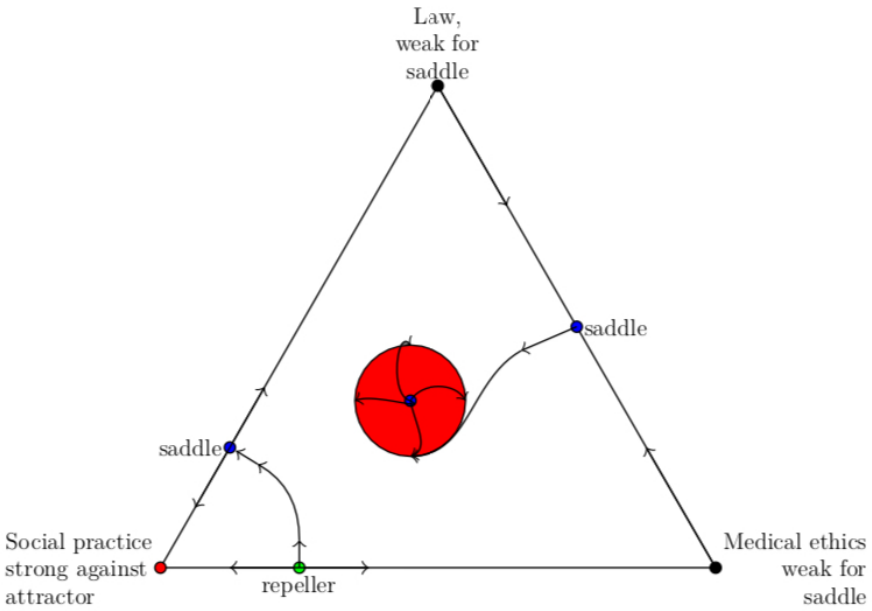


Figure 5.22: U.S. Abortion Dynamics: 1980s −1992 & 2001 − 2008 Federal Liberal Case; 2018− Federal

ality. At other times, when external reference outranked self-reference, the law disapproved abortion. Then the −1 index of interior equilibria suggested an interior saddle so that all

dynamics converged to either the weakly liberal medical ethics, or the strongly conservative consolidation between society and law (Figure 5.23). It explained the aberrant pattern that

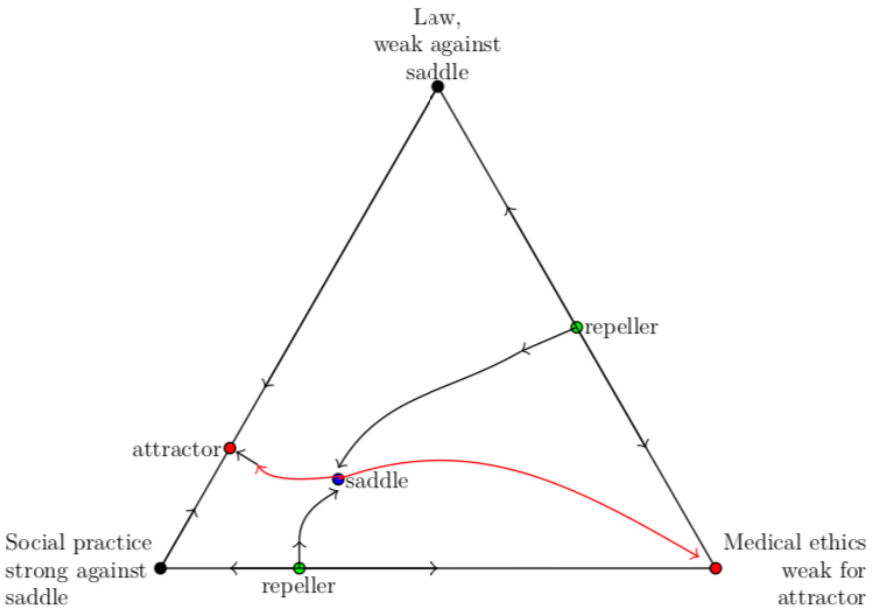


Figure 5.23: U.S. Abortion Dynamics: 1980s −1992 & 2001 − 2008 Federal Conservative Case

laws requiring consent from minors' parents were passed in 35 states and upheld by the U.S. Supreme Court in *Planned Parenthood v. Casey* (1992) [94].

5.3.6 Abortion 1993–2000 Prediction & Policy

Another bifurcation emerged because of mutations of society and law occurring since 1993. The election of President Clinton implied the swinging of social value from conservative back to liberal. He appointed Justices Ruth Bader Ginsberg and Stephen Breyer leading to a 5 : 3 composition of the U.S. Supreme Court with one swing vote . Hence, judicial law continued weakly liberal. Statutory law, however, turned conservative due to the self-interest of increasing numbers of anti-abortionists in the U.S. Congress. Therefore, the law's attitude varied with the weighing *self-reference* and *self-interest* in a particular context. When self-interest overweighed, the law disfavored abortion. Then the theory foresaw a

+1 index of interior equilibria, which given the directions of existing flows was consistent with characterizing an attracting limit cycle in the lower bounded region. It signalized a frustration where the conservative law always attempted but never completely succeeded to break the liberal collaboration between society and medical ethics (Figure 5.24). This was

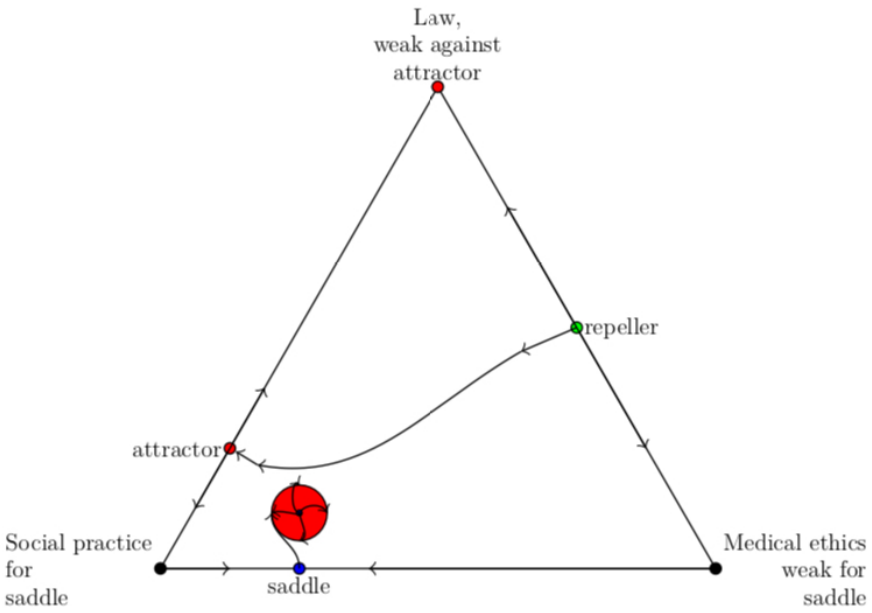


Figure 5.24: U.S. Abortion Dynamics: $1993 - 2000$ Federal Conservative Case

the case with the *Partial-Birth Abortion Ban Act of* 1995 which Congress passed but which President Clinton vetoed. Other times, when self-reference overthrew self-interest, the law permitted abortion. Then all dynamics converge to the left-edge attractor, a stable liberal partnership between law and society, which is not the case in reality (Figure 5.25).

5.3.7 Abortion 2001–2008 Prediction

A further bifurcation developed during the period $2001 - 2008$. The election of President G.W. Bush implied a prevalent conservative values in society. The law again was complicated due to conflicting inherent principles. When self-reference outranked external reference, the law affirmed abortion resulting in an interior attracting limit cycle **equivalent** to the

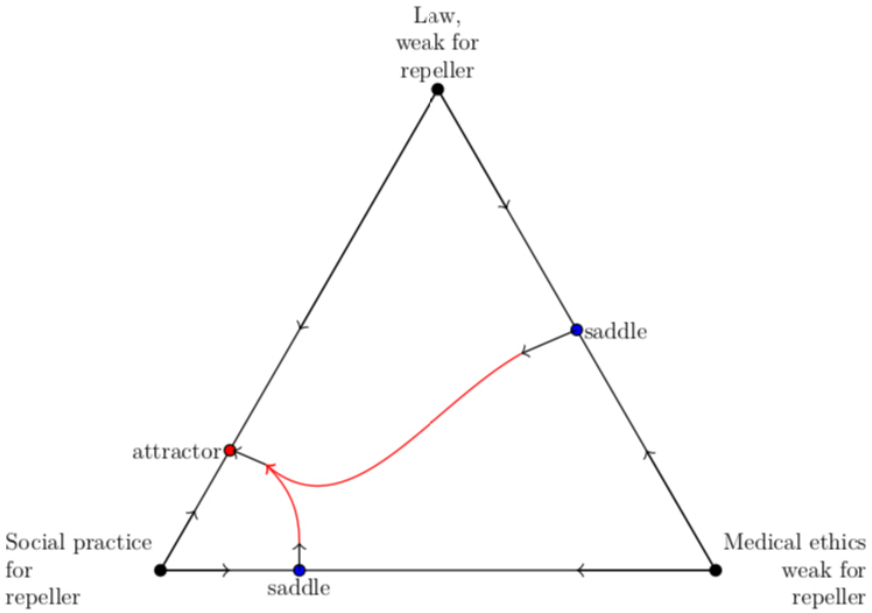


Figure 5.25: U.S. Abortion Dynamics: 2009 − 2016 Conservative States; 2019− Federal Conservative Case

abortion dynamics of 1980s− early 1990s (Figure 5.22).Alternatively, when external reference overturned self-reference, the law prohibited abortion, then a stable attractor would appear, **equivalent** to the 1980s− early 1990s counterpart (Figure 5.23). The latter scenario explained the surprising observations that the U.S. Supreme Court decided that the *Partial-Birth Abortion Ban Act of* 2005 was not unconstitutional, and upheld the *right to free expression* of pro-life groups outside abortion clinics [76].

5.3.8 Abortion 2009–2016 Prediction & Policy

Entering in 2009, bifurcation reoccurred. The economic crisis brought more sweeping liberal values to society. President Obama appointed liberal Justices Sonia Sotomayor and Elena Kagan resulting in a 4 : 4 composition of the Court with one swing vote. States differed in their legislation of abortion. Some passed statutes to provide Medicaid funds for poor women to access abortion services. In these states, such as California and New York, all dynamics converged to the liberal harmony between law and society **equivalent** to the 1970s

dynamics (Figure 5.21). Other states imposed restrictions on use of public funds, waiting periods, mandatory ultrasounds, etc. In these states, including Indiana, Kansas, Texas, North Carolina, the theory projected an interior saddle. All dynamics converged either to the weakly liberal medical ethics or the strongly conservative coalition between law and society, where the latter case was supported by observations in these states (Figure 5.26). For instance, laws were passed requiring abortion providers to obtain admitting privileges

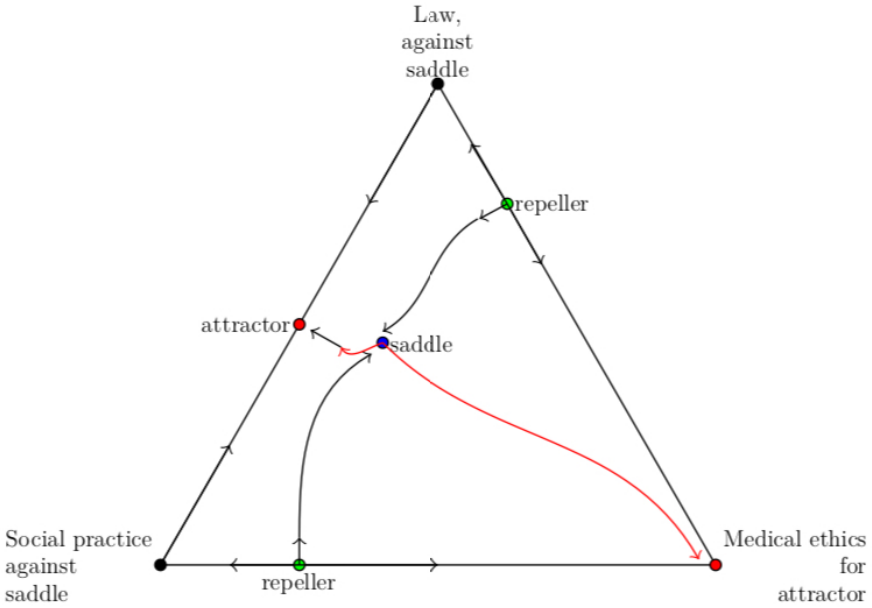


Figure 5.26: U.S. Abortion Dynamics: 2009 − 2016 Conservative States; 2019− Federal Conservative Case

from local hospitals, e.g., *House Bill No.* 2 in Texas (2013) [96], and requiring costly facility upgrading in Louisiana (2014) [97]. Nonetheless, at the federal level, women's rights to abortion were anticipated with a higher probability to be reaffirmed by the liberal consensus among society, law, and medicine again **equivalent** to the 1970s dynamics (Figure 5.21). It matched the reality. For instance, the U.S. Supreme Court struck down the Texas law in *Whole Woman's Health v. Hellerstedt* (2013).

5.3.9 Abortion 2018–2019 Prediction & Policy

Beginning in 2018, bifurcation happened again because of the mutation of social values from liberal to conservative, as evidenced by the election of President Trump. He appointed conservatives Justices Neil Gorsuch and Brett Kavanaugh, resulting in a $4:5$ composition of the U.S. Supreme Court. Legislatively, Congress barred federal funds for abortion. Meanwhile, 39 out of 50 states rejected informed parental consent for minors, 17 states supported Medicaid funding for abortion. Overall, the law is mixed nationwide.

The evolution and prediction, again, rely on the weighing of principles. Taking into account that *Roe v. Wade* was seminal and the $4:5$ composition of the Court was still a relatively balanced division of influence, it is more likely that the judicial law subscribes to *self-reference* and hence still affirms abortion. Therefore, the theory forecasts that dynamics will less likely converge to the conservative society than to the weakly liberal alliance between law and medical ethics (Figure 5.23), which is supported by observations. Five years later, in 2019, the U.S. Supreme Court as currently composed struck down the Louisiana law in *June Medical Services, LLC v. Gee*, reaffirming its respect for *Roe v. Wade* [97, 18].

5.3.10 Abortion 2019– Prediction

If one more conservative Justice is appointed in the future, however, the imbalanced $6:3$ Court composition may allow *self-reference* to be overridden by *external reference* or *self-interest*, and hence transform the law from weakly liberal to conservative. The theory anticipates a convergence to the strongly conservative coalition between society and law **equivalent** to the dynamics in conservative states during $2009-2016$ (Figure 5.26), which awaits further observations in the coming years.

5.4 Pharmaceutical: Opioid epidemic

Besides critical moments of life — birth and death — ethical dilemmas also rise often in the use of drugs such as opioids and devices such as healthcare artificial intelligence. The opioid epidemic describes the rapidly increasing use of prescription and nonprescription opioid drugs in the U.S. since the 1990s. From $1999-2017$, almost 400,000 people died from an overdose of prescription and illicit opioids [85, 72]. On average, 130 Americans die every day from an opioid overdose [31]. Opioid prescription, therefore, confronts an ethical dilemma because doing good to relieve pains conflicts with doing no harm — addiction and overdose death.

5.4.1 Opioid Epidemic 1980s–1990s Prediction & Policy

Prior to the 1980s, the medical standards of care always limited the use of opioids to post-surgical patients only. Therefore, all dynamics converge to the vertex of prohibiting medical ethics (Figure 5.27). Beginning in the 1980s, however, a bifurcation occurred. Both the

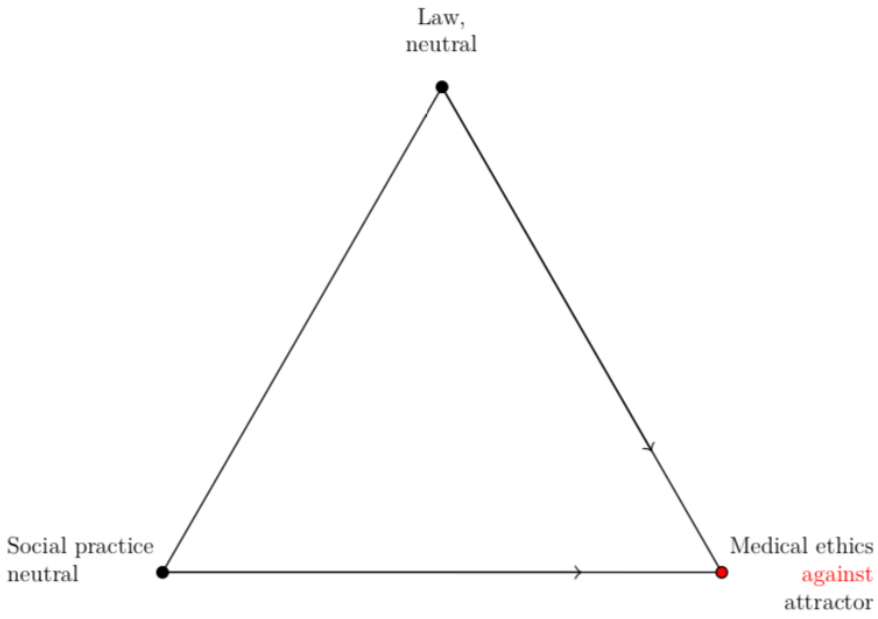


Figure 5.27: U.S. Opioid Epidemic Dynamics: Before 1980s

World Health Organization (WHO) and individual physicians published articles [75] arguing for pain control for *beneficence*. Medical ethics, therefore, shifted from cautious to lax (Figure 5.28). During the 1990s, the Joint Commission on Accreditation of Healthcare Or-

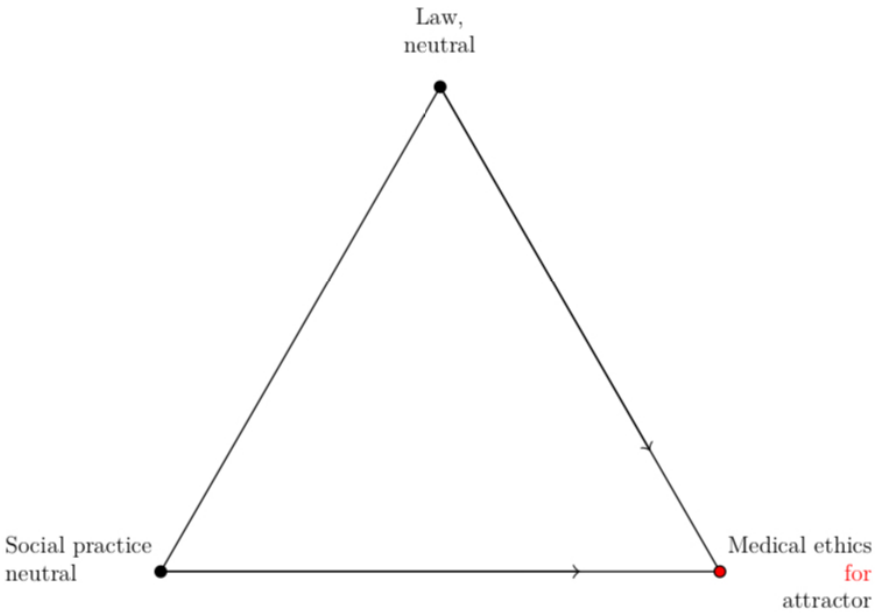


Figure 5.28: U.S. Opioid Epidemic Dynamics: 1980s

ganizations added pain as the fifth vital sign and refused to accredit hospitals that cannot provide evidence of patient satisfaction with pain treatment [49]. Medical ethics, therefore, supported pain control even more strongly.

Meanwhile, in society, *economic needs (or wants)* drove the pharmaceutical company Purdue Pharma to respond to the then new trend of medical practice and falsely advertised its product OxyContin as nonaddictive. Some physicians also published its purportedly nonaddictive properties in medical journals [53]. Taken together, both affirming forces formed an attractor on the bottom edge — an advocatory resonance between industrial practice and medical ethics during the 1990s (Figure 5.29).

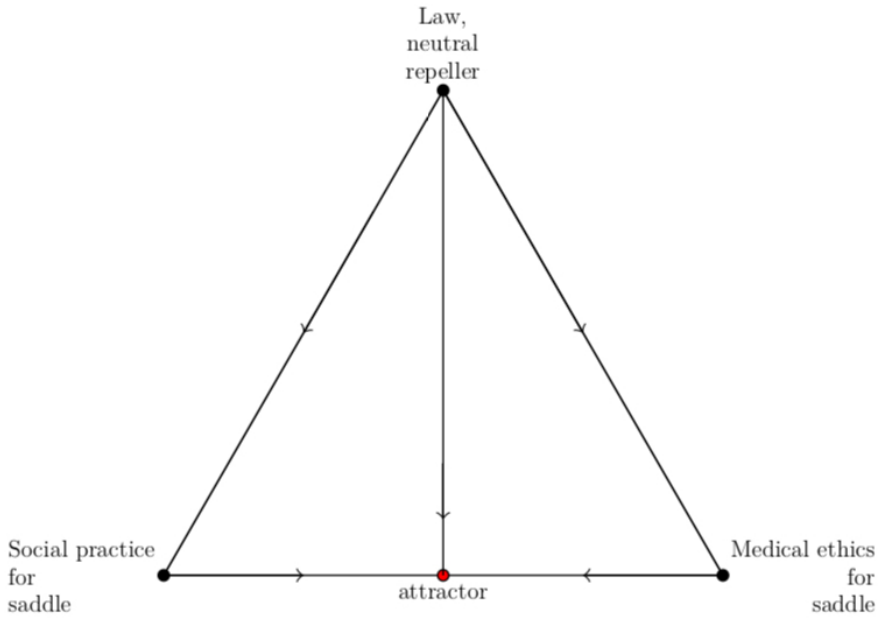


Figure 5.29: U.S. Opioid Epidemic Dynamics: 1990s

5.4.2 Opioid Epidemic 1998–2004 Prediction & Policy

A further bifurcation came about when the law was perturbed. During $1998-2004$, Purdue Pharma funded the American Academy of Pain Medicine and the American Pain Society, which helped OxyContin become expressly permitted in model clinical guidelines [15] and the then-newly-passed *Drug Addiction Treatment Act of* 2000 [68]. According to the theory, all three domains of the same advocatory type resulted in a long-lasting conspiracy for the opioid prescription, which is represented as the interior attractor in Figure (5.30) and supported by the observation in the early 2000s.

5.4.3 Opioid Epidemic mid-2000s Prediction & Policy

Nevertheless, more supply of opioids induced more addictive needs, hence more demands from addicts in society. Around 2000, increasing overdose deaths were scattered throughout cities in the Rust Belt, but had not caught the attention of legal authorities. In 2003, the *Time* magazine reported the hidden epidemic, the extent of which shocked the nation. The

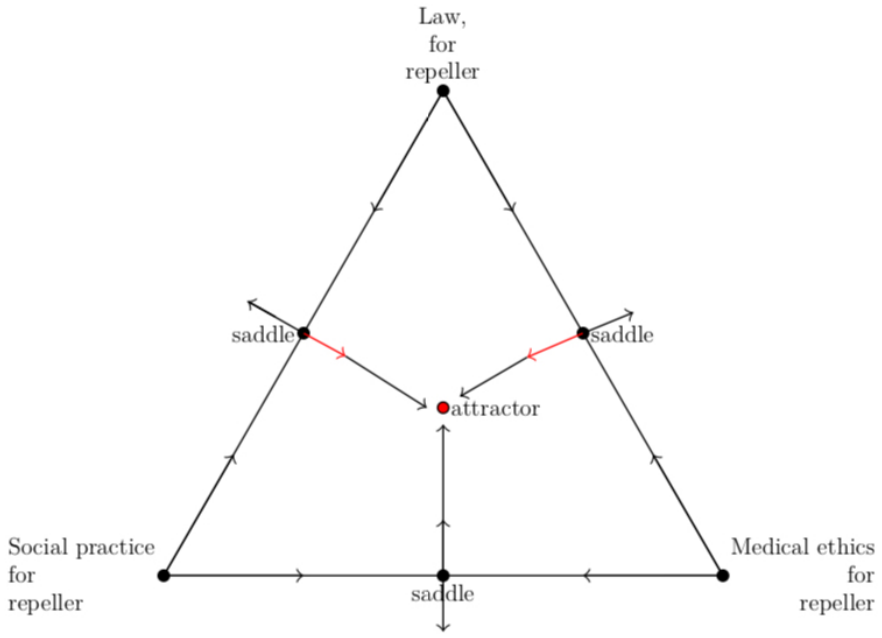


Figure 5.30: U.S. Opioid Epidemic Dynamics: 1998 – 2004

federal Joint Interagency Task Force struck down illicit drug (e.g., cocaine) shipments [71], while OxyContin stayed legal. According to Theorem 3.5, the federal regulation split the attractor on the left edge between law and society in Figure 5.30 into three equilibria — one repeller and two saddles. There are two extreme cases further. Assume continuing influence of medical ethics in Figure 5.31. The theory predicts a +1 index of interior equilibria, which at the lowest level of complexity, is an attractor; the same outcome as in Figure 5.30. It is no wonder, then, that the policy failed to stop the epidemic. Even if hypothetically, medical ethics did exert any pressure further, then the three equilibria adapted their types accordingly — one saddle, and two attractors , which are still stable harmonies between loose law and social practice. In whichever case, the federal policy was doomed to fail (Figure 5.32).

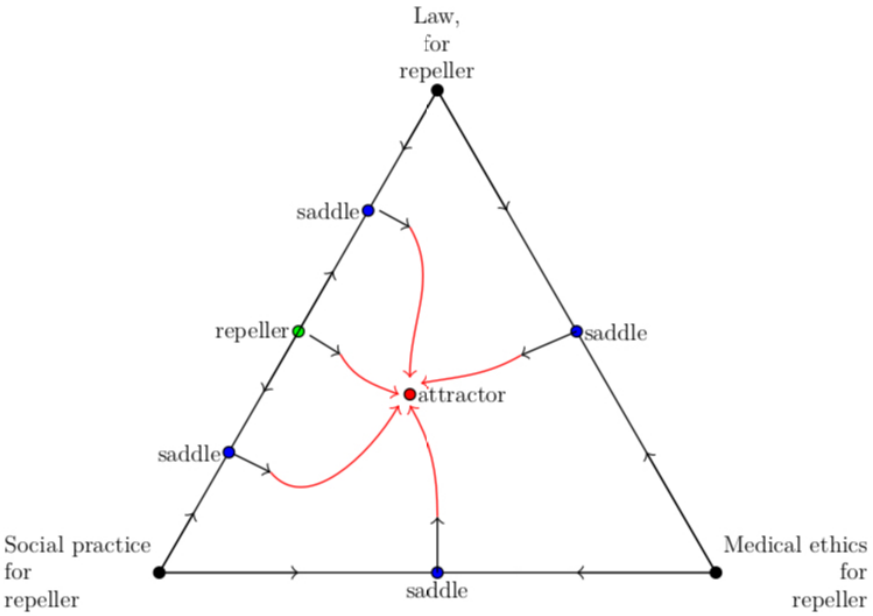


Figure 5.31: U.S. Opioid Epidemic Dynamics: mid-2000s Federal Task Force Policy, Medical Ethics Action Case

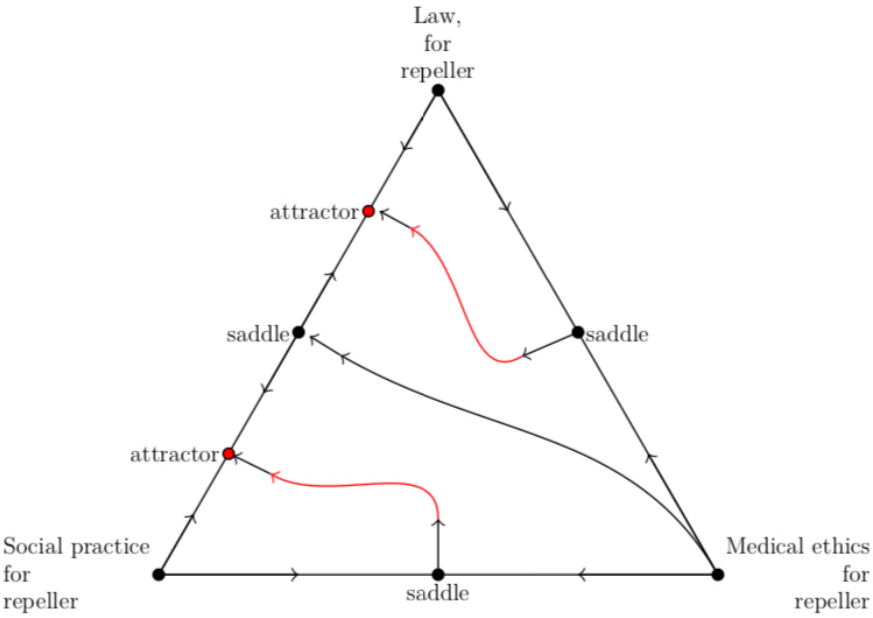


Figure 5.32: U.S. Opioid Epidemic Dynamics: mid-2000s Federal Task Force Policy, Medical Ethics Inaction Case

5.4.4 Opioid Epidemic 2007– early 2010s Prediction & Policy

A bifurcation was born due to the mutation of the law and the variation in the strength of social practice. Judicial law, having remained silent about opioid overprescription in past decades, made its landmark precedent. In *United States of America v. the Purdue Frederick Company, Inc., et al.* (2007), the defendants pleaded guilty to charges of misbranding OxyContin and paid $600 million compensations [33]. Thus, the power of social practice driven by *economic needs* dropped dramatically, but social practice driven by addicts' *physical and psychological needs* endured. Meanwhile, the attitude of medical ethics grew mixed as research revealed both positive and negative results on addiction [78]. Taken together, the altered configuration featured a 0-indexed interior equilibria. The updated prediction suggests that, in the simplest case, all dynamics converge to either the weakly indulgent society or the strongly resistant law (Figure 5.33).

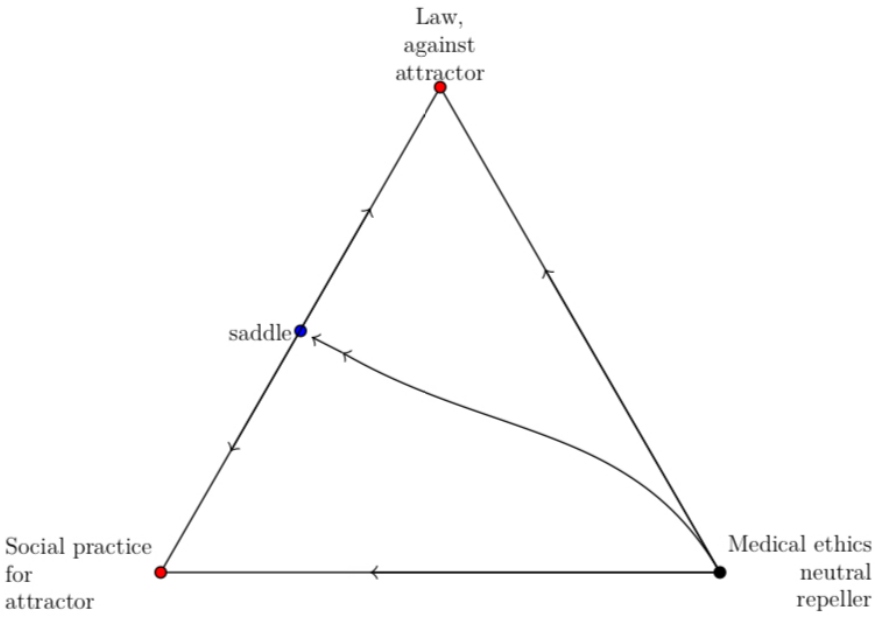


Figure 5.33: U.S. Opioid Epidemic Dynamics: 2007−early 2010s

The latter scenario was supported by subsequent observations that the legislature strengthened prohibition. In 2012, the U.S. Senate started investigating the ties between drug com-

panies and their advocates in WHO and medical groups. And in 2019, 48 out of 50 states sued Purdue Pharma for false advertising [63].

5.4.5 Opioid Epidemic mid-2010s Prediction & Policy

Another bifurcation appeared because of the mutation of medical ethics. In the mid-2010s, state medical authorities such as the Medical Board of California reverted standards of care to curb opioid prescriptions [11]. The theory projected a 0 index of interior equilibria. Given the directions of existing flows, it was consistent with having a repeller and a saddle in the interior. So all dynamics converge either to the weakly decadent social practice, or the strongly resistant union between law and medical ethics, with the latter case matching the reality (Figure 5.34).

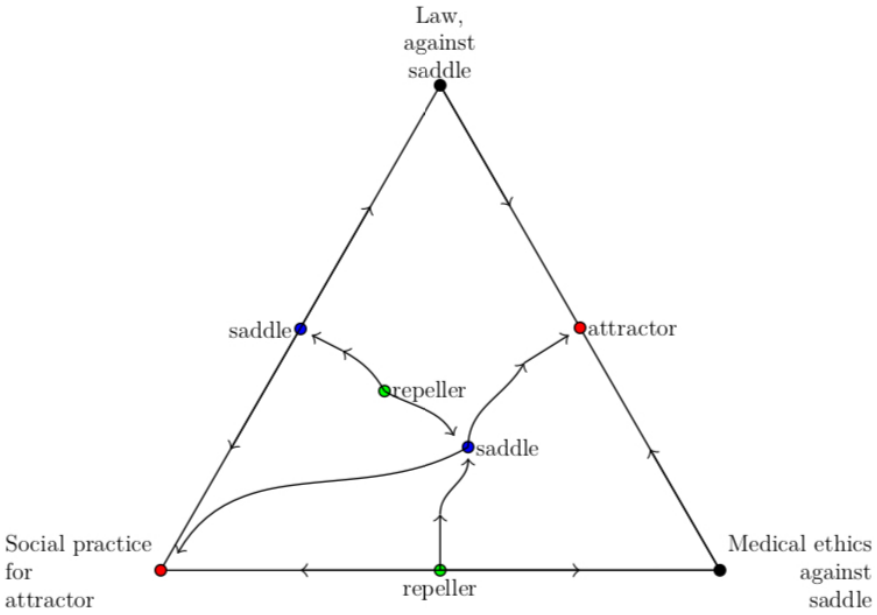


Figure 5.34: U.S. Opioid Epidemic Dynamics: mid-2010s Medical Boards Policy

Government policies with good intentions may or may not lead to favorable outcomes. Therefore, evidence-based projections before implementation are needed for better selection and, after intervention for evaluation, better decision-making in the future. In the mid-2010s, the

CDC also intervened to restrain opioid prescription [29]. The policy split the repeller on the bottom edge between medicine and society in Figure 5.34 into three equilibria — one saddle and two repellers in Figure 5.35. Compared to the outcome without regulation in Figure

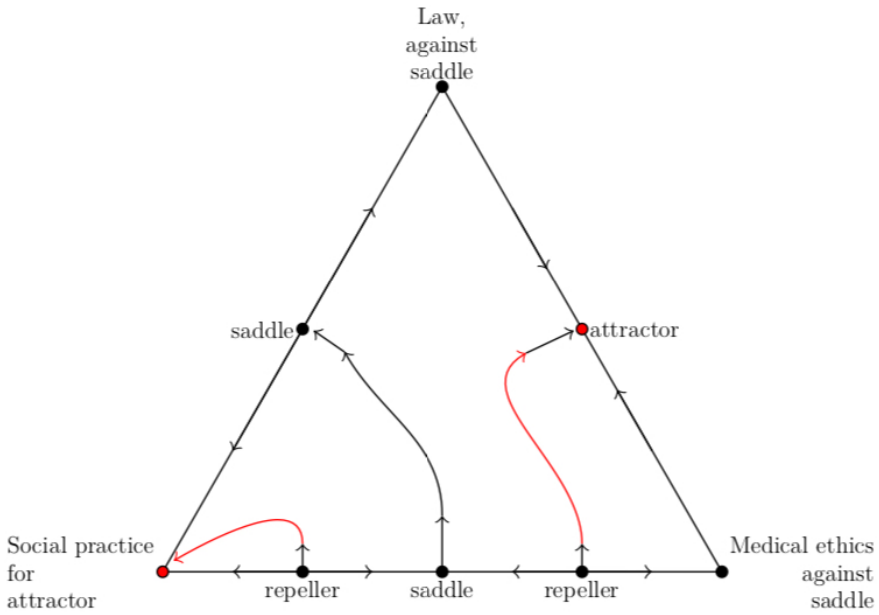


Figure 5.35: U.S. Opioid Epidemic Dynamics: 2015 CDC Policy

5.34, it reduced the area (hence likelihood) of converging to the indulgent social practice, and hence was an effective policy.

5.4.6 Opioid Epidemic 2019– Policy

Policymakers, currently, also face an urgent challenge that if the opioid prescription is overly inaccessible and costly, then addicts may switch to much more available and cheaper opiates such as heroin [78]. Should the restriction be relaxed? If not, then the theory predicts a -1-indexed interior equilibrium; in the simplest case, dynamics will converge to either the weakly decadent society or the strongly resistant union between law and medical ethics (Figure 5.36). If yes, then all outcomes continued as before in Figure 5.36, just like the outcome of the 2015 CDC policy. Both reside in the same **equivalence class**, although

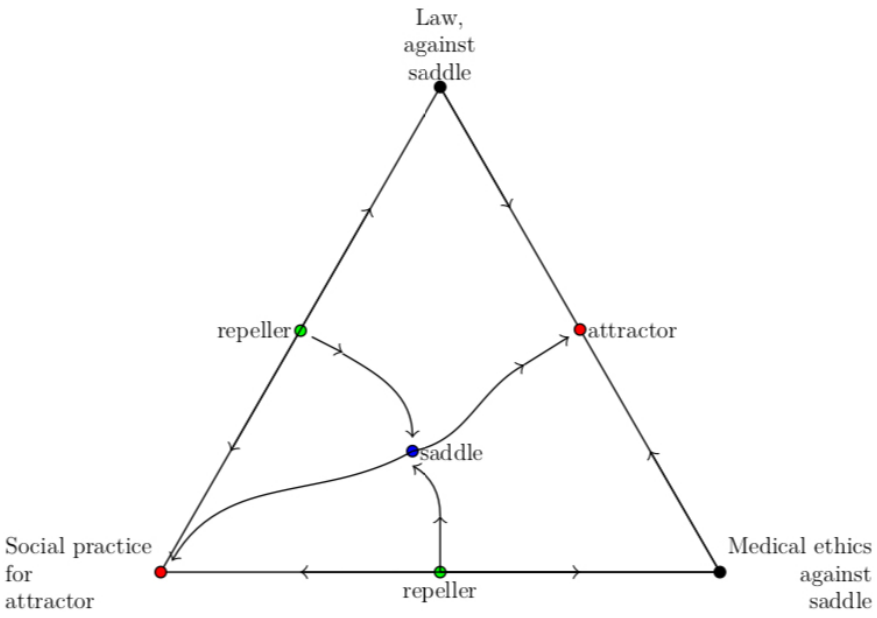


Figure 5.36: U.S. Opioid Epidemic Dynamics: 2019– Federal Policy Option

the policy is relaxation now and restriction then. Therefore, if implemented, the policy will make no fundamental improvement to the status quo (Figure 5.35).

Policies, in retrospect, could have been introduced at an early stage so that hundreds of thousands of lives could have been saved. Suppose that before the *Drug Addiction Treatment Act of* 2000 was passed, a policy targets at the dominance of Purdue Pharma. It breaks the relationship between bold social practice and yet-to-develop law, according to Theorem 3.5, returns two equilibria on the left edge — a repeller below and an attractor above. There are four further cases contingent on the strategic move of medical ethics.

In the first case, medical ethics decides not to entangle in the sheer power of the drug industry over the law (Figure 5.37). The theory anticipates a 0 index of interior equilibria, which in the simplest case characterizes an interior saddle near the upper left-edge attractor and an interior repeller near the lower left-edge saddle. The inaction of medical ethics also generates an additional attractor on the left edge, a possible compromise between society and law rather than being utterly absorbed by the powerful drug company — an effective policy. Notice that although the law's overall characteristic is yet to develop, subgroups

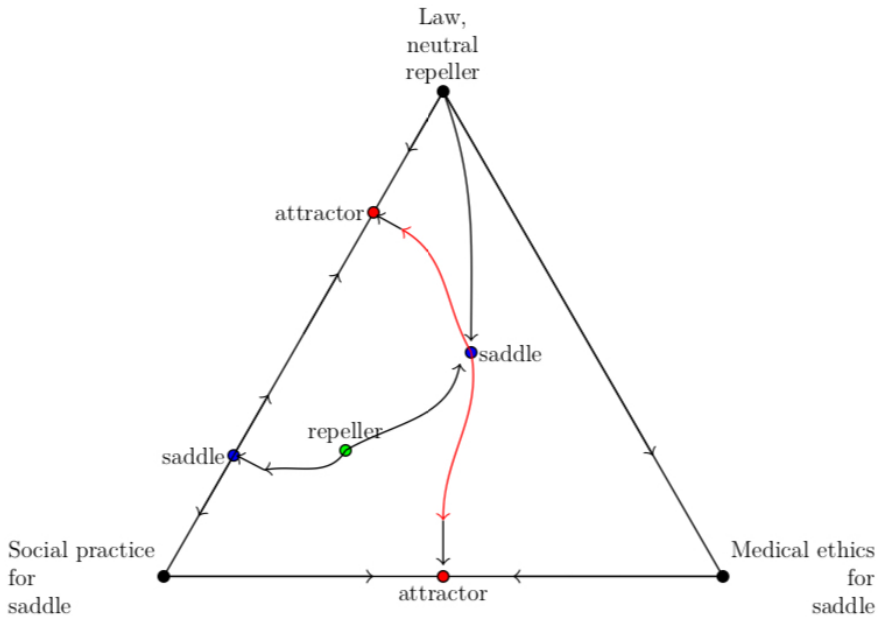


Figure 5.37: U.S. Opioid Epidemic Dynamics: Before 2000 Policy Option Case 1 Success

within the law may have already shaped firm attitude or at least have doubts. For example, some congresspersons rejected or abstained from passing the *Drug Addiction Treatment Act of* 2000 [92].

In the second case, medical ethics strategically joins in the game between society and law, denoted as both interior flows pointing away from the left edge toward the bottom right vertex. The 0 index of interior equilibria suggests a convergence to the attractor on the bottom edge, which warns a conspiracy of medical ethics and social practice for drug indulgence — an unexpected and unwanted outcome (Figure 5.38).

In the third case is that medical ethics decides to influence only the prevalence of drug sales and addicts, denoted as the lower left-edge interior flow pointed outward to the bottom right vertex; and the upper flow inward away from the bottom right vertex. The consequent -1-indexed interior equilibria characterizes an interior saddle (Figure 5.39) and, similar to the first case (Figure 5.37), is an effective policy.

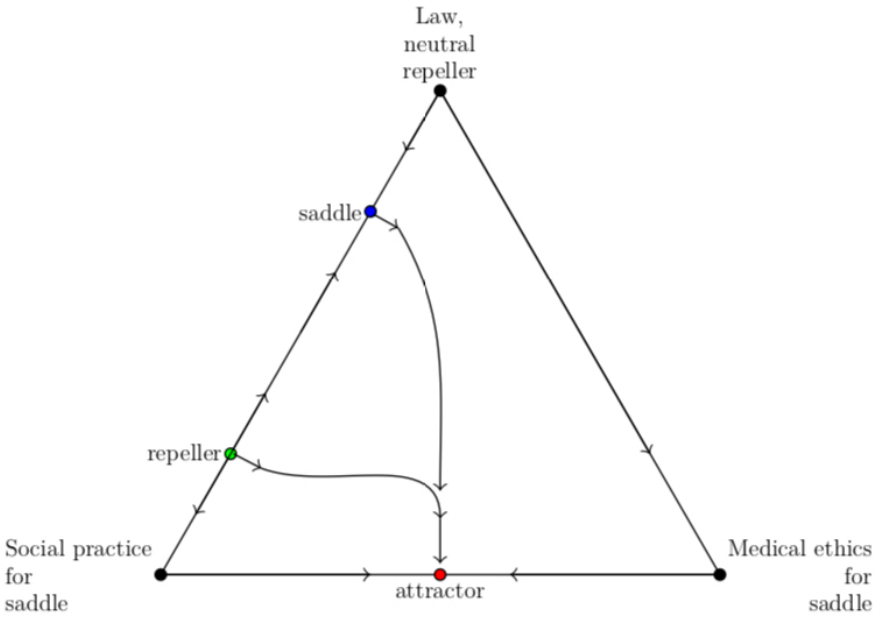


Figure 5.38: U.S. Opioid Epidemic Dynamics: Before 2000 Policy Option Case 2 Failure

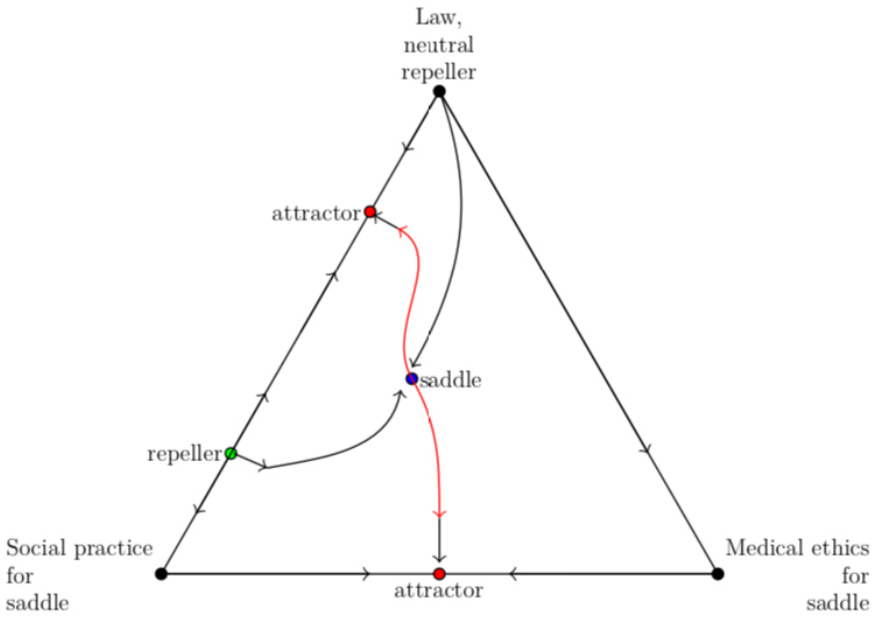


Figure 5.39: U.S. Opioid Epidemic Dynamics: Before 2000 Policy Option Case 3 Success

In the final case is that medical ethics only affects the law and leaves drug sales and addicts alone (Figure 5.40). It yields a +1 index of interior equilibria, which given the directions of existing flows is a repelling limit cycle bounded by the left-edge saddle and bottom-edge

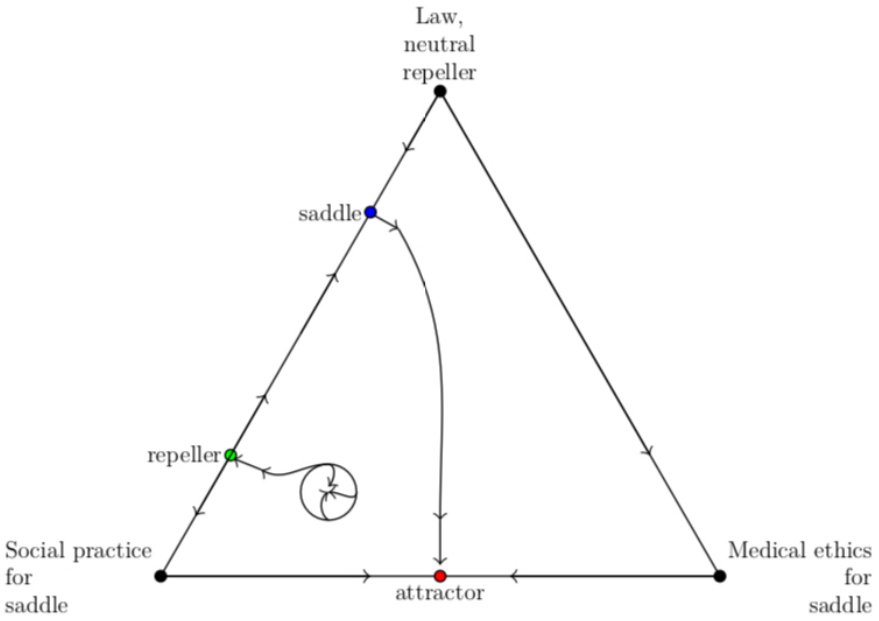


Figure 5.40: U.S. Opioid Epidemic Dynamics: Before 2000 Policy Option Case 4 Failure

attractor. It suggests a frustrating situation in which whenever the law tries to affect the lower-left neighborhood where the social practice of drug addiction is relatively dominant, the legal power will always bounce back and extinguish. The dynamics will always return to the tolerant collusion between addictive society (to drugs and profits) and medical ethics outside the reach of the law — a good intention in vain.

5.5 Device: Artificial intelligence (A.I.) in healthcare

A.I. refers to intelligent machines (computer algorithms and robots) that think or act rationally or humanly. Admittedly, there are many attempts to define an A.I., most of which can be categorized into these four dimensions, which overlap and imply four major approaches to build an A.I. — either through thought process or behavioral performance; either rationalistic based on mathematics or human-centered based on statistics [82]. In fact, A.I. has evolved from mathematical logic-based during the 1960s−1990s to statistical learning-based

since the 1990s, and advanced since 2012 with new methods available especially deep learning [4].

In medicine, in particular, A.I. has been applied to expert systems for imaging and clinical decision support since the 1980s [101]. A.I. has also been quickly adopted in electronic health records (EHRs) and mobile health technology (mHealth) with the help of popularization of the internet since 1995 and smartphones since 2002. Both EHRs and mHealth have demonstrated great potential to collect and analyze personal health data for clinical medicine and public health [44]. As of 2017, 97% of hospitals have installed EHRs [70] and more than $327,000$ mHealth Applications (Apps) were available worldwide [81] In 2018, the FDA defined healthcare A.I. as medical device [1]. In the same year, the AMA announced its definition of A.I. as Augmented Intelligence [6, 19].

Nevertheless, A.I. in general, and healthcare A.I., in particular, impose ethical and technical challenges in data security, non-discrimination, consumer privacy, and data interoperability. These problems in health informatics correspond to principles in medical ethics. Data security pertains to digital information safety and *harm* prevention. Unfair predictions from biased input data violates the *justice* principle. Consumer (e.g., patient) privacy and data interoperability fall in the realm of the *autonomy* principle. When conflicting with one another, the principles cause ethical dilemmas.

Consider this hypothetical case: A patient requests her bypass surgery costs paid by her insurer (e.g., Anthem) and postsurgical electrocardiogram data to be transmitted from her care provider (e.g., Petaluma Health Center in Sonoma County, California) via the EHR patient portal managed by the vendor (e.g., eClinicalWorks) and stored by the cloud computing company (e.g., Amazon), to mHealth Apps (e.g., Apple Watch ECG) on the patient's smartphone developed by the software designers (e.g., Apple). In this case, the *autonomy* principle guides clinicians to respond to the patient's request and share her data. The care provider, however, also knows that the payer Anthem was fined $16 million for exposure of

Patient Health Information (PHI) of 79 million people after a series of cyberattacks [66] and that the vendor eClinicalWorks $132,500 for failing data breach notification [65, 100]. Both may *harm* the current patient's *privacy* and even finance. To share or not to share is the dilemma.

5.5.1 U.S. Healthcare A.I. Prediction & Policy

At the early stage of A.I. in 2012, industrial enterprises driven by *economic needs (or wants)* overpowered law and medical ethics that were both neutral (Figure 5.41). A bifurcation soon

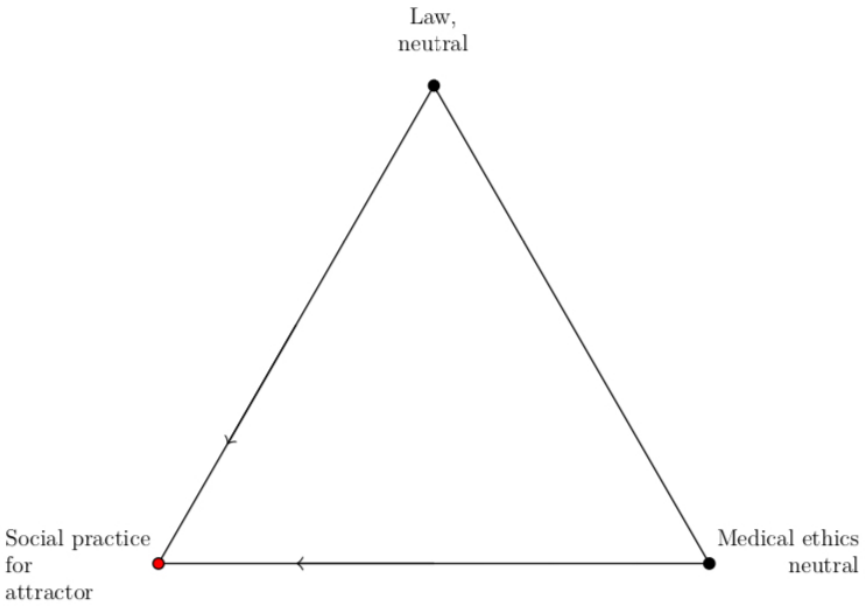


Figure 5.41: U.S. A.I. Dynamics: 2012

developed. In 2013, the original *Health Insurance Portability and Accountability Act* (HIPPA) that regulates providers and payers for patient privacy appended the Final Omnibus Rule that added business associates to be responsible for data security and breach notifications. The restraining law and neutral medical ethics produced two attractors — in reality, the one at the weakly regulatory law is prevailed over by the other at the strongly audacious A.I. industry (Figure 5.42).

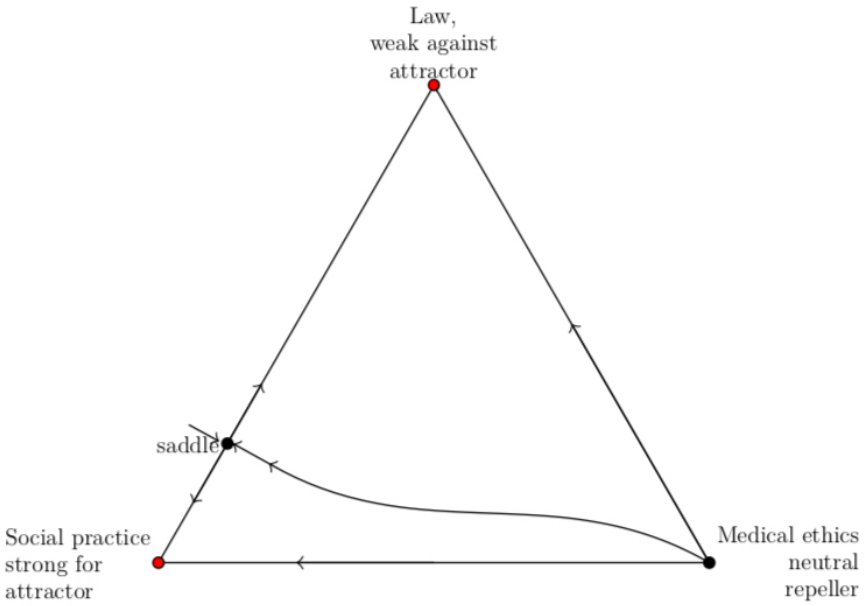


Figure 5.42: U.S. A.I. Dynamics: 2013 HIPPA Final Omnibus Rule

A further bifurcation emerged recently. In 2016, the 21*st Century Cures Act* was enacted to reduce information block and increase PHI data exchange [93]. Moreover, in 2018, the *Federal Trade Commission Act* (FTC) required business associates, especially App developers, to be responsible for the non-PHI data breach [64]. That summer, the AMA announced its definition of A.I. as Augmented Intelligence showing mixed attitude and concern about A.I. replacing physicians especially radiologists and pathologists [6, 19]. Taken together, both the law and medical ethics formed a restrictive partnership and pulled the attractor at the vertex of A.I. enterprises to the interior more dominated by the partnership, which matches reality (Figure 5.43).

Another bifurcation emerged. In 2019 for the first time, the FDA defined healthcare A.I. as a medical device and drafted interoperability standards for Formal Concept Analysis algorithm (FCA) format data which relaxed a certain degree of consumer privacy [1]. Compared to Figure 5.43, the policy further split the left-edge repeller into three unstable equilibria and added an attractor in a larger interior, away from the restrictive partnership of law and medical ethics Figure 5.44. In other words, the lenient policy created more chances for

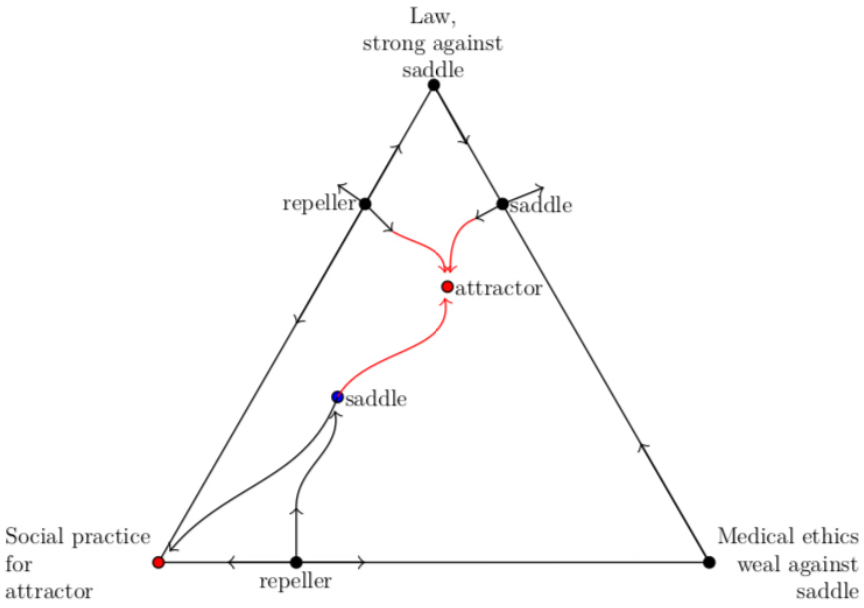


Figure 5.43: U.S. A.I. Dynamics: 2016 21st Century Cures Act

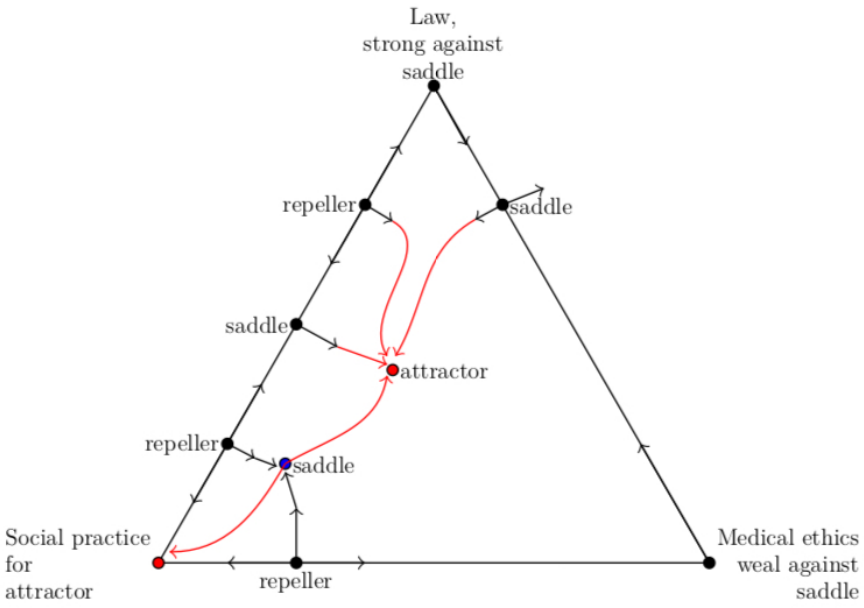


Figure 5.44: U.S. A.I. Dynamics: 2019 FDA & AMA Policies

compromise among the A.I. industry, law, and medical ethics.

5.5.2 E.U. Healthcare A.I. Prediction & Policy

Compared with the U.S., Europe and Asia differ in laws and policies hence evolutions. In the E.U., at the early stage during $2012-2015$, the A.I. industry in general received about $\$2.4-3.2$ billion private investment [32] and dominated the law and medical ethics that were yet to develop (Figure 5.45), which was **equivalent** to the initial state of the U.S. dynamics

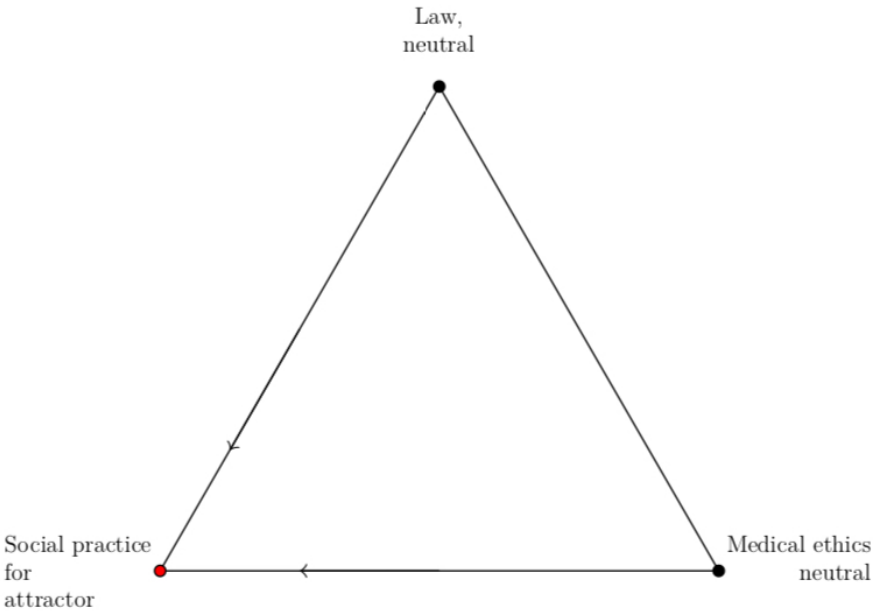


Figure 5.45: E.U. A.I. Dynamics: $2012-2014$

(Figure 5.41). A bifurcation, however, was shaped in 2015 by ethical experts' raising concerns about unfair algorithmic predictions [2, 47]. In the absence of any applicable law, dynamics still converged to industrial practice because the previous state located nearby (Figure 5.46). As time proceeded, the law began to address the issue but still not in a fully-fledged manner (Figure 5.47).

Another bifurcation occured once the law's dominant characteristic matured. In 2018, the E.U. passed the *General Data Protection Regulation* (GDPR) to guard data security and privacy of E.U. subjects regardless of their locations inside or outside of the E.U. [98] The theory predicts 0-indexed interior equilibria. The simplest case that all dynamics converge

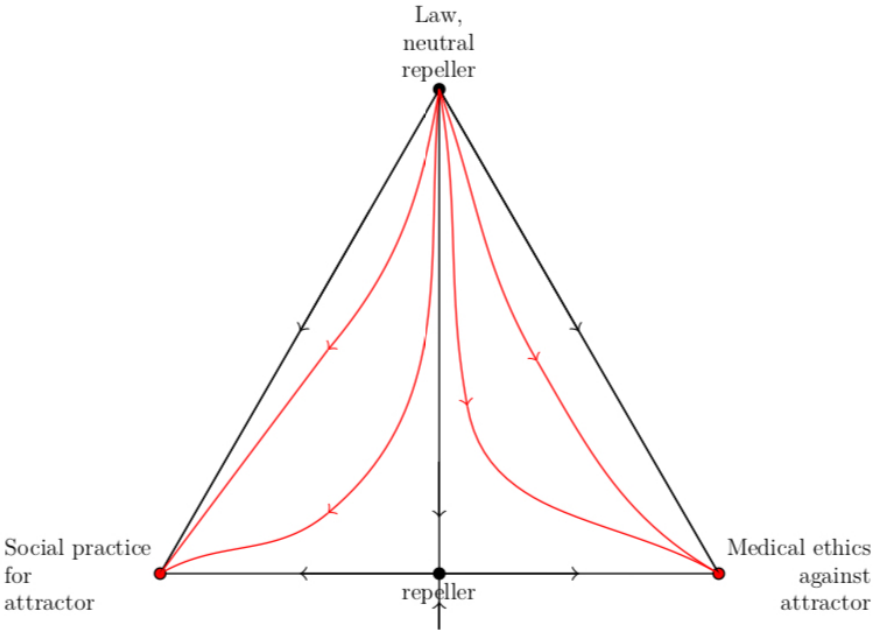


Figure 5.46: E.U. A.I. Dynamics: 2015

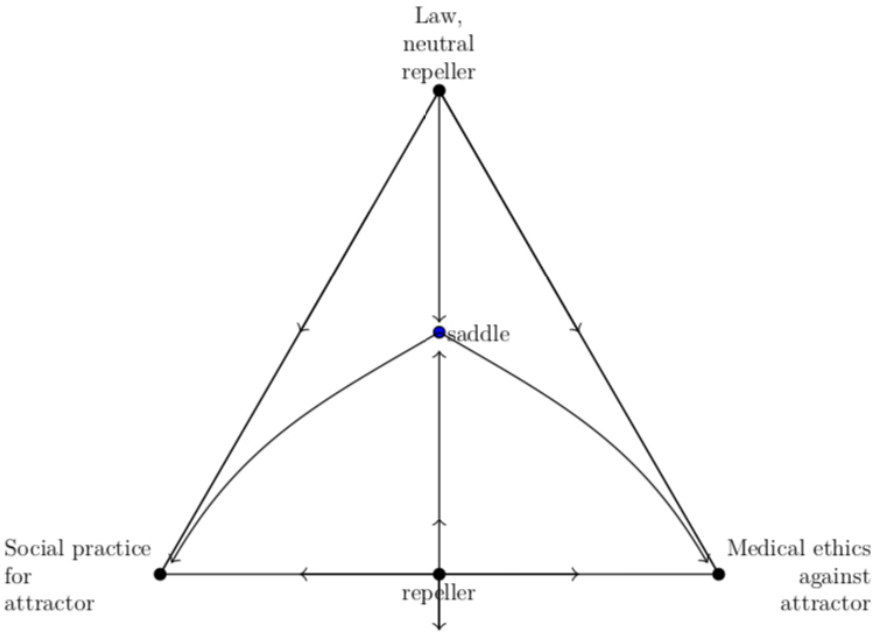


Figure 5.47: E.U. A.I. Dynamics: 2016 – 2017

to the driving A.I. enterprises is less likely given the power battle between law and industry in the E.U. (Figure 5.48) Alternatively, at the next level of complexity, the characterization contains a saddle near the attracting industry and an attractor near the restrictive collaboration between law and ethics (Figure 5.49). The latter matches regional observations. For

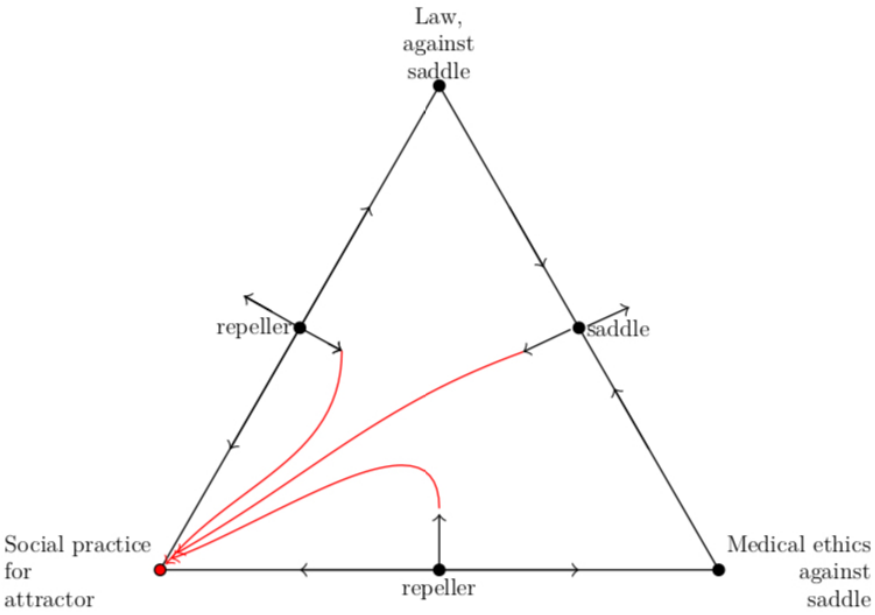


Figure 5.48: E.U. A.I. Dynamics: 2018 GDPR Law Case 1
Low Complexity

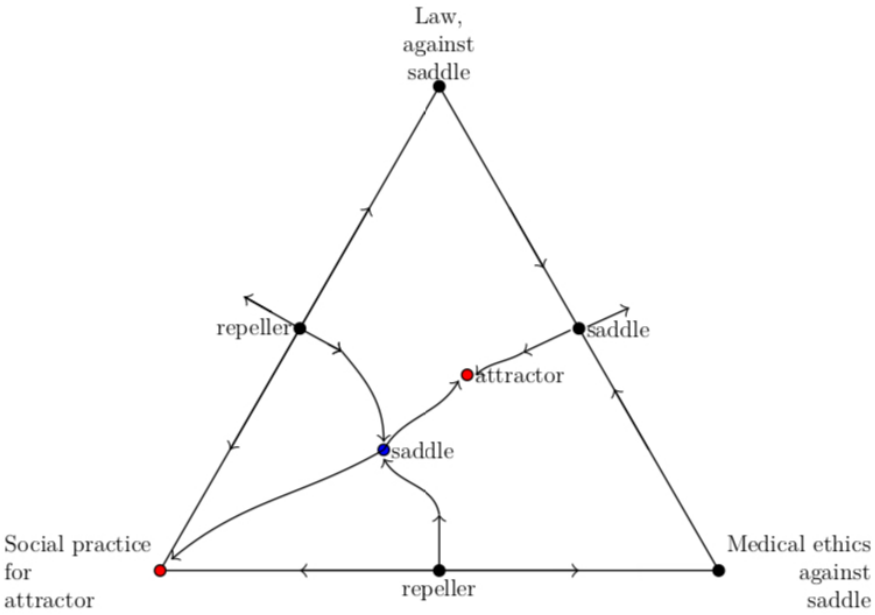


Figure 5.49: E.U. A.I. Dynamics: 2018 GDPR Law Case 1
High Complexity

the first year, GDPR has fined companies including Facebook, €56 million, of which €50 million was against Google for violating the privacy rules [97, 62].

Further in 2019, a bifurcation occurred due to policy interventions. The European Commis-

sion published a guideline on ethical A.I. to promote the idea of fairness. As shown in Figure 5.50, the policy further split the bottom-edge in Figure 5.49 into three unstable equilibria

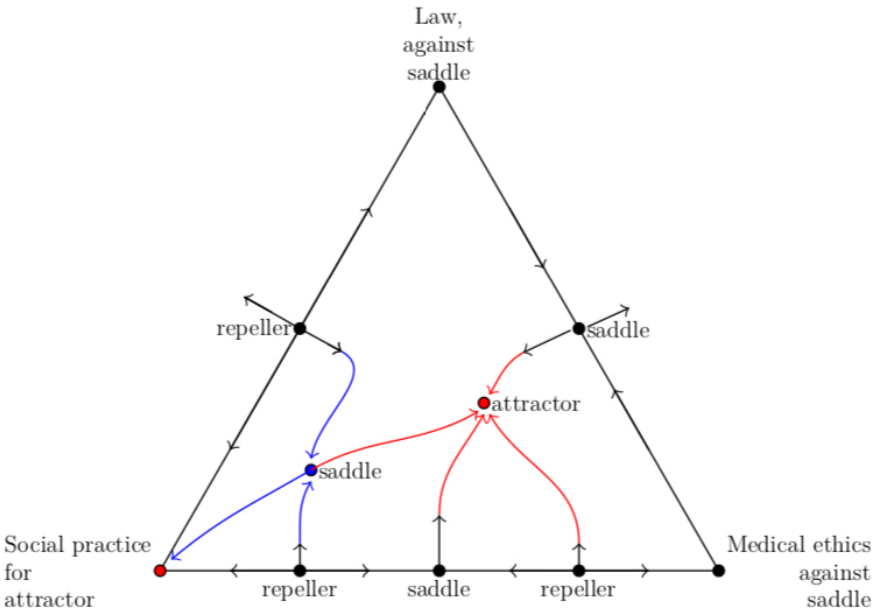


Figure 5.50: E.U. A.I. Dynamics: 2019 Ethical A.I. Policy

and generated two interior equilibria — a saddle near A.I. industry and an attractor with a higher likelihood, compared to Figure 5.49, near the restrictive alliance of law and ethics. The final outcome suggests that in the E.U., *ceteris paribus*, the (healthcare) A.I. enterprises will be highly regulated with some but little influence by the industry, which resonates with the observation.

5.5.3 China Healthcare A.I. Prediction & Policy

In China, conversely, the law has been absent, but policies encouraging. During $2012-2015$, Chinese A.I. enterprises boomed with nearly $\$ 10.5$ billion private investments [32] and shared **equivalent** early dynamics with the U.S. and the E.U. (Figure 5.51) Then a bifurcation arose because of strong national policies: the *Internet Plus A.I. Three Year Action Implementation Plan* was initiated in 2016. The State Council also announced the *New Generation A.I.*

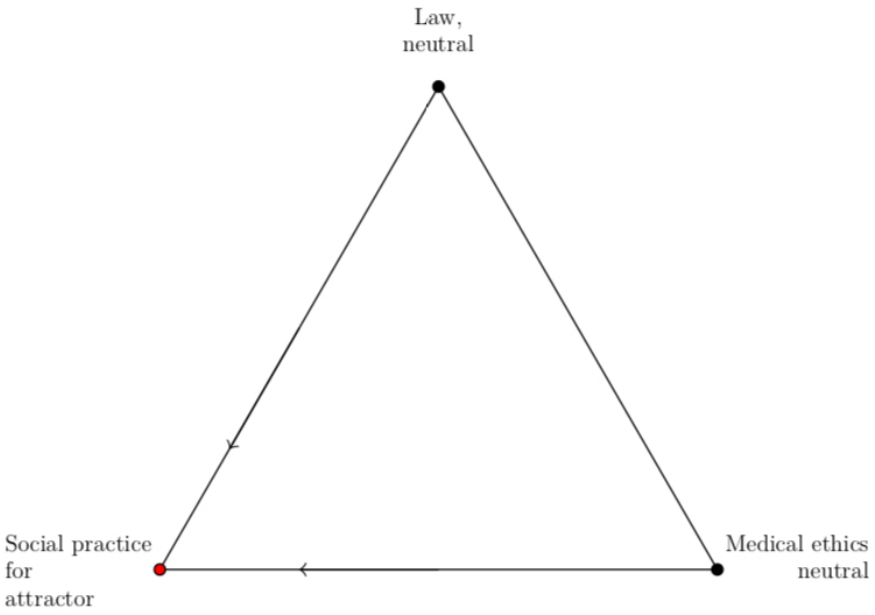


Figure 5.51: China A.I. Dynamics: $2012 - 2014$

Development Plan in 2017, which aimed for China to gain A.I. global dominance by 2030 [23]. To implement policies, the Ministry of Science and Technology opened an A.I. Plan Promotion Office. The series of guiding policies brought about two equilibria on the left edge between society and law. The outcome depends on the strategic move of (medical) ethics.

If ethics does not intervene, then interior flows move away from ethics and toward the two newly-formed edge equilibria (Figure 5.52); and a 0 index of interior equilibria suggests an interior repeller and saddle. The policy, therefore, created more chance to form a stable agreement with the yet-to-develop law with underlying regulating concerns. Otherwise, ethics' involvement can be depicted as both left-edge equilibria sending out interior flows toward the bottom right vertex. The 0-indexed interior equilibria suggests that all dynamics still converge to industry (Figure 5.53). The policies strengthened the complete dominance of the Chinese A.I. industry.

Since 2018, China has paid more attention to ethical issues, which led to a bifurcation by adding an attractor to the vertex of ethics whose strength was still weak (Figure 5.54). In 2019, the A.I. Governance Expert Committee in the Ministry of Science and Technology

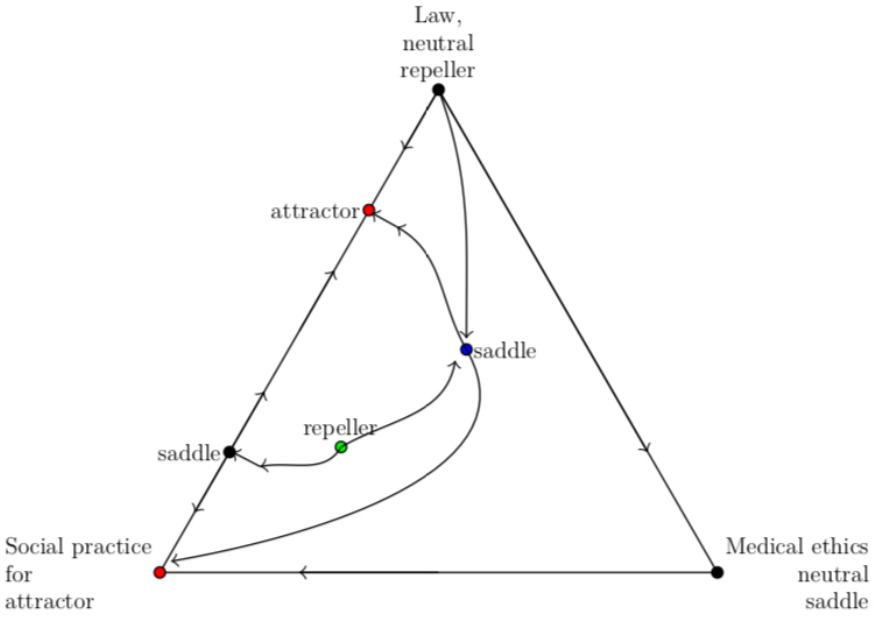


Figure 5.52: China A.I. Dynamics: 2016 – 2017 Policies Case 1 Ethics Inaction

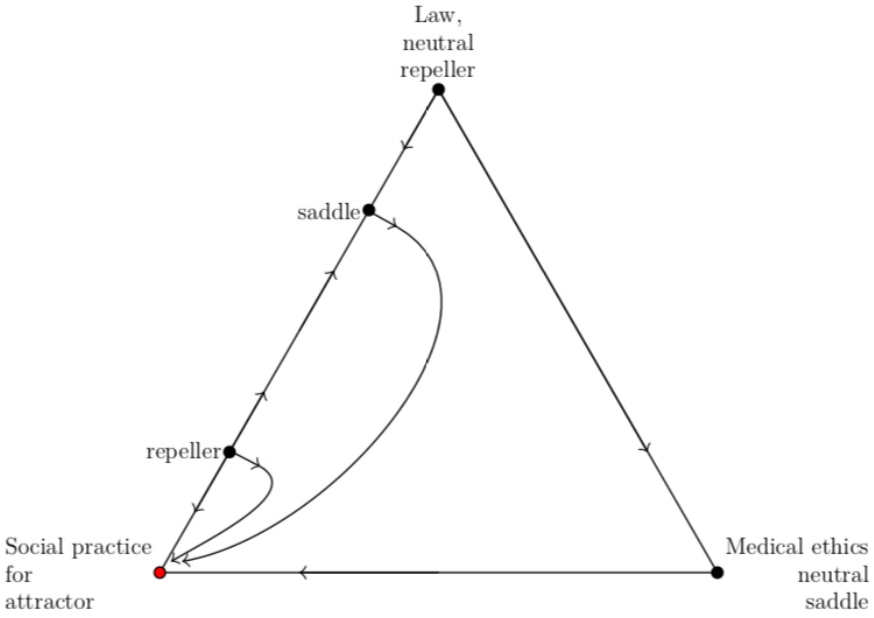


Figure 5.53: China A.I. Dynamics: 2016 – 2017 Policies Case 2 Ethics Action

recommended ethical principles including privacy, security, and fairness [23]. Also, industrial leaders and academicians including Chinese Academy of Sciences, Beijing Academy of A.I., Peking and Tsinghua Universities, and industrial allies, e.g., Alibaba, Baidu, and Tencent

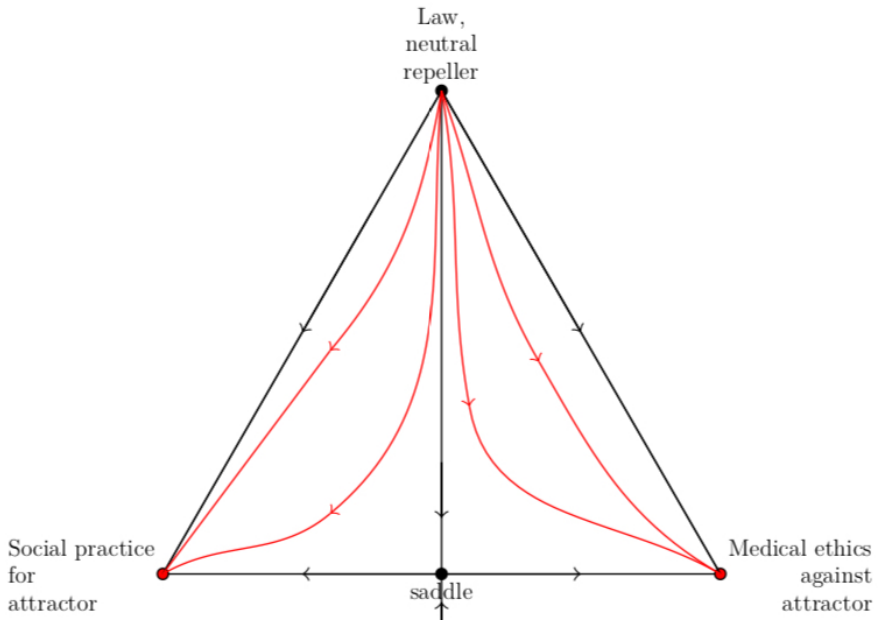


Figure 5.54: China A.I. Dynamics: 2018 Ethics Action

together proposed the *Beijing A.I. Principles* [34].

Despite the lack of law, the policies seeking ethical confinement of A.I. broke the bottom-edge saddle into three equilibria with two side saddles and one in-between attractor which offers a small chance of compromise between industry and ethics (Figure 5.55). Otherwise, a proactive engagement of law will lead to an interior saddle, which purges out the slight chance of compromise between conflicting industry and ethics; hence, is a bad move (Figure 5.56). Which case is valid awaits further observation.

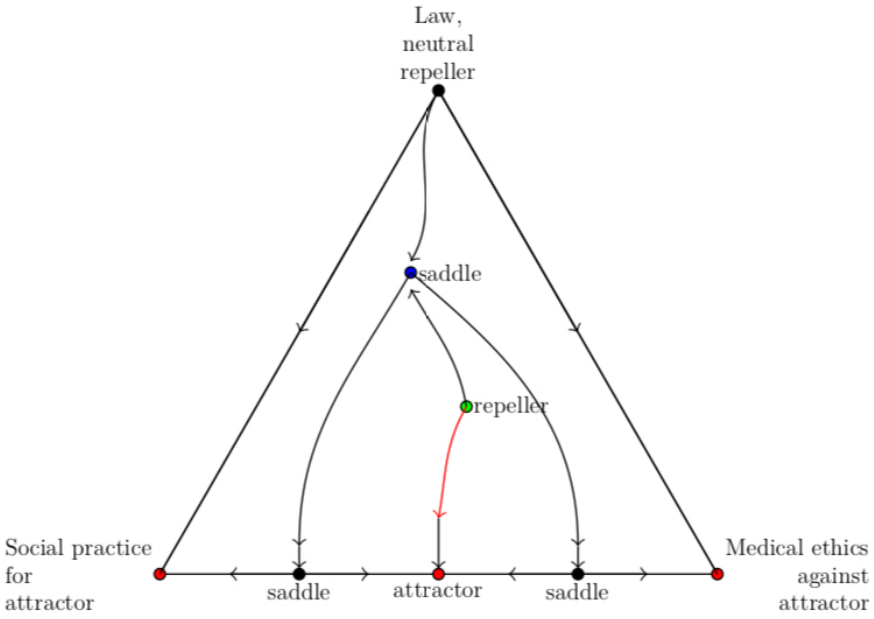


Figure 5.55: China A.I. Dynamics: 2019 Ethics Action Case 1
Law Inaction

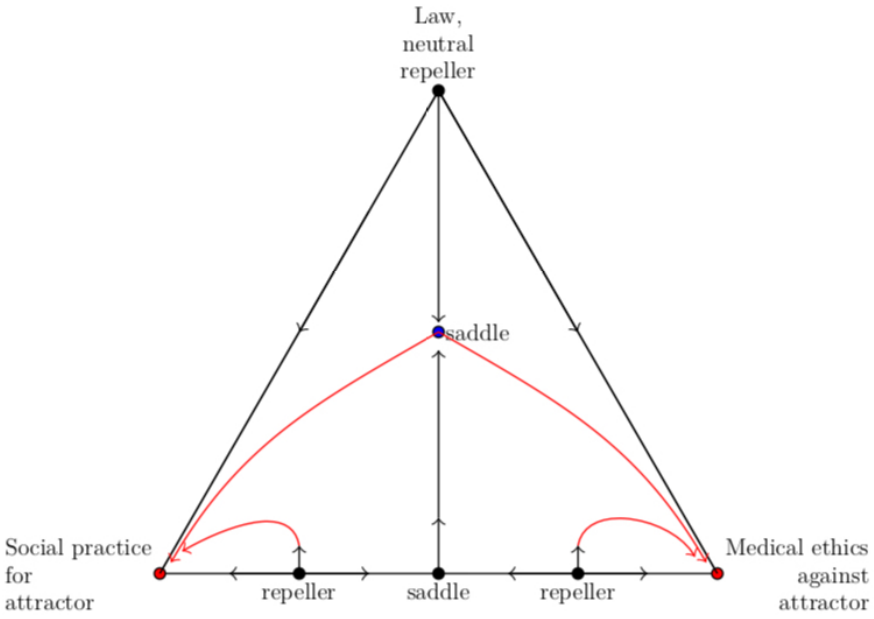


Figure 5.56: China A.I. Dynamics: 2019 Ethics Action Case 2
Law Action

Chapter 6

Discussion and Conclusion

6.1 Complexity: Configuration & Bifurcation

Conclusion 1: There exist bifurcations in the dynamic evolution of each social-medical-legal issue examined.

Conclusion 2: These bifurcations are caused by changes in endogenous or exogenous parameters and contribute to the evolutionary complexity of each case.

Overall, there are two categories of complexity — alternative characterizations of a fixed configuration at the final state, and bifurcations caused by varied configurations at any state. The former involves characterizing 1) the pair of interior equilibria summing to the same index, and 2) the nature of interior equilibria with the same index.

The latter refers to bifurcations caused by parameters, including 3) mutations of vertices, 4) perturbations of edge flows, and 5) insertions of interior flows, resulting from endogenous changes in each domain or exogenous shocks such as policy intervention.

First, social movements mutate the characteristic of social practice. Notably, the 1960−1970s Civil Rights Movement that prioritized disadvantaged groups such as women and terminally-ill patients invoked bifurcations in abortion and withdrawal of life-sustaining support. Prioritizing the need of one social group in a previous state, however, may leave the needs of other groups unmet and hence trigger a backlash in the next state such as the subsequent 1980s Anti-Abortion Movement. Moreover, abortion distinguishes itself from other issues, because the unknown harm of unborn babies is impossible to observe, whereas the direction and magnitude of changes in the unknown harm in other issues such as IVF are evidence-based. Issues with observable harms, therefore, show stable convergence over time, while abortion features an unstable spiral path consisting of limit cycles with time— progressive but never settled.

Second, legal parameters include the proportion of seats taken by political parties in the U.S. Congress and the composition of Justices in the U.S. Supreme Court. Fluctuations in these parameters help predict bifurcations. For instance, during $1993 - 2000$, despite the liberal Clinton administration, Congress became gradually comprised of conservatives and hence passed *Partial-Birth Abortion Ban Act of* 1995.

Third, medical breakthroughs may simultaneously bring about greater unknown harm and good, which vary the weighing of underlying principles of *nonmaleficence* and *beneficence* and hence induce bifurcations. For instance, the 1998 discovery of adult stem cells reduced the possible harm to fetuses and hence gained the support of Bush administration for stem cell research. A similar outcome of acceptance occurred with IVF for assisted reproduction. The creation of iPSCs shared similar dynamics. Also, self-regulation of the medical profession during the 1870s brought forth a bifurcation in abortion. Moreover, the swinging standardization of care yielded oscillation between opioid under- and over- prescriptions.

Fourth, exogenous shocks such as recessions, wars, and media events may also lead to bifurcations. For example, the $2008 - 2009$ economic crisis led the general public to blame

capitalism and conservative moralists and to turn to a prevailing liberal attitude, resulting in a bifurcation in the abortion issue. Also, in 1997, a publicized assisted-death video on the popular television program *60 Minutes* aggravated the unknown harm to a larger scale, and hence provoked societal repugnance against physician-assisted death and stimulated a bifurcation. Frequent news about celebrities having babies using IVF services also partially cultivated the social acceptance of assisted reproduction.

6.2 Simplicity: Equivalence Class

Conclusion 3: There exist equivalence classes regardless of the issues in hand, and of the same or opposite types.

Equivalence classes may exist at various states within one issue, or, surprisingly, across different issues as long as they share similar configurations — same directions of edge and interior flows, respectively. Knowing a dynamic system belongs to an equivalence class provides at least three insights: How are seemingly different and even irrelevant phenomena essentially the same? Why does the evolution of the abortion issue seem to be a swinging pendulum? Where is an infinite source of policy options?

The alternation of three equivalence classes over time largely explains why the abortion dynamics oscillate. The first equivalence class is a set of dynamics in which the law reflects the prevailing social value, as does medical ethics, regardless of their type — against or for abortion — and if medical ethics does not exert additional influence on the other two, then it will result in a stable agreement between law and society only. This was true for abortion during the 1850s (against, Figure 5.18), the 1970s (for, Figure 5.21), the $1993-2000$ liberal scenario at the federal level (for, Figure 5.25), and $2009-2016$ at the federal level and in the liberal states (for, Figure 5.21).

The second equivalence class of the abortion issue occurs when only the law respects the present social values; medical ethics neither agrees nor intervenes, and hence the dynamics converge to either the weakly dissenting medical ethics or the strongly affirming coalition of law and society. This was the case for the 1980s -1992 and the $2001-2008$ conservative scenario at the federal level (Figure 5.23), as well as $2009-2016$ in the conservative states (Figure 5.26).

The third equivalence class happens when the law weakly agrees with medical ethics, despite the strongly implied disagreeing social values, and hence the dynamics converge to either the society alone, or with higher tendency a compromising zone — a never-ending battle between the two sides. This was the case for abortion during 1980s -1992, the $2001-2008$ liberal scenario at the federal level, and $2018-$ present at the federal level (Figure 5.22). The second and the third equivalence classes differ mainly in the law's position — weakly against or for abortion. Together, the dynamics of the abortion issue alternate among the three equivalence classes throughout decades, and hence generate an evolutionary spiral.

Another equivalence class exists when social practice competes with medical ethics while the law is silent; in that scenario, the dynamics will converge to either domain depending on their strengths. This was the case when the dynamics converged to medical ethics in the 1980s Futility Movement (Figure 4.17); and to the predominant A.I. industry in 2015 the E.U. (Figure 5.46) and in 2018 China (Figure 5.54).

Similarly, when social practice challenges the law in the absence of medical ethics, then the dynamics will converge to either domain depending on their strengths. This was the case especially for prohibitionary law and adventurous social practice such as scientific (e.g., stem cell research in the E.U., Figure 5.3; genome editing in the 1990s U.K., Figure 5.14), and industrial practice (e.g., A.I. under HIPPA Final Omnibus Rule in 2013, Figure 5.42; opioids epidemic after federal criminal decision during $2007-2010$s in the U.S., Figure 5.33).

Moreover, an equivalence class may consist of dynamics with only one interior equilibrium — an attractor, which arises when all three domains agree with and exert influence on one another, regardless of their attitude. For example, a consensus among all three domains was reached against abortion during the 1860s (Figure 5.19), against the Medical Futility Movement during the late 1990s (Figure 4.21), and for the opioid overprescription during $1998 - 2004$ in the U.S. (Figure 5.30)

An equivalence class may also contain dynamics with a pair of interior equilibria — a saddle and an attractor— especially when the law reflects opinions of medical ethics experts rather than social values, resulting in a stable dominance by the medical and legal partnership. This was the case for Medical Futility in the mid$-$1990s at its peak (Figure 4.20), and the A.I. issue in which ethical concerns were addressed by law such as the *21st Century Cures Act of* 2016 in the U.S. (Figure 5.43) and the *General Data Protection Regulation of* 2018 in the E.U. (Figure 5.49)

6.3 Policy

Equivalence classes are infinite sources of policy options. Interventions generate equivalence classes for issues in the past, which can inspire more and effective policies for new issues in the future.

Policies that target the interaction between society and law, especially when the law is still developing, create two equivalence classes depending on whether medical ethics plays a part or not. If medical ethics does exert influence on the other two, then the policy will help promote the present social value regardless of its type. For instance, before the enaction of the Dickey Amendment in the early 1990s, the Clinton administration removed the federal ban on human embryo research while medical ethics affirmed the moral rightness of that

research, which resulted in a stable encouraging environment for scientific practice in this field (Figure 5.7). Similar to the policy option to curb opioid overprescription in the absence of law before 2000, the intervention, however, strengthens addictive conspiracy between society and medicine hence is a failure (Figure 5.38). Otherwise, if medical ethics stops imposing pressure, then the policy will cultivate a compromise between the concerning law and the drug producer and addicts, and hence is a success (Figure 5.37).

Furthermore, if the law disagrees with the united society and medicine, then a set of policies can be introduced to alleviate the law-medicine or the law-society tension, resulting in a stable compromise among all three. For instance, despite the prohibitive Dicky-Warner Amendment in the late 1990s, the sympathetic policy of the Clinton administration relaxed the tension between law and scientific practice and produced an interior attracting limit cycle containing unstable yet compromising solutions (Figure 5.8), similar to the issue of mitochondrial replacement therapy (M.R.T.) in the U.K. in 2016 (Figure 5.16) Although genetic editing is prohibited by the *Human Fertilization and Embryology Act of* 1990, the authority implemented a policy that resonated with the British Medical Research Council and created a lenient environment for adventurous scientific practice.

Finally, when relevant laws do not exist, expedient measures could be introduced to break the competition between medical ethics and social practice. This was particularly the case with China on the issues of A.I. (Figure 5.55) and CRISPR for reproduction (Figure 5.12), wherein both industrial and scientific practices violated (international) medical ethics, hence both events could completely converge to either domain — a zero-sum game. Expedient responses before the laws' maturity, however, smartly alleviated both tensions and created stable compromises between both ethics, and industry or science, and hence were effective short-term springboards for long-term legislations.

Equivalence classes, therefore, can serve as an arsenal of policies. Interventions can target at lobbying and mutating each domain, alleviating the tension between any two domains, and

convincing or deterring the third domain's involvement. To brainstorm possible options, one only needs to look into the equivalence class of the current issue in hand, use the theory to examine all past policies — successes and failures — and then craft a particular current version of past successful policies. In this way, policies of good intentions but with undesired outcomes will be avoided and desired outcomes considered. As aresult, evidence-based predictions for policies can be conducted before implementation for better selection, and after intervention for better decision-making in the future.

6.4 Conclusion

This research is the first mathematical analysis to understand the co-evolution of medical ethics, health law, and social practice. It makes several contributions. First, I establish a coordinate system for each of the three domains to understand issues that occurred in each domain driven by underlying principles. Second, I apply a novel mathematical approach developed by Saari (2018) to capture the qualitative features of unknown dynamics among the three domains, including the existence, number, and nature of unexpected interior equilibria. Third, I predict and update bifurcations when dynamics evolve from one state to another. Fourth, I identify root causes of bifurcations, i.e., variations in endogenous or exogenous parameters that vary the weighing of underlying principles of each domain and hence change the dynamic outcomes. Fifth, I discover the existence of equivalence classes in which seemingly different issues have similar configurations and hence similar outcomes. Sixth, I conduct policy analyses for contemporary issues such as abortion, the opioid epidemic, healthcare artificial intelligence, stem cell and genome editing research, and find unexpected and undesired outcomes. I also propose effective policies. In sum, I create a general theory to explain what has happened for existing cases in medical ethics and law, and to predict what can and probably will happen for new cases and what can be done. This research

can serve as a prediction and policy tool to assist the ethical and legal aspects of medical decision-making.

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