Turning Straw into Gold: Novel productive factors and innovation under contested property rights*

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1 Introduction

Technological innovations drive economic growth. Economists have traditionally studied innovations that transform *existing* factors of production, like labor or capital, in a novel way in order to increase productivity, quality or product variety (Romer, 1994; Aghion et al., 2014). Yet, some technological innovations are different in nature. They create *new* factors of production from resources which had previously been overlooked, unowned, or unreachable — they turn straw into gold. Consider Google's use of consumer data in digital advertising or OpenAI's use of online text in training ChatGPT. Each turned online data into a valuable factor. History offers many other important examples, including the use of airwaves in radio broadcasting in the 20th century or the use of overhead public space in distributing electricity by wire in the late 19th century.

Existing factors of production are typically exchanged in markets, with property rights being well established. *Straw-into-gold* technological innovations occur in a very different institutional context. Property rights over new factors are inevitably poorly defined prior to the innovation that creates them and can become contested afterwards. In practice, conflicts over property rights have often been resolved through litigation and regulation,

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as seen in disputes over the ownership and fair use of online data, the allocation of radio spectrum, and the aesthetics and safety of electricity wires.

But why would innovators choose to develop a technology and only settle disputes over property rights afterwards? Why would they not, instead, contract with the relevant parties and try to establish property rights beforehand? Consider an innovator — an entrepreneur or a firm — who has discovered a technology that would turn a heretofore useless or unowned resource into a productive input. Developing the technology while leaving property rights ill defined creates the chance for extraordinary rents if disputes that may arise afterwards are settled in favor of the innovator.[1] But it also risks expropriation, penalties, damages, or outright business failure if they are not. Such is the *innovator's gamble*. Alternatively, the innovator can play it safe, avoiding conflict, by offering a contract to other relevant parties and establishing property rights before developing the technology.[2] In doing so though, the innovator necessarily reveals valuable information: that a new factor potentially exists and counterparties may have claims over it. That is, the innovator *tips their hand*. The information improves a counterparty's bargaining position, giving them power to extract rents. Their bargaining position becomes particularly strong when the technology is groundbreaking. The innovator cannot commit to not develop an extremely profitable technology, even if the counterparty rejected the contract. Thus, the innovator may prefer to gamble instead of tipping their hand.

In this paper, we study straw-into-gold innovations that create new factors with contested property rights. We begin by presenting several case studies of such technological innovations. To support each narative, we collect data from US newspaper articles, court documents, and legislation. Then, we present a model of straw-into-gold technological innovation. We show that innovators find it optimal to develop the technology first and settle conflicts over property rights afterwards — they gamble — *only if* the technology is sufficiently productive and contracting reveals valuable information to the relevant counterparties. Instead, when the innovation is incremental or the contract does not reveal that a productive factor exists, innovators would choose to contract with counterparties and establish property rights beforehand.

Our analysis most directly contributes to the literature on growth arising from ideas and innovations (Romer, 1990; Aghion and Howitt, 1992; Mokyr, 1992). We highlight an economically important class of innovations that has not received focused attention from economists up to now: straw-into-gold innovations which create a novel factor of produc-

[1] In practice, innovators would hire lawyers and lobbyists; consumers may also be a powerful constituency shaping litigation and regulation.

[2] The "other parties" refer to society at large — as represented by the government or through a class action — or counterparties like firms or individuals that potentially have rights over the input.

tion. We describe how and why the economics of this class of innovations differs from the innovations usually studied: the inherent absence of well-defined property rights over the new factor fundamentally changes the innovator's problem due to information revelation when contracting and the chance of extraordinary rents when resolving conflicts. Our analysis reveals a source of potential rents – arising from conflict over ill-defined property rights – that incentivize innovation, complementing Schumpeterian monopoly rents (as inSchumpeter, 2013; Aghion and Howitt, 1992).

Our finding that the absence of property rights over a new factor can induce innovation is also related to the literature on intellectual property rights. A substantial literature argues that strong intellectual property rights, in the form of patents, may be unnecessary – or even deleterious – for innovation. Moser (2013; 2016) reviews historical evidence of innovation in the absence of patent protection. Anton and Yao (2004) and Hall et al. (2014) present trade-offs between patenting and protecting intellectual property informally. Boldrin and Levine (2002; 2008a; 2008b), Bessen and Maskin (2009), and Henry and Ponce (2011) all argue that patents are not necessary for innovation, and that innovation may even be enhanced by weaker intellectual property protection. These papers, however, focus on property rights over the output of a technology or the copying of ideas. In contrast, we focus on contested property rights over resources that are made valuable by the discovery of a technology. Closest to our work are the analyses of Williams (2013) and Murray et al. (2016). They document the adverse consequences of intellectual property rights protection of biomedical research that is used as an input into downstream innovation. Our analysis differs from theirs in that: (i) we do not take property rights as given – they are to be determined in our context either through contracting or conflict; and, (ii) in our context, the innovator may prefer to leave property rights ill-defined.

Finally, in studying the endogenous determination of property rights, our analysis contributes to the literature arising from Coase (1960). Much of this work highlights the cost of insecure property rights for productivity and economic growth (North, 1981; Engerman and Sokoloff, 2005; Acemoglu and Johnson, 2005; Hornbeck, 2010). In contrast, we highlight a dimension of ill-defined property rights that can incentivize innovation and thus growth: weak property rights provide an opportunity for innovators to extract rents. That these rents induce conflict, rather than ex ante contracting, is difficult to avoid given the nature of information revelation when contracting and the necessity of writing incomplete contracts (Tirole, 1999 and 2009; Bolton and Faure-Grimaud, 2010). It suggests a contentious political economy of innovation in which entrepreneurs aim to shape the legal and regulatory environment in their favor, through litigation and lobbying.

2 Straw-into-gold innovations across history

Below we study in depth three cases of straw-into-gold technological innovation across history. To document the broader importance of this class of innovation, in Table we present many other examples in a concise manner.

2.1 Generative artificial intelligence

The origins of artificial intelligence (AI) trace back to the 1956 Dartmouth Summer Research Project, marking the field's official birth. For decades, progress was stifled by limited computing power and scarce data to train AI algorithms. But since the early 2000s, the field has rapidly advanced, driven by breakthroughs in computing and the explosion of big data online. This progress has recently culminated in the emergence of generative AI technologies like ChatGPT or Stable Diffusion, heralding a transformative era in the industry.

ChatGPT is an advanced language model that can generate human-like text based on the input it receives. It was trained on vast amounts of text from books, websites, and other written sources, enabling it to produce responses to a variety of user prompts. The New York Times (NYT) has recently taken legal action against OpenAI — the company behind ChatGPT — alleging unauthorized use of its articles in training the AI model. The core of the complaint is that OpenAI knowingly scraped NYT articles without obtaining a license, violating copyright law. The lawsuit claims that, when users prompt ChatGPT, the AI could generate outputs that closely mimic NYT articles — sometimes outright inventing them — or produce exact copies — what is known as "regurgitation" — thus misleading users and infringing on the newspaper's intellectual property rights. For example, the lawsuit presents Figure 1 as an exhibit and states that:

> "165. On information and belief, Defendants' infringing conduct alleged herein was and continues to be willful and carried out with full knowledge of The Times's rights in the copyrighted works. As a direct result of their conduct, Defendants have wrongfully profited from copyrighted works that they do not own."
>
> The New York Times Company v. OpenAI, Inc., et. al. District Court of Southern New York, 2023.

OpenAI argues that the New York Times lawsuit lacks merit. For instance, OpenAI asserts that their use of publicly available internet data, including from news sources, is

Output from GPT-4:
exempted it from regulations, subsidized its operations and promoted its practices, records and interviews showed.
Their actions turned one of the best-known symbols of New York — its yellow cabs — into a financial trap for thousands of immigrant drivers. More than 950 have filed for bankruptcy, according to a Times analysis of court records, and many more struggle to stay afloat.
"Nobody wanted to upset the industry," said David Klahr, who from 2007 to 2016 held several management posts at the Taxi and Limousine Commission, the city agency that oversees medallions. "Nobody wanted to kill the golden goose."
New York City in particular failed the taxi industry, The Times found. Two former mayors, Rudolph W. Giuliani and Michael R. Bloomberg, placed political allies inside the Taxi and Limousine Commission and directed it to sell medallions to help them balance budgets and fund key initiatives.
During that period, much like in the mortgage lending crisis, a group of industry leaders enriched themselves by artificially inflating medallion prices. They encouraged medallion buyers to borrow as much as possible and ensnared them in interest-only loans and other one-sided deals that often required borrowers to pay hefty fees, forfeit their legal rights and give up most of their monthly incomes.
When the market collapsed, the government largely abandoned the drivers who bore the brunt of the crisis. Officials did not bail out borrowers or persuade banks to soften loan

Actual text from NYTimes:
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Under Mr. Bloomberg and Mr. de Blasio, the city made more than $855 million by selling taxi medallions and collecting taxes on private sales, according to the city.
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Figure 1: Exhibit from *The New York Times Company v. OpenAI, Inc., et. al. District Court of Southern New York, 2023*.

protected by the "fair use" doctrine. This doctrine allows limited use of copyrighted material for purposes like research and education. Moreover, they address concerns about "regurgitation" explaining that these occurrences are unintentional and rare, and that efforts are made to minimize them.[3]

Similarly, Getty Images has filed a lawsuit against Stability AI, the company behind the tool Stable Diffusion. The tool is designed to generate high-quality images from user text prompts, making it a popular choice for AI-generated art. It was trained on a massive dataset of images and text descriptions, sourced from publicly available online platforms such as image hosting websites, art communities, and social media. Getty alleges that Stability AI unlawfully scraped a vast number of their images, resulting in the unauthorized reproduction and potential modification of copyrighted material. The lawsuit also claims that Stability AI's actions were conducted with knowledge of the infringement. For example, the lawsuit presents Figure 2 as proof and states that:

> "58. Upon information and belief, Stability AI has knowingly removed Getty Images' watermarks from some images in the course of its copying as part of its infringing scheme. At the same time, however, as discussed above, the Sta-

[3] See https://openai.com/index/openai-and-journalism/ for these and other counterarguments.

Figure 2: Exhibit from *Getty Images Inc. v. Stability AI, Inc. District Court of Delaware, 2023*.

> ble Diffusion model frequently generates output bearing a modified version of the Getty Images watermark, even when that output is not bona fide Getty Images' content and is well below Getty Images' quality standards."
>
> Getty Images Inc. v. Stability AI, Inc. District Court of Delaware, 2023.

To conclude, generative artificial intelligence has elevated text and image data to a fiercely contested asset, essential to the success of AI technologies. The boundaries around data ownership and its use in training AI models have been loosely defined before the advent of tools like ChatGPT and Stable Diffusion, sparking major legal disputes. By all accounts, the companies behind these tools took a calculated gamble, banking on the expectation that courts and regulatory bodies would endorse their extensive data usage practices without explicit permissions. The evolution of the AI industry might change significantly if the legal framework were to enforce stringent protections for intellectual property going forward.

2.2 Electrification in New York City

In 1882, Thomas Edison opened the first Central Power Plant Station in New York, known as the Pearl Street Station, marking the beginning of electrification in America. This pivotal event set the stage for the widespread adoption of electricity and other technologies like the telegraph or the telephone. To build the electrical infrastructure, utility companies began suspending cables above streets. This resulted in an extensive and often chaotic

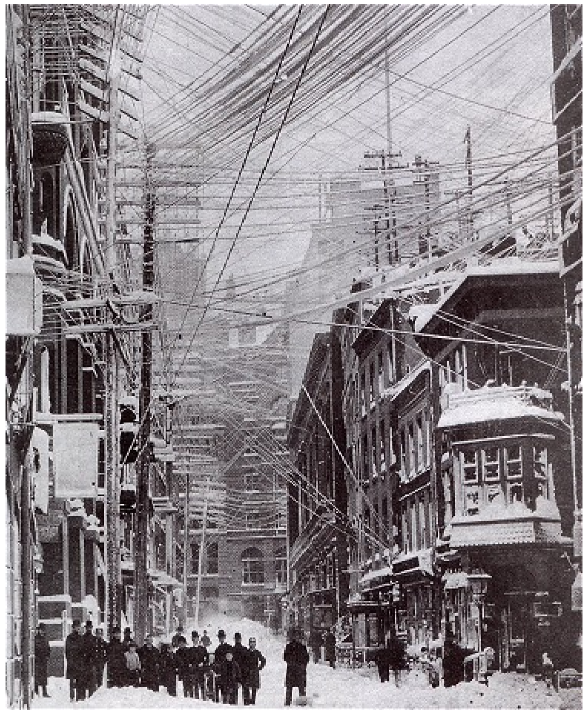


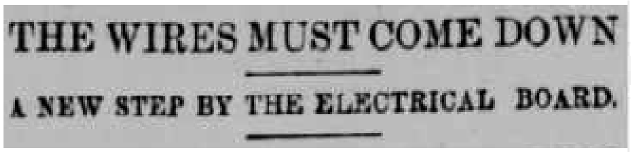
Figure 3: The Great Blizzard of 1888, New York City. Network of overhead wires of power, telephone, and telegraph. Source: *Photograph collection of The Museum of the City of New York.*

network of overhead wires which dramatically altered the visual landscape of major US cities (Figure 3).

The public regarded the intrusive network of overhead wires as an eyesore. Moreover, many of the wires were not well-insulated and were poorly maintained, leading to accidents as people came into close contact with them. Despite their functional importance, the visual impact and hazard of overhead wires led to a growing public outcry and opposition, as reflected in numerous newspaper articles from the period (Figure 4).

Utility companies, aware of the potential risks posed by the overhead wires, expressed concerns during their meetings. For instance, meeting minutes from the Association of Edison Illuminating Companies in 1887 reveal discussions about the dangers of large currents in electric street railways and the potential risks if these systems crossed paths with incandescent circuits. These discussions highlighted the need for protective measures and prompted calls for further investigation into the safety of the overhead systems.

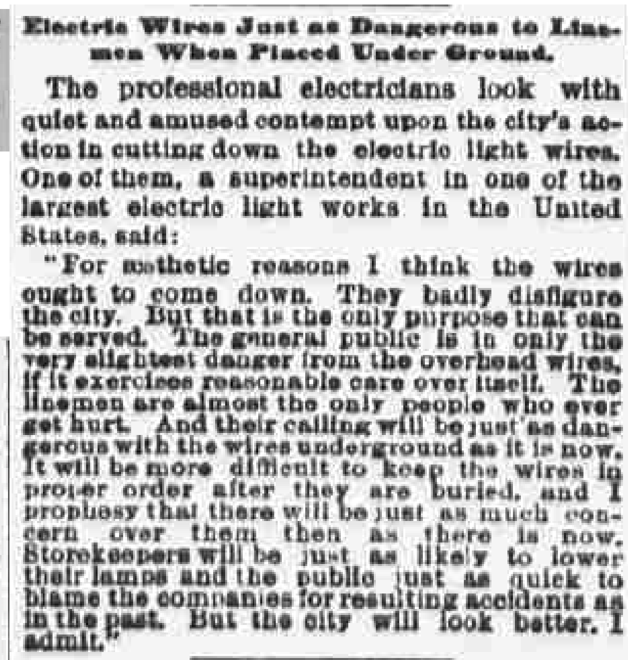
> "MR . EDGAR: There are few electric street railways but what have large currents. In such instances as here and in Boston, if cross should occur with an incandescent circuit we would be very apt to have some music. In Boston we have an ampere output on our railway lines varying from 500 to 1200,



THE WIRES MUST COME DOWN

A NEW STEP BY THE ELECTRICAL BOARD.

New York Tribune. July 06, 1888.

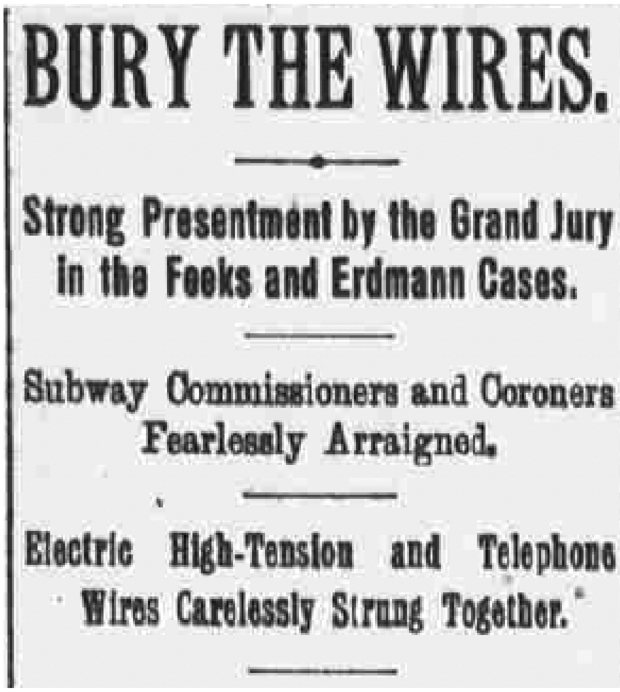


Electric Wires Just as Dangerous to Linemen When Placed Under Ground.

The professional electricians look with quiet and amused contempt upon the city's action in cutting down the electric light wires. One of them, a superintendent in one of the largest electric light works in the United States, said:

"For æsthetic reasons I think the wires ought to come down. They badly disfigure the city. But that is the only purpose that can be served. The general public is in only the very slightest danger from the overhead wires, if it exercises reasonable care over itself. The linemen are almost the only people who ever get hurt. And their calling will be just as dangerous with the wires underground as it is now. It will be more difficult to keep the wires in proper order after they are buried, and I prophesy that there will be just as much concern over them then as there is now. Storekeepers will be just as likely to lower their lamps and the public just as quick to blame the companies for resulting accidents as in the past. But the city will look better, I admit."

The Sun. December 26, 1889.



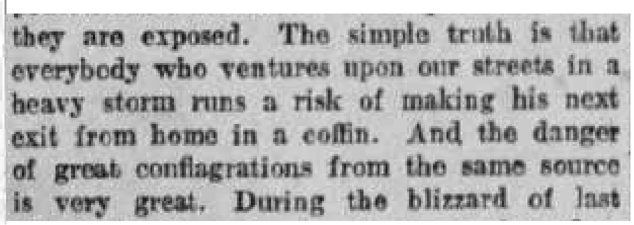
BURY THE WIRES.

Strong Presentment by the Grand Jury in the Feeks and Erdmann Cases.

Subway Commissioners and Coroners Fearlessly Arraigned.

Electric High-Tension and Telephone Wires Carelessly Strung Together.

The Evening World. November 29, 1889.

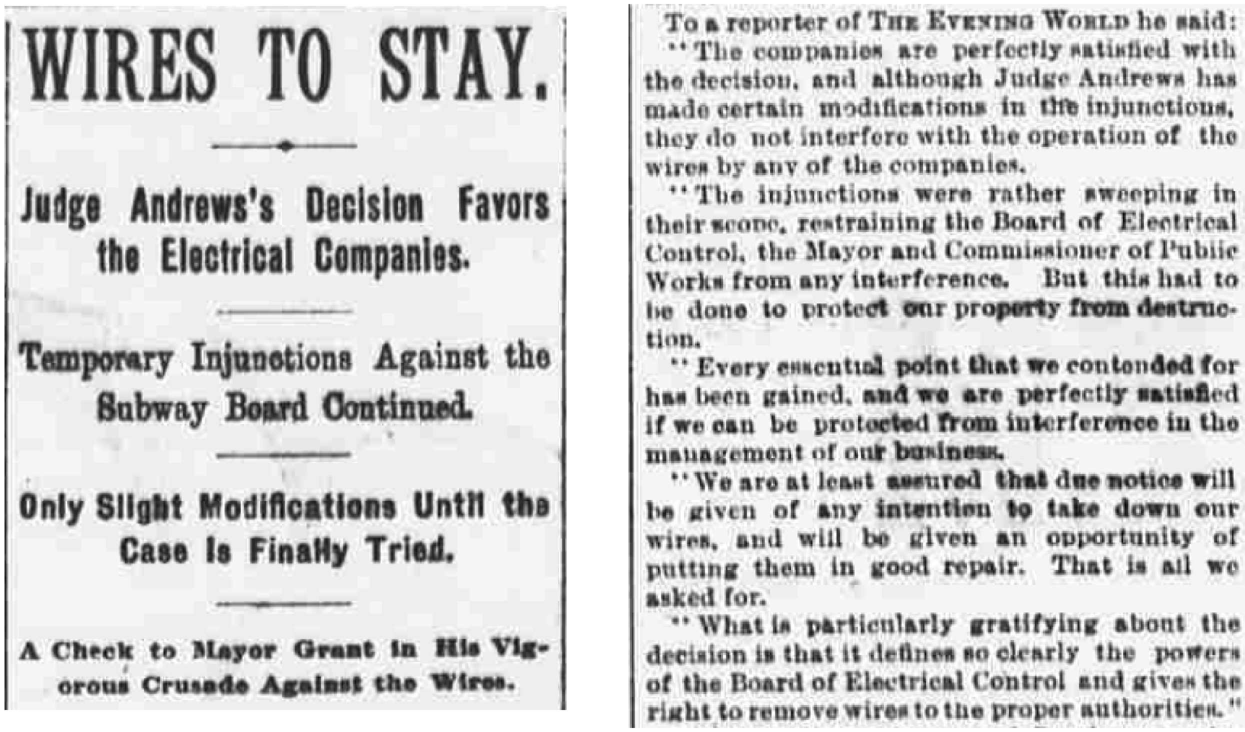


they are exposed. The simple truth is that everybody who ventures upon our streets in a heavy storm runs a risk of making his next exit from home in a coffin. And the danger of great conflagrations from the same source is very great. During the blizzard of last

New York Tribune. January 23, 1889.

Figure 4: Public concerns about aesthetics and safety of overhead wires in New York City

though at times it is only from 200 to 300. I think in overhead systems this large amount of current would be a source of danger, and it is likely to occur in all street railways. There will be numbers of stations that have larger amperage on street railway than on incandescent lighting circuits. MR. GILBERT: I think this subject one of great importance, and that a committee should be appointed to look into the subject and report at the next meeting. I now make a motion to that effect, the committee to be instructed to suggest means of protection. THE PRESIDENT: I think that committee should consist of five who can get data from different points of the country. The question of electric railways is a rapidly growing one [...]"



WIRES TO STAY.

Judge Andrews's Decision Favors the Electrical Companies.

Temporary Injunctions Against the Subway Board Continued.

Only Slight Modifications Until the Case Is Finally Tried.

A Check to Mayor Grant in His Vigorous Crusade Against the Wires.

To a reporter of THE EVENING WORLD he said:

"The companies are perfectly satisfied with the decision, and although Judge Andrews has made certain modifications in the injunctions, they do not interfere with the operation of the wires by any of the companies.

"The injunctions were rather sweeping in their scope, restraining the Board of Electrical Control, the Mayor and Commissioner of Public Works from any interference. But this had to be done to protect our property from destruction.

"Every essential point that we contended for has been gained, and we are perfectly satisfied if we can be protected from interference in the management of our business.

"We are at least assured that due notice will be given of any intention to take down our wires, and will be given an opportunity of putting them in good repair. That is all we asked for.

"What is particularly gratifying about the decision is that it defines so clearly the powers of the Board of Electrical Control and gives the right to remove wires to the proper authorities."

Figure 5: Court favors electrical companies. Source: *The Evening World*. October 29, 1889.

Minutes of Meeting from *The Association of Edison Illuminating Companies*, 1887.

The growing public concern regarding overhead wires eventually led to legislative action. Laws such as Senator Daly's Underground Bill of 1884 were introduced to address the issue and encourage the development of underground wiring networks. However, despite these efforts, utility companies were reluctant to dismantle the existing overhead networks and continued to prioritize them while only gradually transitioning to underground systems (Nye, 1992). In some instances, this resistance led to direct action, including the cutting of overhead cables by those opposed to their continued use.

The legal landscape surrounding the electrification efforts reached a critical point in October 1889, when Chief Justice Judge Andrews of the New York Appeal Court delivered a landmark ruling in favor of the utility companies (Figure 5). The judge argued that the significant investments made by these companies in developing the overhead wired infrastructure justified their continued operation, despite the safety concerns. He criticized the Underground Bill and subsequent regulations, stating that they failed to provide a practical framework for developing an effective underground wiring system. As a result, the ruling allowed the companies to maintain their overhead networks, even in the face of public opposition.

To conclude, the emergence of electricity transformed overhead space from a previously overlooked aspect of urban infrastructure into a valuable and contested resource. Property rights related to this space were not clearly defined beforehand, leading to conflicts over who controlled and could benefit from this newly important aspect of the cityscape. Looking back, utility companies took a gamble, betting that court rulings and regulations would favor them after suspending cables above ground. The profitability of the industry in the years following electrification could have turned quite different had the legal and regulatory environment prioritized the public's concerns regarding aesthetics and safety.

2.3 The Oil Rush in Pennsylvania

Before the oil industry's boom in the 1860s, oil was known as a product, but there was no means of obtaining it in sufficient quantities to support a profitable large-scale industry. This changed in August 1859 when Edwin Drake drilled the first successful oil well in Titusville, Pennsylvania, marking the birth of the modern oil industry. The success of Drake's well ignited a rapid expansion of oil drilling, with over 40 million barrels being produced by 1872, making oil one of the leading exports of the United States (Tarbell, 1904).

The discovery of oil in Pennsylvania led to a rush of activity that resembled a gold rush. The narrow valley of Oil Creek quickly became the focal point of speculative drilling, with numerous wells producing oil by the end of 1860. Titusville, the site of Drake's initial discovery, rapidly transformed into a bustling hub of economic activity, attracting speculators eager to capitalize on the newfound resource. This early period of the oil industry was characterized by rapid and often haphazard development, as both successful wells and dry holes dotted the landscape (Yergin, 2012).

The extraction of oil presented unique challenges, particularly regarding property rights. Oil reservoirs are often spread beneath the surface in ways that do not align with surface property boundaries. When a well is drilled, the pressure within the reservoir causes oil to flow toward the wellbore, potentially draining oil from beneath adjacent properties (Figure 6).

> "What these types of trap have in common is that the oil or gas, or both, that they contain is held under pressure in the pores of the reservoir rock. [...] When that pressure is released, these fluids will find the quickest way to the surface, and if the release is effected by drilling into the reservoir, that way will be up the drill bore. [...] There is no reason why the boundaries of the sands in which the oil or gas is trapped should correspond with, or be wholly con-

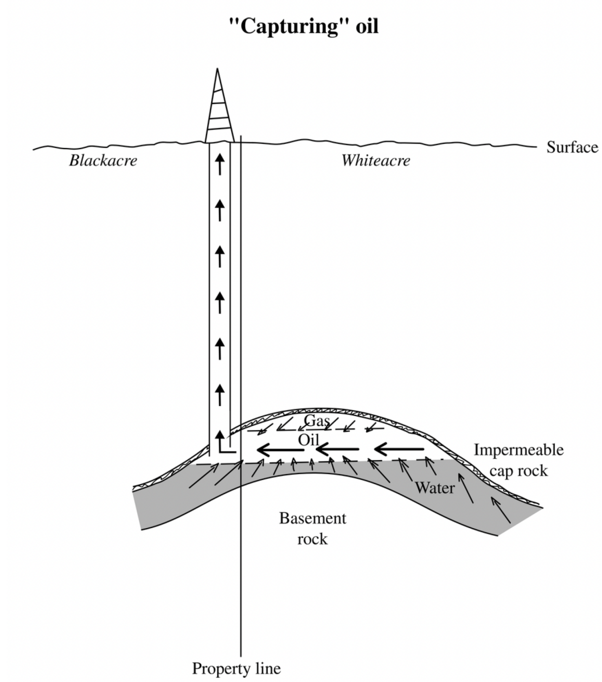


Figure 6: Oil well and the Rule of Capture diagram from Daintith (2010).

> tained within, the boundaries of the surface landholdings that overlie them. But as soon as the reservoir extends across property lines, the movement of hydrocarbons to the base of the wellbore creates a potential property right problem."
>
> "What, then, is the legal position when the oil and gas that was under one owner's land migrate up a wellbore drilled in the legitimate exercise of his or her own property rights by a neighbor?"
>
> Terence Daintith in *Finders Keepers: How the Law of Capture Shaped the World Oil Industry* (Daintith, 2010)

This situation gave rise to the "Rule of Capture," a legal principle that dictated that the oil and gas extracted from a well belonged to the person who extracted it first, regardless of whether the resources migrated from beneath neighboring land. As such, the rule established a legal framework that often favored aggressive drilling practices.

Rooted in common law, the Rule of Capture was developed over several key court cases in the late 19th century that often drew analogies between oil and water (or air). For example, in the 1875 case of Brown v. Vandergrift, Chief Justice Agnew emphasized oil's "fugitive and wandering existence within the limits of a particular tract," setting a precedent for future rulings. In the 1886 case of Wood County Petroleum Co. v. West

Virginia Transportation Co., a dispute arose between the lessor and the lessee of a contract that was “for the sole purpose of excavating for rock or carbon oil.” The well drilled by West Virginia Transportation Co., however, produced only a small amount of oil but a significant quantity of gas. While the royalties for the oil were fully paid, the company refused to pay for the gas, arguing that it was not included in the original contract. The landowner contested this, claiming that since the gas originated from their land, they deserved compensation. The court concluded that natural gas “partakes more nearly of the character of air and water than it does of those things which are the subject of absolute property.” Part of that character was its volatility: “Like water percolating beneath the surface, [natural gas] may, by sinking a well or otherwise, be appropriated for the use of one person on his farm, while the supply may come from an adjoining or many distant farms.” The court noted that the right to appropriate such underground water was absolute, even if it led to the drainage of a neighbor’s well. Consequently, since the gas was emerging naturally during the lawful extraction of oil — a process necessary to avoid forfeiting the lease — the lessees had every right to capture and use it, just as they might with air and water on the property.

The 1892 case of Acheson v. Stevenson marked one of the first applications of the Rule of Capture. This case involved a land partition where portions were sold for urban development with specific drilling prohibitions. Despite these restrictions, an oil well was installed, prompting the plaintiff to demand its shutdown, arguing that it would deplete their oil reserves. The court, however, decided that once the oil left the land of the plaintiff and entered the adjoining property, it belonged to the new landowner unless a specific contract or covenant existed. In the 1893 case of Hague v. Wheeler, the court further explored the implications of the Rule of Capture. Hague and other plaintiffs, who were producing gas from their lease, sought to prevent the defendants from draining their lease through an open gas well on adjacent land. The defendants were allowing the gas from their well to escape into the air, making no profitable use of it. The court held that the plaintiffs could not restrain the defendants from this action, as the right to extract and use resources, even wastefully, was protected under the Rule of Capture. Another notable example was the 1897 case of Kelley v. Ohio Oil Co. In this case, Kelley demanded that Ohio Oil Co. place their oil well farther from his own to prevent the depletion of his oil reserves. The court, however, ruled that “whatever gets into a well belongs to the owner of the well, no matter where it came from. [...] The right to drill and produce oil on one’s own land is absolute, and cannot be supervised by a court or an adjoining landowner.”

Ultimately, Edwin Drake’s and subsequent innovations in drilling technology turned a known resource into a valuable product. The lack of clearly defined property rights regarding extraction and use provided a fertile ground for the development of the oil industry.

> "It is certain [...] the development could never have gone on at anything like the speed that it did except under the American system of free opportunity. Men did not wait to ask if they might go into the Oil Region: they went. They did not ask how to put down a well: they quickly took the processes which other men had developed for other purposes and adapted them to their purpose. [...] What was true of production was true of refining, of transportation, of marketing. It was a triumph of individualism. Its evils were the evils that come from giving men of all grades of character freedom of action.
>
> Taken as a whole, a truer exhibit of what must be expected of men working without other regulation than they voluntarily give themselves is not to be found in our industrial history."
>
> Quote of Ida Tarbell in *A Triumph of Individualism: The Rule of Capture and the Ethic of Extraction in Pennsylvania's Oil Boom* by Brian Black (Black, 1999)

In retrospect, however, it was a gamble by both developers and users of oil drilling technology. The legal landscape in later decades — and the profitability of the industry — could have turned very differently had the courts imposed more stringent rules than the Rule of Capture.

3 A model of straw-into-gold innovation

An innovator has discovered a new technology that would use a previously overlooked or unowned resource, turning the resource into a productive factor. Production with the technology and the new factor would deliver output z. The innovator is evaluating developing the technology at cost κ.

Property rights over the factor are not established before the technology is developed. The productive value of the factor is known only to the innovator beforehand; not to the public who may also have some claims over it. Here, "the public" may refer to society at large — as represented by the government or through a class action — or disparate counterparties like firms or individuals that have potential claims over the factor. Importantly, the very act of developing the technology can create not only adversarial counterparties but also a political constituency of consumers that support it.

The innovator has two options. First, they can choose to develop the technology and resolve the *conflict* over property rights *afterwards* — for example, as a result of litigation in the courts or lobbying and political activism regarding laws and regulations.[4] There is uncertainty about who would win such dispute over property rights. The dispute is resolved in favor of the innovator with probability θ, where nature draws θ from the distribution $F(.)$ with expected value θ^e.

Second, the innovator can offer a *contract* to the public and determine property rights *before* they develop the technology. Importantly, the act of offering the contract reveals to the public that a new productive factor exists and that the may have a claim over it. The public's expectation of the productive value of the factor becomes z^e. Lastly, to offer a contract, the innovator must spend a period of "contemplation" to resolve part of the uncertainty over the outcome of the dispute — that is, to learn the probability θ. This time is spent, for example, reviewing court precedent in similar disputes and past laws defining property rights over similar resources, or lobbying politicians in charge of regulation. The discount factor over the period is β. Such discounting ($\beta < 1$) can come both from true impatience or from the chance that the innovator loses its first mover advantage — a competitor develops the technology before they do — during the period of contemplation.

Figure 7 summarizes the environment just described. We analyze each of the two options next and characterize when each is optimal for the innovator.

3.1 Conflict after innovation

At time $t = 0$, the innovator can spend resources κ and develop the technology. Afterwards, the innovator *gambles* over the dispute regarding property rights over the new factor. They "win" the dispute with probability θ: they pay a zero price for the factor and obtain the full profits of the innovation z. Otherwise, with probability $1-\theta$, the public wins the dispute: the innovator pays a price equal to z for the factor and obtains no profits.[5] The probability θ is uncertain with $\theta \sim F(\cdot)$ and captures the extent to which property rights are already somewhat defined. For example, θ would be higher when court precedent regarding similar disputes have favored the innovator in the past, and θ would be lower when past laws already assign some rights to the public or if regulators are biased against firms. Alternatively, θ is higher when the technology creates a more powerful constituency of costumers that would support it in the eventual dispute.

[4] In essence, this option is reminiscent of the "Move Fast and Break Things" motto of Facebook.

[5] These assumptions imply that trade is efficient after the technology has been developed, since either the innovator or the public obtain the full surplus z.

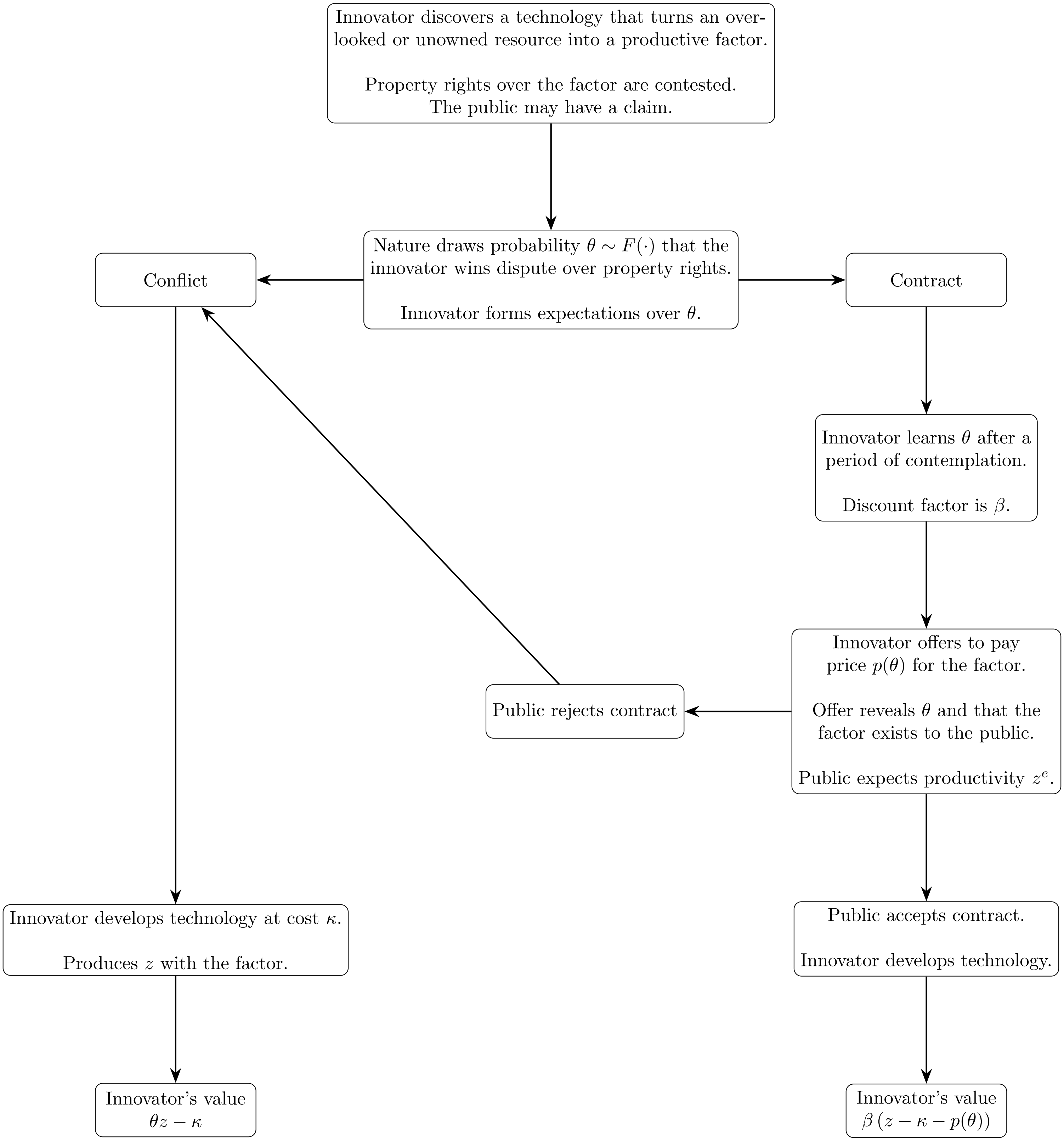


Figure 7: A model of straw-into-gold innovation

Given $\theta^e \equiv \mathbb{E}[\theta]$, the innovator's expected value if they develop the technology is

$$V = -\kappa + \theta^e z$$

and zero otherwise, and the public's value is

$$U = (1 - \theta^e) z.$$

3.2 Contract before innovation

At time $t = 0$, the innovator can learn the probability θ after a period of "contemplation." The discount factor over this period of time is β.[6] With this information, the innovator can offer a contract to the public before developing the technology. Offering the contract reveals to the public that a new factor exists, that it may have some productive value, and that they may have a claim over it. The information about the public's chance of winning an eventual dispute $1 - \theta$ is "hard information" and is thus credibly disclosed to them. The public's expectation of the productive value of the factor becomes z^e after being offered a contract, which may not coincide with the true value z. For example, z^e equals zero when offering the contract does not reveal any information about the factor or the public keeps believing it is useless.

The contract commits the innovator to pay price $p(\theta)$ for the factor to the public, and both parties commit not to re-negotiate or dispute afterwards.[7] This is the sense in which property rights become defined *before* the innovator develops the technology (sinks the cost κ). Alternatively, after learning θ, the innovator can again choose to gamble: develop the technology and resolve the conflict over property rights afterwards. The expected value for the innovator is thus

$$\tilde{V} = \beta \int \max\{z - \kappa - p(\theta), \max\{\theta z - \kappa, 0\}\} \, dF(\theta),$$

where $z - p(\theta) - \kappa$ captures the value of the contract and $\max\{\theta z - \kappa, 0\}$ is the outside option of resolving the conflict over property rights afterwards.

The innovator cannot commit to not develop the technology when it is profitable for them to do so — that is, whenever $\theta \geq \kappa/z$ and so the innovator's gamble has positive

[6] Costly contemplation in complex environments can rationalize why contracts may be left incomplete by contracting parties (Tirole, 2009; Bolton and Faure-Grimaud, 2010). Section 3.4.1 presents an extension where contracts can be more or less incomplete.

[7] This is the most complete contact in our context, since the price is contingent on the true θ. Section 3.4.1 considers an innovator that can offer more or less incomplete contracts; in particular, they can offer a contract *without* learning any information on θ.

expected value. In this case, the act of offering the contract improves the public's bargaining position: it gives the public the option to reject the contract and resolve the conflict over property rights afterwards, obtaining the expected value $(1-\theta)\,z^e$. Thus, in trying to contract beforehand, the innovator inevitably *tips their hand*. Otherwise, whenever $\theta < \kappa/z^e$ and the public believes the innovator's gamble is not profitable, the public's outside option is simply zero. In all, the expected value for the public is

$$\tilde{U} = \beta \int \max\left\{p\left(\theta\right), \mathbb{I}_{\theta \geq \kappa/z^e}\left(1-\theta\right) z^e\right\} dF\left(\theta\right).$$

Lastly, we assume the innovator makes a take-it-or-leave-it contract offer to the public.[8] The price paid for the factor is thus

$$p\left(\theta\right) = \mathbb{I}_{\theta \geq \kappa/z^e} \times \left(1-\theta\right) z^e$$

and so the expected value for the innovator becomes

$$\tilde{V} = \beta \int_0^1 \max\left\{z - \kappa - \mathbb{I}_{\theta \geq \kappa/z^e} \times \left(1-\theta\right) z^e, \mathbb{I}_{\theta \geq \kappa/z} \times \left(\theta z - \kappa\right)\right\} dF\left(\theta\right).$$

3.3 When is conflict optimal for the innovator?

We now analyze the optimal choice of the innovator. Our goal is to show conditions under which conflict is optimal. We maintain the following assumption throughout.[9]

Assumption 1. *The public does not become overoptimistic about the productive value of the factor when offered a contract $z^e \leq z$. Contracting does not take too long compared to the expected probability of winning the dispute $\beta \geq \theta^e$.*

The proposition below shows necessary conditions for conflict to arise.

Proposition 1. *Conflict is optimal for the innovator only if contracting (i) takes them time $\beta < 1$ and (ii) reveals to the public that the new factor is productive $z^e > 0$, and (iii) the true productive value z is large enough.*

The necessary conditions give us the fundamental economics of the innovator's problem. Why could the innovator prefer to resolve the conflict over property rights after developing the technology? In other words, why could the innovator prefer to *gamble*? The issue

[8] Other bargaining protocols, like Nash bargaining, would make the contract even less appealing to the innovator. We assume the innovator makes a take-it-or-leave it offer for simplicity; none of our results hinge on this assumption.

[9] This assumption is conservative given our goal. Conflict is even more appealing when the assumption does not hold.

lies in the revelation of information and lack of commitment. If the innovator learns about θ and offers a contract to the public, then this reveals to the public that the new factor is valuable with expected productivity z^e. That is, the innovator *tips their hand.* As such, the public can extract some rents from the innovator in the states of the world where property rights are defined to their benefit after the technology is developed (their outside option improves). In contrast, when the innovator chooses the conflict option — to gamble — the public is unaware of the value of the factor beforehand and cannot extract such rents. This problem is particularly severe for the innovator when the technology is very profitable (z is high) since the innovator can never commit to not developing it. For low values of z, on the other hand, the innovator can commit not to develop the technology unless the public provides them with some surplus (a low price).

To see this formally — and prove Proposition 1 — first note that the value of the contract option under Assumption 1 is

$$\tilde{V} = \beta \left(\int_{\kappa/z^e}^{1} \left(\theta z - \kappa + (1-\theta)\left(z - z^e\right)\right) dF\left(\theta\right) + \left(z - \kappa\right) F\left(\kappa/z^e\right) \right),$$

and so the difference from between value of conflict and the contract is

$$V - \tilde{V} = (1-\beta)\left(\theta^e z - \kappa\right) - \beta \left(\int_{\kappa/z^e}^{1} (1-\theta)\left(z - z^e\right) dF\left(\theta\right) + \int_{0}^{\kappa/z^e} (1-\theta)\, z dF\left(\theta\right) \right).$$

Trivially, if contracting does not take time $\beta = 1$, then conflict is never optimal $V - \tilde{V} < 0$ — which shows condition (i) is necessary. Moreover, suppose that contracting did not reveal any information to the public: the the public keeps believing it is useless $z^e = 0$. Then, again $V - \tilde{V} < 0$ and conflict is never optimal — which shows condition (ii) is necessary. Taken together, these show that the contracting friction $\beta < 1$ and the revelation of information $z^e > 0$ are both necessary for conflict to arise and, thus, for property rights to be established after innovation has taken place.[10] Lastly, if the productivity z is small enough that $z \to \kappa$, then again conflict is never optimal — showing condition (iii) is necessary too.

Finally, the proposition below shows sufficient conditions for conflict to arise.

Proposition 2. *Conflict is optimal for the innovator if the necessary conditions (i)-(iii) hold, and (iv) contracting reveals to the public that the new factor's productive value z^e is large enough.*

[10] Lack of commitement is necessary as well. Suppose the innovator could credibly commit to not develop the technology (even when profitable) unless the public accepted the contract. The public's outside option would be zero and so would the contract price $p\left(\theta\right)$. Thus, $V - \tilde{V}$ would always be negative and conflict would never be optimal.

Suppose the technology is truly groundbreaking with $z \to +\infty$ and the public learns the true value of the factor $z^e \to z$. This implies that conditions (ii)-(iv) hold. The difference in values satisfies

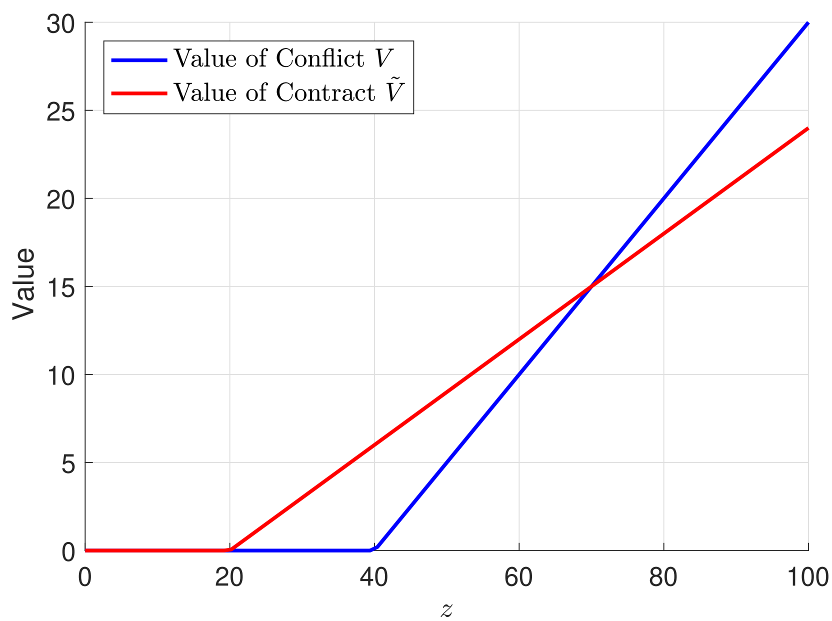
$$\lim_{z \to +\infty} \frac{V - \tilde{V}}{z} = (1 - \beta)\, \theta^e > 0$$

when condition (i) holds ($\beta < 1$). This shows that conditions (i)-(iv) are sufficient for conflict to arise.

In all, when z is large enough, property rights are not established before innovation takes place. Instead, property rights are only established *afterwards* by resolving the conflict through litigation or regulation. The opposite is true for low values of z as the contract is preferred. In this sense, ill defined property rights are associated with groundbreaking technological innovations (high z), as opposed to incremental innovation (low z).

Numerical illustration. The figure below illustrates the results for $\beta = 0.6, \kappa = 20$, $z^e = z$ and θ uniformly distributed over the interval $[0, 1]$. When output z is below the cost $\kappa = 20$, innovation is never profitable. For intermediate z's between 20 and 70, the innovator prefers to offer a contract and determine property rights before developing the technology. For z's larger than 70, the innovator chooses to innovate first and resolve the conflict over property rights after developing the technology.

Figure 8: Innovation values under conflict v. contract



3.4 Extensions

3.4.1 More incomplete contracts

Suppose that, instead of the true θ, a period of contemplation now results in a signal $\tilde{\theta} \sim G_{\theta,\sigma}(\cdot)$ with mean θ and standard deviation σ. A longer period of contemplation delivers a lower σ but is associated with a lower discount factor $\tilde{\beta}(\sigma)$. Hence, there is continuum of possible contracts indexed by σ which are more or less incomplete. At one extreme when $\sigma \to 0$, there is the contract in our baseline with discount factor $\tilde{\beta}(0) = \beta$ and a price $p_\sigma(\theta)$ which is contingent on the true θ. At the other extreme when $\sigma \to +\infty$, there is a rather incomplete contract with $\lim_{\sigma\to+\infty} \tilde{\beta}(\sigma) > \beta$ and fixed price $p_{+\infty}$. For intermediate values of σ, contracts are somewhat incomplete and the price $p_\sigma(\tilde{\theta})$ is contingent on the signal $\tilde{\theta}$. We assume in what follows that the true productivity is revealed to the public $z^e = z$ when contracting. Following the same steps than in Section 3.2, the value for the innovator of a contract σ is

$$\tilde{V}(\sigma) = \beta(\sigma) \int_0^1 \int_0^1 \left\{ \mathbb{I}_{\mathbb{E}_\sigma[\theta|\tilde{\theta}] \geq \kappa/z} \left(\mathbb{E}_\sigma\left[\theta|\tilde{\theta}\right] z - \kappa \right) + \mathbb{I}_{\mathbb{E}_\sigma[\theta|\tilde{\theta}] < \kappa/z} \times (z - \kappa) \right\} dG_{\theta,\sigma}\left(\tilde{\theta}\right) dF(\theta).$$

Next, consider the same polar opposite cases. When $z \to \kappa$, the innovator prefers a contract, since

$$\lim_{z\to\kappa} V - \tilde{V}(\sigma) = \lim_{z\to\kappa} \theta^e z - \kappa - \beta(\sigma)(z - \kappa) < 0.$$

In particular, amongst all contracts, the most incomplete one with $\sigma \to +\infty$ is preferred since it has the highest $\tilde{\beta}(\sigma)$. In the opposite case with $z \to +\infty$, the innovator prefers conflict, since for any σ

$$\lim_{z\to+\infty} \frac{V - \tilde{V}}{z} = (1 - \beta(\sigma))\, \theta^e > 0.$$

In all, the results from our baseline model remain qualitatively the same in the extreme cases. Interestingly, for intermediate cases of z, the innovator may prefer contracts that are somewhat incomplete (finite σ) to either the conflict option or the most incomplete contract ($\sigma \to +\infty$).

3.4.2 Costly conflict

Suppose that the probability of the innovator winning the dispute is now $\pi(e, \hat{e})$; where e and $\hat{e}$ are resources spent by the innovator and the public at costs $(1-\theta)\, e$ and $\theta\hat{e}$ respectively and $\theta \sim F(\cdot)$ is again a random variable. One interpretation of these resources is that they arise from cost of litigation or from lobbying and political activism to capture regulators. The probability function is strictly increasing and concave in each argument. Spending to influence the outcome of the dispute occurs after θ is realized. The Nash equilibrium $\{e(\theta), \hat{e}(\theta)\}$ of the spending game is implicitly defined by the first order conditions

$$\begin{aligned} \pi_1(e, \hat{e}) z &= 1 - \theta \\ -\pi_2(e, \hat{e}) z &= \theta. \end{aligned}$$

Then, the expected value for the innovator under the conflict option is

$$V \equiv \int \{\pi(e(\theta), \hat{e}(\theta)) z - (1-\theta) e(\theta) - \kappa\} dF(\theta).$$

Assume that a unique θ^* exists such that $\pi(e(\theta), \hat{e}(\theta)) z - (1-\theta) e(\theta) \geq \kappa$ if and only if $\theta \geq \theta^*$. Assume that that the true productivity is revealed to the public $z^e = z$ when contracting.The expected value for the innovator under the contract option is

$$\tilde{V} = \beta \int_{\theta^*}^{1} \{\pi(e(\theta), \hat{e}(\theta)) z + \theta \hat{e}(\theta) - \kappa\} dF(\theta) + \beta(z - \kappa) F(\theta^*).$$

Next, consider the same polar opposite cases than in the previous section. When $z \to \kappa$, there is no $\theta^* \leq 1$ for which $\pi(e(\theta), \hat{e}(\theta)) z - (1-\theta) e(\theta) \geq \kappa$. Thus, the innovator prefers the contract option, since

$$\lim_{z \to \kappa} V - \tilde{V} = \lim_{z \to \kappa} \int \{\pi(e(\theta), \hat{e}(\theta)) z - (1-\theta) e(\theta)\} dF(\theta) - \beta(z - \kappa) < 0.$$

In the opposite case with $z \to +\infty$, the resources spent $e(\theta) = e_0$ and $\hat{e}(\theta) = \hat{e}_0$ are finite and independent of θ. Thus, there is no $\theta^* \geq 0$ for which $\pi(e_0, \hat{e}_0) z - (1-\theta) e_0 < \kappa$, and the innovator prefers the conflict option since

$$\lim_{z \to +\infty} \frac{V - \tilde{V}}{z} = (1 - \beta) \pi(e_0, \hat{e}_0) > 0.$$

To summarize, the result from the previous section is robust to this variation of our baseline model.

3.4.3 Adverse selection

Our results show that innovators that have a sufficiently low z choose to offer a contract. This opens up the possibility of adverse selection into contracts. With this in mind, suppose there are two possible types of innovators in the population: those with low $\underline{z} = \kappa$ who would always choose the contract (measure $1 - \mu$) and those with high $\bar{z} \to +\infty$ who may not (measure μ). Moreover, assume that the public has rational expectations z^e. The expected value for the public after being offered a contract is now

$$\tilde{U} = \beta \int \max\left\{p\left(\theta\right), \tilde{\mu}\left(1-\theta\right)\bar{z}\right\} dF\left(\theta\right),$$

where $\tilde{\mu}$ is their perceived probability of a high-z type conditional on a contract being offered. The bargaining position is better for a high-z type but worse for a low-z type compared to our baseline. The offered price is thus

$$p\left(\theta\right) = \tilde{\mu}\left(1-\theta\right)\bar{z}.$$

Suppose $\beta < \theta^e$. Then, the high-z type never offers a contract, since

$$\lim_{\bar{z}\to+\infty} \frac{V\left(\bar{z}\right) - \tilde{V}\left(\bar{z}\right)}{\bar{z}} = \theta^e - \beta\left(1 - \tilde{\mu}\left(1-\theta^e\right)\right) > 0$$

for any $\tilde{\mu}$. And so the rational expectations equilibrium probability is $\tilde{\mu} = 0$. Moreover, the low-z type prefers to offer the contract since

$$\lim_{\underline{z}\to\kappa} V\left(\underline{z}\right) - \tilde{V}\left(\underline{z}\right) = \lim_{\underline{z}\to\kappa} \theta^e \underline{z} - \kappa - \beta\left\{\underline{z} - \kappa\right\} < 0.$$

In all, the case $\beta < \theta^e$ looks like as our baseline, with full separation of the types in equilibrium.

Suppose instead $\beta > \theta^e$ as in Assumption 1. Then the high-z type may offer a contract if the probability $\tilde{\mu}$ is sufficiently low. The low-z types never find it optimal to innovate, since $0 > \tilde{V}\left(\underline{z}\right) > V\left(\underline{z}\right)$ for any strictly positive $\tilde{\mu}$. But, the probability $\tilde{\mu}$ must be 1 in a rational expectations equilibrium if high-z types offer contracts and low-z types do not participate. Thus, this cannot be an equilibrium, since the high-z types would not find it optimal to offer the contract — that is, we arrive to a contradiction. Is there an equilibrium where high-z types randomize? The answer is yes. We guess and verify that the probability

$$\tilde{\mu} = \frac{\beta - \theta^e}{\beta\left(1-\theta^e\right)}$$

is part of an equilibrium where the high-z type is indifferent between randomizing and choosing the conflict option, since

$$\lim_{\bar{z}\to+\infty} \frac{\tilde{V}(\bar{z})}{\bar{z}} = \tilde{\mu}\beta\left(1-\tilde{\mu}\left(1-\theta^e\right)\right) + \left(1-\tilde{\mu}\right)\theta^e = \theta^e = \lim_{\bar{z}\to+\infty} \frac{V(\bar{z})}{\bar{z}},$$

and would not choose to deviate to the contract when others are choosing to randomize, since

$$\lim_{\bar{z}\to+\infty} \frac{\tilde{V}(\bar{z})}{\bar{z}} = \beta\left(1-\tilde{\mu}\left(1-\theta^e\right)\right) = \theta^e.$$

In all, we conclude that when $\beta > \theta^e$, there is an equilibrium where low-z types do not innovate and high-z types offer a contract with probability $\tilde{\mu} = \frac{\beta-\theta^e}{\beta(1-\theta^e)}$.

What share of innovations are associated with conflict? In our baseline and in the present extension when $\beta < \theta^e$, a share μ of innovations are associated with conflict (those with high z). When β is just above θ^e, however, almost all of the innovations are associated with conflict (since there are only high z innovations and $\tilde{\mu} \to 0$ as $\beta \to \theta^e$). Thus, adverse selection can result in an extreme situation where only groundbreaking technologies are developed and property rights are almost surely ill defined beforehand. Lastly, as β increases further, the share of innovations associated with conflict falls and eventually none are (since $\tilde{\mu} \to 1$ as $\beta \to 1$).

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