# Growth at the Resource Frontier*

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**Abstract**

From the Stone Age to the Digital Age, much progress has come from innovations that expand the frontier of usable resources. A distinctive feature of resources outside the frontier is that property rights are poorly defined. Through case studies, we document that innovators often appropriate such resources in anticipation of extraordinary rents, triggering conflicts with counterparties. These observations do not fit neatly into existing frameworks in which property rights precede innovation, appropriation is purely redistributive, or monopoly rents sustain economic growth. Motivated by these observations, we present a model of growth at the resource frontier that minimally departs from traditional models of expanding input varieties. The model rationalizes how property rights emerge as a consequence of innovation, establishes that appropriation rents can sustain economic growth, and ultimately shows that growth at the resource frontier frequently comes together with appropriation and conflict.

## 1 Introduction

Much of human progress has come from transformative innovations that expand the frontier of resources available for economic use. Historically, periods have been defined by the emergence of new materials, from the Stone Age to the Bronze and Iron Ages. Advances in mining and drilling technologies transformed underground fossil fuels into sources

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of energy, ushering in the Industrial Age. In recent decades, the resource frontier has expanded into immaterial and digital domains. Communication technologies converted the electromagnetic spectrum into a medium for radio and television broadcasting, while information technologies have turned data into an input for predicting consumer behavior and training artificial intelligence models.

A distinctive feature of resources outside the frontier is that property rights — who owns them and how they can be used — are typically poorly defined. Because these resources had been overlooked or inaccessible prior to the innovations that revealed their value or brought them within reach, it had not yet been worthwhile or even possible to establish ownership and specify rights over their many potential uses.[1]

Innovators often appropriate resources outside the frontier in anticipation of extraordinary rents, triggering conflicts with counterparties asserting competing claims. Consider generative AI companies that trained models using online content, leading to disputes over fair use; digital advertising platforms that appropriated consumer-generated data, giving rise to conflicts over ownership and privacy; radio broadcasters that took frequencies of the electromagnetic spectrum, interfering with one another's transmissions; and oil prospectors that captured oil from shared underground reservoirs, resulting in disputes with adjacent landholders. In each case, property rights over these resources emerged through litigation and regulation, often validating the initial acts of appropriation and the rents they generated.

These observations of innovation with appropriation at the resource frontier do not fit neatly into existing frameworks in political economy and economic growth. Property rights were not a precondition for innovation but instead emerged as a consequence, and their ambiguity created opportunities rather than being a hindrance, in contrast to standard political economy accounts of development (Coase, 1960; North, 1981; Acemoglu et al., 2001; Porta et al., 2008). Moreover, appropriation was intertwined with innovation and value creation, instead of being merely redistributive or extractive (Persson and Tabellini, 1991; Murphy et al., 1993; Acemoglu and Robinson, 2013). Indeed, the expectation of appropriation rents appears to have driven innovation, a source of incentives missing from theories of economic growth where monopoly rents in production sustain innovation (Romer, 1990; Aghion and Howitt, 1992).

In this paper, we analyze the process of economic growth at the resource frontier. We

[1] Harold Demsetz argued that property rights emerge when the gains from defining them exceed the costs. In Demsetz (1974)'s account, increases in the value of resources, often due to changes in relative prices, create incentives to define property rights. At the resource frontier, the increase in value arises from the innovative activity itself, which reveals previously overlooked uses of a resource or makes them accessible.

begin with detailed historical case studies in which innovations that expanded the frontier led to appropriation, property rights disputes, and extraordinary rents, alongside cases where they did not because property rights were better defined. In addition, we present evidence from U.S. law reviews showing that innovation waves that expanded the resource frontier coincided with waves of appropriation and litigation. Motivated by these observations, we present a model of endogenous growth at the resource frontier. The model is a minimal but conceptually important departure from standard models of expanding input varieties (Romer, 1990; Acemoglu, 2008): it allows innovators to discover and appropriate new resource varieties with poorly defined property rights and turn them into new input varieties.[2]

The model clarifies why innovators may choose appropriation and conflict rather than contract with counterparties to establish property rights beforehand, implying that property rights emerge as a consequence of innovation rather than being a precondition. The expectation of appropriation rents can therefore sustain long-run economic growth, even in the absence of traditional monopoly rents in production, departing from theories in which such rents are necessary to incentivize innovation. Ultimately, growth at the resource frontier frequently comes together with by appropriation and conflict, rather than being separate from or at odds with it, as in accounts where appropriation is purely redistributive or extractive.

## 2 Case Studies of Innovation at the Resource Frontier

This section documents cases of innovation at the resource frontier. Section 2.1 begins with detailed historical case studies that illustrate defining features: a technological innovation turns a previously unrecognized resource into a productive input, property rights are poorly defined beforehand, innovators appropriate the resource in anticipation of extraordinary rents, and conflicts arise with counterparties asserting competing claims.

To support these cases, Section 2.1.6 also documents waves of resource appropriation and conflict using evidence from U.S. law reviews, and Section 2.1.7 presents some simple back-of-the-envelope calculations showing the importance of appropriation rents.

For comparison, Section 2.2 describes cases where innovation did not lead to conflict, either because the new resource in question was abundant, property rights were well-established, or innovations did not expand the resource frontier.

[2] In standard models, innovations also generate new input varieties but they are produced using *known* resources that already trade in markets with well-defined property rights.

## 2.1 Innovation with Appropriation and Conflict

### 2.1.1 Large Language Models and the Appropriation of Online Content

The origins of artificial intelligence (AI) date 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 rapidly advanced, driven by breakthroughs in hardware, computing power, and the explosion of big data online. This progress has recently culminated in the emergence of large language models (LLM's), like ChatGPT and Claude, heralding a transformative era in the industry.

A NOVEL RESOURCE. While training data (e.g., images of faces in training facial recognition software) were previously recognized as valuable inputs into improving AI algorithmic performance, LLM's like ChatGPT relied on a previously overlooked source of data for model training: vast amounts of general online textual content. Such content was available from books, academic articles, websites, and even transcriptions of online video content posted to platforms such as Youtube. This content has proven to be of extraordinary value in training LLM's; freely acquired, it is plausibly a source of substantial economic rents to innovators.[3]

POORLY DEFINED PROPERTY RIGHTS AND APPROPRIATION. Because the value of online content as training data for LLM's was unrecognized, the legal boundaries around the use of such content were loosely defined before the advent of technologies like ChatGPT. Innovators like OpenAI (the company that developed ChatGPT) chose to scrape enormous amounts of online text, appropriating this resource for model training. They have argued that their use of publicly available internet data, including from sources protected by copyright, is legal under the "fair use" doctrine, which allows the use of copyrighted material for purposes like research and education.[4]

CONFLICT. However, a wide range of copyright holders, including The New York Times, the Merriam Webster Dictionary, Encyclopedia Britannica, and the Authors' Guild, have

[3] That freely acquired online content is a source of rents can be seen in contrast to the possibility of payment for corpa of text. This was considered by Meta, in 2023, when the firm discussed the acquisition of Simon & Schuster at a price of $10 per book, with the purpose of acquiring text for model training. See https://www.theguardian.com/books/2024/apr/09/meta-discussed-buying-publisher-simon-schuster-to-train-ai, last accessed March 19, 2026.

[4] See https://openai.com/index/openai-and-journalism/, last accessed March 19, 2026.

filed lawsuits against OpenAI, alleging infringement of copyright that materially harms the plaintiffs.[5] While Anthropic, behind the Claude LLM, has settled a case with authors suing for copyright infringement (agreeing to pay them $1.5 Billion), OpenAI's cases remain unsettled at the time of writing.[6] It is clear that all of the companies that developed LLM's took a calculated gamble by appropriating online text content, banking on the expectation that courts and regulatory bodies would endorse their extensive data usage practices without explicit permissions.

### 2.1.2 Digital Advertising and the Appropriation of Consumer Data

The late 1990s and early 2000s saw the rise of the commercial internet and, with it, new ways to connect businesses to consumers. Search engines, such as Google, and social networks, most importantly Facebook, became important nodes in the world wide web, providing free services to users and generating a huge amount of user traffic. However, traffic did not directly imply monetization: beyond their breakthrough technical products — Google's search algorithm and Facebook's social media platform — both companies depended on pioneering digital advertising models that allowed companies to market their products to consumers in remarkably targeted ways.

A NOVEL RESOURCE. Prior to the innovations of Google and Facebook, personal data such as search queries, clicks, browsing histories, and social interactions were considered a mere byproduct of online activity, described by Zuboff (2023) as "digital exhaust," and holding little obvious economic value. Google transformed these traces of online behavior into a new factor of production — an input into behavioral prediction — when it introduced AdWords (2000) and later AdSense (2003). This relied on storing and analyzing enormous amounts of user data, allowing advertisers to target audiences with unprecedented precision. Facebook followed a parallel path: its platform initially thrived by connecting friends and communities, but a key breakthrough came when it leveraged its massive trove of demographic and social data to sell highly targeted advertising.

POORLY DEFINED PROPERTY RIGHTS AND APPROPRIATION. The extraordinary rents from digital advertising hinged on the absence of clearly defined property rights over

[5] See https://www.theguardian.com/books/2025/apr/04/us-authors-copyright-lawsuits-against-openai-and-microsoft-combined-in-new-york-with-newspaper-actions, last accessed March 19, 2026; and https://fortune.com/2026/03/18/dictionaries-suing-openai-chatgpt-copyright-infringement/, last accessed March 19, 2026.

[6] See https://www.theguardian.com/technology/2025/sep/05/anthropic-settlement-ai-book-lawsuit, last accessed March 19, 2026.

personal data: companies like Google and Facebook did not need to compensate users for the use of their personal data, they simply appropriated it, selling it to third parties, and exploiting it to offer opportunities to advertisers. Because user data was not previously recognized as a valuable resource, property rights governing its use were not clearly established.

CONFLICT. However, consumers eventually demanded digital privacy and property rights over their online behavioral data. Google has been sued for billions of dollars in the US and UK (and ordered to pay consumers hundreds of millions of dollars) for privacy violations.[7] Facebook paid users hundreds of millions of dollars and was fined $5 billion by the US Federal Trade Commission for violating user privacy as a result of the Cambridge Analytica scandal.[8] Regulators, particularly in Europe, have moved to assert users' rights over their data, notably, the General Data Protection Regulation. However, Google has successfully argued that "blocking it from collecting users' account-related data would 'cripple' an analytics service relied on by millions of app developers."[9] Intensive collection and exploitation of user data continues to generate enormous revenue streams for Google and Facebook (we discuss the value of user data in further detail, below).

### 2.1.3 Radio and the Utilization of the Electromagnetic Spectrum

The second half of the 19th century saw James Clark Maxwell propose the existence of electromagnetic waves in the 1860s, and Heinrich Hertz produce radio waves in the 1880s. The "father of radio," Guglielmo Marconi transmitted Morse code across the Atlantic Ocean using radio waves in 1901, and the first commercial radio station, Pittsburgh's KDKA, broadcast in October 1920.

A NOVEL RESOURCE. When radio emerged in the early 20th century, the core innovation lay not only in the technical development of transmitters and receivers, but also in the recognition that the electromagnetic spectrum itself could serve as a factor of production. Airwaves, once considered a scientific curiosity with little economic significance, became

[7] See https://www.legalfutures.co.uk/latest-news/supreme-court-strikes-down-3bn-google-data-protection-claim; https://www.reuters.com/sustainability/boards-policy-regulation/google-defeats-bid-billions-dollars-new-penalties-us-privacy-class-action-2026-01-30/, both last accessed March 19, 2026.

[8] See https://www.theguardian.com/technology/2025/jul/17/mark-zuckerberg-meta-settlement-privacy, last accessed March 19, 2026.

[9] https://www.reuters.com/sustainability/boards-policy-regulation/google-defeats-bid-billions-dollars-new-penalties-us-privacy-class-action-2026-01-30/, last accessed March 19, 2026.

the indispensable medium through which music, news, entertainment, political content, and advertising, could be transmitted to mass audiences.

POORLY DEFINED PROPERTY RIGHTS AND APPROPRIATION. The early years of broadcasting were marked by the rapid entry of local broadcasters, and disorder (e.g., Wu, 2010). By the early 1920s, thousands of amateur and commercial stations transmitted without coordination, often using the same frequencies. Signals collided, programs overlapped, and listeners were left with interference. The problem was not technological, but institutional: broadcasters appropriated frequencies simply by using them, because property rights over the airwaves were undefined.

CONFLICT. It was not ex ante obvious how property rights over the spectrum would be allocated. Indeed, a prominent Illinois Circuit Court case involving the Tribune Company (Tribune Co. v. Oak Leaves Broadcasting Station, 1926) granted property rights on the basis of priority. However, the federal government, with an interest in regulating the resource (and to the benefit of the incumbent broadcasters, such as RCA) responded with the Radio Act of 1927, creating the Federal Radio Commission (FRC) and granting it authority to allocate frequencies "as public convenience, interest, or necessity requires." Acquisition of a license to broadcast was associated with substantial rents. Hazlett (1998, pp. 278-279) writes, "'Public interest' licensing effectively awarded incumbents zero-priced rights, while excluding new entry, thus enhancing license values due to artificial scarcity constraints. Political players (incumbent politicians, bureaucrats, and public interest advocates) shared in the rents by being brought 'into the loop' on broadcast license (and renewal) applications."

### 2.1.4 Drilling and the Capture of Oil from Underground Fields

Before the industry's emergence in the 1860s, oil was already known as a product; however, it was not obtained in sufficient quantities to support a large-scale industry. This changed in 1859, when Edwin Drake drilled the first oil well in Titusville, Pennsylvania. The industry grew quickly, with Ida Tarbell (1904, p. 21) writing, "By the opening of 1872 [oil men] had produced nearly 40,000,000 barrels of oil, and had raised their product to the fourth place among the exports of the United States, over 152,000,000 gallons going abroad in 1871. (...) As for the market, they had developed it until it included almost every country of the earth — China, the East and West Indies, South America and Africa. Over forty different European ports received refined oil from the United States in 1871."

A NOVEL RESOURCE. In her History of the Standard Oil Company, Tarbell (1904, p. 3) describes the transformation of part of Northwestern Pennsylvania from "little better than a wilderness" into "a bustling trade centre, where towns elbowed each other for place, into which three great trunk railroads had built branches, and every foot of whose soil was fought for by capitalists." This was due, quite simply, to "the discovery and development of a new raw product, petroleum."

POORLY DEFINED PROPERTY RIGHTS AND APPROPRIATION. After Drake's successful well, Yergin (1991, p. 29) describes the ensuing oil boom: "What followed immediately was like a gold rush. The flats in the narrow valley of Oil Creek were quickly leased, and by November of 1860, fifteen months after Drake's discovery, about seventy-five wells were producing, with many more dry holes scarring the earth." The rush to drill occurred despite inherent ambiguity of property rights over underground oil: the boundaries of an underground oil field, and the oil extracted by a well, will not respect the boundaries established by above-ground property rights (see Daintith, 2010). Oil drilling and extraction occurred despite this ambiguity: oil prospectors appropriated the resource even if it was extracted from fields lying beneath land owned by their neighbors.

CONFLICT. Unsurprisingly, disputes arose over the extraction of oil from fields with ambiguous property rights. By the late 19th century, the "Rule of Capture" was applied by US courts to assign property rights to the owner of the well from which oil was extracted. The 1889 decision of the Pennsylvania Supreme Court in Westmoreland & Cambria Natural Gas Co. v. De Wit unambiguously stated: "Water and oil, and still more strongly gas, may be classed by themselves, if the analogy be not too fanciful, as minerals ferae naturae. In common with animals, and unlike other minerals, they have the power and the tendency to escape without the volition of the owner. (...) They belong to the owner of the land, and are part of it, so long as they are on or in it, and are subject to his control; but when they escape, and go into other land, or come under another's control, the title of the former owner is gone. Possession of the land, therefore, is not necessarily possession of the gas. If an adjoining, or even a distant, owner, drills his own land, and taps your gas, so that it comes into his well and under his control, it is no longer yours, but his."[10]

[10] See Kramer and Anderson (2005).

### 2.1.5 Complementary Inputs

At times, innovation does not directly transform an overlooked resource but instead requires the use of a complementary input that had previously been ignored, underutilized, or treated as a commons. If innovation is interpreted narrowly as the core technical breakthrough, the complementary input appears peripheral. But if innovation is understood more broadly — as the commercialization, scaling, and deployment of a technology — then the complementary input becomes central to value creation.

Under this broader interpretation, the complementary input is the "resource outside the frontier." Its prior neglect implies that property rights were ill-defined, and its sudden importance creates scope for appropriation and conflict. The relevant innovation lies as much in recognizing how to mobilize this input as in the underlying technology itself.

Classic examples include overhead urban space used for electricity distribution, airspace around airports for commercial aviation, urban airspace for drones, and orbital slots for satellites. In each case, commercialization required access to a resource that was not initially priced, traded, or clearly owned. Some modern platform examples — such as ride-sharing or short-term rentals — can also be interpreted through this lens, as they rely on previously unused capacity whose ownership and permissible use were ambiguous.

### 2.1.6 Waves of Appropriation and Conflict: Evidence from U.S. Law Reviews

We next present systematic evidence from U.S. law reviews, classifying articles according to whether they study appropriation conflicts over specific resources. This evidence reveals a historical shift in the frontier of appropriation — from material resources in the early twentieth century, to immaterial resources mid-century, and to digital resources in recent decades — underscoring one of the paper's central theme: property rights over new resources emerge as a consequence of innovation at the resource frontier.

The figure below presents our results. We first identified articles that analyze legal disputes, doctrines, or regulatory interventions related to appropriation. We then restricted attention to those articles in which appropriation concerns a specific resource. Finally, we classified each article according to the nature of the underlying resource — material, immaterial, or digital — and assigned it to a publication year.

The figure plots the number of such articles by year for each resource class. It therefore captures when legal scholarship has focused on appropriation problems associated with different types of resources, rather than the timing of the underlying technological innovations themselves.

Material resources dominate the legal literature on appropriation in the late nineteenth

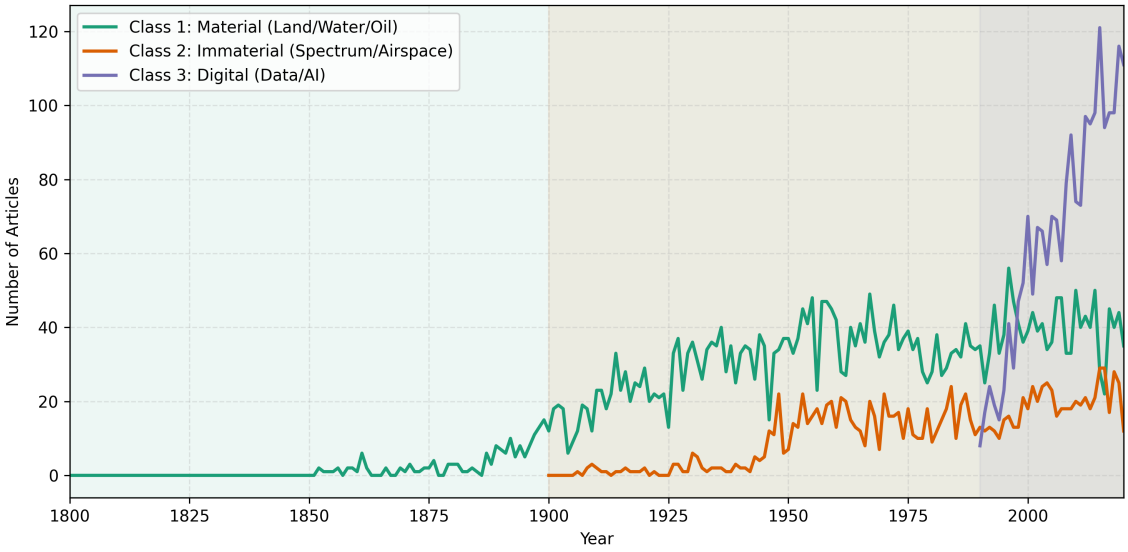



**Figure 1:** Waves of Appropriation and Conflict Articles in U.S. Law Reviews

and early twentieth centuries, with a sharp rise around the turn of the century. This period corresponds to intense legal activity surrounding minerals, land, chemicals, and other physical resources, when rapid industrialization outpaced the development of clear property rights. Immaterial resources — such as spectrum, airspace, and other non-physical natural endowments — rise later and become the primary focus of appropriation-related legal scholarship through the mid-twentieth century. Digital resources appear almost exclusively in the late twentieth and early twenty-first centuries. Beginning in the 1990s and accelerating sharply thereafter, legal scholarship increasingly focuses on the appropriation of data, information, and digital traces.

Overall, the figure documents a systematic shift in the legal frontier of appropriation across resource classes over time. As property rights become established in one domain, appropriation-related conflict and legal attention migrate to new classes of resources.

### 2.1.7 Rents from Appropriation

We now quantify the share of rents attributable to appropriation in two of our case studies: digital advertising and broadcasting. We focus on these cases because there is available empirical evidence that allows us to perform simple and transparent back-of-the-envelope calculations. The details of the derivations are provided in Appendix A.

DIGITAL ADVERTISING. Evidence from Kraft et al. (2023) suggests that targeted advertisements command a price premium of roughly 50 percent relative to non-targeted ads,

and that 74 percent of all of ads are targeted. Combining these pieces of evidence, we estimate that the share of advertising revenue attributable to user-generated data is 27 percent. To express this share in terms of earnings, we scale by net operating margins. For companies like Google or Meta, net operating margins are on the order of 30 to 40 percent.[11] Thus, we estimate that more than 2/3 of operating earnings in digital advertising can be traced to data-enabled targeting. Therefore, the appropriation of user data appears to be a primary source of economic rents for digital advertisers.

BROADCASTING. In a 2017 reverse auction, the FCC asked broadcasters to sell back frequencies that they had been allocated for free decades earlier. Based on data from the auction, Soloveichik (2024) calculates that the value of such spectrum corresponds to approximately 6 percent of the net present value of industry revenue. To express this value in terms of earnings, we scale by net operating margins. Industry evidence indicates that margins for broadcasters are on the order of 9 percent (Damodaran, 2017). Thus, we estimate that roughly 2/3 of earnings are attributable to the frequencies that these broadcasters have been allocated for free decades earlier. As in digital advertising, the appropriation of an initially unpriced resource — in this case, electromagnetic spectrum — appears to be a primary source of economic rents.

## 2.2 Innovation without Conflict

### 2.2.1 Appropriation of Abundant or Non-excludable Resources

Consider renewable energy, animal domestication, or historical silk production in China. These innovations expanded the resource frontier but involved overlooked resources that were abundant or effectively non-excludable. Unlike our previous cases, resource appropriation therefore did not lead to conflict.

Moreover, in such cases, rents arise primarily from product innovation — protected, for instance, by trade secrets or patents — rather than from control over the resource itself. A core mechanism emphasized in this paper, whereby expected rents from appropriation sustain innovation, plays a limited role.

### 2.2.2 Contracting over New Resources

In some cases, innovators expand the resource frontier but choose to contract with counterparties — rather than appropriation and conflict — because property rights are rela-

[11] See https://www.alphaspread.com/comparison/nasdaq/meta/vs/nasdaq/googl.

tively well defined beforehand.

In plastics, DuPont's development of synthetic materials relied on petroleum byproducts that had previously been treated as refinery waste. Because these byproducts clearly belonged to oil companies such as Conoco, DuPont relied on vertical integration and supply agreements to secure access.

A similar pattern appears in the discovery of kaolin clay in Cornwall for porcelain production. William Cookworthy identified the value of local clay deposits, but these deposits were subject to well defined land and mineral rights. Rather than appropriating the resource, Cookworthy negotiated access through agreements with landowners such as Lord Camelford.

The development of boric acid production in Tuscany provides a third example. Francesco de Larderel recognized the value of geothermal lakes — previously unexploited — but these resources fell under the authority of the Grand Duchy. Instead of appropriation, he secured concessions and political backing that granted him rights to exploit them.

#### 2.2.3 Process improvements and Romerian Innovations

Many important innovations do not expand the resource frontier. In turn, they do not generate conflicts over property rights regarding new resources or appropriation rents.

First, innovations which are primarily process improvements, such as the assembly line or the Bessemer process. These increase production efficiency without discovering new resources or creating new inputs.

Second, technologies that create new input varieties out of existing, well known resources — what we refer as Romerian innovations. Examples include steel from iron and coal, computers, early internet technologies, and operating systems. In these cases, resources are already traded in markets with established property rights, and innovation rents arise through monopoly power or intellectual property protection.[12]

## 3 A Model of Growth at the Resource Frontier

This section presents a model of endogenous growth at the resource frontier that formalizes the process we have just described — namely, how innovation expands the resource frontier by creating productive inputs out of previously unrecognized resources

[12] While Romerian innovation can generate speculative rents — particularly when innovators acquire inputs before others update beliefs about their value — these rents stem from informational asymmetries rather than from contested ownership. The innovator can rent or purchase the resource outright; conflict is not intrinsic to the innovation process.

with poorly defined property rights, and how innovators choose between appropriation in anticipation of extraordinary rents versus contracting beforehand. We keep the model as close as possible to standard growth models with expanding input varieties (Romer, 1990; Acemoglu, 2008) so that the differences are stark and easy to see.

## 3.1 Environment

The economy is populated by innovators, a final goods representative firm, and a representative household. Innovators can expand the resource frontier. They discover an idea about how to use a previously unrecognized resource for production. A discovery creates a new resource variety $j$ that can be used to produce a new input variety $j$. At a point in time, the measure of resource and input varieties is $A_t$. The representative firm uses the inputs to produce the final good consumed by the household.

Unrecognized resources do not have established property rights before they are discovered and turned into an input. As such, they do not trade in markets at the time of discovery and can become contested afterwards. The innovator thus has two options. First, they can choose to appropriate the resource.[13] A member of the representative household may have a claim over the resource. We will call this member a *counterparty* from now on. The counterparty may challenge the appropriating innovator. The dispute over property rights is settled as a result of litigation in the courts or by the government dictating laws and regulations, assigning ownership of the resource. Alternatively, the innovator can attempt to contract, paying the counterparty for the contested resource. After property rights are established either of these two ways, the factor trades in a competitive market at price $q_{jt}$.

Next, we describe the representative firm and household's decision problems; the investment, production, and appropriation versus contracting decision problems of innovators; and the economy's technologies for contracting and resolving conflicts over property rights.

[13] Appropriation is equivalent to paying a zero price. That is, the price that would have prevailed if a market existed for a resource that had not been turned into a productive input yet.

## 3.2 Representative Firm and Household

The final good $Y_t$ is produced by a representative firm. The firm demands input varieties $y_{jt}$ and produces with the aggregate production function

$$Y_t = \left( \left( \int_0^{A_t} \left( y_{jt} \right)^{\gamma} dj \right)^{\frac{1}{\gamma}} \right).$$

The firm maximizes profits

$$\Pi_t = Y_t - \int_0^{A_t} p_{jt} y_{jt} dj,$$

given input prices $p_{jt}$.

The representative consumer maximizes discounted utility over the consumption of final goods

$$\int_0^{\infty} e^{-\rho t} \frac{(C_t)^{1-\sigma}}{1-\sigma} dt$$

subject to the budget constraint

$$C_t + \dot{a}_t \leq r_t a_t + \int_0^{A_t} q_{jt} X_{jt} dj$$

where $a_t$ is the value of the portfolio of all firms, $r_t$ is the return on the portfolio, and $X_{jt}$ are service flows from ownership of existing resource variety $j$ with price $q_{jt}$.

## 3.3 Innovators

The innovator can use all existing resources to discover new resource (and input) varieties — to expand the resource frontier. We assume existing resources are perfect substitutes in such investment and the technology is linear. Given investment $\tilde{x}_{it}$ of resource $i$, the innovator discovers $\dot{A}_t$ new varieties according to

$$\dot{A}_t = \lambda \int_0^{A_t} \tilde{x}_{it} di. \tag{3.1}$$

The assumption of perfect substitutatibility immediately implies that all resources will trade at the same price $q_{it} = q_t$ in equilibrium, so we drop the index $i$ from now on.

Production of input variety $j$ uses the corresponding resource. The production technology is linear: $x_{jt}$ units of the resource delivers

$$y_{jt} = x_{jt}$$

units of the input. The flow profits are

$$\pi_{jt} = \left(p_{jt} - q_t\right) x_{jt}.$$

We assume that the firm sets a price $p_{jt}$ equal to a constant markup $\mu$ over marginal cost $p_{jt} = (1 + \mu)\, q_t$. This allows us to easily capture two cases. First, given the representative firm CES production function, the economy with $\mu = \frac{1-\gamma}{\gamma}$ corresponds to the case of monopolistic competition, where $0 < \gamma \leq 1$. Innovators obtain an infinite patent for their differentiated input variety $j$ and charge monopoly prices, as in traditional models of expanding input varieties (Romer, 1994). Second, the economy with $\mu = 0$ corresponds to the case of perfect competition. Other firms cannot be excluded from using the new idea that a previously unknown resource is valuable in production. Such idea is not of a technical nature, so it is not patentable. Nonrivalry implies that the idea diffuses, and the threat of firm entry makes prices fall to marginal cost.

### 3.3.1 Conflict

After a discovery, the innovator can choose to appropriate the resource with poorly defined property rights. If they do, a counterparty with a potential claim can challenge them. Motivated by our case studies in Section 2, we assume this process takes time and the outcome of the dispute over property rights is uncertain.

The counterparty is initially unaware of the innovation and resource appropriation. They learn at some future point in time; an event that follows a Poisson process with arrival rate $\delta$. The counterparty initiates a dispute at that point. The dispute is resolved in favor of the innovator with probability $\theta$, in which case they keep the resource they have appropriated. Otherwise, ownership goes to the counterparty and, in addition, the innovator must pay $\nu$ as a penalty (or in damages) for appropriation. [14] The arrival rate $\delta$ and probability $\theta$ are exogenous for now. We endogeneize them later when considering strategies innovations may use to shape disputes 5.4.2.

The rate $\delta$ captures how fast it becomes known that an innovation has turned a previously unrecognized resource into a productive input, and that the innovator has appropriated it. In expectation, the innovator enjoys the fruits from appropriation for a period

[14] Conflict is zero-sum under these assumptions. One could have assumed that conflict was costly to society. For example, $\kappa$ units of the resource could be lost in the process of assigning property rights (e.g., the cost of litigation or implementing regulation). Moreover, resolving conflicts may take time, following a Poisson process with arrival rate $\alpha$. The rate $\alpha$ would capture how fast institutions are in resolving disputes; for example, disputes make take longer to resolve because courts are sluggish or regulations are slow to be implemented.

of length $1/\delta$ where property rights remain ill-defined. The probability $\theta$ captures the extent to which property rights are already somewhat defined beforehand. For example, $\theta$ would be higher when court precedent regarding similar disputes have favored the innovator in the past, and $\theta$ would be lower when past laws already assign some rights to the public. Alternatively, $\theta$ could be higher when the innovation creates a more powerful constituency of consumers that support it, as in Section 5.4.2.

In all, choosing to appropriate the resource and resolve the conflict over property rights afterwards creates the chance for extraordinary rents if the dispute is resolved in favor of the innovator. But risks expropriation, penalties, damages, or outright business failure when it does not. Such is the innovator's *gamble*. Formally, the expected value for an innovator that chooses to appropriate a resource and begin producing at time $t$ is

$$\mathcal{V}_{it}^{\text{conflict}} = \mathcal{D}_{it} + \mathcal{R}_t,$$

where

$$\mathcal{D}_{it} \equiv \int_t^\infty e^{-\int_t^s r_v dv} \pi_{is} ds$$

are traditional rents from production of the new input variety, and

$$\mathcal{R}_t \equiv \underbrace{\int_t^\infty e^{-\int_t^s r_v dv} e^{-\delta(s-t)} q_s ds}_{\text{Informational rents}} + \underbrace{\int_t^\infty e^{-\int_t^s r_v dv} \left(1 - e^{-\delta(s-t)}\right) (\theta - (1-\theta)\nu) q_s ds}_{\text{Institutional rents}}$$

are expected rents from appropriation of the new resource.[15] The expression for appropriation rents $\mathcal{R}_t$ shows two sources of rents for the innovator at the time of appropriation $t$. First, the innovator enjoys *informational rents* because it takes time for the counterparty to become aware of the innovation and the resource appropriation in order to initiate the dispute — a period of length $1/\delta$ in expectation. Second, the innovator enjoys *institutional rents* because they expect to gain $\theta - (1-\theta)\nu$ units of resources at the time of resolution. Institutional rents may be positive or negative, depending on the penalties or damages paid $\nu$ and the probability $\theta$ of winning the dispute.

For the counterparty, the expected value of initiating the dispute at time $s$ is

$$\mathcal{U}_s^{\text{conflict}} = \int_s^\infty e^{-\int_t^h r_v dv} (1-\theta)(1+\nu) q_h dh,$$

[15] The implicit assumption is that the innovator can sell the new resource at price $q_s$ as soon as the resource is created, even during the period of time where property rights remain ill-defined and the dispute had not yet been initiated nor resolved. Alternatively, one could have assumed that a market for the resource only appears once property rights are defined, and the innovator can only use the appropriated resource for its own production before that.

since it favors them with probability $1-\theta$, assigning them ownership of the resource 1 and payment $\nu$.

### 3.3.2 Contract

Instead of choosing appropriation and conflict, the innovator can attempt to contract with the counterparty and establish property rights beforehand. The innovator offers to pay for the resource to the counterparty, and both parties commit not to re-negotiate or dispute afterwards. Specifically, the contract negotiates a one time payment $\tilde{p}_t$ for the purchase of the resource at time $t$. The conflict option remains available to both parties — it is their outside option.

The expected value of contracting for the innovator is

$$\mathcal{V}_{it}^{\text{contract}} = \mathcal{D}_{it} + \int_t^\infty e^{-\int_t^s r_v dv} q_s ds - \tilde{p}_t.$$

As for the counterparty, they may choose to accept the contract or reject it. The existence of the resource is initially unknown to the counterparty, or equivalently, they believe it is useless. By offering the contract, the innovator reveals to the counterparty that a new resource exists, that it has some productive value, and, importantly, that they may have a claim over it.[16] That is, the innovator gives away the informational rents from the counterparty remaining unaware for some period of time — it is as if the arrival rate was $\delta \to \infty$. In keeping the gambling metaphor, the innovator inevitably *tips their hand* when trying to contract beforehand.

If the counterparty rejects the contract and the gamble is profitable, the innovator would appropriate the resource anyways and settle the conflict over property rights afterwards. That is, whenever $\lim_{\delta\to\infty} V_{it}^{\text{conflict}} \geq 0$ the innovator cannot commit not to appropriate the resource and use it to produce the new input. In this case, the act of offering the contract improves the counterparty's outside option: it gives them the option to reject the contract and resolve the conflict over property rights afterwards, obtaining the expected value $\mathcal{U}_s^{\text{conflict}}$. Otherwise, when the gamble is not profitable, the counterparty's outside option is simply zero; the innovator would never appropriate the resource if the counterparty rejects the contract.

[16] We assume that the information about the counterparty's chance of winning an eventual dispute $1-\theta$ is either common knowledge or it is "hard information" that is credibly disclosed to them. Likewise, the counterparty learns about the true productive value of the resource after being offered a contract, as captured by the stream of profits $\pi_{it}$ and prices $q_{is}$. That is, there is no information asymmetry and the counterparty is neither pessimistic nor overoptimistic. Asymmetric information would create additional scope for contracting when the counterparty is pessimistic, and reduce the scope when they are overoptimistic.

In all, the value of a contract for the counterparty is

$$\mathcal{U}_t^{\text{contract}} = \max\left\{\tilde{p}_t, \mathbb{I}_{\lim_{\delta\to\infty}\mathcal{V}_{it}^{\text{conflict}}\geq 0}\mathcal{U}_t^{\text{conflict}}\right\}.$$

### 3.4 Market clearing

Market clearing in the input market requires that

$$y_{jt} = x_{jt},$$

and in the final goods market

$$C_t = Y_t = \int_0^{A_t} p_{jt} y_{jt} di.$$

Resource $j$ yields a one-unit service flow at each point in time, which can be allocated to producing input $j$, or innovation. Market clearing in the resource market thus requires

$$x_{jt} + \tilde{x}_{jt} = 1.$$

Lastly, the value of the household's firm portfoilio is

$$a_t = \int_0^{A_t} \mathcal{V}_{jt} dj,$$

where$\mathcal{V}_{jt}$ is the discounted value of profits from input variety $j$.

## 4 Equilibrium Characterization

This section characterizes when and why appropriation and conflict arise, and derives an expression for the economy's growth rate along a balanced growth path.

### 4.1 Conflict or Contract?

To develop intuition about the economics of the problem, we begin by considering a partial equilibrium of the model with a constant interest rate $r$, and where the stream of profits $\pi_{it}$, resource prices $q_{it}$ and contract prices $\tilde{p}_s$ grow at a constant rate $g$. The next section endogeneizes all variables in general equilibrium. In particular, we characterize

the equilibrium along a balanced growth path and provide sufficient conditions for conflict to arise.

In partial equilibrium, we obtain the values under conflict

$$\mathcal{V}^{\text{conflict}} = \max\left\{\frac{\pi+q}{r-g} - \frac{\delta}{r-g+\delta}\mathcal{U}^{\text{conflict}}, 0\right\}$$
$$\mathcal{U}^{\text{conflict}} = \frac{1}{r-g}(1-\theta)(1+\nu)q$$

and under contract

$$\mathcal{V}^{\text{contract}} = \max\left\{\frac{\pi+q}{r-g} - \tilde{p}, \lim_{\delta\to\infty}\mathcal{V}^{\text{conflict}}\right\}$$
$$\mathcal{U}^{\text{contract}} = \max\left\{\tilde{p}, \mathbb{I}_{\lim_{\delta\to\infty}\mathcal{V}^{\text{conflict}}\geq 0}\mathcal{U}^{\text{conflict}}\right\}.$$

Figure 2 shows the contract prices $\tilde{p}$ that the innovator is willing to offer (blue region) and the counterparty is willing to accept (red region) as a function of the counterparty's utility under conflict $\mathcal{U}^{\text{conflict}}$. The purple region depicts when contracting arises; outside of this region conflict arises instead.

Consider first the case where $V^{\text{conflict}} < 0$ so that the innovator's gamble is not profitable — $\mathcal{U}^{\text{conflict}}$ is higher than $\frac{r-g+\delta}{\delta}\frac{\pi+q}{r-g}$ in the figure. The counterparty is willing to accept any positive price $\tilde{p} \geq 0$ since their outside option is nil. The innovator is willing to offer any price which makes the innovation profitable under the contract — that is, any $\tilde{p}$ lower than $\frac{\pi+q}{r-g}$ in the figure. As a result, there is always a price at which both parties are willing to contract — the purple region in the figure. Therefore, conflict does not arise and property rights are always established beforehand via contracting.

Consider next the case where $\mathcal{V}^{\text{conflict}} \geq 0$ so that the innovator's gamble is profitable — $\mathcal{U}^{\text{conflict}}$ is lower than $\frac{r-g+\delta}{\delta}\frac{\pi+q}{r-g}$ in the figure. The innovator is now only willing to offer contract prices that are low enough; lower than $\tilde{p} : \mathcal{V}^{\text{conflict}} = \mathcal{V}^{\text{contract}}$ which makes them indifferent — the blue line in the figure. The counterparty's outside option remains nil when $\mathcal{U}^{\text{conflict}}$ is still higher than $\frac{\pi+q}{r-g}$: they accept any positive price $\tilde{p} \geq 0$. The reason is that, if they rejected the contract, the innovator would walk away instead of choosing to innovate under conflict, since $\lim_{\delta\to\infty}\mathcal{V}^{\text{conflict}} < 0$ in this case. Again, there is always a price at which both parties are willing to contract — the purple region in the figure.

Finally, when $\mathcal{U}^{\text{conflict}}$ is lower than $\frac{\pi+q}{r-g}$, the counterparty's outside option improves to $\mathcal{U}^{\text{conflict}}$ because, if they rejected the contract, the innovator would still choose to resolve the dispute over property rights via conflict. Thus, the counterparty only accepts contract prices that are high enough; above the price $\tilde{p} = \mathcal{U}^{\text{conflict}}$ which makes them in-

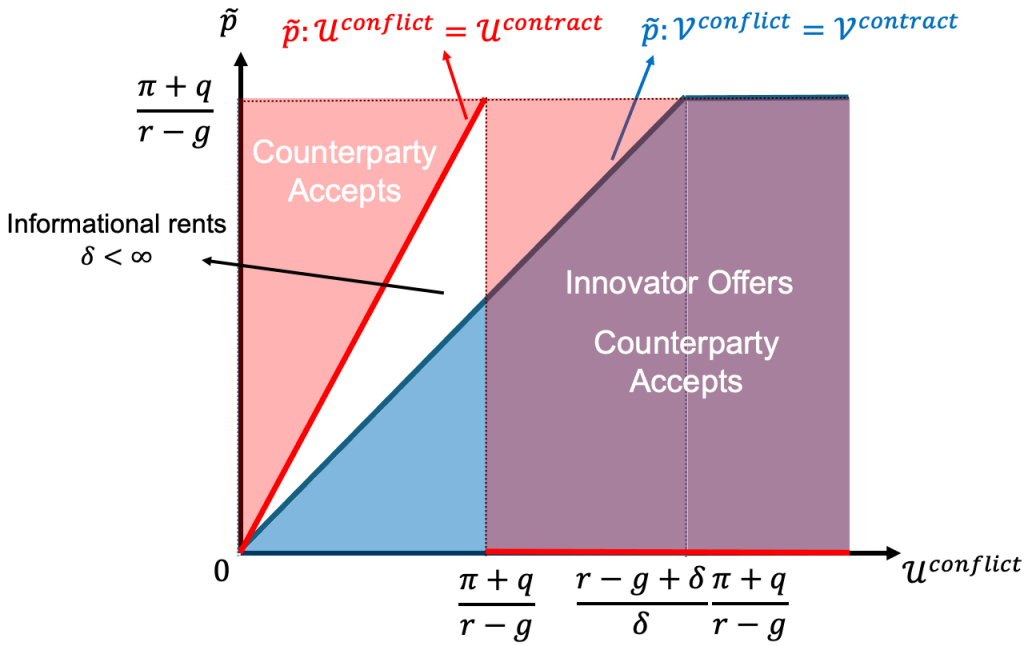



**Figure 2:** Conflict v. Contract

different — the red line in the figure. In this case, there is no possible contract that the innovator is willing to offer and the counterparty accept. Therefore, conflict arises and property rights are established after the time where innovation and appropriation had taken place. The reason is that, by offering the contract, the innovator gives away theyr informational advantage and allows the counterparty to extract some rents. Graphically, the informational advantage just described implies that the indifference line of the innovator — the blue line in the figure — is steeper than that of the counterparty's — the red line. As a result, there is a region where neither the innovator wishes to offer a contract nor the counterparty would accept it — the white region in the figure.

THE ROLE OF INFORMATION REVELATION. Central to conflict arising is the assumption that the act of offering a contract reveals valuable information to the counterparty. That is, that the innovator tips their hand. To see this, suppose that the contract revealed no information about how valuable the new resource was, so the counterparty keeps believing that it is useless — they believe profits $\pi$ and price $q$ are such that $\pi + q = 0$ and thus expect $\mathcal{V}^{\text{conflict}} = 0$. Then, conflict never arises: the innovator can offer to contract at a zero price $\tilde{p}$ and the counterparty would accept it. Similarly, suppose that $\delta \to \infty$ so that the innovator had no informational advantage. Then, there is always a contract price $\tilde{p} = \mathcal{U}^{\text{conflict}}$ that would parties would agree on.

## 4.2 Balanced Growth Path

We now solve for the general equilibrium of our model along a balance growth path (BGP) where: (i) all variables grow at constant rates, (ii) appropriation and conflict delivers positive rents in expectation $\mathcal{R}_t > 0$, and (iii) the contract price is the resource's competitive price $\tilde{p}_t = \int_t^\infty e^{-\int_t^s r_v} q_s ds$.

The following proposition establishes sufficient conditions for conflict or contracting to arise along a BGP, and characterizes the growth rate of varieties $g_A$ in each case. We assume throughout that $\rho < \lambda\mu$ and $\frac{\sigma-1}{\gamma} + 1 > 0$, which guarantee that the growth rate $g_A$ remains positive and that the interest rate $r$ is above the growth rate. We normalize the initial resource price $q$ to 1.

**Proposition 1. (Balanced growth path)** *If* $(1-\theta)(1+\nu) < 1 + \frac{\left(\frac{\sigma-1}{\gamma} + \frac{\rho}{\lambda}\right)\mu}{\frac{\sigma-1}{\gamma}+1+\mu}$ *and* $\delta < \lambda$*, then conflict arises along a balanced growth path and expected appropriation rents* $\mathcal{R}_t$ *are positive. If* $(1-\theta)(1+\nu) > 1 + \frac{\left(\frac{\sigma-1}{\gamma}+1+\frac{\rho}{\lambda}\right)\mu}{\frac{\sigma-1}{\gamma}+1+\mu}$ *and* $\delta > \lambda$*, then contracting arises along a balanced growth path and the resource's competitive price is in the contracting set.*

*The growth rate of varieties is the solution to*

$$g_A = \frac{\lambda\left(\mu + \mathcal{R}\left(g_A\right)\right) - \rho}{\frac{\sigma-1}{\gamma} + 1 + \mu}, \tag{4.1}$$

*where the expected appropriation rents are*

$$\mathcal{R}\left(g_A\right) \equiv 1 - \frac{\delta}{\rho + \delta + \left(\frac{\sigma-1}{\gamma} + 1\right) g_A}(1-\theta)(1+\nu) > 0$$

*when conflict arises along a balanced growth path and* $\mathcal{R}\left(g_A\right) = 0$ *when contracting does.*

*Proof.* See Appendix B.1. □

The first part of the proposition shows sufficient conditions for conflict to arise along a balanced growth path, and for appropriation rents to be positive in expectation. Intuitively, this is the case when the probability $\theta$ that the innovator wins the dispute over property rights is high enough or the penalty $\nu$ is low enough — the counterparty's expected rents $\mathcal{U}^{\text{conflict}}$ are small enough, as illustrated in Figure 2 — and when the rate $\delta$ at which counterparties learn about the innovation and appropriation is sufficiently low to generate large enough informational rents. The second part shows sufficient conditions for contracting to arise, and for the resource's competitive price to be in the contracting

set. Again, contracting arises when the counterparty's expected rents $\mathcal{U}^{\text{conflict}}$ are large enough, and the competitive price is feasible when the rate $\delta$ is high enough so that the innovator's expected appropiation rents are sufficiently small.

Regarding the growth rate $g_A$, there are two key equations that characterize innovation and growth. First, optimality of the innovator investments in discovering resource varieties requires that returns to an additional variety are equal to its marginal cost $\lambda \mathcal{V}_t = q_t$. This implies that

$$\lambda \left( \frac{\pi}{q} + \mathcal{R}\left(g_A\right) \right) = \tilde{r}$$

where profits over marginal cost are $\frac{\pi}{q} = \mu x$, and the effective discount rate is $\tilde{r} \equiv r - \frac{\dot{q}_t}{q_t} = \rho + \sigma g_A$ from the household's Euler equation and goods market clearing. Second, the accumulation equation together with market clearing in each resource market implies that the growth rate $g_A$ of varieties is

$$g_A = \lambda \left(1 - x\right).$$

Together, these conditions imply the BGP growth rate $g_A$ in Proposition 1.

# 5 Implications of Growth at the Resource Frontier

This section presents the main implications of our model of growth at the resource frontier, contrasting with those of existing frameworks in political economy and economic growth.

## 5.1 Property Rights Emerge as a Consequence of Innovation

Much work emphasizes the cost of insecure property rights for economic growth, and well-established property rights over ideas and new products as a precondition for innovation (Coase, 1960; North, 1981; Acemoglu et al., 2001; Engerman and Sokoloff, 2005; Porta et al., 2008; Hornbeck, 2010).

We qualify this view in two ways. First, when it comes to growth at the resource frontier, firms innovate precisely because property rights over overlooked or inaccesible resources are poorly defined — expecting rents from appropriation. Second, property rights emerge as a consequence of innovation, not a precondition. Formally, there is a period time — of length $1/\delta$ on average — where property rights remain ill-defined after

innovation and appropriation have taken place, but before a counterparty learns about them and initiates a dispute. Property rights become established only after the dispute is resolved.

The above changes the role fo the state even in typical market economies. The state does not only protect property rights over ideas and new inputs, it allocates property rights over resources outside the frontier as well.

## 5.2 Appropriation Rents Sustain Innovation and Growth

From models of expanding input variety (Romer, 1990; Jones, 1995) or capital vintages (Jovanovic and Yatsenko, 2012) to models of creative destruction (Aghion and Howitt, 1992; Grossman and Helpman, 1991), traditional models of innovation-driven growth share two key features. First, innovations turn *known* resources that trade in markets with well-defined property rights into new input varieties, capital vintages or higher-quality goods. Second, innovations grant firms with monopoly rents from production — for example, because of patents over new inputs — that justify their costs.

Equation 4.1 makes these statements precise when contracting arises. In this case, our model reduces to a standard growth model. In particular, the growth rate coincides with that of a "lab-model" of expanding varieties (Acemoglu, 2008):

$$g_A = \frac{\lambda\mu - \rho}{\frac{\sigma-1}{\gamma} + 1 + \mu}.$$

This is a direct consequence of assuming that contracting occurrs at the resource's competitive price; in the standard model, existing resources trade in competitive markets. As a result, absent monopoly rents in the output market from producing new inputs — when markups $\mu = 0$ — the economy does not innovate nor grows in the long-run.

In our model of growth at the resource frontier, however, innovation turns previously unrecognized resources into new input varieties, and traditional monopoly rents in the output market are not required to sustain long-run growth. Instead, expected rents $\mathcal{R}$ from appropriating unrecognized resources may suffice. To see this clearly, the growth rate in 4.1 when markups $\mu = 0$ is

$$g_A = \frac{\lambda\mathcal{R}\left(g_A\right) - \rho}{\frac{\sigma-1}{\gamma} + 1}.$$

Therefore, the prospect of securing ownership over the resource and earnings rents $\mathcal{R}$ is enough to generate positive long-run growth $g_A > 0$. In all, we find that economic rents

from appropriation of resources can sustain economic growth at the resource frontier, beyond traditional monopoly rents that have been the focus of a large literature.

## 5.3 Growth at the Resource Frontier Often Comes with Appropriation and Conflict

The appropriation of resources is typically seen as being purely redistributive or even extractive and predatory (Persson and Tabellini, 1991; Murphy et al., 1993; Acemoglu and Robinson, 2013). In these accounts, appropriation and conflict are therefore either separate from or at odds with economic growth.

In our model, growth at the resource frontier frequently comes together with appropriation and conflict.[17] To show this, we conduct a large-scale simulation in which all model parameters are drawn jointly from uniform distributions over specified supports. For each draw, we impose basic feasibility and structural restrictions to ensure a well-defined balanced growth path, classify the equilibrium regime using the model's sufficient condition for conflict, and compute the implied growth rate $g_A$. This produces a cross-sectional dataset of parameterizations with an associated growth rate and a binary indicator for whether appropriation and conflict arises.

To study the relationship between growth and conflict without conditioning on any single parameter, we bin observations by the realized growth rate and compute, within each bin, the share of parameterizations that exhibit appropriation and conflict.

Figure 3 shows a strong, monotonic relationship: the share of parameterizations exhibiting appropriation and conflict rises sharply with the growth rate and then flattens at high levels of $g_A$. At low growth rates, appropriaton and conflict are relatively infrequent, while at higher growth rates they become the dominant regime, with the conflict frequency approaching an upper plateau.

## 5.4 Political Economy

### 5.4.1 Should the state limit appropriation?

Household utility along a balanced growth equilibrium is

$$U = \frac{1}{1-\sigma} \frac{\left(1 - \frac{1}{\lambda} g_A\right)^{1-\sigma}}{\rho + \frac{\sigma-1}{\gamma} g_A},$$

[17] From equation (4.1), one can already see that a higher probability $\theta$ will be associated with higher appropriation rents — and so higher growth together with conflict.

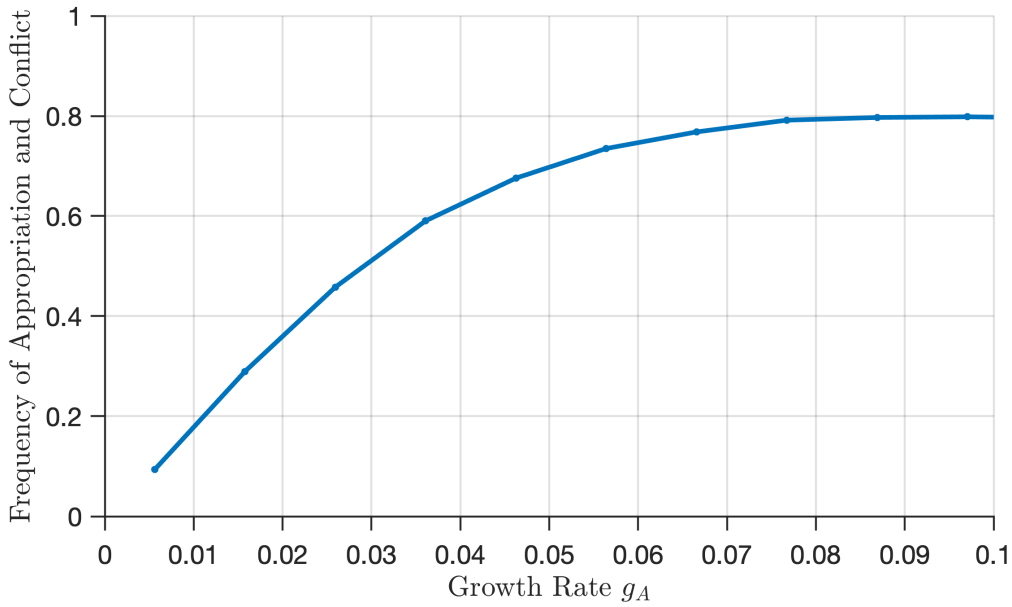



**Figure 3:** Frequency of Appropriation and Conflict, conditional on Growth

where we have normalized the initial number of varieties to 1. A higher growth rate thus increases future consumption, but crowds-out current consumption becauses of resources spent in discovering new varieties — cost $\frac{1}{\lambda}$ — and resolving conflicts — cost $\kappa$. The optimal growth rate balances these forces

$$g_A^* = \frac{1}{\sigma}(\lambda - \rho\gamma).$$

How can a government implement the optimal growth rate? Suppose that a government controls how linient the courts are towards innovators that appropriate resources. That is, they choose the probability $\theta$ of innovators' winning a dispute or the penalties $\nu$. Then, the optimal growth rate is implemented by setting

$$(1-\theta)(1+\nu) = \left(\mu - \frac{1-\gamma}{\gamma}\right)\left(1 - \frac{1}{\sigma}(\lambda - \gamma\rho)\right)\frac{\rho + \delta + \left(\frac{\sigma-1}{\gamma} + 1\right)\frac{1}{\sigma}(\lambda - \gamma\rho)}{\delta},.$$

The case of monopolistic competition $\mu = \frac{1-\gamma}{\gamma}$ implies that $\theta^\star = 1$ is *exactly* optimal — the government should allow full appropriation. An economy with even lower markups (as with perfect competition $\mu = 0$) implies a corner solution with $\theta^\star = 1$ if $\sigma \geq 1 - \frac{\rho\gamma}{\lambda}$. Otherwise, there is an interior solution $\theta^\star < 1$ if $\sigma < 1 - \frac{\rho\gamma}{\lambda}$ or if markups are higher than under monopolistic competition $\mu > \frac{1-\gamma}{\gamma}$.

### 5.4.2 Innovators' strategies for shaping disputes over property rights

Innovators have strong incentives to shape how the state's coercive power is applied (to increase $\theta$). In earlier eras this meant influencing the use of force; today it more often means steering litigation outcomes, legislation, and regulation — raising the likelihood that policy tilts in their favor.

They can pursue this through lobbying, regulatory capture, or the "traffic of influence," tactics that may secure advantageous rules but risk being socially wasteful. Another route is to redirect the trajectory of innovation itself so that it better serves influential constituencies and aligns with public objectives, making the firm more likely to win favor from state actors.

These strategies can be genuinely useful if they expand consumer surplus — say, by lowering markups $\mu$ the innovator expects a higher probability $\theta$ of winning disputes because of political support of consumers. Yet they also carry dangers. When firms tailor technology to government priorities, they may render it more relevant to state power, including in dual-use applications that blur civilian and military or surveillance purposes.

# 6 Conclusions

Economic thought has long emphasized innovation as a central source of economic growth, with well-defined property rights preceding innovation and enabling firms to capture rents that incentivize discovery. A parallel tradition has highlighted the appropriation and extraction of resources, pointing to their redistributive and deleterious effects.

Yet, from the Stone Age to the Digital Age, much of human progress has been driven by innovations that expand the frontier of usable resources. Property rights over resources outside the frontier have typically been poorly defined, and innovators have often appropriated them — expecting extraordinary rents and triggering conflicts with counterparties advancing competing claims. Motivated by these observations, we developed a model of growth at the resource frontier. The model rationalizes how property rights emerge as a consequence of innovation, establishes that expected rents from appropriation can sustain long-run growth, and ultimately shows that growth at the resource frontier is frequently accompanied by appropriation and conflict.

These results suggest a different view of how economies grow and of the relationship between property rights and innovation. Rather than being a precondition for innovation, property rights arise from the resolution of disputes following innovations expanding the resource frontier. Moreover, innovators act before ownership is clearly defined

in anticipation of rents from appropriation. As a result, appropriation and conflict are not incidental to, or at odds with, the process of economic growth, but a central part of how new resources are incorporated into the economy. In the future, the same forces are likely to shape further expansions of the resource frontier, as innovations enable access to domains such as the deep sea and outer space where property rights remain poorly defined.

Our analysis of economic growth at the resource frontier raises important questions. For policymakers, a central challenge is how to balance the opportunities for growth from resource appropriation against the costs of conflict and the downstream consequences of wealth accumulation and concentration driven by appropriation rents. For academics, there is a clear need for systematic empirical study of growth at the resource frontier. We currently have only a partial understanding of the contribution to aggregate growth from innovations that expand the frontier of usable resources, and even less evidence on its effects on conflict, law, and the evolution of property rights, making this a promising area for future research.

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# Online Appendix for:
# Growth at the Resource Frontier

This online appendix contains the proofs and derivations of all theoretical results for the article "Growth at the Resource Frontier."

**Any references to equations, figures, tables, assumptions, propositions, lemmas, or sections that are not preceded "A.," "B.," "C.," "D.," "E." or "F." refer to the main article.**

# A Calculations for the Rents from Appropriation

## A.1 Digital Advertising

Let $p^u$ denote the price of untracked (contextual) ads, $p^t$ the price of tracked (targeted) ads, and $mc$ the marginal cost of an ad. Likewise, let $a^u$ and $a^t$ denote the corresponding ad quantities, with $a = a^u + a^t$. We can thus write earnings for an advertising platform as

$$\begin{aligned} Earnings &= p^u * a^u + p^t * a^t - mc * a \\ &= \underbrace{(p^u - mc) * a}_{\text{Pure profits } \pi} + \underbrace{(p^t - p^u) * a^t}_{\text{Rents from data } \mathcal{R}} \end{aligned}$$

The first term captures baseline operating profits that would obtain absent data-driven targeting. The second term isolates rents from data, i.e., the incremental revenue generated by tracking relative to contextual advertising.

Two pieces of evidence discipline this decomposition. Kraft et al. (2023) finds that targeted advertisements command a price premium of roughly 50 percent relative to non-targeted ads, and that 74 percent of all of ads are targeted. Combining these pieces of evidence, we estimate that the share of advertising revenue attributable to user-generated data is

$$\alpha \equiv \frac{\text{Revenue from targeting}}{\text{Total Revenue}} = \frac{(p^t - p^u) * a^t}{p^u * a^u + p^t * a^t} = \frac{\left(\frac{p^t}{p^u} - 1\right) * \frac{a^t}{a^u}}{\frac{p^t}{p^u} * \frac{a^t}{a^u} + 1} = \frac{0.5 * \frac{0.74}{1-0.74}}{1.5 * \frac{0.74}{1-0.74} + 1} \approx 0.27.$$

Moreover, assuming net operating margins $\mu = \frac{\text{Earnings}}{\text{Total Revenue}}$ are 40 percent in the industry, the share of earnings attributable to data-enabled targeting is $\alpha/\mu \approx 2/3$. The value is even higher assuming a margin of 30 percent.

## A.2 Broadcasting

We begin from estimates reported in Soloveichik (2024). In the 2017 FCC reverse auction, UHF broadcasters received $10.05 billion in exchange for relinquishing 14 spectrum units in the 600 MHz band (Gilroy, 2017). Using industry revenue data and standard assumptions, they estimate a net present value of approximately $12 billion per spectrum unit; implying that the value of spectrum corresponds to 6.15 percent of the net present value of industry revenue. Or equivalently, that the flow value of the spectrum is 6.15 percent of the flow of revenues.

Using a 9 percent net operating margin, we compute that the share of operating earnings that can be attributed to the spectrum is roughly two-thirds (6/9).

# B Proofs and Derivations

## B.1 Poof of Proposition 1

We consider a symmetric equilibrium and drop all $i$ indices from now on. Firm profits are

$$\pi_t = \mu \left(1+\mu\right)^{-\frac{1}{1-\gamma}} \left(q_t\right)^{-\frac{\gamma}{1-\gamma}} C_t,$$

and the first order conditions for the representative firm and household are

$$\begin{aligned} c_t &= \left(p_t\right)^{-\frac{1}{1-\gamma}} C_t \\ 1 &= A_t \left(p_t\right)^{-\frac{\gamma}{1-\gamma}} \\ r_t &= \rho + \sigma \frac{\dot{C}_t}{C_t}, \end{aligned}$$

where we have normalized the price of aggregate consumption good to 1.

Innovator's optimal investment implies that the price of all factor varieties are equalized $q_{it} = q_t$ and that the returns to an additional variety are equal its marginal cost

$$\lambda \mathcal{V}_t = q_t.$$

The market clearing conditions are

$$\begin{aligned} a_t &= A_t \mathcal{V}_t \\ 1 &= \tilde{x}_t + x_t \\ c_t &= x_t \\ \dot{A}_t &= \lambda A_t \tilde{x}_t. \end{aligned}$$

Next, we solve for the balanced growth path. We denote by $g_q, g_A$,and $g_C$ the growth rates of factor prices $q$, varieties $A$, and consumption $C$ along a BGP. We normalize the

price level $q = 1$. The equilibrium conditions result in

$$\begin{aligned}
1 &= A\left(1+\mu\right)^{-\frac{\gamma}{1-\gamma}} \\
g_A &= \frac{\gamma}{1-\gamma} g_q \\
x &= \left(1+\mu\right)^{-\frac{1}{1-\gamma}} C \\
g_C &= \frac{1}{1-\gamma} g_q \\
r &= \rho + \sigma g_C \\
1 &= \lambda \mathcal{V} \\
g_A &= \lambda\left(1-x\right) \\
\pi &= \mu x
\end{aligned}$$

Moreover, when the contracting price is the competitive price $\tilde{p} = \frac{1}{r-g_q}$ and given expected rents from appropriation

$$\mathcal{R} = 1 - \frac{\delta}{r - g_q + \delta}\left(1-\theta\right)\left(1+\nu\right),$$

we can write the value for the innovator as

$$\mathcal{V} = \frac{\pi + \mathbb{I}_{\text{conflict}}\mathcal{R}}{r - g_q}.$$

Together, with the innovator's optimality condition, the above implies that the growth rate of varieties is the solution to

$$g_A = \frac{\lambda\left(\mu + \mathcal{R}\left(g_A\right)\right) - \rho}{\frac{\sigma-1}{\gamma} + 1 + \mu},$$

where $\mathcal{R}\left(g_A\right) = 1 - \frac{\delta}{\rho+\delta+\left(\frac{\sigma-1}{\gamma}+1\right)g_A}\left(1-\theta\right)\left(1+\nu\right)$ in the case of conflict and $\mathcal{R}\left(g_A\right) = 0$ in the case of contracting.

### B.1.1 Sufficient conditions for conflict with positive appropriation rents

We have shown in Section 4.1 that conflict arises if and only if the following inequality holds

$$\left(r-g\right)\mathcal{U}^{\text{conflict}} \equiv \left(1-\theta\right)\left(1+\nu\right) < \pi + 1.$$

Moreover, there are positive appropriation rents $\mathcal{R}(g_A)$ if and only if

$$\mathcal{R}(g_A) \equiv 1 - \frac{\delta}{\rho + \left(\frac{\sigma-1}{\gamma} + 1\right) g_A + \delta} (1-\theta)(1+\nu) \geq 0.$$

Using the expression for the $\mathcal{V}$ and the fact that $1 = \lambda \mathcal{V}$, these are equivalent to

$$(1-\theta)(1+\nu) < \frac{\rho + \left(\frac{\sigma-1}{\gamma} + 1\right) g_A + \delta}{\lambda}$$
$$(1-\theta)(1+\nu) \leq \frac{\rho + \left(\frac{\sigma-1}{\gamma} + 1\right) g_A + \delta}{\delta}$$

Therefore, if $\delta < \lambda$, then the first inequality immediately implies that the second one holds, so there are positive appropriation rents $\mathcal{R}(g_A) > 0$. Lastly, using that $\pi = \mu\left(1 - \frac{1}{\lambda} g_A\right)$, we can write the first inequality as

$$(1-\theta)(1+\nu) < \mu\left(1 - \frac{1}{\lambda} g_A\right) + 1.$$

Using that $g_A \leq \frac{\lambda(\mu+1)-\rho}{\frac{\sigma-1}{\gamma}+1+\mu}$, a sufficient condition for the inequality to hold is

$$(1-\theta)(1+\nu) < \mu \frac{\frac{\sigma-1}{\gamma} + \frac{\rho}{\lambda}}{\frac{\sigma-1}{\gamma} + 1 + \mu} + 1.$$

### B.1.2 Sufficient conditions for contracting at the resource's competitive price

Contracting arises if

$$\left(r - g_q\right) \mathcal{U}^{\text{conflict}} \equiv (1-\theta)(1+\nu) > \pi + 1$$

and the resource's competitive price $\tilde{p} = \frac{1}{r - g_q}$ is in the contracting set if

$$\frac{\delta}{r - g_q + \delta} (1-\theta)(1+\nu) \geq 1.$$

Using the expression for $\mathcal{V}$ and the fact that $1 = \lambda\mathcal{V}$, these are equivalent to

$$(1-\theta)(1+\nu) > \frac{\rho + \left(\frac{\sigma-1}{\gamma}+1\right) g_A + \lambda}{\lambda}$$
$$(1-\theta)(1+\nu) \geq \frac{\rho + \left(\frac{\sigma-1}{\gamma}+1\right) g_A + \delta}{\delta}.$$

Therefore, if $\delta > \lambda$, the first inequality implies that the second is satisfied too. Moreover, replacing with the BGP growth rate $g_A$, we have that the first inequality becomes

$$(1-\theta)(1+\nu) > \mu \frac{\frac{\sigma-1}{\gamma} + 1 + \frac{\rho}{\lambda}}{\frac{\sigma-1}{\gamma} + 1 + \mu} + 1.$$

## B.2 Optimal Policy

Household utility is

$$\begin{aligned} U &= \int_0^\infty e^{-\rho t} \frac{\left(C_0 e^{g_C t}\right)^{1-\sigma}}{1-\sigma} dt \\ &= \frac{(C)^{1-\sigma}}{1-\sigma} \int_0^\infty e^{-\left(\rho + \frac{\sigma-1}{\gamma} g_A\right) t} t dt \\ &= \frac{A^{\frac{1-\sigma}{\gamma}}}{1-\sigma} \frac{\left(1 - \frac{1}{\lambda} g_A\right)^{1-\sigma}}{\rho + \frac{\sigma-1}{\gamma} g_A}. \end{aligned}$$

Therefore, the optimal growth rate is

$$g_A^* = \frac{1}{\sigma}(\lambda - \gamma\rho)$$

which is implemented with

$$\theta^* = 1 - \frac{1}{1+\kappa} \frac{1}{\sigma} \left( \frac{\rho\gamma}{\lambda} + \frac{\sigma-1}{1+\lambda\kappa} \right) \left( \mu(1+\lambda\kappa) - \frac{1-\gamma}{\gamma} \right) - \frac{1}{1+\kappa} \frac{\lambda\kappa}{1+\lambda\kappa}.$$

$$(1-\theta)(1+\nu) = \left(\mu - \frac{1-\gamma}{\gamma}\right) \left(1 - \frac{1}{\sigma}(\lambda - \gamma\rho)\right) \frac{\rho + \delta + \left(\frac{\sigma-1}{\gamma}+1\right) \frac{1}{\sigma}(\lambda - \gamma\rho)}{\delta},$$

$$(1-\theta)(1+\nu) = \left(\frac{1}{\gamma} - \frac{\lambda^{\frac{1}{\gamma}}}{\lambda}\right) \frac{\rho + \delta + \left(\frac{\sigma-1}{\gamma}+1\right) \frac{1}{\sigma}(\lambda - \gamma\rho)}{\delta}$$

where $\mathcal{R}\left(g_A\right) = 1 - \frac{\delta}{\rho+\delta+\left(\frac{\sigma-1}{\gamma}+1\right)g_A}\left(1-\theta\right)\left(1+\nu\right)$